Pedestrian Simulation Methodology of Evacuation in the Area of Cotopaxi's Lahar Influence with SUMO.

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Abstract

Ecuador is one of the countries in the region crossed by "La Cordillera de los Andes" and the main problems are volcanic eruptions and all the consequences that they may cause. Cotopaxi volcano has been reactivated and the geologists and geographers engineers have concluded that the eruption would generate lahars that follow the river's course and would destroy everything in the lower basin. To prevent human losses there are available Geoinformatics tools to analyze and give solutions in this matter. The growth of risk management demands several tools (software) that allow finding a solution with less field contact. In this context, a microscopic pedestrian simulation was performed in SUMO (Simulation of Urban MObility) as a deterministic evacuation. The pedestrian demand was generated with the DUAROUTER method that obtains the routes that the personflows should follow from a source point -that must be in the risk zone- to a sink point that belongs to the safe zone. Then, a simulation and an output file that contains information of pedestrian density was obtained and was joined to be represented in a heatmap. In conclusion, SUMO and Open Source are suitable tools for taking decisions because with the results of the simulation it can be related the distance and trips time with the capability of evacuate.

1 Introduction

Ecuador, being in a subduction zone of the Nazca plate with the South American plate is a high-risk country in terms of volcanic and seismic hazard (Ortiz Panchi, 2013).

Cotopaxi volcano is an active stratovolcano with rhyolitic and andesitic magmatism (Hall & Mothes, 2008) which is part of the chain of volcanoes in the Andes mountain range in Ecuador and is 5897 m high being one of the highest volcanoes around the world (Carrillo Gallegos, 2013).

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The Cotopaxi volcano has presented eruptive periods of 300 to 3600 years (Hall & Mothes, 2008) and according to historical data -from 1532- it has representatives eruptive periods with pyroclastic emissions and long lahar flows, and Volcanic Explosivity Index equal to 4 (VEI = 4) (Gaunt et al., 2016).

Since 2015, the reactivation of the Cotopaxi volcano has taken the attention of several Institutions and national and international researchers, the ones who submitted their analyses of emissions and geological risks of the volcano. Publications about risks of the Cotopaxi volcano (Aguilera & Toulkeridis, 2006), and how to avoid human losses with evacuation routes (Padilla & Bosque, 2014) was performed before the reactivation of the volcano with preventives aims and are a key piece for the development of the current work. This information is important for different National Services specialized in defense and risks who are the responsible of spread the information and make management risks plans (Servicio Nacional de Gestión de Riesgo y Emergencias, 2019). For instance, these institutions have reached several important events, such as an eight-hour simulacrum (Maisanche, 2015), but likely the behavior of people within an emergency will differ in several ways of this type of simulacrum.

The Ecuadorian Risk Management Secretariat (2015) in its Contingency Plan against a possible eruption of the Cotopaxi volcano quantified vulnerability considering urban growth and determined that within an area of 913.57 km2, approximately 93,412 inhabitants are exposed to the threat of lahars due to the eruption of Cotopaxi volcano, where Cotopaxi and Pichincha would be the most affected provinces.

Padilla & Bosque (2014) determined safe zones and evacuation routes before the arrival of lahar flows to “Los Chillos” valley. They proposed two types of possible evacuations: 1) horizontal evacuation for people who are near the safe zone, and 2) vertical evacuation for people who cannot go out to safe areas and need to evacuate to the top of buildings.

Different Open Source (OS) software and other Geoinformatics tools have been created to simulate different scenarios that allow manage many variables and take the necessary aspects to show as real as possible emergency situations, observe deficiencies and improve -in this case- evacuation times and routes. Simulation of Urban MObility (SUMO) is an OS package created to simulate microscopic and continuous traffic that will allow getting a better approach to people evacuation (Alvarez Lopez et al., 2018).

The simulation of vehicles traffic -within the area studied by Padilla & Bosque (2014)- has been solved using SUMO (Sánchez Carrasco, 2019). However, people who can’t evacuate in a vehicle need a pedestrian evacuation plan; considering the traffic jam and possible crashes that convert the vehicular evacuation into a pedestrian evacuation.

The microscopic simulation methodology with the pedestrian approach will be developed into the current research to “Los Chillos” valley within Rumiñahui canton where there are two possible scenarios: 1) Out of work and academic hours where there is only Rumiñahui’s population, and 2) in work hours where the population triples (El Telégrafo, 2016). In this regard, the output files of SUMO will show the pedestrian density and a macroscopic schema to make conclusions and take better desitions.

2 Materials and methods

2.1 Study area

The area of influence is located in “Los Chillos” valley, Rumiñahui canton, in the places that are affected by the lahars produced by an eventual eruption of the Cotopaxi volcano, considering the nearby sectors as safe places (Figure 1).

The Rumiñahui canton has an area of 139 km2 and is in the micro-basin of the San Pedro River. The main channel is the Pita River that is formed from the top of the volcanoes: Rumiñahui, Cotopaxi, and Pasochoa (GADMUR - Dirección de comunicación social, 2018).

The Rumiñahui canton is at the southeast of the Pichincha province. It has three urban parishes and two rural parishes. Sangolquí parish is the capital of the canton, which is in the area of greatest affectation, along with San Rafael parish, before the lahars produced by an eruption of the Cotopaxi volcano.

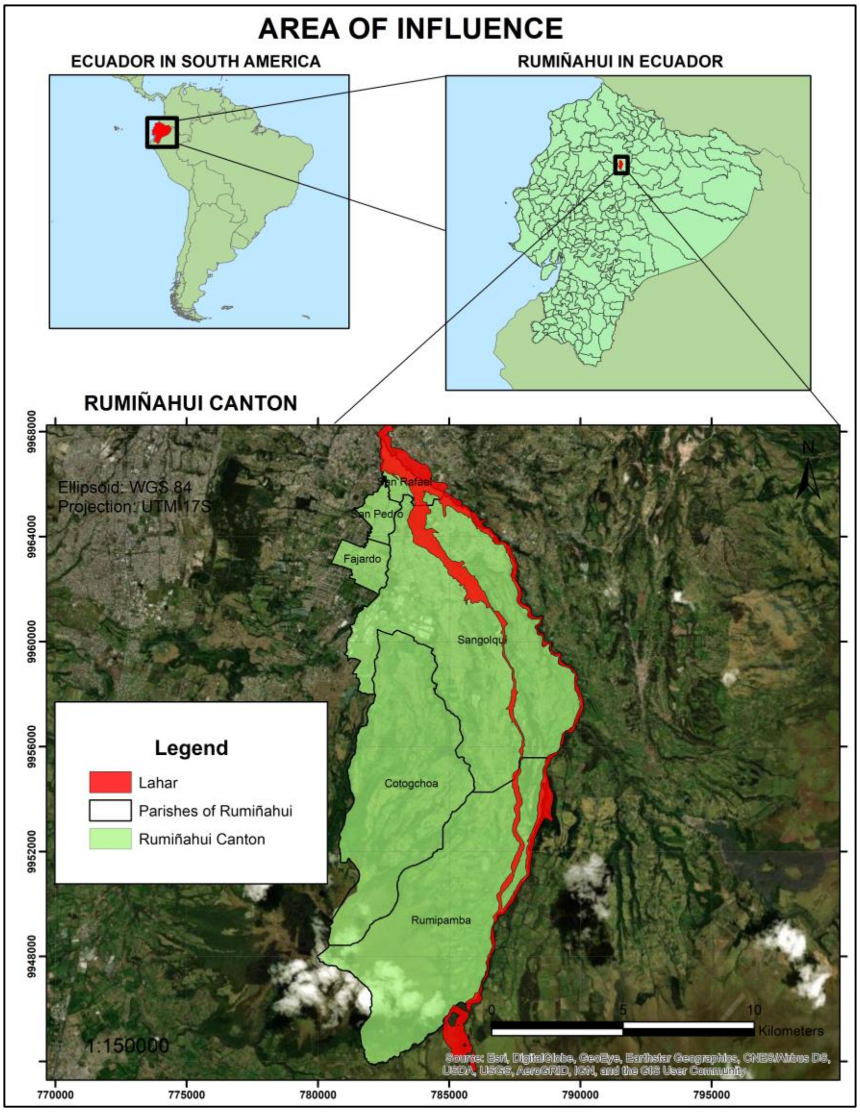

Figure 1 Area of influence

The area affected by lahar flow and evacuation routes (Padilla & Bosque, 2014) were collected in wide research of years exploring how to decrease de risk of an eventual Cotopaxi's volcano eruption.

2.2 Pedestrian microscopic simulation

A microscopic simulation model shows every single element and its respective behavior within a period of time in a given area (Ramos Ferrer, 2017). The method applied for microscopic simulation (Figure 3) was mainly taken from Microscopic Traffic Simulation using SUMO (Alvarez Lopez et al., 2018) and complemented with the deep information found in the SUMO User Documentation (DLR, 2020)

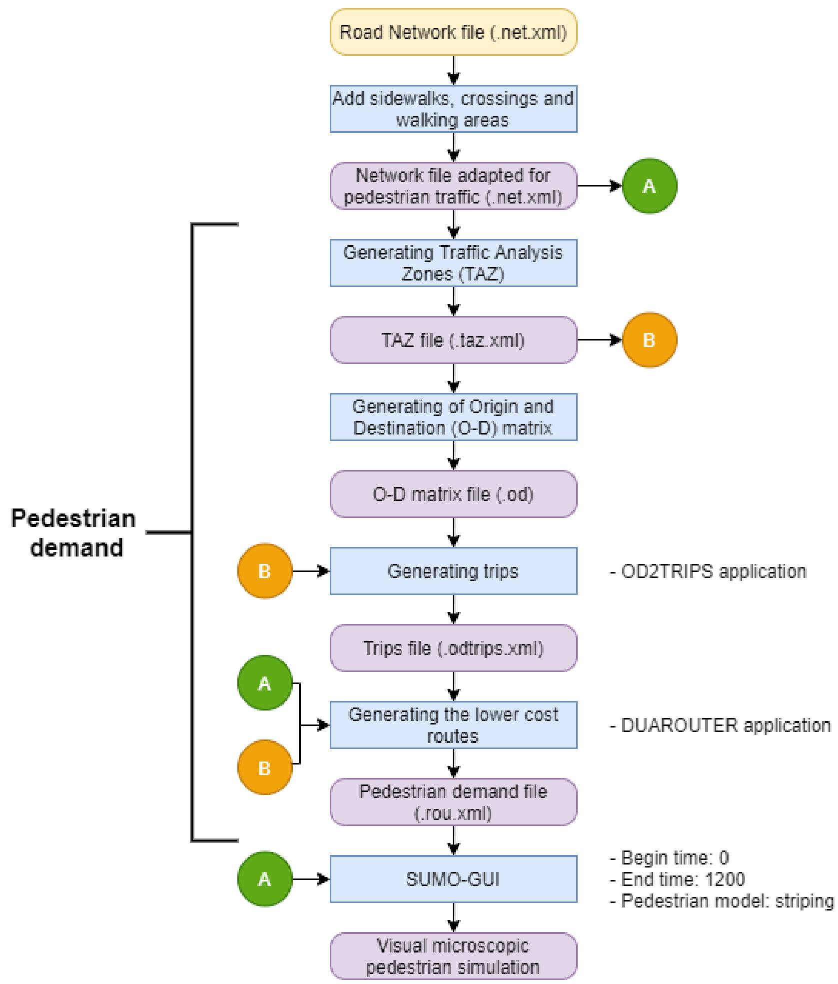

Figure 2 Microscopic simulation methodology.

The first input required for the simulation is a road network that will be imported from OpenStreetMap (OSM), and -in pedestrian simulation- the next step is to add: 1) sidewalks, 2) crossings and 3) walkingareas (Alvarez Lopez et al., 2018).

Then, the pedestrian demand is necessary, and it was generated with DUAROUTER. The data for pedestrian demand was taken from the last population census of Ecuador (INEC, 2010). For the pedestrian demand the requirements are: Traffic Analysis Zones (TAZ), Origin and Destination (O-D) matrix, OD2TRIPS and DUAROUTER (Alvarez Lopez et al., 2018).

The Traffic Analysis Zones (TAZ) were generated with a text editor where the sources and sinks were specified manually following some evacuation routes that were determined by Padilla & Bosque (2014). TAZ went into a process of an Origin and Destination (O-D) matrix which describe in each of its cells the pedestrian demand for the respective TAZ (Alvarez Lopez et al., 2018).

OD2TRIPS is an application included in the SUMO package that converts the O-D matrix to individual trips (Alvarez Lopez et al., 2018), for instance if a cell in the O-D matrix had 100 pedestrians with OD2TRIPS it will become in 100 individuals pedestrians with their respective ID.

As mentioned above, DUAROUTER uses three files (TAZ, O-D matrix and OD2TRIPS output file) for the pedestrian demand generation. It imports different demand definitions and calculates pedestrian routes using the definition of the shortest route using Dijkstra's algorithm (Alvarez Lopez et al., 2018). The output will be the evacuation route of every single pedestrian in the road network.

The simulation in SUMO-GUI shows how the pedestrians use the edges of the network and where the traffic collapse. For this porpose, a configuration file with the extension .sumocfg with two inputs was generated: 1) network file, and 2) pedestrian demand; and three parameters: 1) begin time -0-, 2) end time -1200-, and 3) pedestrian model -striping- that are important values for the behavior of the simulation, mainly the pedestrian model that allows or not the pedestrian interaction.

2.3 Pedestrian macroscopic simulation

There are different kinds of macroscopic simulation models like histograms, scalar values, traffic (pedestrian) density, among others (Ramos Ferrer, 2017). In this case the model for the macroscopic simulation is the pedestrian density, which means the map representation of the number of pedestrians that walked on each edge (Ramos Ferrer, 2017).

Figure 3 below shows the heuristic methodology used for macroscopic simulation.

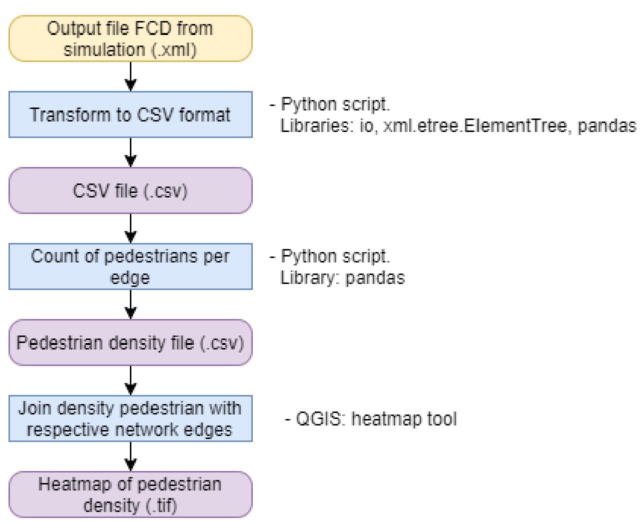

Figure 3 Macroscopic simulation methodology.

The FCD (Floating Car Data) output is obtained from the simulation and contains information of name, position (x, y, z, edge), angle and type (just pedestrians in this case) of every pedestrian in every second in the simulation (Alvarez Lopez et al., 2018). FCD files need to be managed to be represented on a map. In this way two Python scripts were written, one to convert the XML file into a CSV file and the other one to count the number of pedestrians that walked on every edge of the network. This final file contains the pedestrian density (number of pedestrians per edge) of the network during the period of simulation.

3 Results and discussion

The methodology has been applied twice. The first simulation has been performed with population census data (out of working hours) of the INEC (2010) and the second one with an approximation of the floating population within working hours. The hotspots of the working hours are: San Luis Shopping and El Triángulo.

Figure 4 Screenshot of simulation within working hours in Southeastern San Luis Shopping.

Figure 4 above shows in red the pedestrian flows moving along the evacuation routes and interacting among them because of the 'striping' pedestrian model.

Once the simulation period ends (20 minutes), it returns the data of how many people did not reach the safe areas. Most of these people were in central areas where evacuation involves more time to be reached and the time to take any evacuation action is shorter than other places in the network.

One of the areas where the evacuation was not completed is San Luis Shopping. To solve this problem, a vertical evacuation was simulated where the northeast area of San Luis Shopping was located as a starting conflict zone, and the point of arrival (safe zone) was the mall on its upper floors. When the simulation was executed with these conditions the evacuation was completed in the area.

El Triángulo is the other hotspot where approximately 13% of people who began the evacuation could not complete it in the time of 20 minutes which is the arrival time of the lahar to that area. Analyzing the FCD file with the descriptions of every pedestrian in every second of the evacuation, it can be seen that the people who could not complete the evacuation were those who began the evacuation after 1 minute 9 seconds and the distance they had to travel was greater than 700 meters. This is because there is interaction among pedestrians, and bottlenecks occur at some points due to road accessibility.

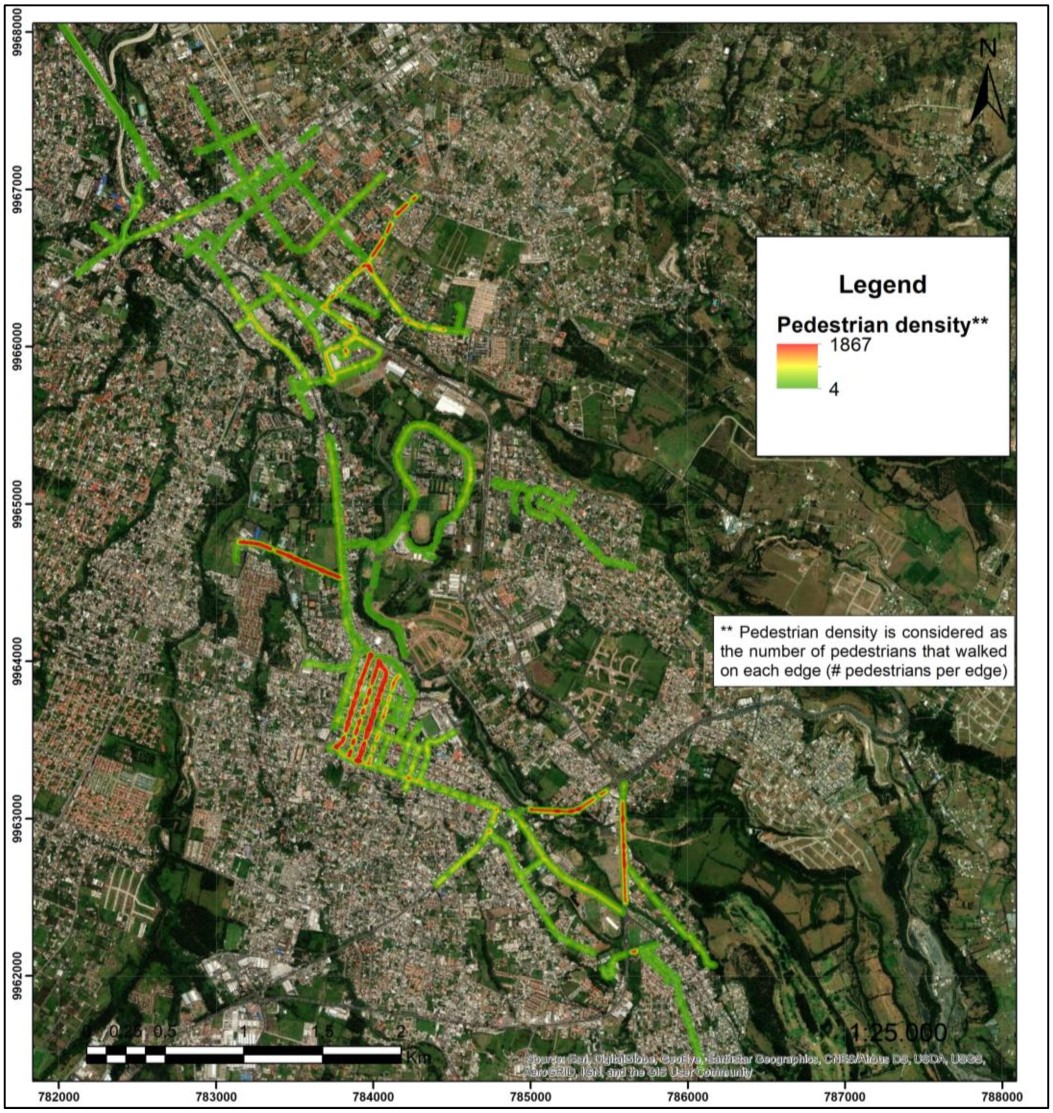

Figure 5 Map of pedestrian density in evacuation routes out of working hours

Figure 5 above is represents the resident pedestrian evacuation where there is not a problem with the evacuation. It can be seen that even the places with a higher pedestrian density can complete the evacuation as they are near to safe zones.

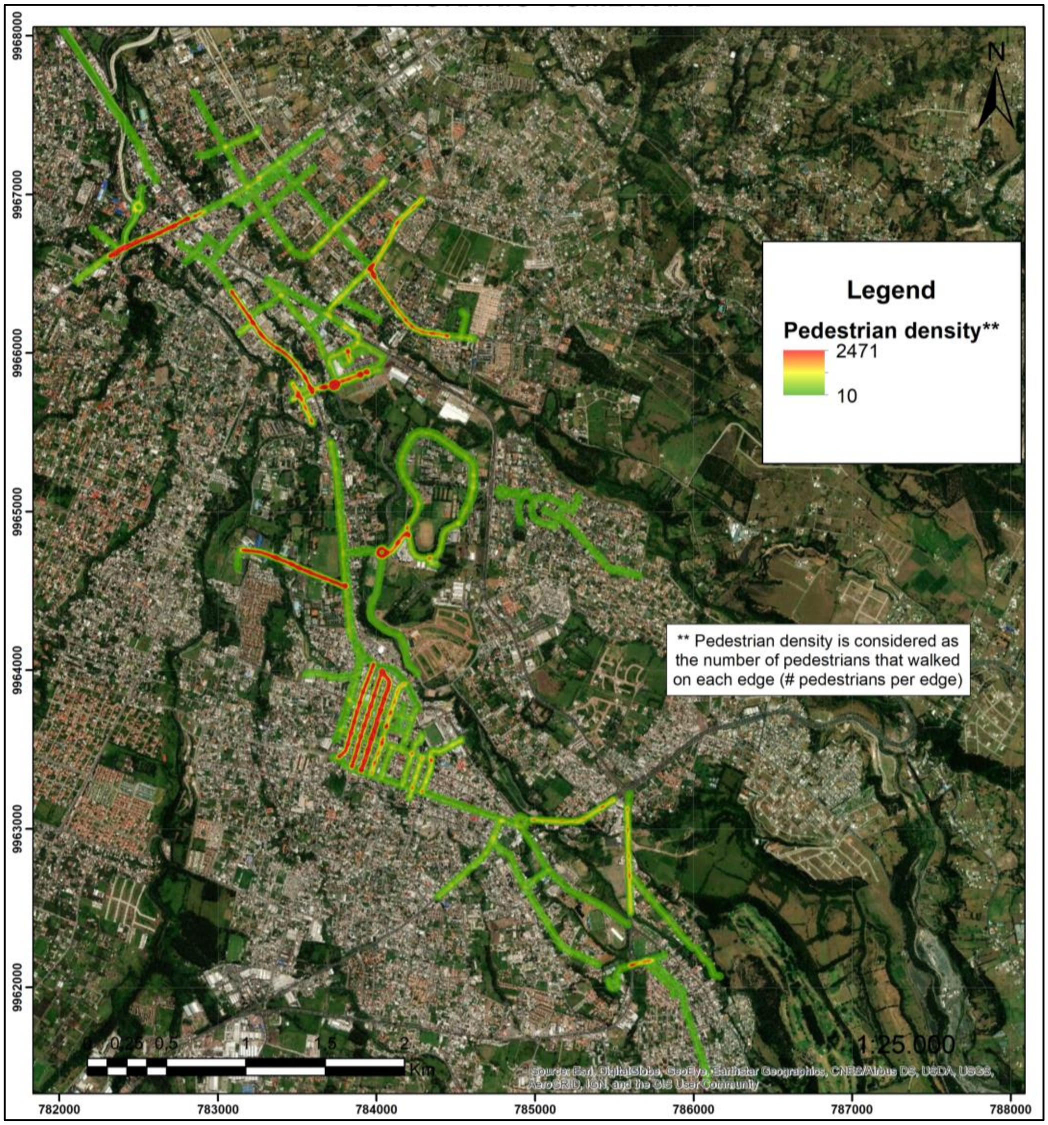

Figure 6 Map of pedestrian density in evacuation routes within working hours.

Figure 6 above shows clearly the hotspots where the evacuation becomes difficult when the population triples within working hours. Mainly activities within this hours are academic and business that make growing population in the hotspots.

4 Conclusion

The evacuation simulation in SUMO (microscopic simulation) together with the appropriate geospatial analysis and representation (macroscopic simulation) are very useful tools for taking decisions respect to many kinds of risk management. Taking into account that Ecuador has a large number of population that lives or works in vulnerable areas to different risks like volcanic eruptions, tsunamis, landslides, among others. Therefore, previous to a contingency plan, an evacuation simulation can be generated and it would optimize resources. Additional, this simulation of evacuation was helpful to see how would complement a vertical evacuation for this emergency.

Rumiñahui canton needs to improve road planning and development. This will help pedestrians avoiding bottlenecks, find shorter routes in the road network and reach faster the safe zones.

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