

Spatial Analysis of the Semeru Eruption Disaster Area

Utami, W.,^{1,5} Sugiyanto, C.,² Rahardjo, N.,³ Juliyani, A.,⁴ Richasari, D. S.,⁵ and Nurhadi, N.^{6,7*}

¹Doctoral Program of Environmental Science, Universitas Gadjah Mada, Indonesia

²Faculty of Economics and Business, Universitas Gadjah Mada, Indonesia

³Faculty Geography, Universitas Gadjah Mada, Indonesia

⁴Geo-Information for Spatial Planning and Disaster Risk Management, Universitas Gadjah Mada, Indonesia

⁵Sekolah Tinggi Pertanahan Nasional, Indonesia

⁶Center for Environmental Studies, Universitas Gadjah Mada, Indonesia

⁷Faculty of Social and Political Sciences, Universitas Gadjah Mada, Indonesia, E-mail: nurhadi@ugm.ac.id

*Corresponding Author

DOI: <https://doi.org/10.52939/ijg.v19i8.2783>

Abstract

Semeru, the most active volcano in Indonesia, erupted again in December 2021. This study aimed to map the impact of damages due to the eruption and map the incompatibility of land use with the Spatial Planning. The study was carried out through multitemporal spatial analysis to map the impact of the eruption damages, while the analysis of suitability and land use direction was carried out by overlaying land use maps with Spatial Planning maps. Sentinel-1B image data were analyzed using a maximum likelihood approach to obtain land use classification before and after the eruption. The results of the study showed that the eruption had an impact on the destruction of 1001.2 Ha of High-Density Forest, 624.9 Ha of Medium-Density Forest, 450.8 Ha of Rice Fields, 436.7 Ha of Agricultural Fields, 91 Ha of Settlements, and 3.1 Ha of Water bodies in Lumajang Regency. The results of the analysis show that in the affected area, there is a spatial plan direction of a residential area of 109.7 Ha. In addition to that, the high impact of the disaster is also due to the incompatibility of land use in the conservation area as a residential area of 515.4 Ha.

Keywords: Land Use, Semeru Eruption, Sentinel, Spatial Planning

1. Introduction

Semeru with an altitude of 3676 meters above sea level is the highest volcano in Java and one of the most active volcanoes in Indonesia [1] and [2], with explosive activity that can take place continuously [3]. Previous research shows that Semeru has repeatedly erupted starting in 1818 and continued until a major eruption occurred on December, 2021 [4]. The peak of the Seloka Jonggring Crater is an active crater with moderate to large explosions and several large explosions occurred in 1909, 1981, 2007 and 2012 [5] and [6]. After the 2005 eruption, researchers predicted that a larger Semeru explosion could occur, therefore various studies, technologies, and installation of tiltmeters were carried out to monitor Semeru's activities as part of disaster mitigation efforts [1] [7] and [8].

According to previous studies [9], the magnitude of Semeru that has increased, the depth of the eruption source that has become quite shallow, only hundreds of meters, the increasing gas phase of magma, and the occurrence of mountain deformation make Semeru a big threat that needs to be watched out for [3] and [10].

As a type A volcano, Semeru is not only dangerous because it erupts at the summit crater, but also because there is a threat of a possible eruption on the side; it erupted in the fissure in 1941 [11] and [12].

The level of hazard and risk of Semeru in the middle to lower slope area of the volcanic apron is very high because it is a path of volcanic material [13]. In this area, lava flows and hot cloud falls are a threat that cannot be resisted [7] [14] and [15]. However, conditions that occur in Indonesia show that some local communities still live in these areas due to limited land, due to the high price of land in disaster-safe areas, and the economic potential, bringing people to endanger themselves by living in disaster-prone areas [16]. In the case of Semeru, one of the lava flow and hot cloud paths always passes through the Curah Kobokan River and Lengkong River [13] and [17], destroying Curah Kobokan Hamlet, Sapiturang Village that is filled with settlements and people's activities. Data related to the Semeru eruption from time to time are presented in Table 1.



Table 1: Semeru volcano eruption activity

Year	Affected Area (Valley/River/Distance)	Impact	Activity/Magnitude
1884 -1963 10-11 Dec, 1884 – 14-18 Apr, 4 and 7 Sep, 1885	Kobokan, Besuk Semut, Kembar	85 died, 2 Villages, Plantation	Crater Lip Avalanche, Lava Tongue
Jan, 1886 – Aug, 1887 Feb – Oct, 1888 Jan, 1889 – May, 1891, 1892,1893	Peak Area		Explosion, Lava
22-23 May - 10 Jul and 1 Oct, 1895	Besuk Sat, Tunggeng, Pancing, Lengkong	80 Died, Destroyed Agricultural Land	Explosion, 10 ⁶ m ³ , Overflow, Lava Flow
May – Jun, 1896 and Jan, 1897	Peak Area, Tunggeng		Extruded Lava
Feb, 1898, Jan-Mar-Dec, 1899, Mar 19 -11 Apr, 1900, 1901-1905, 1907, 1908	Peak Area		Explosion
22 Mar, 1909 – Sep, 1910	Besuk, Tunggeng, Lateng 35 km	220 Died, 38 Villages, 1450 Houses, 110 km ² Damaged Land	Overflow, Tunggeng, Pakel-Lateng
Jan-Feb, 16 Nov, 1991, 28 Aug, 1912, 23-26 Jun, 1913,1914	Peak Area, Glidik; Besuk Semut, Kobokan, Rejali	Agricultural Land	Explosion, Lava
21 Sep, 1941 – Feb, 1942, 12-18 Jun, 1945	Besuk Semut, Lengkong, 6.5 km of Lava Flow	Farmland and Irrigation Channels	6.5 Km Lava, Eruption with 1,400-1,775 m Altitude
Feb-May, Oct-Dec, 1946 Mar-Jun, 1947, 1948	Peak Area, Kobokan, Rejali	Casualties, Land in Sumberwuluh	Sediment Cover in Sumberwuluh
23 Jul, 28 Aug, Nov-Dec, 1950, November, 1951, 1952, Nov, 1954	Peak area, Besuk Sat, Besuk Semut; Kobokan, Lengkong, Peak Area	Land Damage	Explosion, Lava Flow, Dome Growth, Lava
1955-1957 1958-1960 (Apr-May-Aug)	Lengkong, Rejali, Tunggeng, Lateng Peak Area, Glidik of 1 km	220 Died, Damage to Land and Settlements	Avalanche, Dome Growth, Sediment Flow up to Lumajang
1961	Lengkong, Semut, Glidik Peak, Laden, Kobokan		3 km High Ash Column, “Strombolian” Eruption Type
1963-1964	Kobokan, Lengkong, Besuk Semut, 8 km		Strombolian, 3,000 m High Ash Column
1967-2003 (Dome Growth Occurred)			
31 Aug-Sept, 1967	Peak Area, Kobokan, Rejali, Liprak	Damage in Sumberwungkal Village	Explosion, Dome Collapse
9 Mar, 1968	Glidik, Kobokan, Rejali, Liprak up to 4.5 km	5 Died, Damage in Sumberwungkal	Avulsion from Rejali to Liprak at 500 m Altitude
1969, 1972, 1973	Vent Area, Glidik, Besuk Kobokan	Damage to Fertile Land	Volcanic Material Flow, Dome Growth
22 Aug, 1974, 22 Jul, 1975, 16 Sep, 1976	Vent Area, Liprak, Regoyo, Rejali, Kembar, Tretes	Sumberwulangkal, Land Damage	Explosion, Dome Growth
13 Nov, 1976	Glidik, Lengkong, Kobokan, Rejali, Liprak, Mujur, Kembar	133 Died Villages was Destroyed, 335 ha	Avulsion and Lava Flood
1, 14, 16, 23 Dec, 1977, 1980	Peak Area, Hot Clouds of 10 km to Besuk Kembar, Besuk Kobokan	Several Villages, Settlements, Fertile Lands were Destroyed	Lava Tongue 6.4 10 ⁶ m ³
28, 29, 30 Mar and 3, 5 Apr, 1981	Lengkong, Kembar, Bang, Glidik 7-11 km	252 Died, 152 Missing, 365 Injured	Dome Collapse 6.2 10 ⁶ m ³ . Landslide in the Fissure (1,600-2,000 m altitude), 6.0 10 ⁶ m ³
14 May, 1981 16 May, 1982 – Jan, 1983	Besuk, Tengga, Tunggeng, Mujur, Lengkong	918 ha of Rice Fields, 16 Villages Damaged	Lava, Materials, and Pyroclastic Flows
10 May, 1985, 15-18 Aug, 1985	Peak Collapse, Tretes, Kobokan, Kembar of 5 km	70, Jogosari Village, Liprak	Explosion of 1 km, Dome Collapse, Deposit 5 10 ⁶ m ³
Jul 1986 – 1987 and 10 May, 1988	Rejali, Tretes, Kobokan, C Lengkong, 5 km		Explosion, Dome Growth 5 10 ⁶ m ³
21 Dec, 1990,1991	Jonggring-Seloko Vent Kembar, Kobokan		Strombolian, Explosion, Dome Floor Collapse
1992	Peak Area	3 Died, Damage to Settlements and Land	Explosion, Lava Extrusion, 1 km Column Height

3 Feb, 1994 and Dec, 1994	Scar, Koboan, Lengkong; 11.5 km, Kembar, 7.5 km (750 m altitude)	15 died, 275 Evacuated, Summersari Village, Damage to Oro Oro Ombo and Renteng	Dome Collapse, Hot Clouds up to 11 km Forming a Lava Tongue
20 Jul, 1995	Kembar, Koboan, C Lengkong, SE 7.5-11.5 km (840 m Latitude)	Land Damage, People Evacuated	Dome Collapse
Aug-Sep, 1996	Kembar, 2 km		Pyroclastic Flow, Dome Collapse
Jul-Nov, 1997	Vent Area, Scar SE, 2 km, C Lengkong	2 International Tourists	Explosion 3.7-4.9 km High Column
Mar-Sep, 1999	Peak Area, Kembar		Explosion, Dome Growth, 9 Km High Column
May, Jul, Dec, 2000	Peak Area, Kembar, Koboan, 3 km	2 Volcanologists Died, 5 Injured	Explosion
2001-2002	Vent and scar, Kembar, 2.5 km		Very High Column, Hot Clouds
23, 29, 30 Dec, 2002	Vent Area and Scar, Bang, SSE, 9 km to Supit near Pronojiwo, 750 m Altitude 1.5 - 4 km Avalanches	Forest Destruction, Supit, Pronojiwo	Increased Activity Since Mar 2002, Explosion, Dome Collapse
Mar-May, 2003	Peak Area, Bang, and Kembar 1.5-3.75 km		Explosion, Dome Growth and Dome Collapse
15-22 May, 2008	Hot Clouds to Besuk Kobokan of 2,500 m		Eruption of 500 m High
2009	Incandescent Lava Flow to Pronojiwo		Lava Dome
Jan, Feb, Mar, 2010	1,460 kg SO ²	12,000 Residents Evacuated	Explosion, Lava Flow
2013			
1 Dec, 2020	Hot Clouds and Incandescent Lava	Residents Evacuated	Eruption, Hot Cloud Fall of 2-11 km
4 Dec, 2021	Hot Cloud Fall of 11 km to Curah Kobokan Pronojiwo	2,417, 19 Ha Land Affected, 51 Died, Settlements, Infrastructure, Forests Were Destroyed	Hot Cloud Fall from the Middle of the Lava Tongue of 1,500 m from the Summit to Besuk Kobokan

Table 1 shows that Semeru eruptions have become one of the deadliest disaster threats and even destroyed parts of Lumajang Regency [7]. The incidence of eruptions is very frequent, resulting a high number of casualties/injured victims as well as great losses and damages from time to time. This condition should make the community and government prepared and optimize mitigation so that when a disaster occurs, the number of victims and losses can be suppressed. However, the number of victims after the Semeru eruption on December 4, 2021, with the type of volcanic and strombolian eruption, is still very high: death toll up to 51 people, 7 people missing, 104 people injured, and thousands of residents (10,395 people) displaced at 121 shelter points. The eruption also buried and destroyed several settlements, forests, farms, infrastructure, and residents' agricultural land [18].

The high death toll and damages caused by Semeru is a sign that the government and community have not yet optimized disaster mitigation. Several problems that occur in Indonesia related to the high risk of disaster are influenced by inaccuracies in spatial planning policies, inappropriate land use [19], undeveloped community preparedness, limited infrastructure to

carry out evacuations, and the high level of community vulnerability [19] and [20]. In this context, land use is certainly one of the important things and becomes a control to be regulated so that the number of victims and damages can be reduced [21]. According to research [22] that spatial planning and proper land use in disaster-prone areas is one of the main mitigations in reducing the number of people potentially exposed to disaster. The integration of disaster hazard data into spatial planning is one of the mainstays of several countries in reducing the risk level [23]. Based on the problems above, this study aimed to analyze the impact of damages caused by the eruption of Mount Semeru, analyze spatial planning policies, and map land use mismatches in the study area.

2. Methodology

This study was conducted in Lumajang Regency which was severely affected by the Semeru eruption. The morphology of the mountain that leads to the southeast and the direction of the flow and wind to the south and southeast makes pyroclastic material and hot clouds hit several sub-districts in Lumajang Regency. The description of the study area is presented in Figure 1.

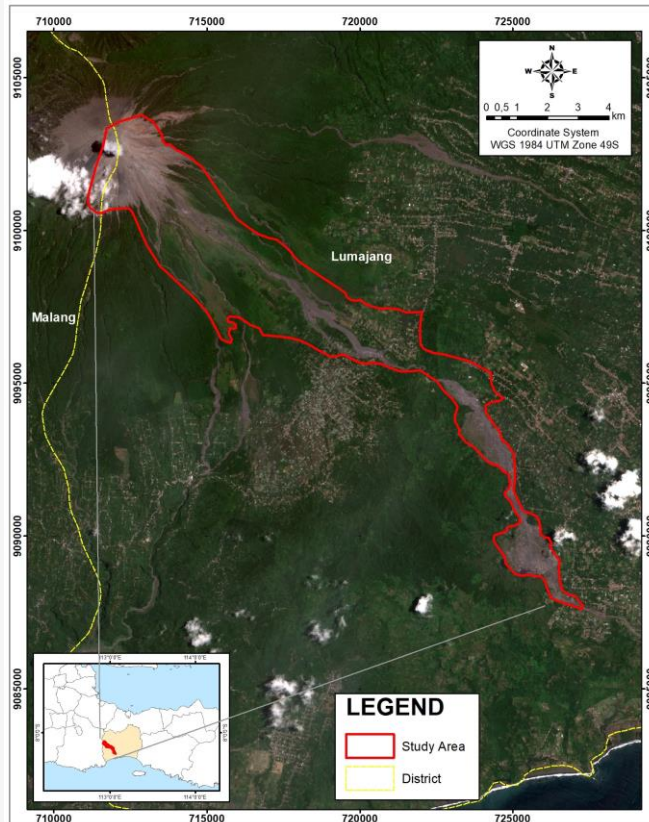


Figure 1: Research location in Lumajang Regency, East Java Province, Indonesia
(Source: Sentinel-1B, Accessed via Sentinel Hub EO, <https://apps.sentinel-hub.com/eo-browser/>)

The data in this study includes satellite imagery of Sentinel-1B before the Semeru eruption recorded on October 12, 2021, Image of Sentinel-1B after the eruption on December 11, 2021 accessed via sentinel hub EO, map of regional spatial planning from the Lumajang Regency Regional Regulation Number 2/2013 concerning the spatial planning for the Lumajang Regency area for 2012 - 2032, and map of disaster-prone areas 2021 from the Ministry of Energy and Mineral Resources. Sentinel imagery with a temporal resolution of once every six days covering the area and the ability to have a spatial resolution of up to 5 m was chosen in this study. Utilization of remote sensing image as in the study of [6] was quite effective in monitoring land use; image data analysis was also useful in prioritizing safety because several volcanologists have become victims of Semeru eruptions [4]. Sentinel-1B image analysis was carried out using the maximum likelihood approach to obtain land cover/land use maps before and after the eruption. In this image classification, eight types of land uses were obtained: settlements, paddy land, agriculture land, high-density forest, medium-density forest, water bodies, and open space.

To map the damage impact of the Semeru eruption, an overlay of land use maps before and after the eruption was carried out. Meanwhile, to map whether the spatial planning direction has included disaster mitigation, an overlay of the Lumajang regency spatial planning map with a map of the Eruption Hazard-Prone Area was carried out. In this study, spatial analysis was also carried out based on the existing conditions of land use through overlaying land use maps and the regency spatial planning map. Spatial analysis was carried out based on the affected area [24]. It is hoped that this land use will be able to become the basis for formulating post-disaster rehabilitation and reconstruction policies as well as formulating disaster-based spatial planning. The research flow chart is presented in Figure 2.

3. Result and Discussion

3.1 Impact of the Semeru Eruption

Mapping after an eruption is an important part in monitoring the impact of the disaster, both direct (incandescent lava, hot clouds, pyroclastic material) and indirect (lava floods carried by rainwater) impacts.

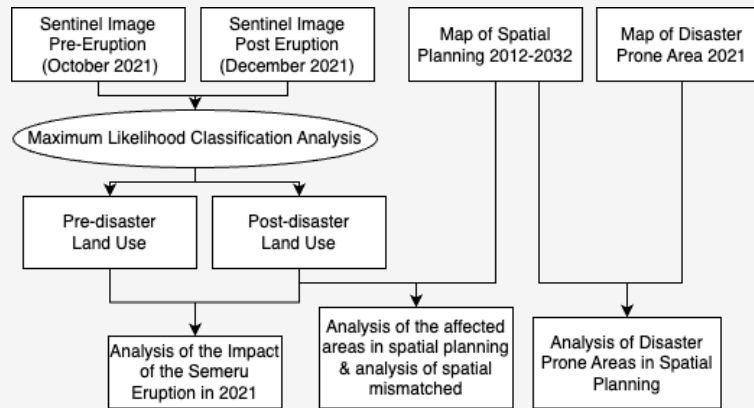


Figure 2: Research flow chart

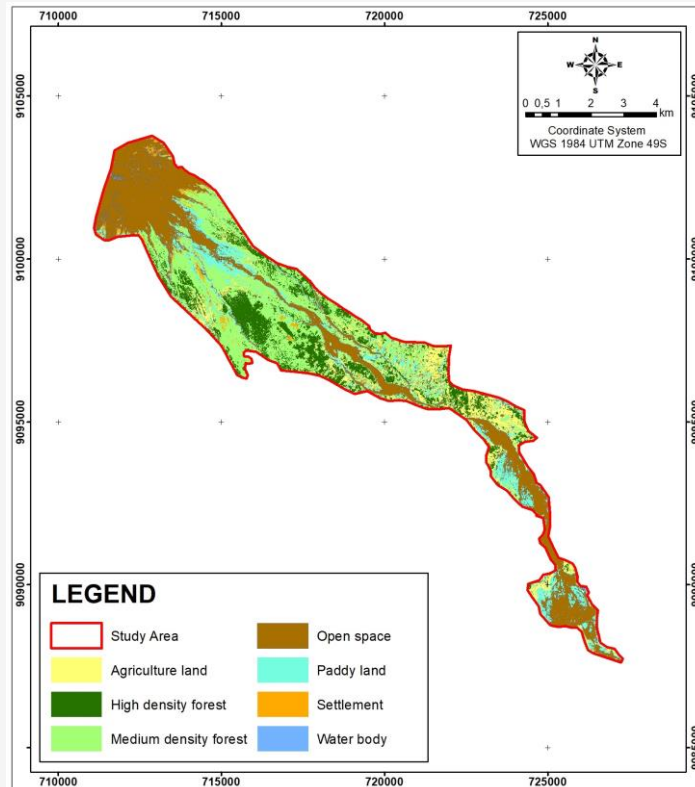
Table 2: Damages due to the Semeru eruption

No.	Land use	Pre-eruption area (Ha)	Post-eruption area (Ha)	Change/affected area (Ha)	Percentage (%)
1	Settlement	129.8	38.8	-91	-70.11
2	Paddy land	484.7	33.9	-450.8	-93.01
3	Agriculture land	474.4	37.7	-436.7	-92.05
4	High density forest	658.5	335.7	-624.9	-94.90
5	Medium density forest	1,036.5	353.1	-1,001.2	-96.59
6	Water body	6.9	3.8	-3.1	-44.93
8	Open space	1,902.1	4,096.8	2,194.7	115.38

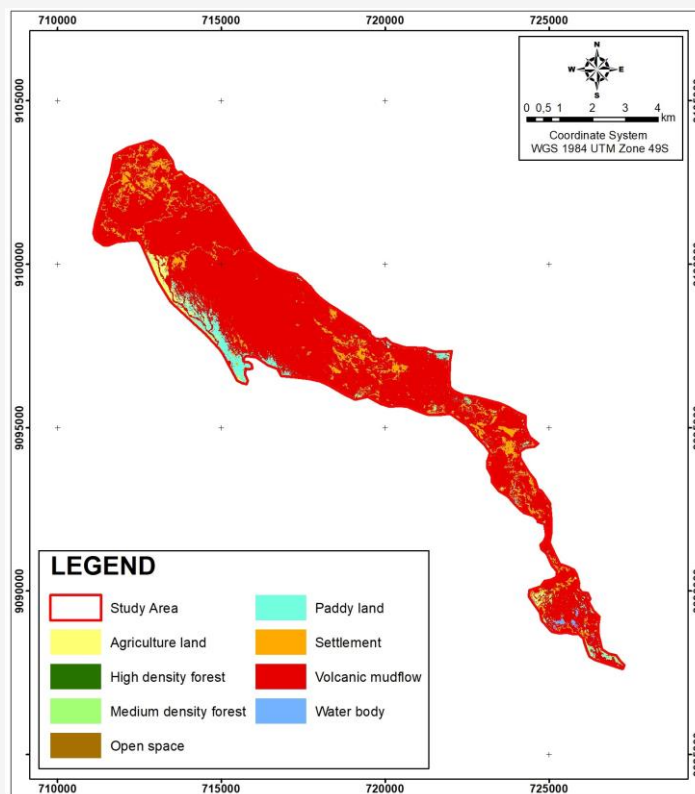
Remote sensing images available in real time and multitemporal supported by machine learning technology (maximum likelihood classification) for data processing are able to produce information related to the value of post-disaster damage effectively and efficiently. Eruption impact data, volcanic magnitude, volcanic morphology, and flow direction are also important parts of mapping the disaster vulnerability map [25] and [26]. Several studies have shown that the internal structure of Semeru has weak zones indicating the presence of magma and magma output as well as pyroclastic material leading to the southeast and south [8]. The active crater, which is open on the southeast side, and the activity of Semeru, which has been dominated by small explosions since 1967, has resulted in frequent explosive activity [3]. The amount of energy from magma to the surface and the amount of gas and material from the volcano caused a large eruption in 2021, whose impact was much more severe than the eruptions of several previous years. Based on the results of the overlay map of land use before and after the eruption, the impact of damage to the Semeru eruption can be mapped in Figure 3. Data from the spatial analysis

are as shown in Figure 3, while the damages due to the Semeru eruption in 2021 is presented in Table 2.

Based on Figure 3 and Table 2, the recent Semeru eruption had a massive impact on the destruction of settlement areas of up to 91 Ha. This condition was due to the residents' settlements being relatively close to the center of the eruption and located in the area around Besuk Kobokan River. In addition, the avalanche of hot clouds up to 11 km and the amount of pyroclastic material produced in the December 2021 eruption caused high casualties and buried residents' settlements. In addition to that, agriculture land of 436.7 ha and community paddy land of 450.8 ha were destroyed by hot clouds and covered with pyroclastic material. The eruption also destroyed the forest (high density forest and medium density forest) and the flora and fauna in it up to 1,626.1 ha. The results of Sentinel 1 B image analysis showed that the land cover around the post-eruption of the Besuk Kobokan river and its surroundings is dominated by pyroclastic cover or becomes a stretch of open land. Data related to the impact of the eruption in Lumajang Regency are presented in Figure 4. Administratively, the impact of the Semeru eruption in Lumajang Regency is presented in Figure 5.



(a)



(b)

Figure 3: (a) Pre-eruption land use on 12 October 2021; (b) Post-eruption land use on 11 December 2021

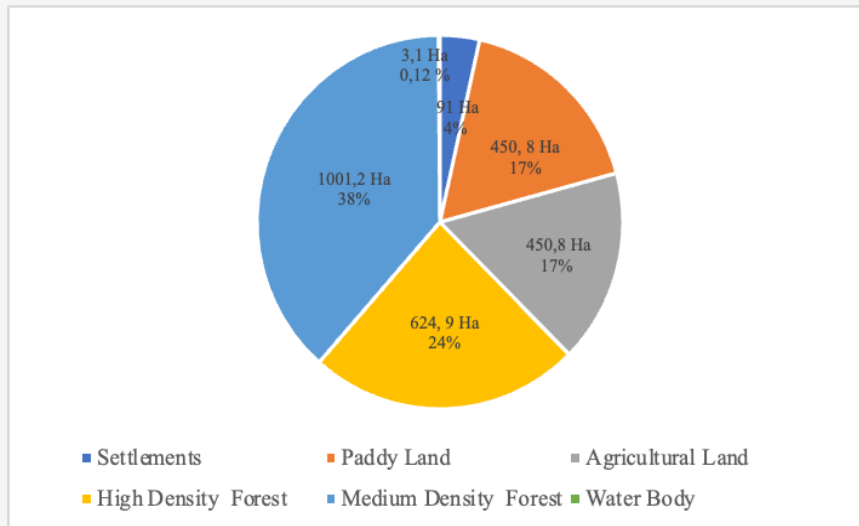


Figure 4: Impact of the Semeru eruption in 2021

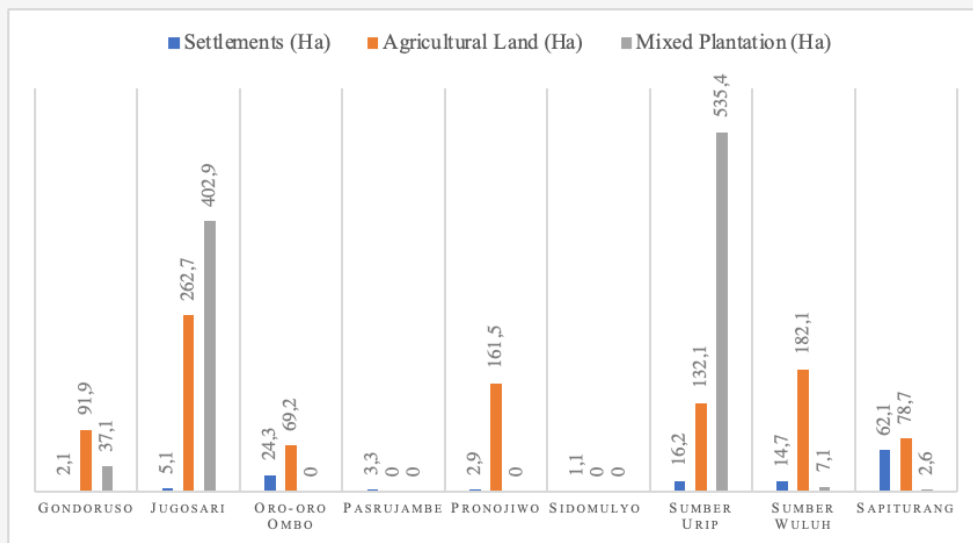


Figure 5: Villages affected by the Semeru eruption in 2021

Sapiturang and Oro-oro Ombo are villages whose settlements were greatly affected by the Semeru eruption. Moreover, most of agricultural land in Jugosari, Sumber Wuluh, and Pronojiwo villages as the basis of community life were destroyed by the eruption. Some of these villages are villages that are in a very close radius to the peak of Semeru and are in the direction of the flow of hot clouds and pyroclastic material. Based on the spatial analysis above, it is shown that land use in disaster-prone areas affects the level of vulnerability and risk that will be affected by the disaster. Land use regulation policies are certainly an important part so that the level of disaster risk can be minimized [21] and [27]. It is hoped that proper land use arrangements

will be able to provide protection for community safety and livelihood sustainability [28] and [29].

3.2 Integration of Regional Spatial Planning as an Effort for Disaster Risk Reduction

The policy of mainstreaming spatial planning as the main control to reduce the level of disaster risk as the vision of the Sendai Framework (2015-2030) has been implemented in several countries. According to Kato and Huang [21] in their study stated that Japan implements a policy of directing the use of space to prevent the adverse effects of climate change, as does India [28]. The implementation of spatial planning and monitoring policies of land use are also set in Peru to protect residents from the threat of disaster [22].

This condition explains that several countries are very concerned about the safety and sustainability of people's lives by integrating disaster mitigation through the integration of disaster hazard maps in a single spatial planning unit. Restrictions on land use in disaster-prone areas are set so that the number of victims and losses can be minimized. The results of the overlay analysis of the disaster hazard map with the regional spatial planning map show that the spatial planning policy does not yet direct the Semeru Disaster Prone Area III area as a fully protected/national park area. The results of the spatial analysis show that there are still directions for settlements in the Disaster-Prone Area III (DPA III) in the RTRW. This condition caused the community settlements in Sapiturang and Oro-oro Ombo villages to be mostly affected by the Semeru eruption. An illustration of several directions for spatial use that have not fully paid attention to disaster mitigation efforts is presented in Figure 6.

Based on the analysis through the overlay of the spatial planning map and the map of disaster-prone areas (DPA) determined by the Regional Disaster Management Agency (BPBD), it is shown that there are directions for land use as settlements in the DPA III area of 171.4 Ha. In some cases, DPA III appears to be the most vulnerable area to be affected by hot clouds, incandescent lava, and other pyroclastic material ejections. Therefore, the regulation of land use, where settlements are not allowed in the DPA III area, becomes a disaster risk reduction strategy [30]. Based on Figure 8, it shows that in DPA III not all of them have been designated as national park areas. There are still directives for other uses, namely for settlements and agricultural land. This condition causes a large number of victims and

losses when a disaster occurs. In this context, the authors recommend that DPA III should be designated as a national park. The results of the analysis related to the overlay of the two maps produce data on the area of the spatial planning in the DPA III and DPA II areas as shown in Table 3.

3.3 Incompatibility of Land Use with Regional Spatial Planning

Government policies as an effort to protect the community as well as to maintain the sustainability of life and the environment are embodied in the spatial planning regulation. However, after a spatial analysis, namely the overlay between the spatial planning map and the existing land use map, there is a mismatch of land use, especially in the local protected area. The condition of the spatial distribution of land use discrepancies, especially in DPA III and DPA II with the direction of the Spatial Planning in Lumajang Regency, is presented in Figure 7. The violation of the regional spatial planning which was carried out intentionally or unintentionally by the community resulted in the high number of victims and losses due to the disaster. The need for settlements and the lives of people who are very dependent on natural resources have implications for several areas in the protected area being used as settlements. Figure 7 and Table 4 show that there has been a violation of the regional spatial planning in the area that is supposedly functioned as a conservation area of 10.3 ha, national park area of 335 Ha and production forest area of 170 ha to be used by the community as their settlement area. This inappropriate land use change has an impact on increasing the risk suffered by the community when a disaster occurs [31].

Table 3: Directions for regional spatial planning in disaster-prone areas

No.	Disaster-Prone Areas (DPA)	RTRW Directive		
		Settlement (Ha)	Farmland (Ha)	Mixed Garden
1	DPA III	171.4	1,037.3	731.8
2	DPA II	168.3	2,076.1	532.9

Table 4: Incompatibility of land use with the spatial planning (RTRW)

No	Incompatible of land use with spatial planning	Large (Ha)
1	Settlement in production forest	170.04
2	Settlement in conservation area	10.31
3	Appropriate	3,604.10
4	Settlement in national park	335.06
5	Other inappropriate	10,723.04

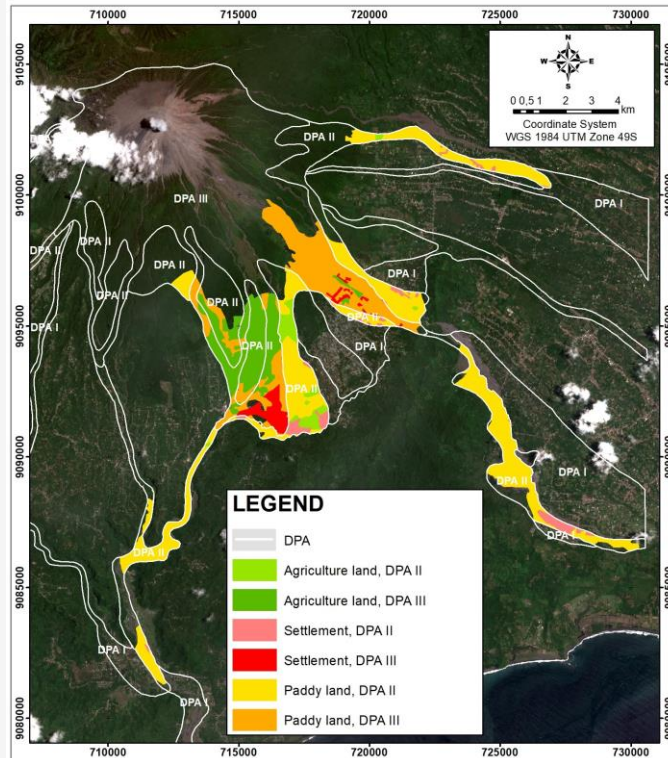


Figure 6: Spatial planning map in disaster prone areas
(Sources: Spatial planning map 2012-2032, disaster prone areas map 2021)

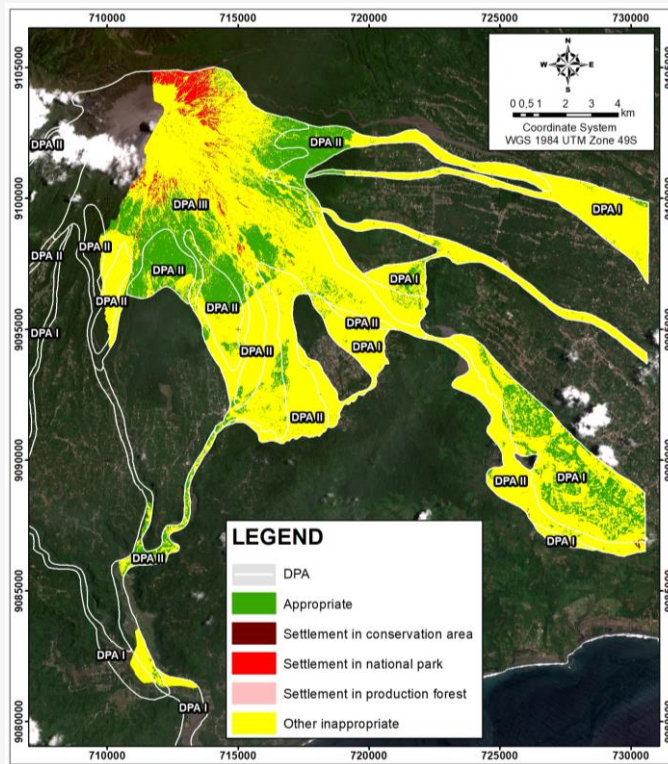


Figure 7: Map of incompatibility of land use with the regional spatial planning
(Sources: Land use map 2021 and Spatial panning map 2012-2032)

The lack of control over the use of space and neglect of spatial planning violations have a negative impact on the massive post-eruption damages. This study also conducted an overlay analysis of the map of the area affected by the disaster with the Lumajang district spatial planning map for the period 2012 to 2034. It is hoped that this map will be taken into consideration in formulating appropriate regional spatial planning policies for disaster-affected areas. The results of overlaying a map of the area damaged by the Semeru eruption with the spatial planning map are presented in Figure 8. Data on the area of the spatial planning in the area affected by the Semeru eruption in 2021 are presented in Table 5. Based on Figure 8 and Table 5, it is shown that the

location that is quite severely affected by the Semeru eruption in the Spatial Planning is directed to settlements covering an area of 109.07 ha, as well as rice field area of 2,208.94 ha. Based on this data, the government should make revisions to the spatial planning, especially in areas that are quite severely affected. Restrictions on the direction of land use for settlements should be carried out so that the community is safe from future disasters. Furthermore, observing the results of the map overlay of the affected area and the disaster-prone Area, then the area affected by the Semeru eruption that is covered by pyroclastic material is not only in the DPA III area.

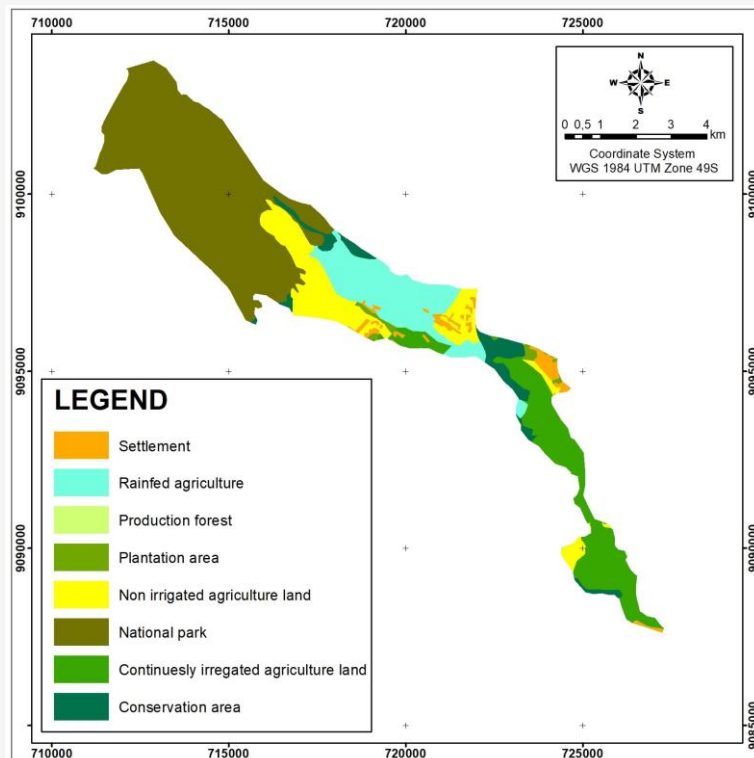


Figure 8: Map of spatial planning year of 2012 - 2032 in the area affected by the Semeru eruption

Table 5: Map of spatial planning in eruption affected area

Spatial Plan Direction	Area (ha)	Percentage
Settlement	109.07	3
Production Forest	1,265.38	29
Agricultural field	526.04	12
Rice Field	2,208.94	51

Table 6: Disaster-prone areas affected by the Semeru eruption

Spatial Planning Direction	Area	Percentage
DPA III	2,663.07	13
DPA II	1,087.99	2
DPA I	511.50	62

However, after the 2021 eruption, the area of DPA II is 1,087.99 ha and DPA I is 511.50 ha which is actually more severely affected. Disaster impact data based on the level of disaster vulnerability is presented in Table 6.

Based on Table 6, it is necessary to review the policy for determining the area of DPA III by involving volcanologists, the government, and the community so that the determination is agreed upon by all parties. Socialization to the community to understand the direction of land use in DPA III, building awareness, and community preparedness are very necessary so that in the future, when there is another eruption, the number of victims can be reduced. In addition, based on this study, a review of the regional spatial planning is also needed so that areas severely affected by the eruption can be directed as national parks, forests, and/or protected areas. Strict regulations regarding land use directions in disaster-prone areas, especially in DPA III and monitoring of land use in these areas is urgently needed, considering that Semeru is the most active volcano in Indonesia. Post-disaster management policies, namely rehabilitation and reconstruction, should be carried out appropriately by avoiding disaster-prone locations. The construction of settlements to relocate residents should prioritize locations that are safe from disasters and pay attention to the livelihoods/life of the community [29]. This relocation effort and spatial planning policy need to be a concern considering that community land has been destroyed and similar eruption disasters may occur again. Risk-based spatial planning policy by [32] taking into account the level of disaster risk, livelihoods, infrastructure as well as social and economic conditions are expected to be able to realize a sustainable community life.

4. Conclusions

The Semeru eruption starting in the year 1818 until December 2021 shows this volcano is very active and has very strong explosive energy which has a negative impact on the loss of life and damages to forests, paddy land, agricultural land, and community settlements. The magnitude of the impact caused by the Semeru eruption in 2021 which resulted in up to 51 deaths, 10395 people being displaced, damage to settlements of up to 131.8 hectares and damage to agricultural land of up to 899.5 hectares indicates a very high level of vulnerability and disaster risk. This condition is partly due to the people's residences and land use for agricultural land being very close to the erupting volcano. There are still directions for spatial planning in DPA III as agricultural land and as

settlements which are one of the causes of high losses. In this case, the right land use policy, namely the prohibition of the existence of permanent houses in DPA III, is a preventive step so that risks can be minimized. Post-eruption shows that the impact of the disaster is getting wider so that a review of the determination of DPA III needs to be considered by involving all stakeholders. The mismatch of land use in disaster-prone areas also needs to be regulated considering that Semeru has a very short re-eruption period. Re-arrangement of DPA III and risk-based spatial planning is one of the main controls so that people live safely and are able to realize sustainable livelihoods and live.

Acknowledgements

The authors would like to thank Sentinel Hub EO for providing multitemporal sentinel image data, thanks to the Ministry of Energy and Mineral Resources for providing the Semeru eruption hazard map. The authors are also grateful to the Government of Lumajang Regency for agreeing to provide a spatial planning map for the 2012-2032 area

References

- [1] Nishi, K., Hendrasto, M., Mulyana, I., Rosadi, U. and Purbawinata, M. A., (2007). Micro-tilt changes Preceding Summit Explosions at Semeru Volcano, Indonesia. *Earth, Planets Sp*, Vol. 59(3), 151–156. <https://doi.org/10.1186/BF03352688>.
- [2] Perwita, C. A., Maryanto, S. and Budianto, A., (2012). Karakteristik Gempa Letusan Gunung Semeru, Jawa Timur Tahun 2009, Vol. 1(3), 229–234.
- [3] Smekens, J. F., Clarke, A. B., Burton, M. R., Harijoko, A. and Wibowo, H. E., (2014). SO₂ Emissions at Semeru Volcano, Indonesia: Characterization and Quantification of Persistent and Periodic Explosive Activity. *J. Volcanol Geotherm Res.*, Vol. 300, 121–128. <https://doi.org/10.1016/j.jvolgeores.2015.01.006>.
- [4] Solikhin, A., Thouret, J. C., Gupta, A., Harris, A. J. L. and Liew, S. C., (2012). Geology, Tectonics, and the 2002-2003 Eruption of the Semeru Volcano, Indonesia: Interpreted from High-Spatial Resolution Satellite Imagery. *Geomorphology*, Vol. 138(1), 364–379. <https://doi.org/10.1016/j.geomorph.2011.10.001>.

- [5] Starheim, C. C. A., Gomez, C., Davies, T., Lavigne, F. and Wassmer, P., (2013). In-flow Evolution of Lahar Deposits from Video-Imagery with Implications for Post-Event Deposit Interpretation, Mount Semeru, Indonesia. *J. Volcanol Geotherm Res*, Vol. 256, 96–104. <https://doi.org/10.1016/j.jvolgeores.2013.02.013>.
- [6] Kassouk, Z., Thouret, J. C., Gupta, A., Solikhin, A. and Liew, S. C., (2014). Object-oriented Classification of a High-Spatial Resolution SPOT5 Image for Mapping Geology and Landforms of Active Volcanoes: Semeru Case Study, Indonesia. *Geomorphology*, Vol. 221, 18–33. <https://doi.org/10.1016/j.geomorph.2014.04.022>.
- [7] Hasib, M., Maryanto, S. and Nadhir, A., (2009). Analisis Komponen Volatil Dan Laju Alir Lava Pada Erupsi Gunung Semeru, Jawa Timur. *Brawijaya Physics Student Journal*, Vol. 1(1), 1–3. [Online]. Available: <https://www.neliti.com/id/publications/157835/analisis-komponen-volatil-dan-laju-alir-lava-pada-erupsi-gunung-g-semeru-jawa-timu>.
- [8] Ayu, H. D., Susilo, A., Maryanto, S. and Hendrasto, M., (2013). Penentuan Struktur Internal Gunungapi Semeru Berdasarkan Citra Atenuasi Seismik. *Nat B*, Vol. 2(2), 145–152. <https://natural-b.ub.ac.id/index.php/natural-b/article/viewFile/218/183>.
- [9] Nishimura, T., Iguchi, M., Kawaguchi, R., Surono, Hendrasto, M. and Rosadi, U., (2012). Inflation Prior to Vulcanian Eruptions and Gas Bursts Detected by Tilt Observations at Semeru Volcano, Indonesia. *Bull Volcanol*, Vol. 74(4), 903–911. <https://doi.org/10.1007/s00445-012-0579-z>.
- [10] Iguchi, M., Surono, S., Nishimura, T., Hendrasto, M., Ohkura, T., Ishihara, K., Yoshimoto, M., Nakada S. and Hokanishi, N., (2012). Methods for Eruption Prediction and Hazard Evaluation at Indonesian Volcanoes. *J Disaster Res*, Vol. 7(1), 26–36. <https://doi.org/10.20965/jdr.2012.p0026>.
- [11] Wahyudin, D., (2010). Aliran Lava Produk Letusan Celah Tahun 1941 Serta Kemungkinan Terjadinya Letusan Sampung Baru Di Gunung Semeru Jawa Timur. *J Lingkungan dan Bencana Geol*, Vol. 1(3), 199–211.
- [12] Umam, M. F., Alhidayah, Y. and Fauziyah, R., (2019). Analisis Material Endapan Vulkan Gunung Semeru Kabupaten Lumajang. *Maj Pembelajaran Geogr*, Vol. 2(1), 92–98. <https://jurnal.unej.ac.id/index.php/PGEO/article/view/11522>.
- [13] Gomez, C., Lavigne, F., Sri Hadmoko, D. and Wassmer, P., Insights Into Lahar Deposition Processes in the Curah Lengkong (Semeru Volcano, Indonesia) Using Photogrammetry-Based Geospatial Analysis, Near-Surface Geophysics and CFD Modelling. *J Volcanol Geotherm Res*, Vol. 353, 102–113. <https://doi.org/10.1016/j.jvolgeores.2018.01.021>.
- [14] Thouret, J. C., Oehler, J. F., Gupta, A., Solikhin, A. and Procter, J. N., (2014). Erosion and Aggradation on Persistently Active Volcanoes-A Case Study from Semeru Volcano, Indonesia. *Bull Volcanol*, Vol. 76(10). <https://doi.org/10.1007/s00445-014-0857-z>.
- [15] Utami, W., Rahmat, A., Sialagan, B., Exaudia, S. and Turnip, A., (2021). Settlement Suitability Analysis Based on the Catastrophic Eruption of Sinabung. *IOP Conf Ser Earth Environ Sci*, Vol. 884(1). <https://doi.org/10.1088/1755-1315/884/1/012056>.
- [16] Doyle, E. E., Cronin, S. J., Cole, S. E. and Thouret, J. C., (2010). The Coalescence and Organization of Lahars at Semeru Volcano, Indonesia. *Bull Volcanol*, Vol. 72(8), 961–970. <https://doi.org/10.1007/s00445-010-0381-8>.
- [17] Thouret, J. C., Lavigne, F., Suwa, H., Sukatja, B. and Surono, (2007). Volcanic Hazards at Mount Semeru, East Java (Indonesia), with Emphasis on Lahars. *Bull Volcanol*, Vol. 70(2), 221–244. <https://doi.org/10.1007/s00445-007-0133-6>.
- [18] BNPB, (2021). Laporan-Harian-PUSDALOPS-22122021. Indonesia. <https://pusdalops.bnpb.go.id/2021/12/24/laporan-harian-pusdalops-bnpb-rabu-22-desember-2021/>.
- [19] Utami, W., Wibowo, Y. A., Hadi, A. H. and Permadi, F. B., (2021). The impact of mangrove damage on tidal flooding in the subdistrict of Tugu, Semarang, Central Java. *J Degrad Min Lands Manag*, Vol. 9(1), 3093–3105. <https://doi.org/10.15243/jdmlm.2021.091.3093>.
- [20] Nasution, B. I., Kurniawan, R., Siagian, T. H. and Fudholi, A., (2019). Revisiting Social Vulnerability Analysis in Indonesia: An Optimized Spatial Fuzzy Clustering Approach. *Int J Disaster Risk Reduct*, Vol. 51. <https://doi.org/10.1016/j.ijdr.2020.101801>.
- [21] Kato, S. and Huang, W., (2020). Land Use Management Recommendations for Reducing the Risk of Downstream Flooding Based on a Land Use Change Analysis and the Concept of Ecosystem-Based Disaster Risk Reduction. *J Environ Manage*, Vol. 287. <https://doi.org/10.1016/j.jenvman.2021.112341>.

- [22] Torres Mallma, S. F., (2019). Mainstreaming Land Use Planning into Disaster Risk Management: Trends in Lima, Peru. *Int J Disaster Risk Reduct*, Vol. 62. <https://doi.org/10.1016/j.ijdrr.2021.102404>.
- [23] Gonzalez-Mathiesen, C., Ruane, S. and March, A., (2021). Integrating Wildfire Risk Management and Spatial Planning – A Historical Review of Two Australian Planning Systems. *Int J Disaster Risk Reduct*, Vol. 53. <https://doi.org/10.1016/j.ijdrr.2020.101984>.
- [24] Haryana, I. K., Fikriyah, V. N. and Yulianti, N. V., (2006). Application of Remote Sensing and Geographic Information System for Settlement Land use Classification Planning in Bantul based on Earthquake Disaster Mitigation (Case Study: Bantul Earthquake, May 27th 2006). *Procedia Environ Sci*, Vol. 17, 434-443. <https://doi.org/10.1016/j.proenv.2013.02.057>.
- [25] Becerril, L., Cappello, A., Galindo, I., Neri, M. and Del Negro, C., (2013). Spatial Probability Distribution of Future Volcanic Eruptions at El Hierro Island (Canary Islands, Spain). *J Volcanol Geotherm Res*, Vol. 257, 21–30. <https://doi.org/10.1016/j.jvolgeores.2013.03.005>.
- [26] Ulloa, H., Iroumé, A., Picco, L., Mohr, C. H., Mazzorana, B., Lenzi, M. A. and Mao, L., (2016). Spatial Analysis of the Impacts of the Chaitén Volcano Eruption (Chile) in Three Fluvial Systems. *J South Am Earth Sci*, Vol. 69, 213–225. <https://doi.org/10.1016/j.jsames.2016.04.008>.
- [27] Azadi, H., Petrescu, D. C., Petrescu-Mag, R. M. and Ozunu, A., (2020). Special Issue: Environmental Risk Mitigation for Sustainable Land Use Development. *Land Use Policy*, Vol. 95. <https://doi.org/10.1016/j.landusepol.2020.104488>.
- [28] Dash, P. and Punia, M., Governance and Disaster: Analysis of Land Use Policy with Reference to Uttarakhand Flood 2013, India. *Int J. Disaster Risk Reduct.*, Vol. 36. <https://doi.org/10.1016/j.ijdrr.2019.101090>.
- [29] Utami, M., Ardianto, W. and Afiq, Y. A., (2019). Analisis Spasial untuk Lokasi Relokasi Masyarakat Terdampak Tsunami Selat Banten Tahun 2018. *BHUMI J Agrar dan Pertanah*, Vol. 5(1). <https://doi.org/10.31292/jb.v5i1.323>.
- [30] Widodo, D. R., Nugroho, S. P. and Asteria, D., (2018). Analisis Penyebab Masyarakat Tetap Tinggal di Kawasan Rawan Bencana Gunung Merapi (Studi di Lereng Gunung Merapi Kecamatan Cangkringan, Kabupaten Sleman Daerah Istimewa Yogyakarta). *J Ilmu Lingkungan*, Vol. 15(2). <https://doi.org/10.14710/jil.15.2.135-142>.
- [31] Su, Q., Chen, K. and Liao, L., (2021). The Impact of Land Use change on Disaster Risk from the Perspective of Efficiency. *Sustain*, Vol. 13(6). 1–14, 2021, <https://doi.org/10.3390/su13063151>.
- [32] Saunders, W. S. A. and Kilvington, M., (2016). Innovative Land Use Planning for Natural Hazard Risk Reduction: A Consequence-Driven Approach from New Zealand. *Int J Disaster Risk Reduct*, Vol. 18. 244–255. <https://doi.org/10.1016/j.ijdrr.2016.07.002>.