Spatial analysis of a volcano's risk assessment

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Abstract: Volcanic risk maps were generated from existing hazard maps and socio-economic data using traditional graphics software but applying standard and basic procedures the same as when in a recognized Geographic Information System (GIS) platform. Geographic information on a volcano's hazards and deposits, as well as the municipal boundaries in the area, were spatially analyzed resulting in the generation of volcanic risk zones in the area. The existing maps spatially analyzed were all georeferenced with one another previously. Using the concept of "risk" involving the existence of danger or hazard and human/non-human elements being affected by the hazard itself or its consequence, risk analysis of the volcano was spatially completed. Traditional GIS procedures were applied to the georeferenced data, such as topological and spatial overlay using the technical drawing software. The risk maps generated were different levels of risk maps (high, medium and low) for the lava, pyroclastic and lahar flow hazards. In an environment devoid of an operational GIS hard- and software, and cash-strapped for almost all other related expenses but has technical manpower equipped with the fundamental knowledge on the subject matter, volcanic risk assessment was successfully completed. This risk assessment procedure can provide answers to the questions such as what type of volcanic hazard is going to affect which area and what socio-economic parameter will be affected and where.
Keywords: GIS, volcanic risk and hazard maps, geoinformation, spatial and topological analysis, risk assessment and analysis

1. Introduction

Risk assessment of a volcano is the subject matter of this paper. The assessment involves spatial analysis of the volcano and its vicinity using the geographic information and the socio-economic data of the area. These are the maps of the area – topographic and hazard – and its socio-economic profile. Thus, spatial analysis of the volcano is done in order to come up with the risk assessment of the area using its topographic and hazard maps and the socio-economic data. Canlaon Volcano (10°24.7'N, 123°7.9'E) in Negros Oriental Province, Philippines, is the study area for this research.

Geographically, information on Canlaon Volcano and vicinity was analyzed, processed and manipulated in a digital environment. The topographic, geologic and hazard maps of Canlaon are available in digital environment (Canvas software/format) and spatial analysis was done in this platform. Eventually, the resulting risk maps were derived in Canvas environment. The study area (Fig. 1) covers an extent from approximately 10º10'N to 10º40'N latitude and approximately 122º47'E to 123º24'E longitude.

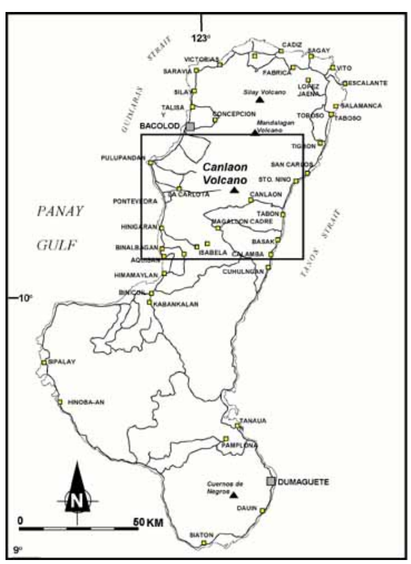


Fig. 1. Canlaon Volcano and vicinity

The existing geologic and hazard maps of Canlaon Volcano by the Philippine Institute of Volcanology and Seismology (PHIVOLCS) are dated February 2000. These maps are made using the National Mapping and Resource

Information Authority (NAMRIA) 1:50,000 topographic maps dated 1950s with additional data on the city, municipal and barangay boundaries coming from the local municipal/city planning offices as of March 1999. Population, infrastructure, and the like are data obtained from the Negros Occidental Province Socio-Economic Profile valid until 2005 and some Internet sites like the Wikipedia.

2. Risk context

"Risk" of an area is defined in terms of how much of the area concerned is enclosed within a hazard zone. Several definitions of the term "risk" were encountered from among the literature on this topic. Based on the literature, the concept of risk involves a) the existence of danger or hazard; and b) the existence of human and non-human elements being affected by the hazard itself or its consequence. If there exists a relationship between these two factors then there is a risk that can be discussed.

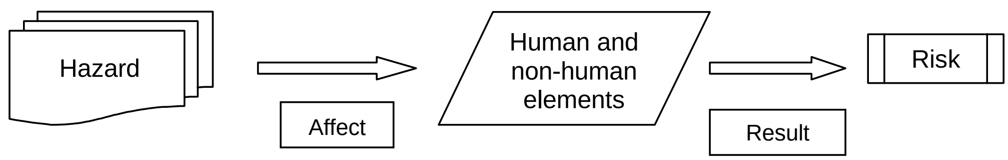


Fig. 2. Data flow diagram of the concept of "risk"

Fig. 2 is the diagram illustrating the conceptual foundation or existence of "risk." If there is a danger affecting people or things (or vice versa, i.e., if there are people or things that are affected by some danger) then there is a risk involved. In reporting risk assessment, therefore, the statement should include information on the hazard that is going to affect the area and what elements and places will be affected.

3. Methodology and analysis

The first things considered in the risk assessment of Canlaon Volcano are the available data. The topographic and geologic maps of Canlaon Volcano consist of layered information all co-registered with one another. Specifically, the layers needed for the risk assessment procedure are as follows:

1) municipal boundary
2) coastline and river
3) road
4) contour/elevation lines
5) delineation/zones of lava flow, pyroclastic flow, and lahar hazards
6) delineation/zones of lava flow, pyroclastic flow, and lahar deposits

Spatially, there is data on hazard and volcanic deposit extent of Canlaon Volcano available in PHIVOLCS, delineation of which is mapped using the NAMRIA 1:50,000 topographic maps and the boundary maps from the local planning offices. The map information were digitally converted and maintained using the Canvas software.

The other type of data needed for the risk assessment aside from the spatial data is the socio-economic data, which is found in the Negros Occidental Provincial Socio-Economic Profile and some Internet site. These data include population and infrastructure like roads, bridges, etc. Almost all of these profiles are in tabular form listed per municipality. There exists a georeferenced layer of the municipal boundaries, which suitably complements the hazard and deposit layers for the risk analysis. Hence, the three primary layers of co-registered GIS data used for risk assessment are the Canlaon volcanic deposit and hazard layers and the municipal boundary layer.

Following the conceptual data flow diagram of risk, there exist the two parameters for risk to be present – the volcanic hazards from Canlaon Volcano and the population and infrastructure in the area. The presence of the hazards affects the people, roads, bridges and everything within Canlaon Volcano and vicinity. Therefore, there is a risk involved in this scenario.

The fundamental GIS procedure done to the georeferenced spatial data of Canlaon was the topological overlay procedure. This basic process involves putting together two or more layers of geographic information into one. Spatially, this means putting together one layer on top of the other to generate another layer. Overlay is a GIS operation in which layers with a common, registered map base are joined on the basis of their occupation of space [1]. Overlay of the layers containing the hazard and deposit delineation over the layers containing the topographic data, like the municipal boundary, gives which areas and how much of the areas are susceptible to the hazard. This is the general assessment of the volcanic risk in the area.

In a GIS, the layers of geographic information consist of any of these geographic features: points, polygons and/or lines. In terms of spatial correlation, a relationship between polygons, points and/or lines could be a result of any spatial process between them. These spatial processes could be addition, subtraction, intersection, union, or buffer.

All the primary spatial data being used for risk analysis (volcanic hazard and deposit, and municipal boundary) are polygon layers (Fig. 3, 4 and 5). Intersection of these polygon layers is the spatial process performed. As an example, intersection of the lahar hazard layer with the municipal boundary layer gives the spatial distribution of the area affected by the lahar hazard. The municipal boundary layer has population data coming from the Socio-economic data, thus, there exists the lahar risk for the municipalities.

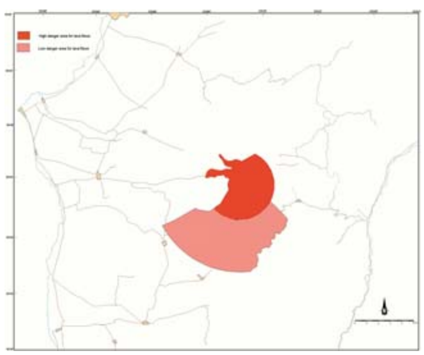
4. Risk zones generated

The layers used in the risk analysis are the lava flow, pyroclastic flow, and lahar hazards containing the hazard delineations or zones and the volcanic deposits showing lava flows, debris avalanche, fluvial and pyroclastic flows. These are as follows:

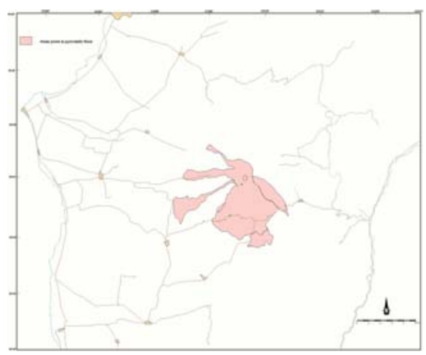
1) Lava flow
    a) High lava flow hazard
    b) Low lava flow hazard
    c) Lava flow deposit
2) Pyroclastic flow
    a) Pyroclastic flow hazard
    b) Pyroclastic flow deposit
    c) Debris avalanche deposit
    d) Fluvial deposit
3) Lahar
    a) Lahar prone

The intersection of the high lava flow hazard with the municipal boundary layer gives the areas at high risk to lava flow. Intersection of the low lava flow hazard with the municipal boundary layer was subtracted from the high risk to lava flow polygon. The result is the polygon at medium risk to lava flow. There is the layer showing the lava flow deposits around Canlaon Volcano, which was also intersected with the municipal boundary layer. From this polygon, the high and medium risk to lava flow polygons were subtracted to generate the polygon for low risk to lava flow. Thus, three layers were generated for lava flow risk: high risk, medium risk and low risk.

The delineation of the lava flow risk was considered to generate the risk zone for lava flow hazard based on the principle that mapping out of that volcanic product validates the existence of the danger in the covered area. The fact that lava flow deposit was present in the area supports the notion that the area is at risk to lava flow. Giving it the minimum value point in the degree of its risk, the lava flow deposit layer was used to generate the low risk to lava flow polygon.



a)



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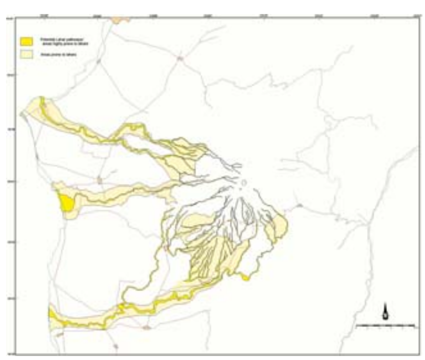

c)

Fig. 3. Canlaon Volcano hazard layers a) Lava flow; b) Pyroclastic flow; c) Lahar

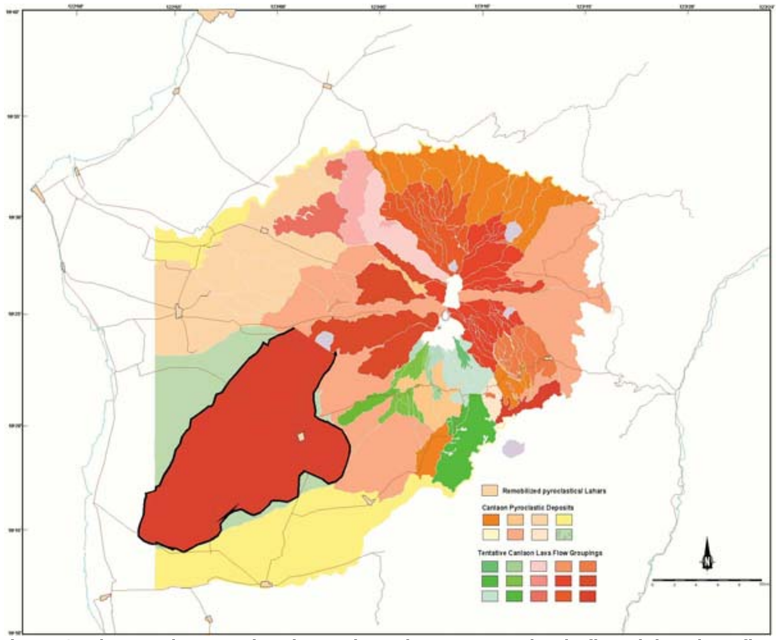

Fig. 4. Canlaon Volcano volcanic products layers: Pyroclastic flow, lahar, lava flow

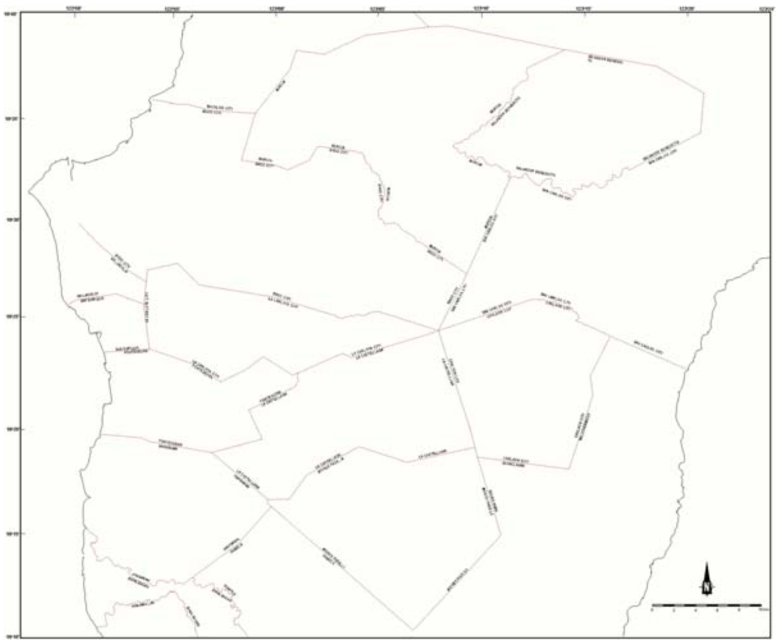

Fig. 5. Municipal boundary layer, Canlaon Volcano

For the pyroclastic flow risk, spatial analysis used the layers showing delineation of pyroclastic flow hazard and deposits, debris avalanche and fluvial material. Intersection of pyroclastic flow hazard and municipal boundary gives the area at high risk to pyroclastic flow. The polygons containing deposits of pyroclastic flow, debris avalanche and fluvial material were combined. The sum of these polygons was intersected with the municipal boundary layer. The high risk to pyroclastic flow polygon was subtracted from the resultant polygon of this intersection giving the low risk to pyroclastic flow area. The pyroclastic flow hazard has, thus, two risk areas – high risk and low risk zones.

Finally, for the lahar risk analysis there is only one hazard layer available, the lahar prone layer. This layer was intersected with the municipal boundary layer giving the areas at risk to lahar hazard. There is no other lahar hazard layer or zone in the hazard map by PHIVOLCS, so this risk could only be derived from that hazard layer.

The risk maps, thus, generated for Canlaon Volcano are the following: High Risk Map to Lava Flow (Fig. 6), Medium Risk Map to Lava Flow (Fig. 7), Low Risk Map to Lava Flow (Fig. 8), High Risk Map to Pyroclastic Flow (Fig. 9), Low Risk Map to Pyroclastic Flow (Fig. 10), and Lahar Risk Map (Fig. 11).

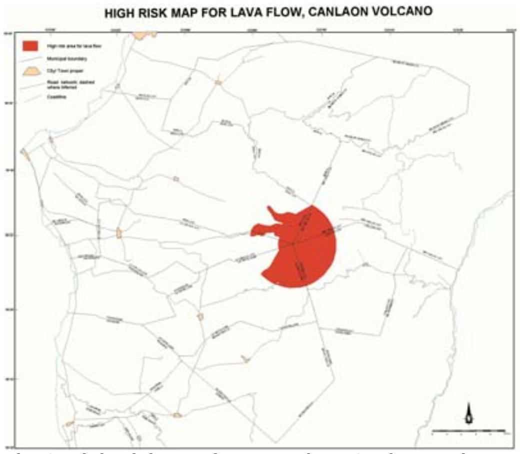

Fig. 6. High Risk Map for Lava Flow, Canlaon Volcano

Fig. 7. Medium Risk Map for Lava Flow, Canlaon Volcano

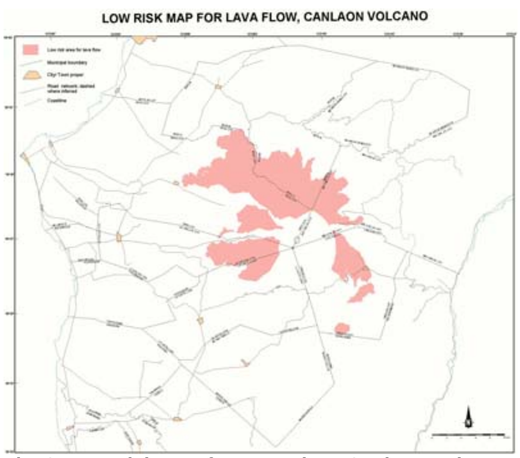

Fig. 8. Low Risk Map for Lava Flow, Canlaon Volcano

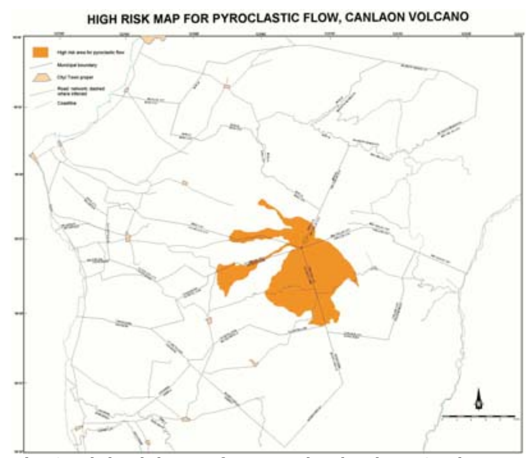

Fig. 9. High Risk Map for Pyroclastic Flow, Canlaon Volcano

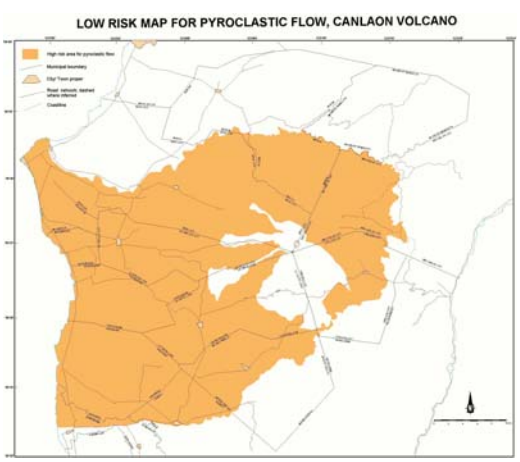

Fig. 10. Low Risk Map for Pyroclastic Flow, Canlaon Volcano

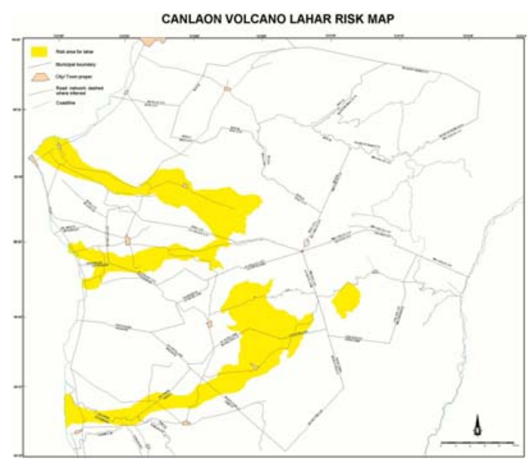

Fig. 11. Lahar Risk Map, Canlaon Volcano

5. Conclusion

Presented in this paper are risk zones for a volcano derived from spatial analysis of the georeferenced data on volcanic hazards, deposits and municipal boundary, all done in a traditional graphics software environment. Some hazard layers were directly intersected with the municipal boundary layer to obtain risk zones. Some deposit layers were combined and then subtracted to or from the next level risk zones in order to generate the lower level risk zones. In summary, there are six risk maps generated for the Volcano and these are the high, medium, and low risk maps for lava flow; high and low risk maps for pyroclastic flow; and the lahar risk map.

Spatial analysis of the geographic information on the volcano's hazard and deposit as well as the municipal boundaries in the area resulted in the generation of volcanic risk zones. The risk assessment answers the questions on 1) what type of volcanic hazard is going to affect which area (where) and 2) what socio-economic parameter will be affected and where. Successful completion of volcanic risk assessment was done in an environment devoid of an operational GIS hard- and software due to lack of financial capacity but instead relying on the technical manpower equipped with the fundamental knowledge of geoinformation concept.

Primary socio-economic information derived from this particular risk assessment procedure for Canlaon Volcano is listed in Table 1.

In conclusion, risk assessment for Canlaon Volcano was made from spatial analysis of available geographic information generating risk maps and deriving information for socio-economic planning, disaster mitigation, and preparedness plans in the area.

Table 1. Summary of volcanic risk assessment for Canlaon Volcano

Municipality/City	Population	Hazard	Infrastructure/Facility
Bacolod City	429,076		Bridges, private ports, airport, hospital/health center, road system, school, firefighting facility
Bago City	141,721	Partially high risk and partially low risk for pyroclastic flow and lava flow; partial risk for lahar flow	Hospital/health center, road system, school
Binalbagan	58,280	Partially low risk for pyroclastic flow and partial risk for lahar flow	Hospital/health center, road system, school, firefighting facility
Canlaon City	46,548	Partially high risk and partially low risk for pyroclastic flow; partially high, medium and low risk for lava flow; and partial risk for lahar flow	Bridges, hospital/health center, road system, school
Guihulngan	17,733		Hospital/health center, road system, school
Himamaylan City	88,684		Bridges, ports, hospital/health center, road system, school, firefighting facility
Hinigaran	74,497	Partially low risk for pyroclastic flow and partial risk for lahar flow	Bridges, hospital/health center, road system, school, firefighting facility
Isabela	48,719	Partially low risk for pyroclastic flow and partial risk for lahar flow	Bridges, hospital/health center, road system, school
La Carlota City	56,408	Partially high risk and partially low risk for pyroclastic flow; partially low risk for lava flow; and partial risk for lahar flow	Hospital/health center, road system, school, firefighting facility
La Castellana	59,102	Partially high risk and partially low risk for pyroclastic flow; partially high, medium and low risk for lava flow; and partial risk for lahar flow	Bridges, hospital/health center, road system, school, firefighting facility
Moises Padilla	34,658	Partially low risk for pyroclastic flow; partially medium risk for lava flow; and partial risk for lahar flow	Bridges, hospital/health center, road system, school
Murcia	54,358	Partially low risk for pyroclastic flow and partial risk for lahar flow	Bridges, private ports, hospital/health center, road system, school
Pontevedra	42,089	Partially low risk for pyroclastic flow and partial risk for lahar flow	Hospital/health center, road system, school, firefighting facility
Salvador Benedicto	17,259		Hospital/health center, road system, school
San Carlos City	118,859	Partially high risk and partially low risk for pyroclastic flow and lava flow	Bridges, airport, hospital/health center, road system, school
San Enrique	22,091	Partially low risk for pyroclastic flow and partial risk for lahar flow	Bridges, hospital/health center, road system, school
Valladolid	32,576	Partially low risk for pyroclastic flow	Bridges, hospital/health center, road system, school
Vallehermoso	33,914		Hospital/health center, road system, school

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