SAFEVolcano: Spatial Information Framework for Volcanic Eruption Evacuation Site Selection-allocation

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Summary

Volcanic disasters are commonly difficult to predict accurately in terms of when the events come, how big the magnitude, where the spatial extent of the impact, and who will be exposed. In the worst condition, people at risk confuse where they should evacuate themselves, alhough they already know that they are in danger. Similarly, stakeholder who responsible for evacuating people may have difficulties to manage evacuation site during critical times. To solve this problem, we propose SAFEVolcano, a GIS-based framework for managing evacuation camp selection-allocation considering the dynamic of the volcanic disaster extent. As an implementation example of the framework, we developed and demonstrated ArcGIS Python Plugin, which is available at http://goo.gl/zdTRxG.

KEYWORDS: GIS; emergency response; volcanic eruption; evacuation management, evacuation shelter selection-allocation.

1. Introduction

Volcanic eruption occurrences are commonly difficult to predict accurately in term of when the events come, how big the magnitude, where is the spatial extent of the impact, and who will be exposed. Such situation occurred at Merapi in 2010 confused people during the evacuation process (Jenkins et al., 2013; Mei et al., 2013; Surono et al., 2012), caused the death of about 2,000 people at El Chichón Volcano Mexico in 1982 (Tilling, 2009), and caused the misunderstanding between the authorities and the population during an emergency situation at Kelut Volcano in 2007(De Bélizal et al., 2012). Effective management in evacuating people at risk is one of the successful keys to deal with those situation (Mei et al., 2013). In fact, people in the active volcano commonly have been prepared evacuation planning whenever the disaster come. Similarly at Merapi in 2010, but the plan was unworkable due to the failure of the prediction (Mei et al., 2013). Managing the unpredicted situation need adaptable spatial information to various situation (Marrero et al., 2013). The excellences of spatial data to support disaster management are highlighted by some works (Cole et al., 2005; Cutter, 2003; Donohue, 2002; Laituri and Kodrich, 2008; Leonard et al., 2008; Marrero et al., 2013; Mehta et al., 2013; Mei et al., 2013; Mei and Lavigne, 2013; Rivera et al., 2010; Tsai and Yau, 2013).

Particular works on evacuation simulation using spatial data has been presented for several purposes namely destroyed building evacuation (Lo et al., 2006; Zheng et al., 2009), volcanic eruption evacuation transport routing (Marrero et al., 2013, 2010), evacuation shelter site selection purposes (Chu and Su, 2012; Kar and Hodgson, 2008; Kılcı, 2012; Liu et al., 2011).They present useful method for building evacuation shelter inventory database using some physical and social parameters. Meanwhile, evacuation management also aims to allocate people to safe site effectively. The procedure should determine the capacity of each refuge and define who will be in the shelter. Geographically, grouping people from the same place is important, because moving people in this case also means moving social capital that is essential for disaster resilience (Dynes, 2006; Tobin et al., 2007). In this operation, estimating the number of fatalities like Marrero et al. (2012) and distributing refugee into each shelter like Kongsomsaksakul et al. (2005) are needed. The contingency plan in Rivera et al. (2010) provides more integrated flow in making decision to select and allocate evacuation shelter during a volcanic crisis in Ubinas Volcano Peru. They categorized the hazard zone

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as small, medium, high explosion that convince the flexibility of the plan. Several possibilities for people at risk allocation also has been developed. However, that is not a GIS-oriented procedure so that further study is needed for generic GIS application.

Based on the explanation, although there are several related studies on hazard evacuation site suitability selection (Kar and Hodgson, 2008), earthquake evacuation site suitability selection (Chu and Su, 2012; Liu et al., 2011), shelter capacity distribution (Kongsomsaksakul et al., 2005), and tools evacuation time simulation(Marrero et al., 2010). However, the available method does not address problems in evacuation shelter selection-allocation in integrated way. Therefore, we propose SAFEVolcano i.e., a systematic GIS framework to estimate people at risk, select safe evacuation camp away from harmful area and allocate people at risk for each location based on occurring volcanic hazard extent.

2. SAFEVolcano Framework

2.1. Input Data Requirements

1. Center coordinate of the crater (volcanic vent) of the volcano, this data is used to calculate proximity of population to the center of hazard. The source can be from GPS or imagery.
2. Hazard scenarios, multiple scenarios of hazard are needed to anticipate the probabilities of hazard occurrences. This data can be obtained from modeling result like VORIS (Scaini et al., 2014), TITAN2D (Charbonnier and Gertisser, 2009), LAHARZ (Darmawan et al., 2014), VOL-CALPUFF (Barsotti et al., 2010), FLOWGO (Harris and Rowland, 2001) or Q-LavHA (Mossoux et al., 2014).
3. Population, this data can be provided from official statistical data. The data can be based on administrative boundaries or postal address for better aggregation.
4. Road networks which can be provided by GPS survey (Marrero et al., 2010; Mei et al., 2013), scanning traditional map (Marrero et al., 2010) or image interpretation.
5. Evacuation site and its capacity, this data can be provided from image interpretation, public facilities like schools, churches/mosques are commonly used as temporary evacuation camp during crisis. Suitability assessment can be applied (Kar and Hodgson, 2008) for better result in the evacuation camp inventory data building.
6. Hazard characteristics data based on certain pre-eruption occurrence that are about seismic data (Mei et al., 2013) and direction of the vent (Scaini et al., 2014).
7. Digital Elevation Model (DEM), it is used to get slope information in the evacuation route selection process.

2.2. GIS Operation Framework

Generally the SAFEVolcano framework is described in the Figure1 and the detail of the operation is presented in Figure 2.

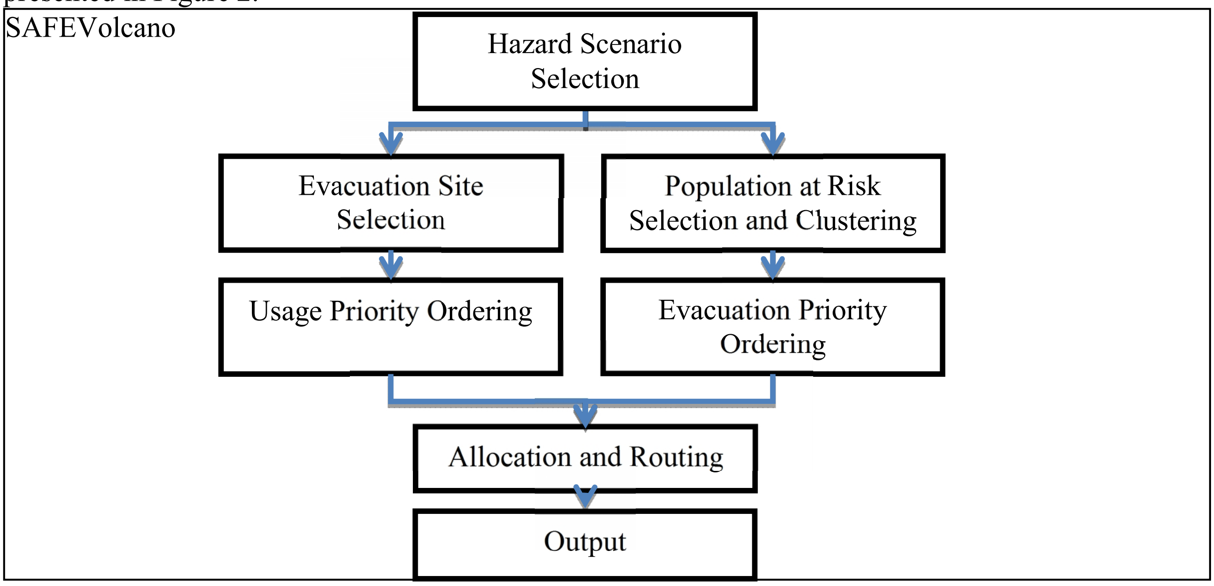


Figure 1. General Framework

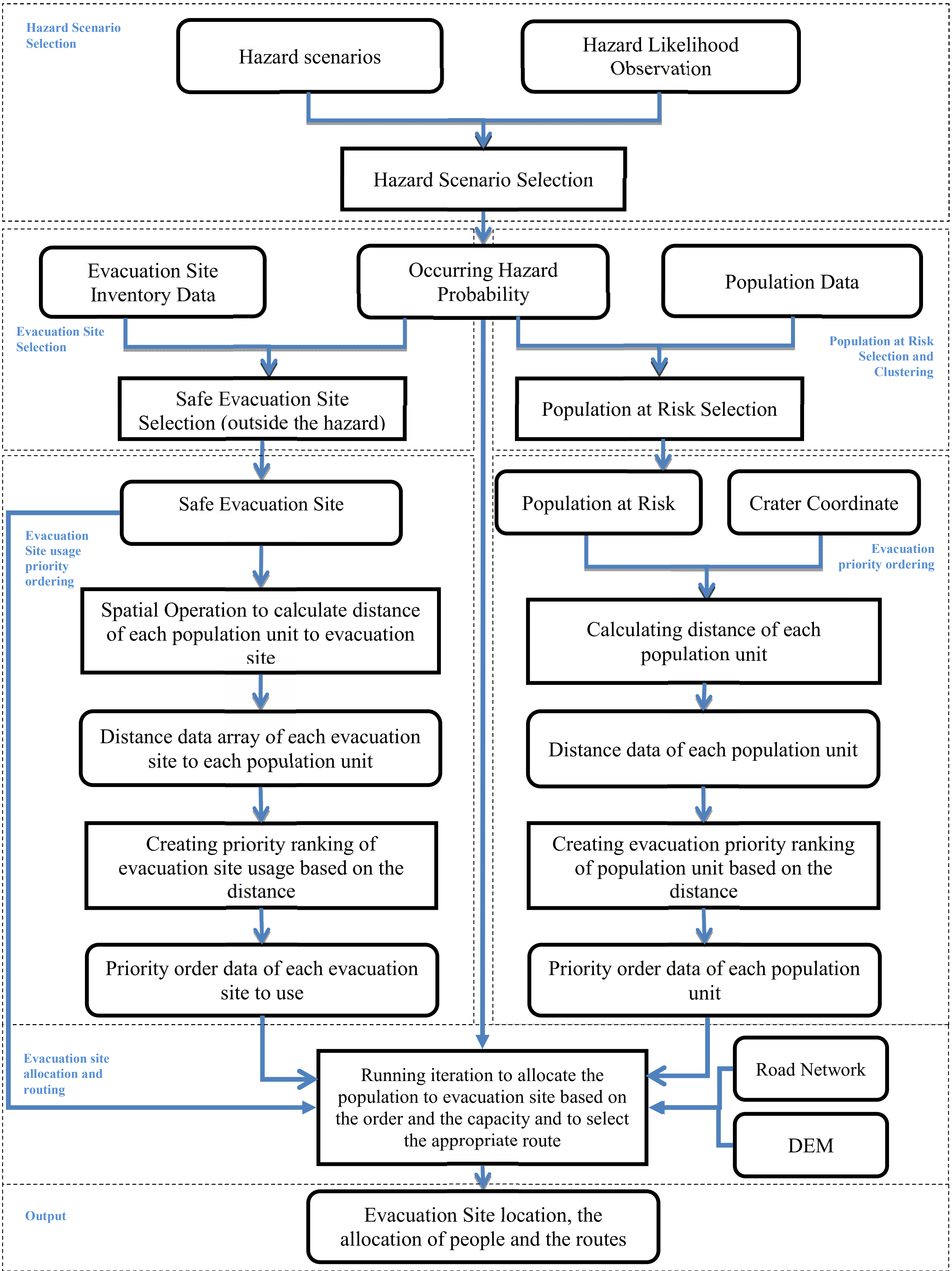


Figure 2. Detailed Framework

2.2.1. Hazard Scenario Selection

The operation aims to select the most applicable hazard model to the occurring/upcoming disaster event based on the likelihood. A wide range of magma compositions and eruption styles are used to develop these scenarios (Scaini et al., 2014). During disaster responses, there are several criteria can be used to observe the upcoming hazard namely seismicity and visual changing around the crater (Mei et al., 2013). Moreover, based on the observed seismic intensity, the characteristic of the upcoming eruption can be forecasted (Chouet, 1996).

2.2.2. Safe Evacuation Site Selection

The purpose of this processing is to select safe evacuation sites. Flexible plan is needed to anticipate many possibilities of hazard occurrence (Marrero et al., 2013). The operation can be simply performed using disjoint topological operation in GIS to select the evacuation site (POINT) outside the occurring hazard zone (POLYGON) from evacuation site database.

2.2.3. Population at Risk Selection

Exact selection of the people at risk is important to minimize evacuation cost (Whitehead, 2003). This processing aims to highlight the population units which are located on the hazard zone and estimate the number of population. The population unit commonly grouped as postcode (Robert Berry et al., 2010) or municipal area (Mei et al., 2013). The operation can be simply performed using overlapping topological operation in GIS to select the population unit (POLYGON) that overlaps with hazard zones (POLYGON).

2.2.4. Distance Calculation of Each Population Unit to the Crater and the Priority Ranking of Evacuation Process

We assumed that the proximity to hazard center (crater) will be higher in the risk. Therefore, the nearest population unit needs to be evacuated firstly, followed by the next range based on the distance. To apply this assumption, shorting the population unit based on the proximity is needed. The distance is measured from the CENTROID of population unit to the given coordinate of the crater (POINT). There are many algorithms to perform this operation, for example Euclidean distance (Danielsson, 1980).

2.2.5. Distance Calculation of Each Population Unit to Evacuation Site Based on Road Network Routing and Priority Shorting of Evacuation Site Usage

Similarly, finding optimum distance from evacuation unit to the evacuation site is needed to enhance transport time effectively (Marrero et al., 2010). Therefore, knowing the distance in the rank is important to short the priority of evacuation site usage. The distance is measured from the CENTROID of population unit to the given safe evacuation site (POINT).

2.2.6. Evacuation Site Allocation

Finally, we design iteration procedure to distribute people at risk to safe evacuation site considering the social grouping based on their origin (population unit), the evacuation site capacity, the population unit priority to evacuate, and the evacuation site priority to use. After the allocation operation is performed, then the following routing selection operation is employed to each pair of population unit and evacuation site.

2.2.7. Evacuation Route Selection

GIS operation such as least-cost path is applicable in the route selection procedure. In this selection process, some physical criteria should be considered namely slope (Yu et al., 2003), accessibility of road network (Liu et al., 2006) and the hazard occurrences (Uno and Kashiyama, 2008). It is assumed that the most suitability routes for evacuation are the shortest way to get evacuation site location, with the flattest slope, widest and best road condition, and if possible away from the hazardous area. Using this assumption, we made classification of slope based on the steepness (Yu et al., 2003) and road network based on the road type classification, and the hazard based on the intensity/magnitude.

3. Implementation Example

Based on the framework, we use Python to develop geoprocessor plugin in ArcGIS as provided in the Figure 3. The script and the dataset example are available at http://goo.gl/zdTRxG. Using the dataset (Figure 4 to 9), we demonstrate the operation of this framework. The result of population at risk, the selected evacuation site, the number of evacuees allocated, and the routes directing from the population origin to the selected evacuation site is provided in the Figure 10.

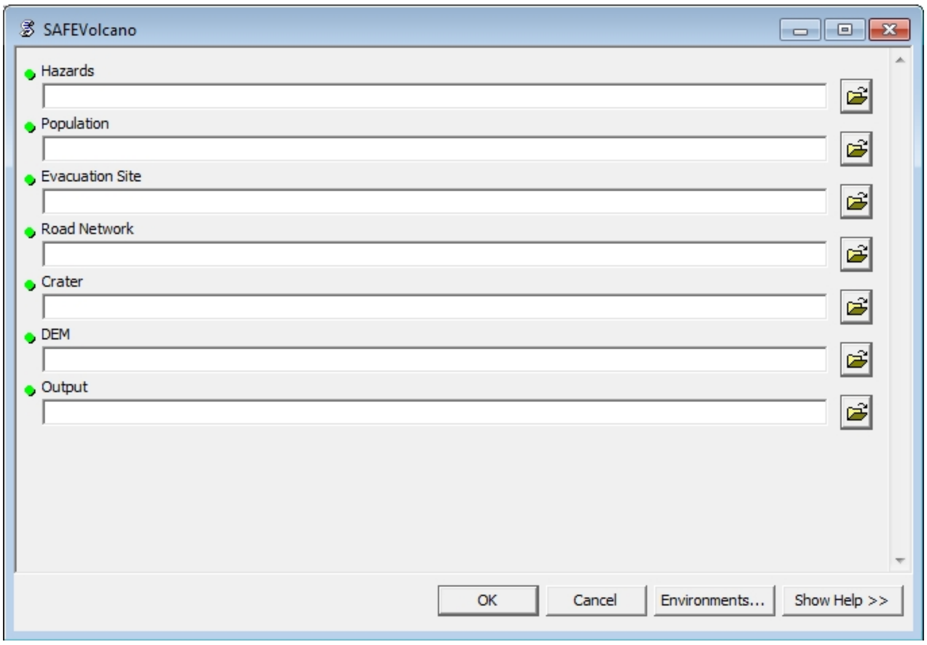


Figure 3. Example of SAFEVolcano Implementation Using ArcGIS Python Plugin

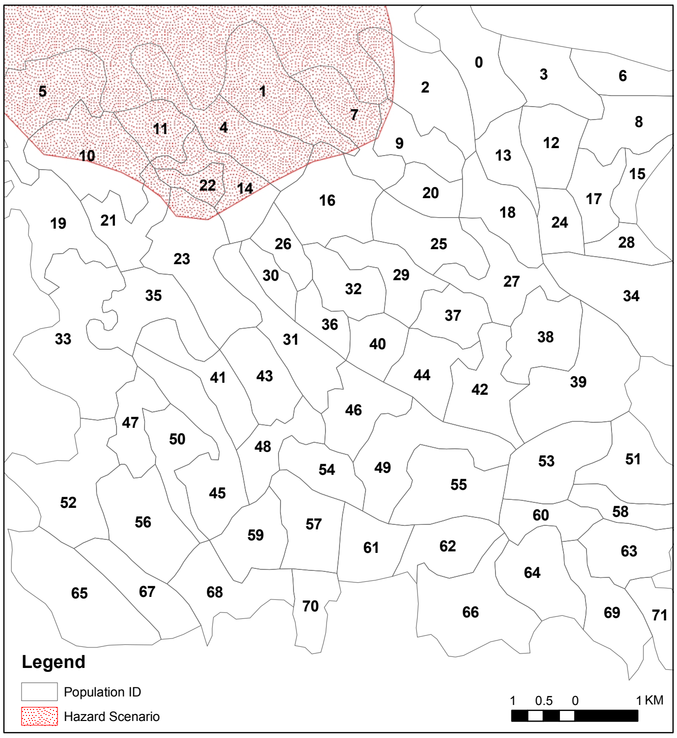


Figure 4. Hazard Scenario 1 (Showing the surrounding population unit with the ID)

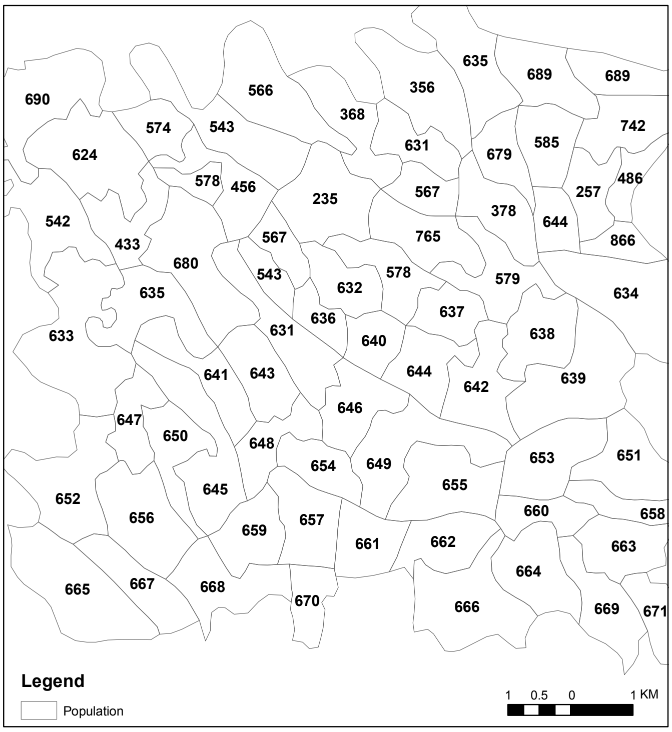


Figure 5. Population Unit (Showing the number of inhabitant)

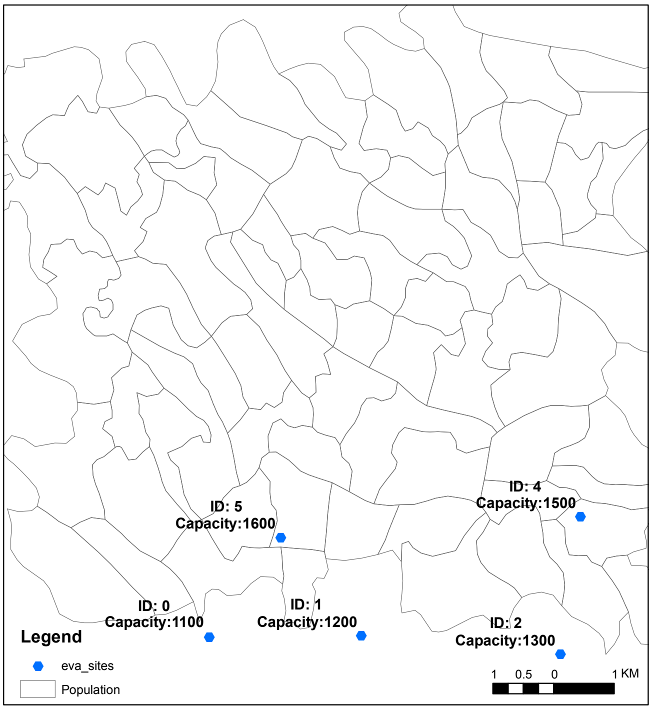


Figure 6. Evacuation Sites

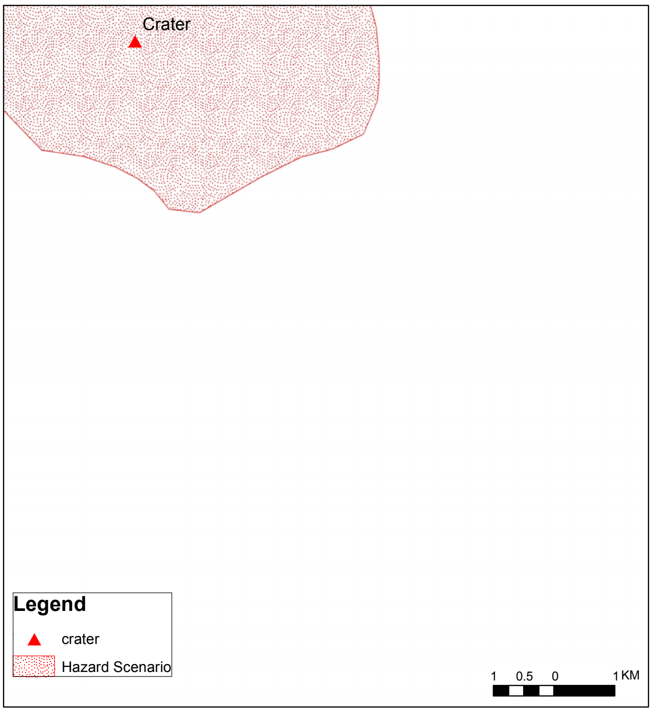


Figure 8. Crater (Volcanic Vent) Location

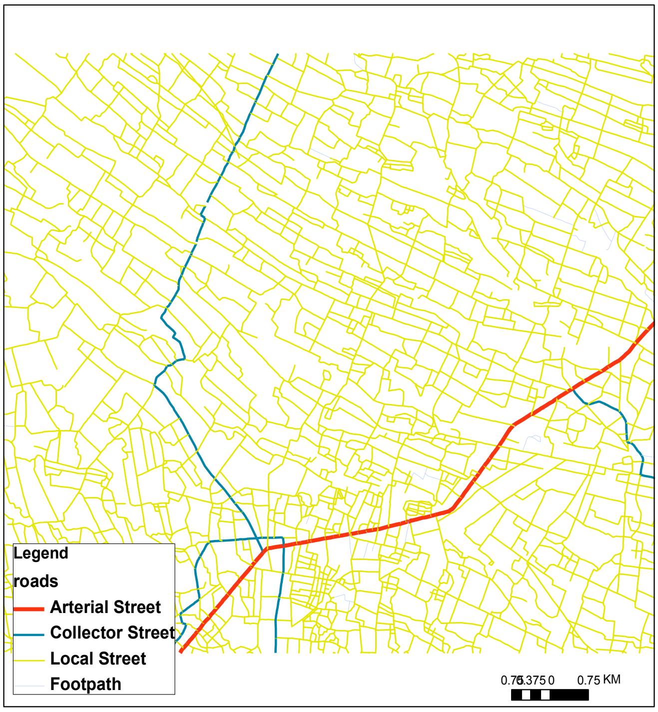


Figure 7. Roads Network

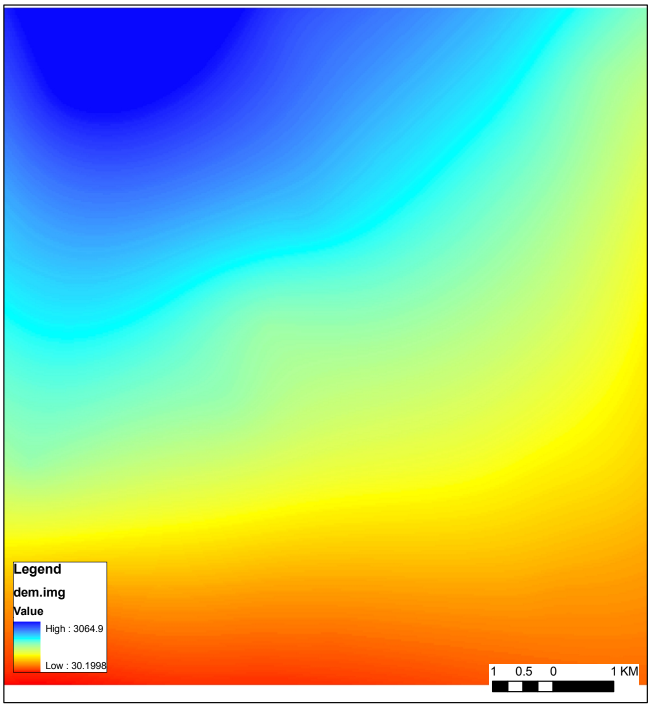
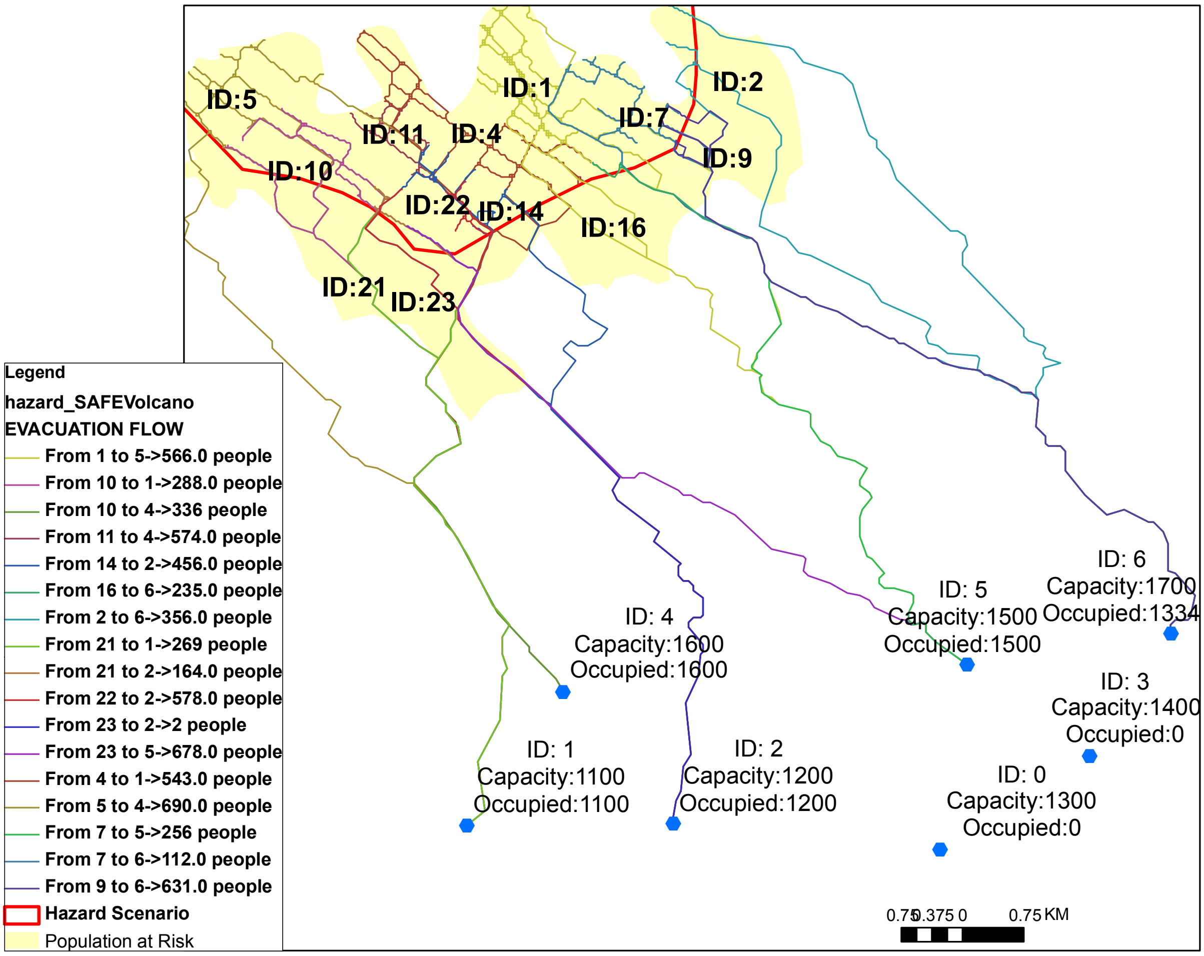


Figure 9. Digital Elevation Model



Attributes of hazard_SAFEVolcano

FID	Shape	Id	FLOW	SOURCE_ID	SITE_ID	EVACUEES
0	Polyline	1	From 11 to 4->574.0 people	11	4	574
1	Polyline	2	From 5 to 4->690.0 people	5	4	690
2	Polyline	3	From 10 to 4->336 people	10	4	336
3	Polyline	4	From 10 to 1->288.0 people	10	1	288
4	Polyline	5	From 4 to 1->543.0 people	4	1	543
5	Polyline	6	From 1 to 5->566.0 people	1	5	566
6	Polyline	7	From 21 to 1->269 people	21	1	269
7	Polyline	8	From 21 to 2->164.0 people	21	2	164
8	Polyline	9	From 14 to 2->456.0 people	14	2	456
9	Polyline	10	From 22 to 2->578.0 people	22	2	578
10	Polyline	11	From 23 to 2->2 people	23	2	2
11	Polyline	12	From 23 to 5->678.0 people	23	5	678
12	Polyline	13	From 7 to 5->256 people	7	5	256
13	Polyline	14	From 7 to 6->112.0 people	7	6	112
14	Polyline	15	From 16 to 6->235.0 people	16	6	235
15	Polyline	16	From 2 to 6->356.0 people	2	6	356
16	Polyline	17	From 9 to 6->631.0 people	9	6	631

Record: 1 Show: All Selected Records (0 out of 17

Figure 10. Evacuation Site Selection-Allocation and Routing Result

When the predicted hazard is changed, the evacuation scenario can be generated rapidly. Figure 11 provide an example of different input of the hazard scenario. In this scenario (hazard scenario 2), it is forecasted that the occurring eruption will be bigger than the previous one (hazard scenario 1). Consequently, the impacted population areas are wider, and the number of populations is bigger. As result, almost all of the evacuation sites are fully occupied to allocate people at risk.

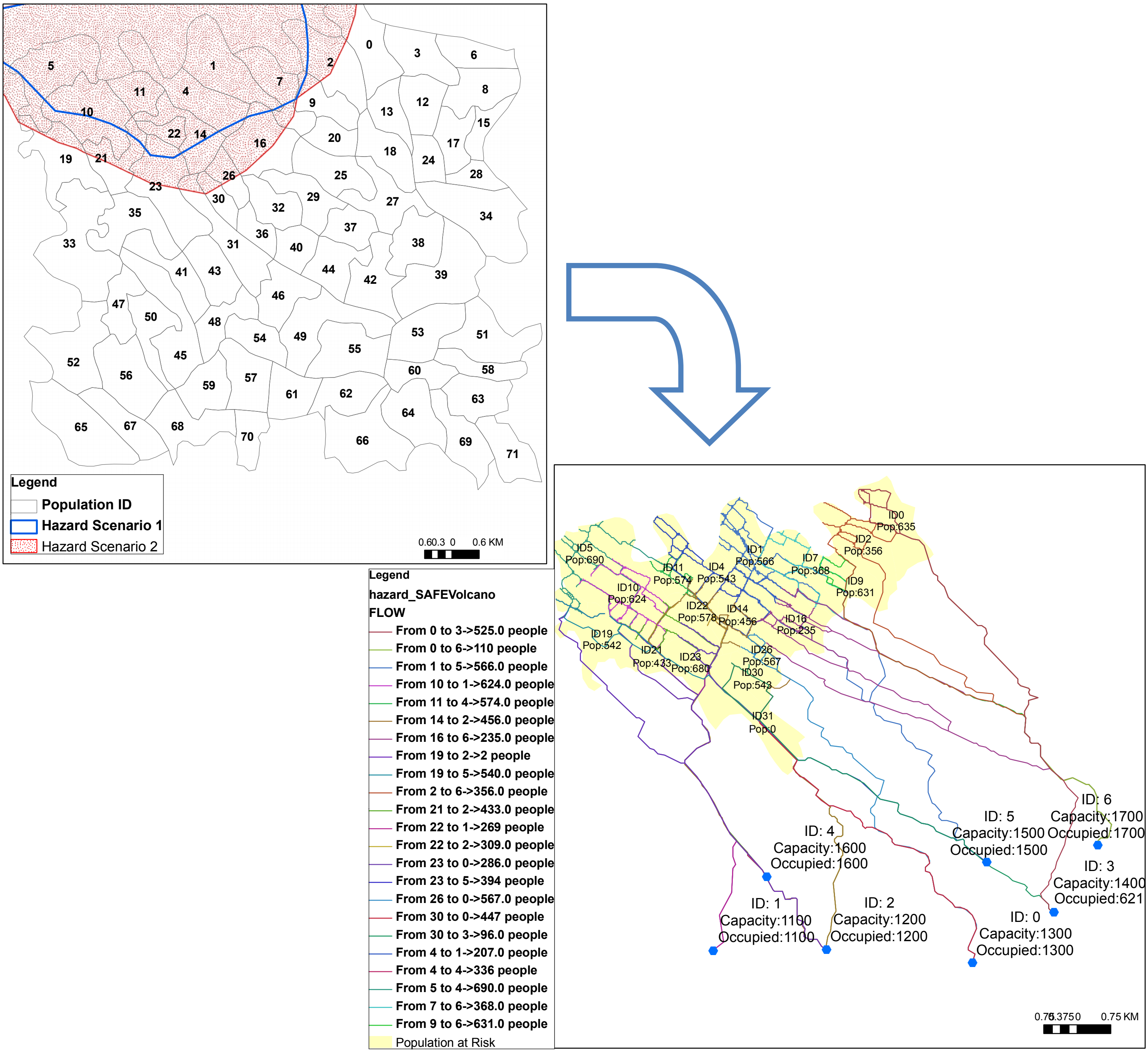


Figure 11. Evacuation Site Selection-Allocation and Routing Result with Bigger Scenario of Eruption (Hazard Scenario 2)

4. Limitation

A problem emerged when we evaluated the results of population at risk estimation. Figure 12 provided an overview of this limitation which is clearly shown the different between the spatial extent of predicted hazard and the extent of population at risk. The selection of the population at risk, in this spatial operation, is based on the overlapped area between population unit and the hazardous area. Population Unit ID 23, for example, the exposed area is about half of the total area, but its entire inhabitant is calculated in the estimation of population at risk. The spatial operation is unable to simply divide the number of population with the proportion of exposed area because the residential areas are commonly not evenly distributed. Therefore, the accuracy of population at risk estimation is depend on the level of population unit detail.

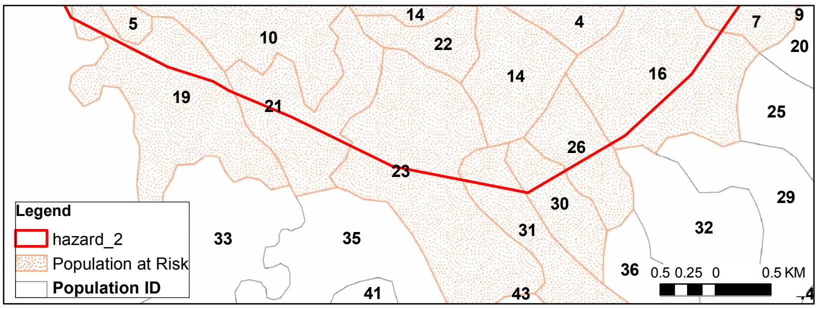


Figure 12. Spatial Processing Limitation in Population at Risk Estimation

5. Conclusion and Future Works

Volcanic eruptions are commonly unpredictable so causing the mislead of evacuation process. Supporting data to manage evacuation site during a critical time is needed. GIS-based framework can be used to manage evacuation camp selection-allocation as well as to select the routes considering the dynamic of the volcanic disaster extent. Future research related to this framework is needed primarily for optimize the hazard scenario retrieval, optimize population clustering, optimize the distribution of people at risk.

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7. Biography

Jumadi is the first year Ph.D. student at the University of Leeds. He holds MSc in Geoinformation for Spatial Planning and Risk Management (Double Degree MSc Program between UGM, Indonesia and ITC University of Twente, The Netherlands). His research interests are GIS and Disaster Management.

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