Applications and Advantages of Hazard Maps for Volcanic Eruptions in the Philippines

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Before Pinatubo Volcano erupted cataclysmically in 15 June 1991, National and Local governments were armed with their best defense for averting a terrible volcanic disaster. As early as 3 weeks prior to eruption, the Philippine Institute of Volcanology and Seismology, Department of Science and Technology (PHIVOLCS-DOST) and the U.S. Geological Survey drew a hazard map showing the major threats and their probable extent of damage. This hazard map embodied a rapid assessment of volcanic hazards that was a result of careful geological mapping. With the help of the media, some non-government organizations and the authorities, a massive information campaign was sought to disseminate the information contained in the hazard map. As one result, by the time the eruption was well underway, virtually all areas damaged by the eruption was evacuated of people. Conservative estimates suggest that at least 5,000 lives were saved by this advanced warning. In addition, millions of dollars were saved by moving equipment out of harm's way. About a decade later, the very same lessons learned at Pinatubo were applied on Mayon Volcano, during its multiple eruptions in 1999, 2000 and 2001. It is truly fortunate that techniques from volcano surveillance to basic geological mapping to interaction with national and local governments and the public sector have been successfully applied, resulting in the saving of many in communities surrounding Mayon.
In the following, I present the importance of volcanic hazards mapping as an indispensable tool for public safety and sustainable development in areas where active volcanoes occur. Some general methods are discussed and examples are given from the invaluable experiences of Pinatubo and at Mayon

Volcanic eruptions generally pose a combination of hazards at the same time. From the same material of magma, differences in eruption styles produces different erupted products. But perhaps the ultimate complication occurs when rains coincide with an eruption. The combination of water and hot volcanic deposits facilitate transport of volcanic sediment or debris into lowlands that are often populated. Sometimes this rain is due to topographic effects but coincidence may bring a typhoon and an eruption together. Massive debris flows, mudflows or lahars thus swept many lowland areas surrounding Pinatubo Volcano in June 1991 with the passage of Typhoon Yunya over the volcano. This seemingly rare coincidence underscores the need for considering many scenarios of volcanic eruption, even if such scenarios are deemed very unlikely. A small chance of possibility should therefore be treated just like any scenario and be disaster mitigation measures should be prepared for the possibility accordingly.

Volcanic hazards come in many forms. An eruption produces several phenomena, each with its own kind of hazard. These are summarized in the following:
1.Pyroclastic flows are turbulent mixtures of hot volcanic debris and gases that sweep down from a volcano at high speeds. Because pyroclastic flows travel so quickly and are so hot, they kill nearly everything in their paths. Pyroclastic flows are also known to surmount topographic barriers so that hills and ridges facing a volcano are not necessarily safe from the devastating effects of these flows.
2.Lava flows may travel more slowly than pyroclastic flows but the often hard lava deposits they

leave behind mean that previously cultivated land become unsuitable for agriculture for a very long time. Lava flows are also very hot and move like a bulldozer, destroying mostr structures in their paths.
3.Ashfalls are deceptively dangerous deposits. Roofs collapse under their sheer weight, especially when saturated with water. After all, volcanic ash is still pulverized rock material. When airborne, volcanic ash becomes a grave threat to aircraft. The small ash particles in an ash cloud are tiny enough not to be discerned readily when dispersed. However, ash particles can clog and damage aircraft engines, causing a phenomenon called flameouts.
4.Lahars perhaps inflict more damage to other hazards because these form during and long after eruptions have ceased. The combination of pyroclastic debris and water produces a cement-like slurry.

Volcanic eruptions are usually short-lived events with some exceptions. Large eruption episodes such as the 1991 Pinatubo eruption lasted only for about 10 hours. Smaller eruptions like a typical Mayon eruption may last between a day to 3 weeks. However, effects of these eruptions on the land are quickly diminished as nature rapidly reclaims land. In addition, effects of a volcanic eruption are usually localized, affecting only the vicinity of the volcano (again, with exceptions).

Volcanic hazards and their impacts, especially for instances when loss of life have been nil, may place a population in a complacent mode. One grave mistake authorities and surrounding communities might make is to place a low prioroty to volcanic disaster mitigation in areas with an active volcano. Hazard maps are one way to determine a volcano's destructive potential and to prepare for by establishing and observing safety zones.

Hazard maps provide an overall view of the placement of a community's resource usage and whether such resources are at risk.

The cost of establishing and maintaining a volcano monitoring program is admittedly high, From the above table, the costs incurred with systematic observation and deployment of equipment and personnel at Pinatubo ran in the millions od US dollars. However, from conservative estimates by the U.S. Geological Survey, the value of equipment saved is about ten times as much as the initial investment. This estimate of money saved does not include the value placed for human lives which is often, arguably, priceless.

The cost-benefit comparison for the Mayon eruption is less dramatic than the Pinatubo Volcano example. However, it is still evident that the many lives saved by safely evacuating communities out of the danger zone make the monitoring and eruption prediction a worthwhile effort.

The organization of volcanic disaster mitigation is considered under a national program supervised by a governing council called the National Disaster Coordination Council or NDCC. Under this national level are the different councils grouped according to political units from the regional then to provincial and down to the village level. One advantage of this scheme is to ensure that even the smallest political unit is represented and its needs during natural disasters are recognized.

In practice, the Provincial levels are most effective in mobilizing a disaster mitigation effort in a community. This is perhaps due to the recognition and strong representation of a Provincial Government to the National Government in terms of requesting for resources necessary for evacuation and disaster mitigation activities. The Office of Civil Defense (OCD) has also a strong unit and liaison with the National Government OCD.

Volcanic disaster mitigation in the Philippines is embodied in a policy, guidelines and disaster preparedness manual or handbook. This document lays down the guiding principles for planning activities. In addition, this plan identifies all necessary agencies, offices and departments which must cooperate with the NDCC in achieving disaster mitigation activities during natural calamities.

Hazard maps play an important role in identifying the location, magnitude and countermeasures to be undertaken during volcanic crises.
In the planning process, PHIVOLCS is expected to arrive at volcanic hazard maps to show basic information about volcanic activity. The hazard maps become the basis for an action plan that would detail the areas to be evacuated, evacuation routes and evacuation centers. These details must satisfy a certain set of criteria according to the needs of communities at risk so that maximum safety is ensure at all times.
Planning officers also consider inputs from volcanic hazard maps as a consideration for zoning practices and for land-use, among others.

Disaster mitigation always involve a varied number of interest groups in the public and private sectors. Hazard maps provide a concise and simplified way of directly showing specific hazards and the extent of possible or probably damage. Hazard maps, when properly explained, directly guide authorities to concentrate precious resources to priority areas. Maps are the only way to show and explain boundary zones on safey and danger.

Moreover, hazard maps allow all sectors to plan their responsible participation in the disaster mitigation process. Often a public or private entity that is reluctant to leave their properties are convinced to evacuate only when presented by some graphic scenario which is easier to understand than a purely textual or verbal report.

Planning for, and action to avert loss of life and property are only made possible if there is an overall view of the situation. In this regard, specific measures for siting evacuation shelters and safe passage to these centers are best portrayed by hazard maps.

The establishment of evacuation routes, shelters and appropriate engineering countermeasures are only possible when the extents of hazardous volcanic processes are known. In terms of developmental needs, safe location of lifelines such as water, power and communication facilities are best determined from hazard maps.

To arrive at appropriate hazard maps for an active volcano, it is necessary to devote certain resources such as basic skill on the production of base maps and geological mapping of the various deposits produced by the volcano.

The visit of Chairman of the National Disaster Coordinating Council (NDCC) of the Philippines, in this case, to Mayon Volcano (Jan 2001) and vicinity shows the high level support and attention given by the National Government to potential volcanic disasters. From the on-site inspection by the Chairman of NDCC, the requirements of volcanic disaster mitigation activities are given priority, expecially in terms of logistics from the Department of National Defense, that cannot be provided by other government units.

At the Provincial Government level, where on-site measures for volcanic disaster mitigation take place, hazard maps are presented before various sectors of the Province, from the Office of Civil Defense to Regional government offices, to City and Municipal officials and the media, so that concerns of all these representatives and actions to address specific problems are discussed and resolved.

The true test of disaster mitigation plans in this case are realized with the occurrences of major volcanic eruptions. With no casualties and more than 80,000 residents temporarily evacuated to shelters, the Mayon 2000 and 2001 preparation and response were heralded as examples of "near-perfect disaster mitigation".

The Pinatubo eruption in 1991 impacted such a large area of Luzon that these impacts are easily detected from space satellites. About five major river channels are seen in this Landsat image, where major pyroclastic flows and repeated lahars or volcanic mudflows ravaged the surrounding communities. The Pinatubo 1991 eruption is now recognized as the largest volcanic eruption in the world in nearly a century, with impacts that showcase the awesome and devastating effects of an explosive eruption. The eruption blew off the top of the Pinatubo mountain and in its place formed a void now filled with mostly rain and groundwater. As time goes by, Pinatubo's landscape continuously changes, with dramatic modifications to surrounding land. Yet this latest Pinatubo eruption is but a small to moderate one, as indicated by studies on it historical eruptions.

Prior to the June 1991 eruptions of Pinatubo, several questions became key focal points to consider when arriving at a disaster mitigation plan. Scientists since April knew that Pinatubo was reactivating and that as each day passed since heightened activity was detected, that a volcanic eruption was likely. But the main questions were:
1.What were the types and magnitudes of past eruptions by Pinatubo?
2.How long ago were the eruptions?
3.To what extent did pyroclastic flows and other destructive volcanic processes occur?

It became evident from maps evolving at the time that Pinatubo was capable of very large and explosive eruptions. This was determined from the extensive pyroclastic deposits found in excess of 40 kilometers away from the Pinatubo summit.

Carbon 14 age dating also suggested that Pinatubo erupted quite recently, from about 500 to 1,000 years ago. In addition, these ages meant that 500 years had already past since the latest eruption.

On these and other characteristics of Pinatubo, volcanologists began to translate geological information into a hazard map.

Major river channels are good candidates to consider as likely pathways for volcanic flows. Both pyroclastic flows and lahars follow gullies radiating from a volcano although with large volume flow, channels are often overtopped. At Pinatubo, volcanologists identified the main waterways as the primary paths to be taken by future volcanic flows.

This sketch of a hazard map was presented to national and local government authorities on 28 May 1991. It showed the major river channels draining the volcano as the likely paths for volcanic flows. In addition, a broad area to the west of the Pinatubo summit dome and to a lesser extent to the east, were identified as areas susceptible to pyroclastic flow hazard.

Ashfall distribution is highly affected by prevailing winds. The map shows two main lobes that are caused by the Southwest and Easterly winds prevailing over the Pinatubo area.

Digital mapping using a GIS program allows PHIVOLCS to model some of the volcanic flows in terms of their distribution and extents. Some factors such as volume and even velocities can be determined for a specific channel, using data from periodic ground-based geodetic observations. Used against a backdrop of remotely sensed image data, this lahar hazard map of Pinatubo shows different zones according to degrees of risk in a simplified scale of low, moderate and high risk.

Images acquired through time are useful for comparing how specific hazards evolve so that appropriate countermeasures may implemented. In the Synthetic Aperture Radar images above, it is evident that the Pasig-Potrero River has swelled to encompass a larger populated area. The changes depict some kind of imbalance in river water (caught from the corresponding watershed) and sediment supply to the drainage capacity downstream. Note, however, that other drainage channels do not display the dramatic changes and remain largely the same in configuration and size even with seasonal increase in water supply brought by the monsoon rains.

The four images from 1991 to 1998 show the diminished sediment cover over pre-eruption terrain. This is shown above as as a progressive decrease in pyroclastic deposits through time, as these are remobilized and redistributed downstream by the drainage (river) system. Note how the areas surrounding the caldera or crater become more red which signifies the return of vegetation. Reduction of sediment supply on the upper and middle slopes plus the return of vegetation cover are indicators of diminished lahar hazards. This is good news to the lowland areas which have been trying to recover form the devastating effects of repeated lahar episodes.

However, as also shown clearly in this set of images, the caldera lake has progressively increased in diameter showing the accumulation of water. As early as May 2000, the Volcano Monitoring and Eruption Prediction Division of PHIVOLCS brought to the public's attention the danger of a crater lake breakout. The lake breakout was inevitable as the lake levels rose from continued rains and landslides caused by detachment of loose deposits from the caldera walls.

The caldera lake finally broke through naturally on July 2002 even after attempts were made to breach the lowest portion of the caldera rim in September, 2001.

Mayon Volcano in Southeast Luzon is another example of a modern best country practice in the application of hazard maps. As a result of diligent monitoring and unsurpassed cooperation between authorities and scientists, there have been zero casualties for the eruptions in the Years 2000 and 2001.

Mayon is the most active volcano in the country, and has erupted about 47 times since 1616. There are 13 municipalities and one City located around the volcano. About 20,000 to 25,000 people live within and close to the Permanent Danger Zone, an area enclosed by a 6 kilometer radius from the summit crater.

Hazards brought about by Mayon eruptions and post eruption activity are usually caused by pyroclastic flows, lahars, lava flows and ash. Here we view Mayon to the North with a continuous steam being emitted that drifts westward by prevailing winds.

The rocky foreground is the river channel of Mabinit, which is a pathway for pyroclastic flows and lahars.

Lava flows occur as discrete tongues or elongate lobes of andesitic lava that course through upper gullies. From geological mapping, lava flows are known to reach some 6 kilometers from the active crater.

Pyroclastic flows and related phemonena such as volcanic surges are the most dangerous of the eruption hazards at Mayon. Pyroclastic flows observed in 1984, 2000 and 2001 were clocked at about 55 meters per second as they rushed toward the middle slopes. In general, pyroclastic flows do not go well beyond 6 kilometers from the summit although some historical eruptions (1897) clearly demonstrate the capability of pyroclastic flows to reach farther downstream and into the gulf area to the southeast. This observation is therefore incorporated in the hazard map for Mayon.

Lahars may inflict greater damage than other eruption related hazards because mudflows may occur even long after the eruption has stopped. Lahars are caused by rainwater seeping into and remobilizing loose pyroclastic debris. The resulting water-sediment mixture which may be very hot if remobilized just after an eruption, is often compared with a slurry not unlike that of wet cement but which can flow very rapidly. In addition, lahars often flow into the lowlands, following the major river channels and fanning out or spreading over the gentle slopes. Thus lahars are a major concern by residents and authorities as opposed to a flood, because lahars leave behind a chaotic assemblage of rock and sand, destroying structures and existing crops.

Airborne ash are often distributed near and far from the volcanic source by prevailing winds. Ashfall accumulations on top of houses and buildings are known to cause roofs to collapse. The Sulfur in volcanic ash, when mixed with rainwater, produces sulfuric acid or acid rain, which is harmful to crops. In addition ash particles suspended for a long time in higher altitudes are a great threat to aviation, causing in some instances aircraft engines to stall.

A concluding step in the production of a hazard map is to consider multiple hazards and arriving at a zonation scheme. In the case of Mayon, because of its highly conical symmetry, it is more conservative to consider that hazards may occur at all sides of the volcano and not just at one particular river gully. An examination of the deposits emplaced by the Year 2000 eruption validates some previous observations on the extent of deposits to be erupted. The red elongate deposits show the extents of lava flows while the orange colored areas show the extent of pyroclastic flow deposits. It is evident that both these hazards are, in general, contained within a 6-kilometer radius zone as reckoned fro the summit crater.

For additional safety, en "Extended Danger Zone" was recommended in the southeast, considering that the "runout" or extent of reach by pyroclastic flows and volcanic surges may exceed 6 kilometers

This slide shows a comparison between hazards, which resulted from the Year 2000 and Year 2001 eruptions.

The two hazard maps are similar except for a significantly larger Extended Danger Zone in the southeast sector. This change was necessary because during the 2001 eruption, explosions destroyed a portion of the upper slopes, causing two gullies to merge at their upper reaches.
Disaster mitigation officials have used these maps for determining the quickest, safest, and most efficient way to evacuate residents prior to a major eruption.