Estimating erosion in volcanic deposits on Mount Pinatubo (Philippines) using a DTM overlaying technique

C.J. van Westen
(International Institute for Aerospace Survey and Earth Sciences, ITC, PO Box 6, 7500 AA Enschede, The Netherlands)
and
A.Daag
(Philippines Instute for Volcanology and Seismology, Quezon City, Philippines)

Abstract

The eruption of the Pinatubo Volcano on June 15, 1991 deposited approximately 5 to 7 km^3, of pyroclastic flows. The pyroclastic flow deposits affected eight major watersheds around the slopes of the volcano and radically altered the hydrological regimes, leading to unprecedented amounts of erosion and sediment delivery in the form of destructive lahars. One of the eight watersheds, the Sacobia catchment, was studied in detail. The Sacobia watershed is situated on the eastern slope of the volcano and drains 2 major rivers: Sacobia and Pasig.

The rapidly changing geomorphology of Sacobia watershed before, during and 3 consecutive years after the eruption was investigated in this study. To quantify the volumes of pyroclastic flow material and the yearly erosion, five Digital Terrain Models (DTM) were made, and analysed using a the Map calculation in the ILWIS 2.1 geographic information system (GIS).

Introduction

Mount Pinatubo is situated on the island of Luzon, about 80 km northeast of Manila, the capital of the Philippines. The main eruption of Mt. Pinatubo occurred on June 15 1991. An overview of the area surrounding Mount Pinatubo, and the deposits resulting from the 1991 eruption, as well as the lahar deposits from 1991 till 1994, is shown in figure 1.

The rapid erosion or removal of the 1991 pyroclastic flow deposit is one of the major social and scientific concerns after the 1991 eruption of the Pinatubo Volcano because this generates life threatening and destructive lahars of enormous magnitude which will continue to occur for several years, as long as there is a sufficiently large volume of loose pyroclastic flow material (see figure 2).

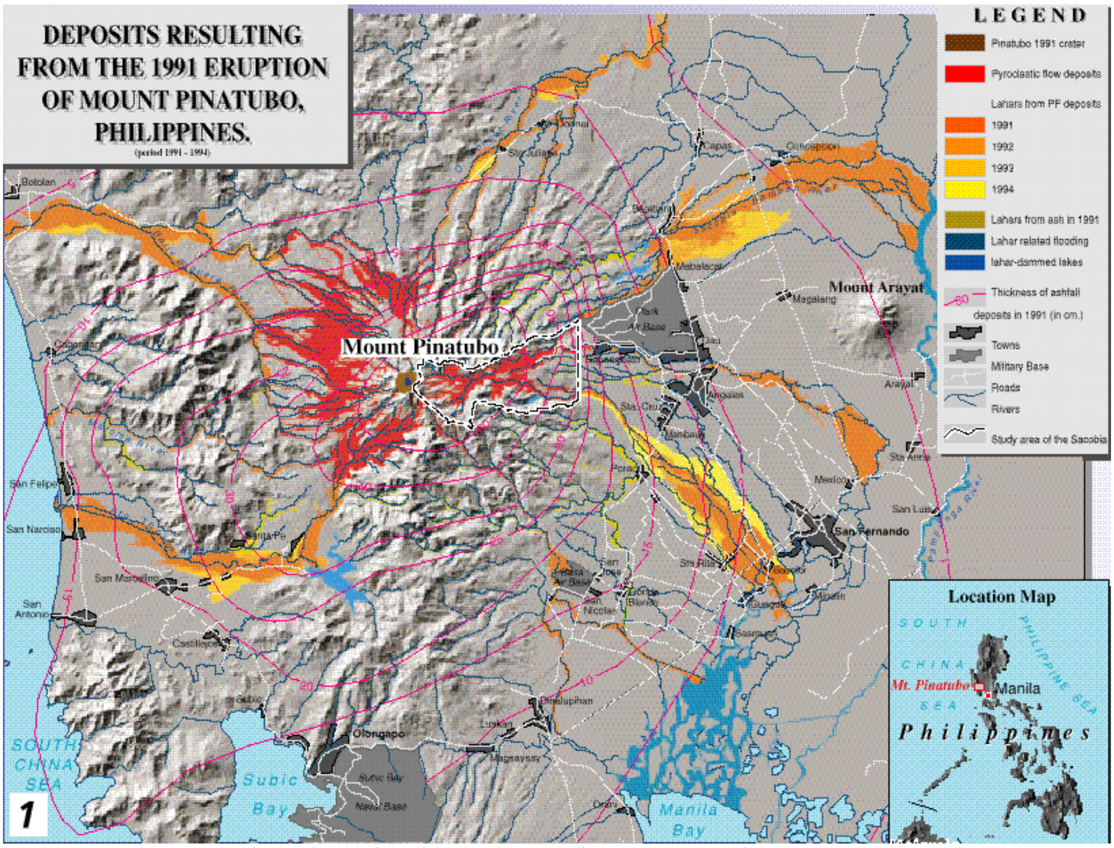

Figure 1. Deposits resulting from the 1991 eruption of Mount Pinatubo

Figure 2. Lahars resulting from pyroclastic flow deposits

Construction of DTMs

The main objective of this study was to evaluate the decrease of the volume of potential lahar source material in the Sacobia watershed during three years after the eruption, and to make a sediment balance. To investigate this the following activities were undertaken:

1. Elaboration of geomorphological maps for the pre- and post-eruption situations, up till 1993. This was done in order to evaluate the changes in the catchment areas and their importance in producing lahars. An example is shown in figure 3.
2. Creation of Digital Terrain Models for each year, from which the thickness of pyroclastic flows, and the yearly eroded volume can be calculated.

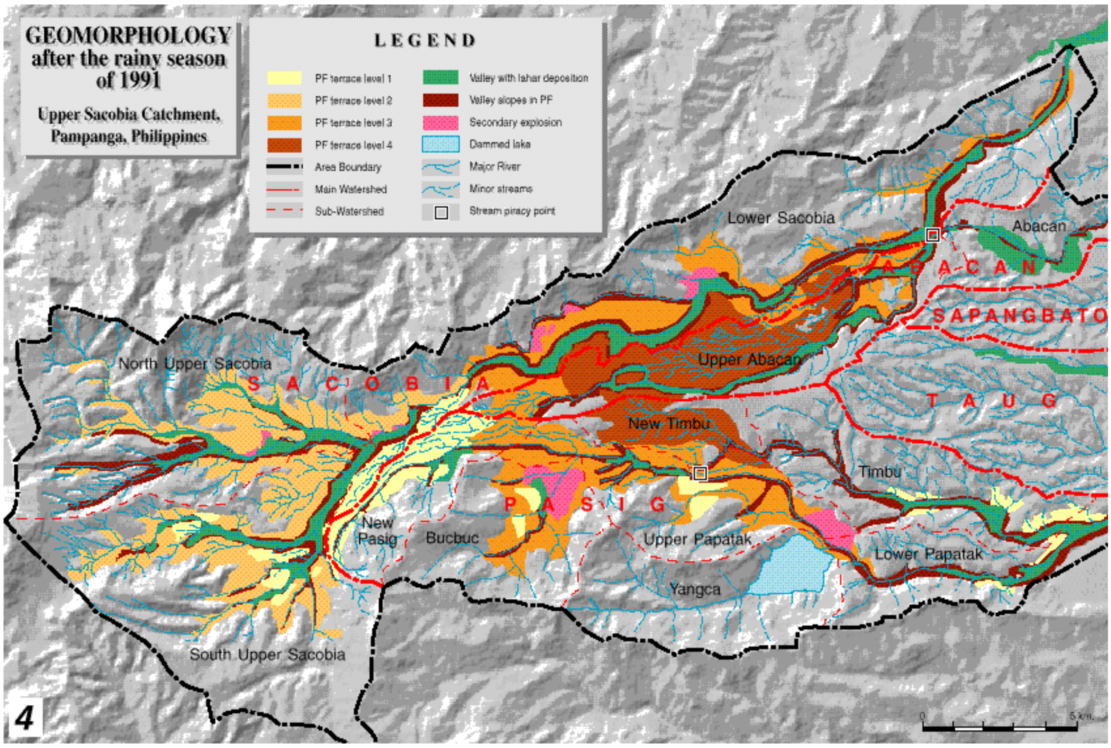

Figure 3. Geomorphological situation after the first rainy season following the eruption.

To calculate the volume of the 1991 pyroclastic flow deposits and the yearly eroded sediment volumes, a DTM overlaying technique using GIS was applied. For this procedure it was necessary to construct DTMs of several periods: i.e. the pre-eruption DTM; the post-plinian eruption DTM which renders the undisturbed deposits of the 1991 pyroclastic flows; a post-lahar 1991 DTM; a post-lahar 1992 DTM; and a post-lahar 1993 DTM.
The pre-eruption DTM was generated by digitizing the contourlines, with a 20-meter interval, from the 1986 topographic base map prepared by the US Defense Mapping Agency. The DTM was rasterized using a pixel size of 20 meters.
To calculate the volume of the 1991 pyroclastic flow deposit, a post-plinian eruption DTM was reconstructed to render the features of the original and undisturbed 1991 deposit. In constructing the post eruption DTM, oblique stereo photographs from July 1991 were used since they still show the original level of the new deposit. Contacts of

the pyroclastic flows in relation to the surrounding topography were plotted on the enlarged topographic base map. Additional isolines were digitized across the deposit. Then the altitudes of the new pyroclastic flow level were masked into the pre-eruption DTM to fully reconstruct the post-1991 plinian DTM. To be able to calculate the volume of erosion of the 3 yearly post-lahar seasons, a DTM of each post-lahar season was made. An estimation of the temporal erosion was done by calculating the volume of the valleys and large gullies generated after each lahar season. These features were interpreted from the post-rainy season photographs. The vertical incision depth of valleys and gullies was estimated in the field for a limited number of sites. The depths at other inaccessible sites, were measured with a parallax bar. Unfortunately, analytical photogrammetric work could not be conducted due to the absence of precise ground control points in the study area, the inaccessibility of the terrain and the fact that a precise GPS was not available. Due to the use of simple parallax measurements, the minimum mappable depth of gullies in this study is about 5-10 meters. A very large number of points have been measured with the parallax bar to minimize the error.

In a GIS the boundaries of gullies were plotted over the 1991 pyroclastic flow deposits. The depth measurements made with the parallax reading were subtracted from the heights of the 1991 pyroclastic flow level to obtain the elevation along stream lines. The elevations of the remaining gully slopes were interpolated. Larger valleys were represented as polygons. The area of the polygons together with the measured valley depths were subtracted from the heights of the post-eruption DTM. The sloping valley walls were masked separately, and their DTM values were calculated by interpolating the height value of the top and bottom of the valley.

The same procedure was followed for the situations after the 1992 and 1993 rainy seasons, each time subtracting the newly eroded areas from the DTM of the previous year.

DTM overlaying method

In order to calculate the yearly erosion and sedimentation volumes the Digital Terrain Models were used in a Geographic Information System (ILWIS 2.1 for Windows). This package contains a very powerful Map Calculation tool with which the results were obtained.

The volume of pyroclastic flow material covering the Sacobia watershed was calculated by subtracting the DTM after the eruption from the one before the eruption. The positive values in the resulting map indicate the thickness of pyroclastic flow deposits, whereas the negative values represent the lowering of the terrain as a result of the formation of the crater. Volumes were obtained by multiplying the thickness in each pixel with the area of the pixel (the square of the pixelsize). After that the volumes were aggregated for the various subcatchment by crossing the subcatchment map with the volume map and summing up all positive values.

The next step was to calculate the amount of erosion and sedimentation that took place in the catchment during the first rainy season after the eruption.

Several situation are possible:

- erosion in pyroclastic flow deposits
- erosion in other deposits
- sedimentation.

The calculation of the erosion and sedimentation volumes which occurred during the second and third rainy season, in 1992, is slightly more complex, since there may be further erosion in PF or other deposits, erosion in sedimented material from the previous year, or sedimentation.

Results

Based on the five DTM's, the volume of pyroclastic flows and the subsequent erosion during three years, were calculated for each catchment. A schematic overview of some cross sections is shown in figure 4.

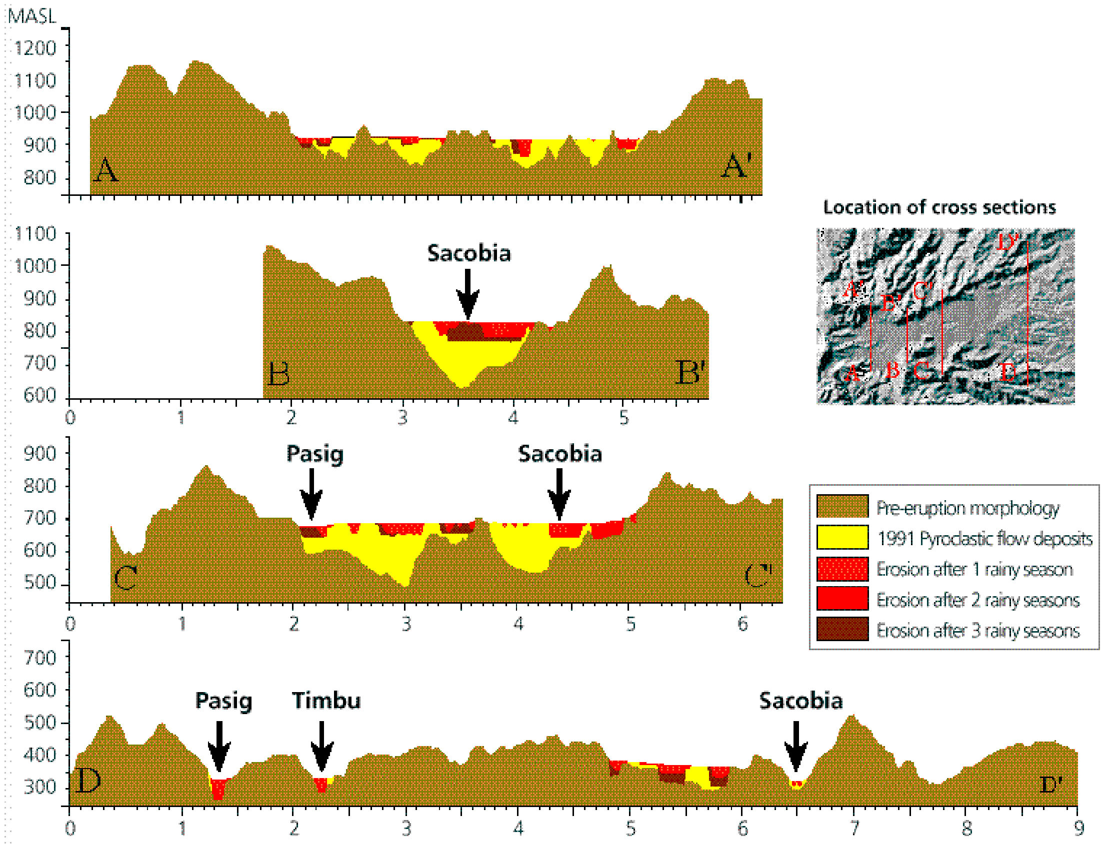

Figure 4: Cross sections showing the elevation of the pyroclastic flow deposits and the subsequent erosion.

A comparison was made between the result obtained by this study and those obtained by other authors, using different methods. The total volume of pyroclastic flows was estimated by several authors, either using cross sections, photogrammetric techniques or estimation of lahar volumes. Although there are differences, the order of magnitude is the same. The erosion volumes calculated by comparing DTM's are slightly higher than the volumes of lahars. This can be caused by the fact that redeposition took place within the area and that not all materials were transported to the areas surrounding the volcano, on which the lahar estimates are based. When the resedimentation volumes are subtracted from the total erosion the values match rather well.

If the erosion values for the three years are compared it is clear that there is a large decrease in volume from 1991 till 1992, also expressed by a decrease in lahar volumes. The next year (1993) however, is not fitting into this exponential decay curve, since it had an erosion rate, which was higher than the previous year. This was mainly caused by the occurrence of the secondary explosion, as a result of which the upper Sacobia catchment was captured by the Pasig, and the erosion rates in the Pasig increased dramatically. Secondary explosions can still occur within the area for a number of years, until the pyroclastic material has sufficiently cooled off. Another factor which may prevent the exponential decay of erosion and lahar volumes is the break-out of lahar dammed lakes. In 1994 the break-out of the lake in the Yangca catchment caused a lahar in the lower Pasig area, which covered an area which was larger than in the previous years. Therefore the lahars will continue to be an important hazard in the footslopes for a number of years. The most critical factor in predicting the future behaviour of lahars is the estimation of the potential erodable pyroclastic flow deposits which are still present in the area. To fully understand this use should be made of analytical photogrammetrical techniques, which will provide more detailed, and reliable results.

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For more information:

On the ILWIS GIS package:
ITC-ILWIS Group
Hengelosestraat 99
P.O.Box 6
7500 AA Enschede
The Netherlands
Tel: +31 53 4874337
Fax: +31 53 4874484
e-mail: ILWIS@ITC.NL

On the work presented here:
Dr. C.J. van Westen
ITC
P.O.Box 6
7500 AA Enschede
The Netherlands
Tel: +31 53 4874263
Fax: +31 53 4874336
e-mail: Westen@itc.nl