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GIS Based Potential Volcanic Hazard Zonation in Ethiopia the Case of Aluto Volcano

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Abstract
Aluto volcano is one of the active volcanoes found in the Central Main Rift of Ethiopia. The present activities of Aluto volcano indicate the existence of future potential eruption. But, there are no considerable studies conducted in this area concerning the potential volcanic hazards. This study was mainly focused on predicting future Aluto volcanic hazards and preparing potential volcanic hazard zone map. Intensive field study was made to have insight about the past erupted volcanic units and the geomorphologic conditions of the study area. Accordingly, the future Aluto volcanic eruptions such as pyroclastic flow and fall deposits, dome collapse, vulcanian and Sub-plianian types of eruptions that will consist of pyroclastic flows and pyroclastic falls, ignimbrite-forming eruptions, slightly explosive strombolian type of eruptions which leads to the formation of scoria/cinder cones and basaltic eruption and phreato-magmatic eruptions were foreseen to erupt from different vents. The potential volcanic hazard map was prepared based on elevation, slope angle, drainage networks and distance from the central Aluto caldera. Analisis of the four factors were made based on multi-criteria evaluation method intigrated with Geographical Information System methodology. Consequently, the potential volcanic hazards of the study area were classified to Very high, High, Moderate, Low and Very low potential volcanic hazard levels. The hazard map can be used for the purpose of land use planning and as a base to conduct further studs concerning Aluto volcanic hazards. Awareness creation contneous follow up of Aluto Volcano and further studies such as vulnerability assessment are essential for emergency management and volcanic disaster risk reduction in the study area.
Keywords: Aluto Volcano, Geographical Information System, Multi Criteria Approach, potential volcanic Hazard

1. Introduction

Aluto Volcano found in the Central Main Rift of Ethiopia (CMRE) between lack Ziway and Lake Langano. The study of Aluto volcano started for the purpose of geothermal power exploration by the joint Ethiopian Institute of Geological Surveys (EIGS) and the United Nation Development Program technical teams (UNDP, 1973). Then it was followed by Lloyd (1977) and others which included detailed geological and surface hydrothermal alteration studies. Kebede et al., (1984) conducted detailed geological study at 1:20,000 scale. Biggs et. al.,(2011) demonstrated investigation of the surface deformation occurring at Aluto volcano and other volcanic edifices in the CMRE from 1993 to 2010. Studies conducted for the geothermal exploration power exploration (DI Paola, 1983, 1986, 1972 and Kebede, 2002), indicated existence of hot springs, fumaroles and hot grounds in several parts of Ethiopia.

Biggs et. al, (2011) showed the existence of magma at shallow depth. Hence this and other studies had proved that Aluto is an active volcano with high probability of future eruption.

As estimated by Hutchison et al., (2016), 10,000–50,000 people have been living on and surrounding Aluto volcano as well as in the nearby towns such as Zeway, Adami Tullu and Bulbula. But fewer attempts were made concerning the study of volcanic hazards related to Aluto Volcano. Conducting studies relates to volcanic hazards at Aluto helps to reduce the risk of volcanic disaster in the study area. Hence the current study was aimed to infer the future eruption style and future eruption products and to prepare the potential volcanic hazard map for Aluto and its surroundings.

2. Methodology

2.1. Description of the study area

The study area is located in the CMER. The Ethiopian Rift is the extension of East African Rift (EAR). Aluto volcano which is considered as an active volcano is found between 7^{o} 45'N -7°50'N and 38^{o} 48' E - 38°41'E to South East of Addis Ababa. It is bordered by 2 lakes Lake Ziway and Lake Langano in the northern and Southern directions respectively (figure 1).

The altitude of the study area is ranging from 2479m (the submit of Aluto volcano) to1485m around the two lakes. Towns like Ziway, Adami Tulu, Bulbula and Batu as well as morthan 20 rural admnistrative kebeles are found in and around Aluto volcano.

The Aluto area is characterized by semi-desert acacia and scrub. Aluto has only two seasons namely dry (October-February) and rainy season (June- September) and there is small amount of rain fall from the month

February to May (38-70mm). The annual mean rainfall is 1500 mm. The maximum daily temperature ranges between 20^0C-25^0C with daily maximum temperature as high as 35^0C during the dry season

On Aluto mount due to lack of potable water and the low rainfall permanent settlement was limited and the surrounding people use the land mainly for range and crop cultivation. But recently after the development of geothermal project people have started forming permanent settlement in the area.

Cereal crop, livestock raring, irrigation, fishing (from lake Ziway and Lake Langano), trade and tourism are the main economic activities practiced in the study area.

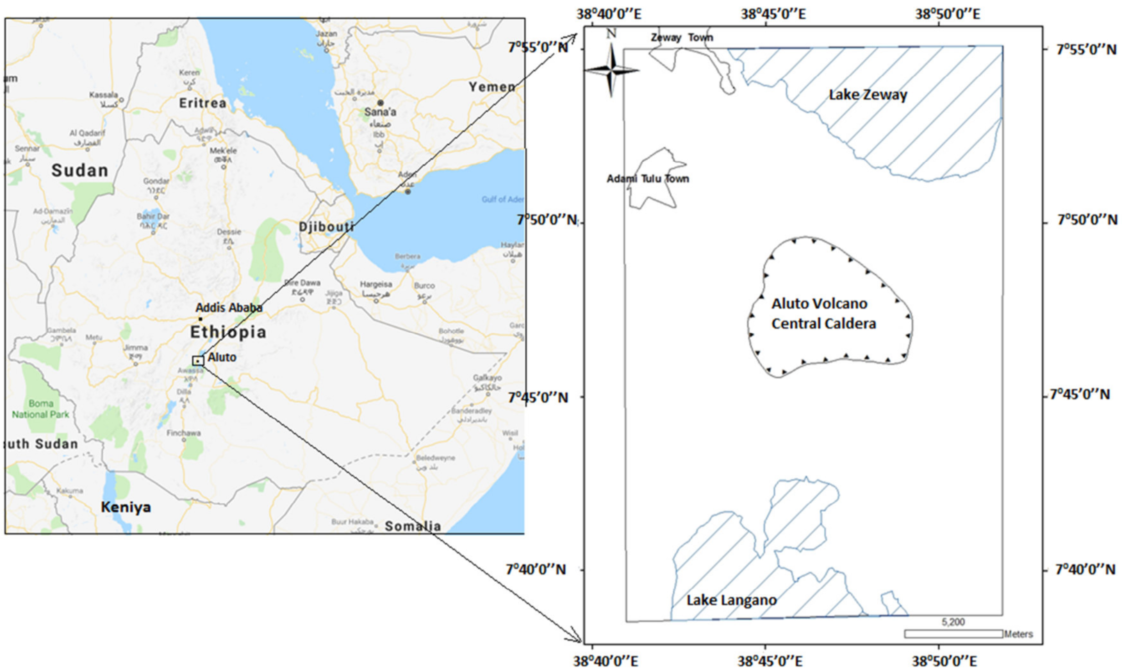

Figure 1: Location map of Aluto Volcano

The geology of Aluto has been studied by Altaye et al. (1983) mainly for the purpose of geothermal exploration. The eastern portion of Aluto volcano has been mapped by Abebe et al. (1998) and included in their 1:50, 000-scale Geological Map of the Lake Ziway-Asela region. Based on these two maps, further field investigations were carried out to get a better understanding of the variety of eruptive products, their areal extents, their physical characteristics, their thickness variations as well as the tectonic structures.

Preliminary reconnaissance of the area was made to have an overview on the topographic features, nature of rock exposures, accessibility, and workability in the area. On the basis of existing geological maps and lithologic descriptions of the area, various outcrops, stratigraphic sections were studied in detail. Geological and volcanic structures were observed and mapped. In addition, various features like hot springs, fumaroles, hot grounds, and vents were observed and field records were taken for detail analyses and further descriptions. The location and elevation of important features were recorded using a hand-held GPS apparatus.

Published and unpublished geological maps and related geological reports mainly from the Geological Survey of Ethiopia (GSE) and topographic maps of the study area were obtained from the Ethiopian Mapping Agency (EMA) and used as secondary sources of information.

Information assembled from field study together with secondary data and the previous studies were used to understand the past eruption products and current manifestations of Aluto volcano. Hence the types of erupted volcanic products and current manifestations were helped to foresee the future possible hazardous products of Aluto volcano.

Information about the current topographical conditions of the study area such as Elevation, Drainage Networks and slope were derived from DEM of 30m*30m resolution downloaded from Global Land Cover Facility (GLCF). The drainage networks were used to develop the drainage density factor. Distance map was prepared using buffering techniques. All the four factors including elevation, slope angle, drainage density and distance from the central caldera of Aluto volcano were used to prepare the potential volcanic hazard level. Hazard factors generation and potential hazard zonation were completed using GIS methodology.

2.2. Method of Data Analyses

2.2.1. General morphology, structure and Volcanic Geology of Aluto

The study area is located in the Central Main Rift of Ethiopia (CMER). The Ethiopian Rift is the extension of East African Rift (EAR). The extensional tectonic processes and intense volcanic activity are taking place in the

MER and the Afar Rift (AR). The Erta'ale lava lake, the eruptions from several volcanoes such as Dabbahu in 2005, Karbahi in 2007 and 2009, the explosive eruption of Nabro in 2011, hydrothermal manifestations in Afar rift, and CMER particularly at Aluto and Chabbi Volcanoes and surface deformation of Aluto, Corbetti, Haledebi are indicators of existence of magma at shallow depth beneath the MER and Afar rift (Biggs, 2011). Aspinall et al (2011) reported the presence of 65 active volcanoes in Ethiopia distributed within the MER and Afar rift.

Aluto volcano is characterized by steep cliffs in its southern and south-western flanks and a depression at its centre**,** lies on the offset between the Gedemsa-East Ziway and Ziway-Shala segments of the Wonji Fault Belt (WFB) (Mohr et al., 1980). The structural and volcanic evolution of Aluto is hence controlled by the influence of the WFB faults. Displacement of these faults is manifested by a stepped-fault structure also evidenced by the results from the deep geothermal wells (Wolde Gabriel et al., 1992; Gianelli & Tekle mariam, 1993). A range of age 0.27-0.021 Ma has been reported on Aulto rocks (Laury & Albritton, 1975; EIGS-GLE, 1985; Wolde Gabriel et al., 1990).

Aluto and other volcanoes such as O'a and Corbetti volcanoes possibly erupted during the 0.25 Ma (Di Paola, 1972; Lloyd, 1977; Mohr et al., 1980; Wolde Gabriel et al., 1990). Before volcanism commenced at Aluto, the Langano-Ziway basin was well developed and occupied by ancestral lakes (Street, 1979).

Voluminous parasitic silicic volcanism has continued up into Holocene times from Aluto Calderas (Dakin & Gibson, 1971; Di Paola, 1972) as shown by the number of ash and pumice layers within the late Pliestocene and Holocene lake deposits of the Bulbula Plain and East of Lake Abijata and in the Lakes Langano and Abijata sediment cores (Street, 1979). Intermittent late Holocene activity of Aluto is demonstrated by obsidian flows and pumice breccias dated at about 2 Ka and ash layers in the Macho area west of the volcano (Gianneli & Teklamariam, 1993).

The eruptive activity of Aluto has produced a wide variety of effusive and explosive products. The volcanism are of Late Pleistocene-Holocene age representing multiple flows dominated by pumice, ash and recent obsidian flows. The volcanic succession appears to have been erupted at frequent intervals during the Late Quaternary (UNDP, 1973). Altaye et al (1983) have identified 12 volcanic units within Aluto volcano. The following volcanic units of Aluto (Figure 2) have been reconstructed based on present field studies and on the works of Altaye et al (1983), Kebede et al (1984) and Le Turdu et al (1999).

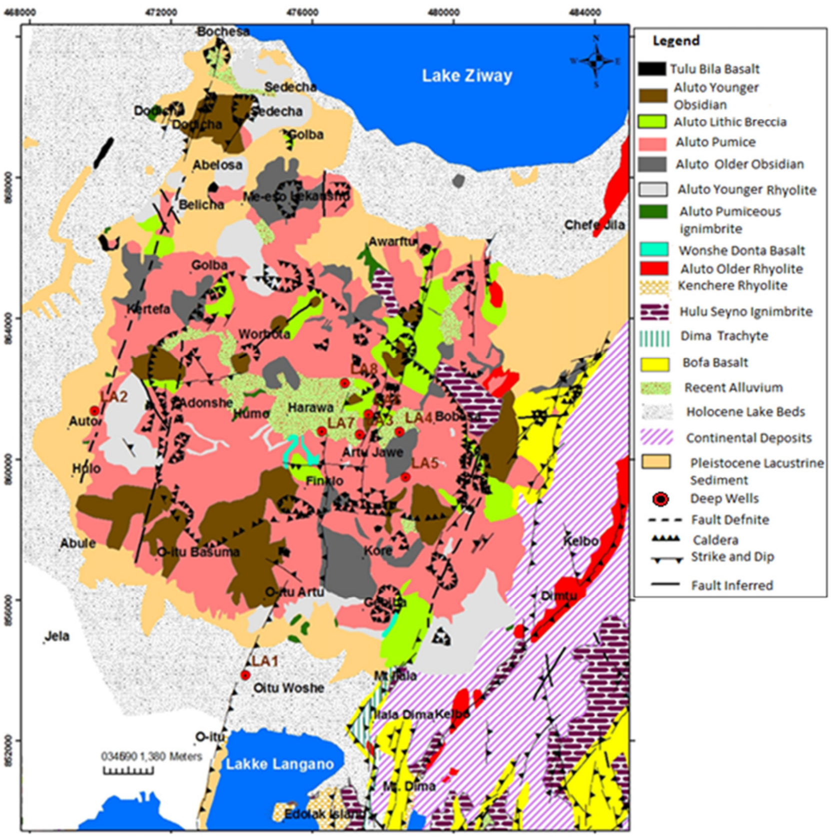

Figure 2: Geological map of Aluto volcano Adopted from Altaye et al. (1983).

2.2.2. Current Manifestations of Aluto Volcano

At present Aluto volcano is characterized by activity such as hot springs, hot ground, fumaroles, high temperatures, uplifting and subsidence (Biggs et al., 2011; Hutchison et al., 2016). The region around Aluto and

Aluto volcano itself are characterized by thermal manifestations (UNDP, 1973 and Lloyd, 1977).

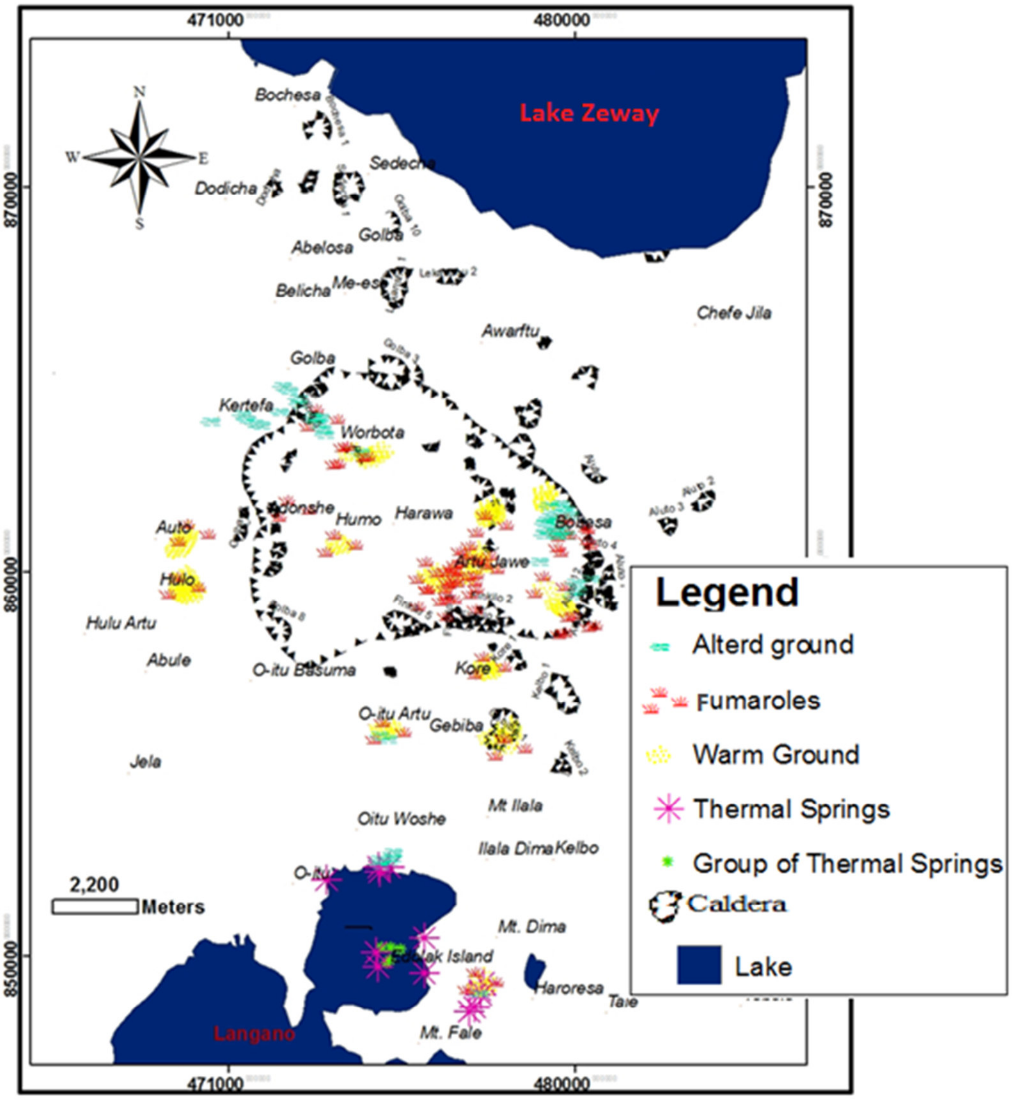

Figure 3: Distribution of fumaroles, hot springs, warm and altered grounds in the study area

2.2.3. High Temperatures

The thermal manifestations of different features of Aluto volcano as recorded by Kebede et al., (1984) are indicated as follows.

1. Group or single weak fumaroles and/or steaming ground (55 ^{O}C - 95 ^{O}C)
2. Warm and altered grounds with or without steam vents (40 ^{O}C -96 ^{O}C)
3. Group or single hot springs (51 ^{O}C -97 ^{O}C)
4. High temperature at depth

High temperatures 181^{O}C - 335 ^{O}C were recorded at depth of 1317m -2500m from eight wells (Figure 2) drilled in Aluto-Langano and Aluto complex from 1981 to 1985 for exploration of geothermal energy (ELC, 1986, and Endeshaw, 1988).

2.2.4. Ground Deformation

Significant deformations of volcanoes in the CMER were observed at volcanoes like Aluto, and other neighboring volcanoes such as Corbetti, Bora, and Haledebi from 1993 to 2010 (Biggs et, al., 2011). Accordingly the largest displacements were observed at Aluto volcano; showed that deformation process is happening at Aluto and its neighbor volcanoes due to the magmatic process at shallow depth (<10 km) (Hutchison et al., 2106 and Biggs et al., 2011).

2.2.5. Volcanic Hazard Factors Analysis

The four factors identified for pair-pairwise comparison including Elevation, Slope, Distance from central caldera and Stream density were reclassified into five sub categories based on their contribution for potential volcanic hazard (Table 1). Factor reclassification and assigning of hazard levels were made based on field investigation and literatures.

Table 1: Reclassified and ranked factors

Factors	Sub-factors	Ranking	Level of Hazard
Elevation (meter above sea level)	1485-1604	1	Very Low
	1604-1714	2	Low
	1714-1873	3	Moderate
	1873-2062	4	High
	2062-2479	5	Very High
Slope(degree)	0-3	5	Very high
	3-6	4	High
	6-12	3	Moderate
	12-25	2	Low
	25-30	1	Very Low
Distance from Caldera (kilometer)	0-3	5	Very high
	3-8	4	High
	8-10	3	Moderate
	10-15	2	Low
	15-20	1	Very Low
Stream Density	0-1	1	Very High
	1-3	2	High
	3-4	3	Moderate
	4-6	4	Low
	6-10	5	Very Low

2.2.6. Elevation and distance from caldera

Volcanic eruptions usually occur from the top of the volcanic mountain and the flowage materials such as (lava, pyroclastic materials and lahars) flow down to the lower elevations. The highest places of the volcano are where volcanic products are initially produced and they are areas primarily affected by volcanic hazards. The speed of the volcanic materials such as lava flows gradually decrease in temperature and speed as they flow to distant areas from their source vents (Miller, 1989). This condition of cooling and retarding in speed are faster when there is less supply of the volcanic materials and when lavas are viscos. As the volcanic materials are getting cooler and moves slower there is the chance of escaping by moving to the higher elevated areas (Miller, 1989).

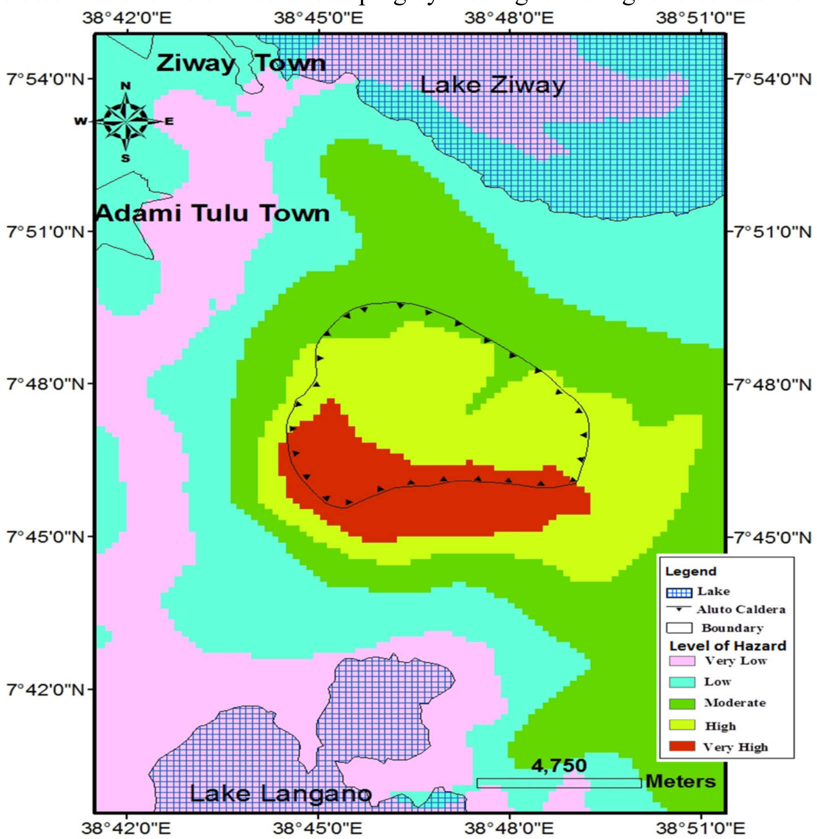

Figure 4: Hazard level map in relation to elevation factor based on table 1.

The present study indicated that higher volume of hazardous volcanic products such as lava flows, tephra falls were observed with more concentrations in Aluto central caldera. Similarly the recent field study revealed that places relatively at higher elevation and inside and closer to Aluto central caldera were areas with high to very high level of volcanic hazard potential. As areas get farther away from the central caldera and other vents volcanic hazard materials were decreased in types and thicknesses. Only sparse ash fall and lahars were observed in most areas outside the Aluto volcano. Hence as the distance become farther away from the volcano, the level of hazard gets lower and lower (Figure 5).

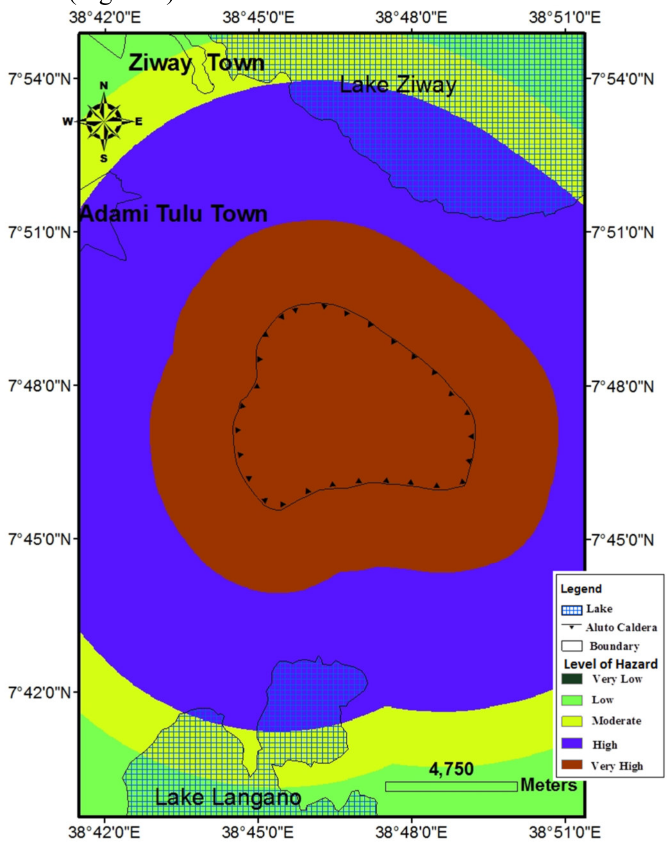

Figure 5: Hazard level map in relation to distance from centeral caldera of Aluto volcano based on classification made in table 1.

2.2.7. Drainage Networks

Lavas, lahars and pyroclastic materials initially flow following pre-existing valley networks, gullies and channels (Rossi, 1997; and Hickson et.al, 2013). After filling valley networks, gullies and channels they flow to other spaces depending on the nature of volcanic materials and continuity of their supply from their sources.

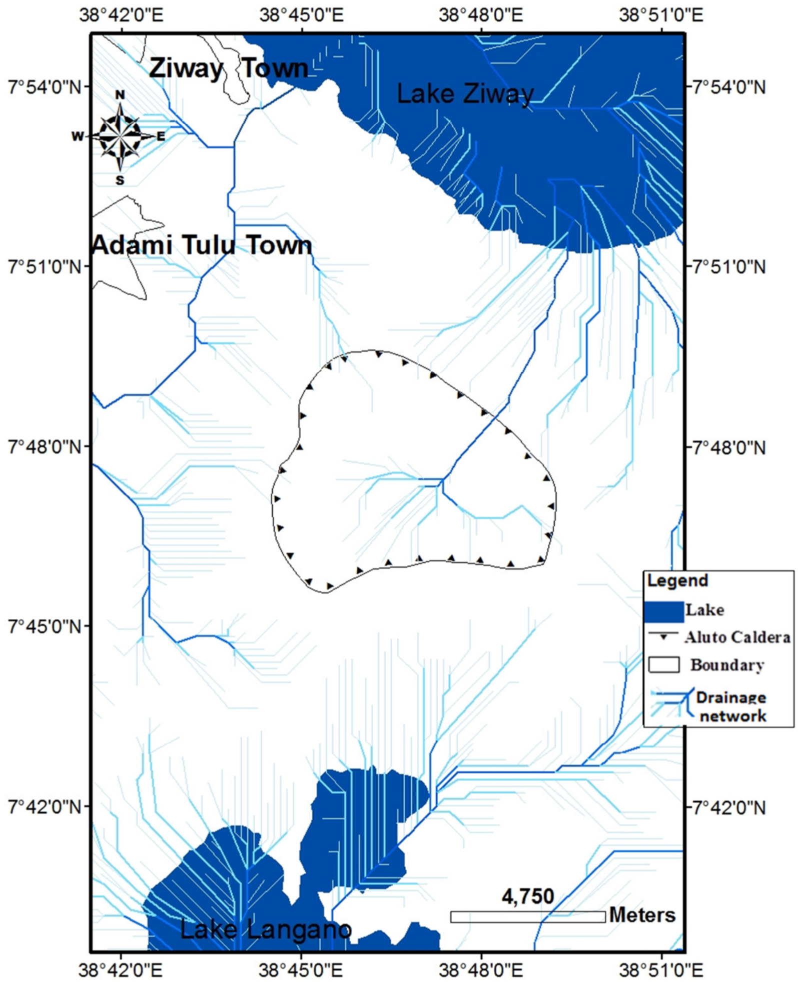

Figure 6: Drainage networks of the study area extracted from DEM.

The existence of valley networks, gullies and channels make the volcanic products to concentrate to specific areas and to follow a single pass especially in the case of flowage materials. This condition makes the flowage volcanic products not to spread throughout wider spaces. But in areas where there are no such valley networks, gullies and channels, even few volcanic materials spread throughout wider areas and can cause very high hazards. Accordingly, Aluto volcano and its surroundings are characterized by several valleys networks, gullies and channels (Figure 6) that can be good drainage for flowage volcanic materials. Most of these gorges and valleys are where already avoided by human.

The drainage density and related potential volcanic hazard level of Aluto volcano was mapped as in figure (7) using GIS methods.

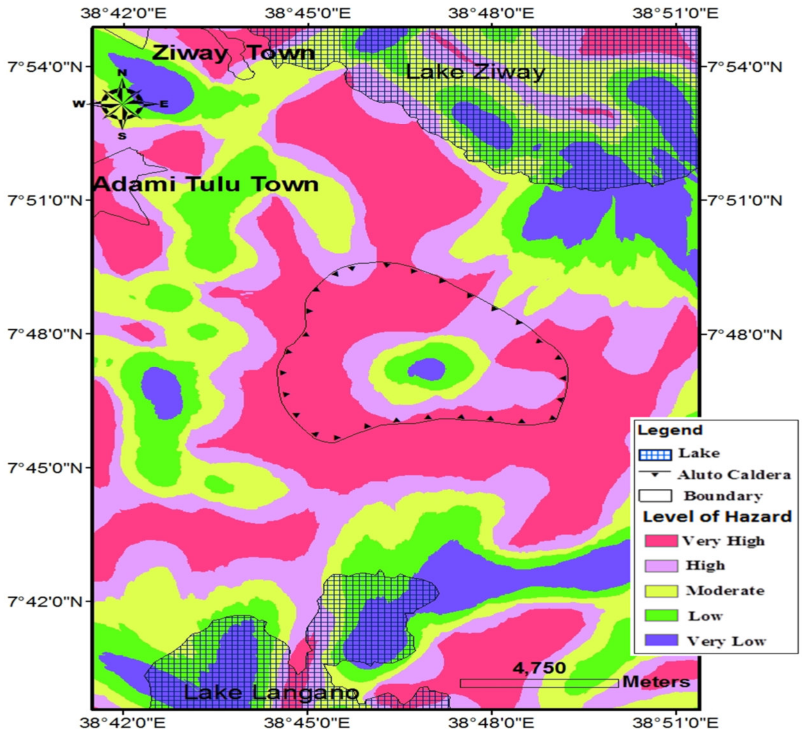

Figure 7: Level of Aluto volcanic hazard as a result of DD in reference to table 1.

2.2.8. Slope

Flowage materials when appeared onto the flanks of the volcano, they move down slope under the influence of gravity (Miller, 1989).

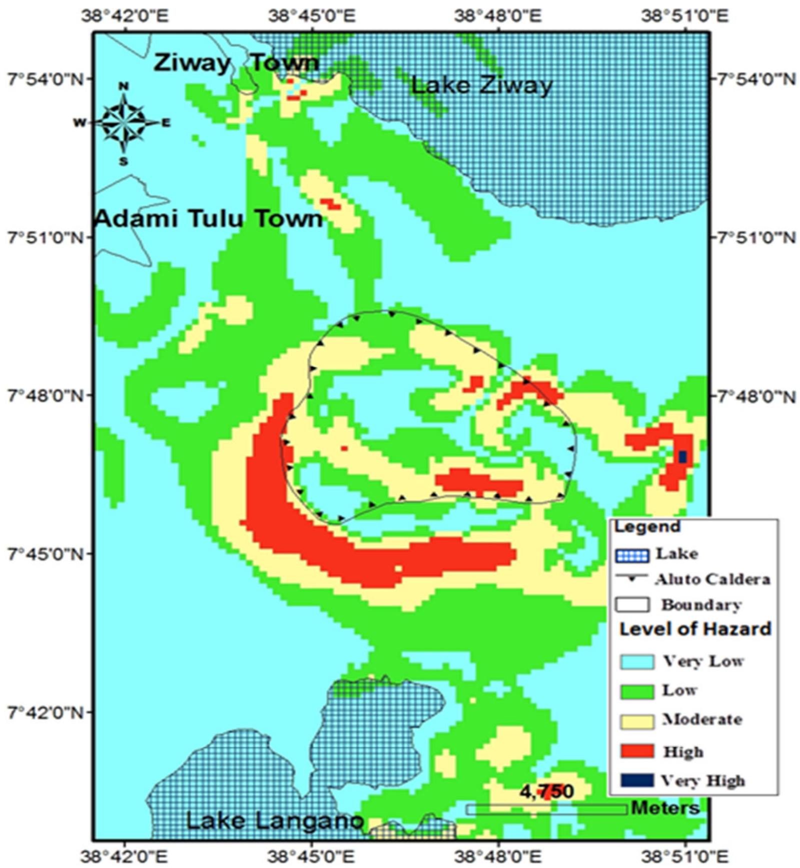

Figure 8: Aluto volcanic hazard level due to the areas slope based on table 1.

The nature of the slope with the composition, temperature, and other factors of the volcanic materials, determines the speed and distance of the flowage volcanic products (Miller, 1989). The steepness of slope can result in collapsing of unstable viscous lava domes that can generate high distractive pyroclastic flows (Miller, 1989). Increasing in the steepness of slope can also greatly increase the flow velocity of fluidal lavas, resulting in 'lava falls' and rough tortuous lava surface (Miller, 1989). Hence change in slope can also cause change in the velocity of flowage materials. The velocity of materials at steepest slope is higher than the slopes at flat areas. In areas with lowest slopes the flowage volcanic materials moves very slowly and have the chance to persist in an area for long time and can cause prolonged damages.

Similarly the slopes with lowest degree were mapped as areas with very high volcanic hazard and areas with highest slopes were mapped as very low volcanic hazard areas (Figure 8).

2.2.9. Volcanic Hazard Zonation

Pair- wise comparisons between the four factors were made using method developed by Saaty1977 and followed by various steps of calculation to arrive on final decisions. This methodology has recently been used widely in other fields of science, even though there are limitations of references for volcanic hazard assessment (Torrieri et al. 2002; Aceves-Quesada, 2006).

Step 1. Construction of pair-wise matrix

Knowledge of field study and literatures were used for evaluation and construction of pair-wise matrix in terms of importance of each criterion as indicated in equation 1.

$$\begin{bmatrix} c11 & c12 & c13 \\ c21 & c22 & c23 \\ c31 & c32 & c33 \end{bmatrix} \quad \text{………………eq.1}$$

Table 2: Pair-wise comparison matrix of the four Criteria

Criteria	Elevation	Slope	Drainage Density	Distance from Caldera
Elevation	1	0.5	0.3333	0.25
Slope	2	1	0.5	0.3333
Drainage Density	3	2	1	0.5
Distance from Caldera	4	3	2	1
Total	10	6.5	3.8333	2.0833

Step 2. Normalization of Pair-wise Matrix

After the construction of pair-wise matrix, normalized pair-wise matrix was generated by using equation 2.

$$\frac{\mathbf{cij}}{\sum_{i=1}^{n}\mathbf{cij}} = \mathbf{xij} \quad \text{…………..eq. 2}$$

- Where **xij** is the normalized value
- **Cij** is the value of the pair- wise matrix

Table 3: Normalized Matrixes

Criteria	Elevation	Slope	Drainage Density	Distance from Caldera
Elevation	0.1	0.076923	0.086949	0.120002
Slope	0.2	0.153846	0.130436	0.159987
Drainage Density	0.3	0.307692	0.260872	0.240004
Distance from Caldera	0.4	0.461538	0.521744	0.480008
Total	1	1	1	1

Step 3. Factors Weights Calculation

Following the normalization process Saaty's method of eigenvectors or relative weights of each contributing factors were calculated based on equation 3.

$$\mathbf{wij} = \frac{\sum_{j=1}^{n}\mathbf{xij}}{\mathbf{n}} \text{…………eq.3}$$

Where **wij** is weighted matrix and used as the weight of contributing factor and adopted for volcanic the four factors factors.

Table 4: Weight of the four hazard factors

Factors	Factor Weight
Elevation	0.095968
Slope	0.161067
Drainage Density	0.277142
Distance from Caldera	0.465822
Total	1.0000

Step 4. Checking for Consistency Ratio (CR)

CR checking for the pair-wise matrix was made using equation 4.

$$\mathbf{CR} = \frac{cI}{RI} \text{…………………….…....eq.4}$$

$$\mathbf{CI} = \frac{\lambda max - n}{n-1} \text{…………………..eq. 5}$$

Where,

CI is the Consistency Index provides a measure of deviation from consistency. Since CR < 0.1 is promising, if value < 0.1 is not achieved rechecking the above steps is a must.

- **n**= number of criteria used and
- λ_{max} = average value of the consistency vector
- **RI**=0.9. It is found in table (6).

Table 5: The value of RI for different number of criteria Saaty (1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The calculated Cr value is 0.043819. Since the Cr value equal to or less than 0.1 is reasonable (Saaty 1977), the rating of factors in this study indicates much lower than the threshold values of 0.1.This indicates the achievement of a high level of consistency in the pairwise judgments and the determined weights were accepted.

Step 5. Calculating Volcanic Hazard Rank (VHR)

Following the step of checking CR, VHR values were calculated using equation 6 by using Raster Calculator in Arc map 10.2. VHR were used to map the potential volcanic hazard of Aluto volcano. VHR ranges from 1 to 5. The meanings of VHR are described below.

- VHR=1 is Very Low Potential volcanic hazard
- VHR=2 is Low potential volcanic hazard
- VHR=3 is Moderate potential volcanic hazard
- VHR=4 is High potential volcanic hazard
- VHR=5 is Very high volcanic hazard

$\mathbf{VHR} = \sum \mathbf{wi} * \mathbf{fij}$…………………eq.6

Where,

- **Wi** is the calculated weight of factor "i".
- **fij** is weight assigned for sub factor "i" of class "j".

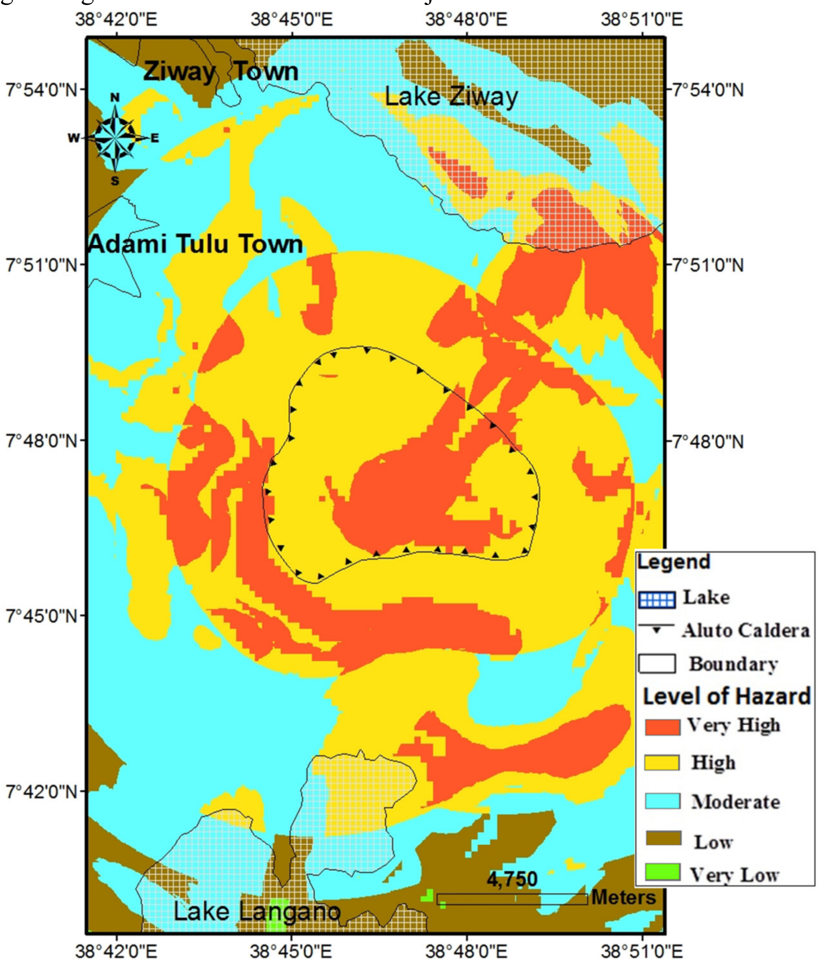

Figure 9: Potential Volcanic hazard zonation map of Aluto Volcano and surroundings based on calculated VHR.

3. Results and Discussion

3.1. Volcanic Hazard

Assessment of volcano hazards at Aluto was made based on the assumption that future volcanic activities will most likely to be similar to what has happened in the past. Because of lack of historic records on the activity of the volcano, it is difficult to estimate the future behavior of the volcano. But the only approach is to consider the youngest eruptions and events preserved in the deposits they produced. Previous investigators have studied and mapped the volcanic units and in a few studies volcanic product dating were made. The available information from the past and current studies has provided pertinent knowledge to learn about the types of past events and by inference, to identify areas that could be affected by future events. At Aluto, many of the older eruptive products are covered by younger deposits and perhaps some of the finer and thinner fall deposits have subsequently been eroded away by surface erosion. Hence, the past 2 Ka is assumed to be representative of the type of activity that has occurred throughout the volcano's lifetime.

3.1.1. Inference on Past Eruptive Styles

During field study volcanic products such as lava flows (rhyolitic lava of different ages, obsidian lava of different ages), pyroclastic flow deposit (ash flow deposit mixed with lthic fragments and pumice flows deposit), pyroclastic falls (pumice fall and ash fall),and felsic lava domes have all been found. This volcano is characterized by multiple vents from which past volcanic eruptions took place. The volcanic products found in and surrounding the calderas are indicating the type of volcanic products released during their last eruptions. Yet there is mixing of erupted volcanic products since many of the vents are closer to each other. The existing volcanic products pyroclastic falls and pyroclastic flows covered wider area than other types of volcanic products. The existence of pyroclastic flows and pyroclastic falls in wider areas of the complex and outside the complex of Aluto volcano and felsic lava domes infer that the past eruption type of Aluto volcano was dominantly explosive types of eruptions.

The felsic lava flows and felsic domes have resulted from slightly explosive strombolian type of eruption which resulted to the formation of scoria cones and basaltic eruptions. The ash air falls found outside of Aluto complex are indicators of the occurrence of pherato magmatic eruptions. The pyroclastic flows and pyroclastic falls probably resulted from Vulcanian type of eruption. Ignimbrite forming eruptions and pyroclastic deposits that possibly resulted from dome collapse are also common.

3.1.2. Predictable Volcanic Eruptions and Hazards of Aluto

The past volcanic products observed during field work together with the present manifestations of Aluto volcano (the existence of numerous fumaroles, hot springs, hot ground, high temperature at the surface and presence of magma at shallow depths, presence of lakes and faults and ground deformation) imply that the future eruptions of Aluto volcano will possibly include lava flows and explosive eruption types.

The possible explosive eruption types and hazards from Aluto may include any one of the following:

- Pyroclastic flow and fall deposits which will accompany dome collapse
- Vulcanian and Sub-plianian types of eruptions that will consist of pyroclastic flows and pyroclastic falls.
- Ignimbrite-forming eruptions
- Slightly explosive strombolian type eruptions which leads to the formation of scoria/cinder cones and basaltic eruption
- Phreato-magmatic eruptions. This type of eruption will possibly occur from vents lying on faults connected to the ground water or connecting lake Ziway and Lake Langano. Magmatic vents located on fumaroles and hot springs will also result in phreato-magmatic eruptions. The phreato-magmatic eruptions that will likely occur here can be caused by felsic or basaltic magmas interacting with water and producing pyroclastic flows and falls and maar type eruptions.

Based on the variety of past eruptive products described in earlier sections as well as future eruption types the potential hazards are inferred to be:

- Hazards from flowage phenomena (lavas and pyroclastic)
- Hazards from tephra fall and
- Emission of volcanic gases

3.2. Potential Volcanic Hazard Zones

The volcanic hazard zonation map (Figure 9) prepared for the study area has classified in to five hazard zones as very high hazard zone, high hazard zone, moderate hazard zone, low hazard zone and very low hazard zones based on the calculated VHR. Thus, the ratio of hazard zones of the mapped area is classified as indicated in table (Table 6).

The distributions of pervious volcanic units map (Figure 2) indicate the rationality of the new hazard map. According to the hazard zonation map, the central regions of Aluto volcano is found in areas of high to very high hazard level zones. Because of their lower slopes and lower altitudes, few parts of the Lake Ziway and lake

Langano regions may face high to very high magnitude of flowage and fall hazards possibly result from nearby vents found at at lower elevations. Areas at a distant from the mount Aluto such as Ziway/Batu and Adami Tulu towns and the northern part of Lake Ziway and Southern part of Lake Langano will face very low to moderate level of hazard result from probable volcanic ash falls.

Table 6: Ratio of Potential volcanic hazard zones of the study area

Value	Area(m^2)	Ratio	Volcanic Hazard Zone
1	5519700	0.91	Very Low
2	101167200	16.72	Low
3	216030590	35.70	Moderate
4	197511300	32.64	High
5	84842096	14.02	Very High
Total	605070886	100.00	

4. Conclusion and Recommendations

Prior studies and the current manifestations such as high temperatures from geothermal exploration wells, hot springs, fumaroles and hot ground as well as recent ground deformation indicate the existence of magma at shallow depth. Hence, Aluto is an active volcano with possibility of future eruption results to different eruption that can produce different hazardous volcanic products. The predicted volcanic products include lava flows and dome collapse, pyroclastic flows, lahars, tephra falls and volcanic gasses.

The volcanic hazard map produced during the current study was classified the potential volcanic hazard into five different levels. Multi-criteria approach model developed by Staaye 2080 with the integration of GIS software is adopted to evaluate the hazard index. Accordingly all parts of Aluto volcano and few areas outside Aluto volcano were mapped as areas of “high” to “very high” potential volcanic hazards. As the distance from the volcano increased the level of potential hazard decreased. This property and the previous volcanic unit map indicate the current potential volcanic hazard map zonation is valid.

The volcanic hazard map produced in this study will help the community to understand the level of potential volcanic hazard in their area and to make their own decisions to reduce possible volcanic impacts. But this is possible only when the concerned bodies deliver sufficient information. Local governments, none governmental organizations and the policy makers can also use the hazard map to plan for the safety of the people living in the study area. Additionally, this study can be applied to many other volcanoes found in Ethiopia because it requires low cost and short time. Finally, we recommend conducting further studies and continuous monitoring of Aluto volcano to reduce the likely effects result from the potential eruption.

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