Creating a Risk Map for Loss due to Volcanic Eruptions

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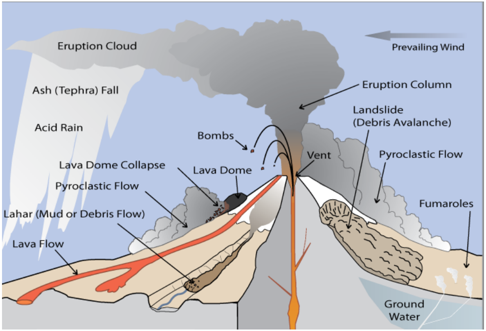
1. In volcanic regions of the world there is a need for insurance against loss due to volcanic eruptions.
2. A difficulty is how to accurately price this insurance - this comes from the difficulty in assessing the risk for a given location.
3. Multiplicity of hazards: Lava flows, Lahars, Pyroclastic flows, Tephra etc.



1. The aim is to create a map of a particular country, or region of a country, which shows the expected annual loss (or probable maximum loss) due to volcanic hazards at each geographic location.
2. Requires:
   - Underlying exposure map.
   - For each location, a probability distribution for the loss due to the eruption of each nearby volcano.
   - For each volcano, a probability of eruption in 1 year.
3. 'Nearby' will be taken to mean within 100km.
4. Population with be taken as the measure of exposure and fatalities will be taken as the measure of loss.

1. Consider a region with population E_Y which is within range of N_I volcanoes. Let Y be a r.v. representing number of fatalities due to volcanic eruption. Then for a given loss $p \in [0, E_Y]$ we wish to compute the *excess loss rate* $\nu(p) = \sum_{i=1}^{N_I} \mathbb{P}(Y > p|A_i)\mathbb{P}(A_i)$. Here A_i denotes the event that volcano i erupts.
2. Aim: To obtain values for $\mathbb{P}(Y > p|A_i)$ by fitting a parametric model for $Y|A_i$ using the fatalities dataset. (Obtained from WTW)
3. $P(A_i)$ is the probability that volcano i erupts at least once annually. This could be estimated for each volcano using historical eruption data.

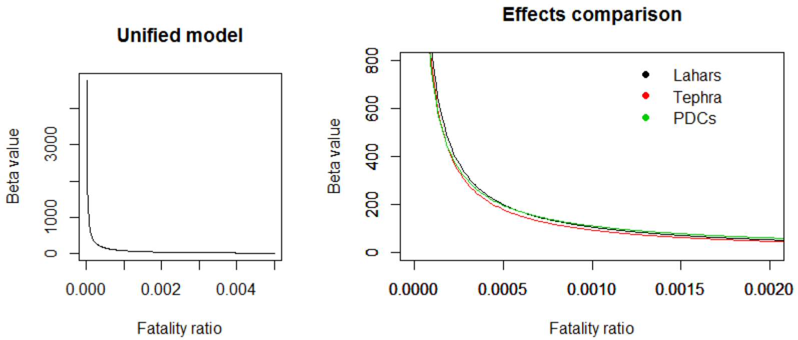
Suppose that the number of fatalities in a region with exposure E_Y due to volcano A_i follows a scaled Beta distribution: $Y|A_i \sim Beta_{E_Y}(\alpha_i, \beta_i)$. The scaling is so that the loss distribution has support $[0, E_Y]$. The excess loss rate is then:

$$\begin{aligned}
\nu(p) &= \sum_{i=1}^{N_I} \mathbb{P}(Y > p|A_i)\mathbb{P}(A_i) \\
&= \sum_{i=1}^{N_I} \left(\int_p^{E_Y} f_{Y,i}(p)\, dy \right) \mathbb{P}(A_i) \\
&= \sum_{i=1}^{N_I} \left(\int_p^{E_Y} \frac{\Gamma(\alpha_i + \beta_i)}{\Gamma(\alpha_i)\Gamma(\beta_i)} \left(\frac{y}{E_Y} \right)^{\alpha_i - 1} \left(1 - \frac{y}{E_Y} \right)^{\beta_i - 1} \frac{1}{E_Y}\, dy \right) \mathbb{P}(A_i)
\end{aligned}$$

where $p \geq 0$ is the level of loss.

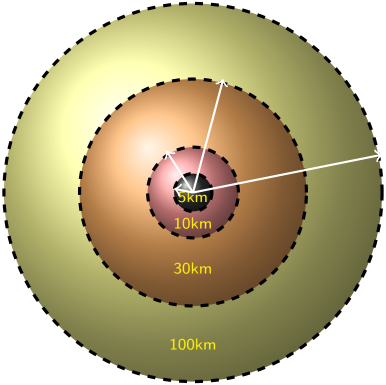
The fatalities data was filtered for eruptions located in either Indonesia, the Philippines or Papua New Guinea. A maximum likelihood estimate $(\hat{\alpha}, \hat{\beta})$ of the parameters of the fatality distribution of an arbitrary volcano in those countries was then obtained.

Fitted distributions:

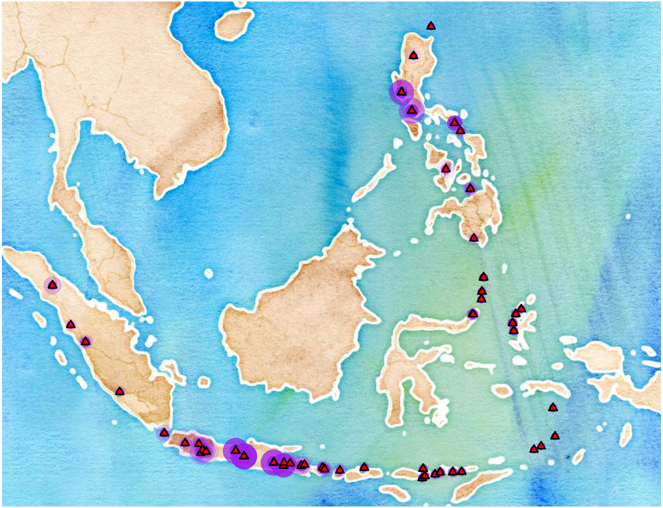


Ideally, rather than using all the eruption data, a separate model would be created for eruptions corresponding to each Volcanic Explosivity Index (VEI).

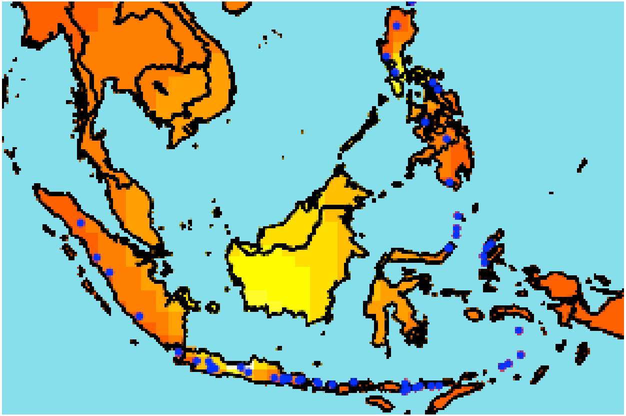
1. The loss distribution at a given point will also depend on the distance from the volcano. A separate model could be created for each annulus of a given volcano for which exposure and fatalities is recorded: (The fatalities dataset contains population exposure at radii 5km, 10km, 30km and 100km).



Exposure map for concentric rings at each volcano (using fatalities dataset):



More comprehensive exposure map using kriging:



1. Current limitations:
   - Fatalities are not an ideal proxy for loss.
   - Insufficient data in current dataset to fit separate models for volcanoes of differing maximum VEI.
   - More historical eruption data required to statistically estimate the annual probability of eruption.
2. Possible further work:
   - Considering more complex models for the loss e.g. mixtures of distributions.
   - Using spatial methods to assign risk to areas outside a 100km zone of a volcano.