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ERUPTION HAZARD AND CHALLENGES OF VOLCANIC CRISIS MANAGEMENT ON A SMALL ISLAND: A CASE STUDY ON TERNATE ISLAND – INDONESIA

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ABSTRACT: Ternate Island is a volcanic island formed by the product of Gamalama volcano since thousands of years ago until the present time. It covers 111.4 km^2 and inhabited by more than 200,000 people. Its small size and dense population make it vulnerable to eruption hazards. This study aims to analyze the Gamalama volcano eruption hazard and the challenges of crisis management due to eruption on the small volcanic island of Ternate. This research also offers potential solutions for reducing the risk of catastrophic eruptions on small volcanic islands. Data on eruption events, including the type of eruption and the impact are collected and analyzed to see various potential eruption hazards. Besides, the analysis was also carried out to find potential solutions for volcanic risk management on small volcanic islands. The results show that the Ternate Island has the potential volcanic hazard, (primary), i.e., ejecting and incandescent of volcanic material (volcanic ash, sand, gravel, and bomb), lava flow, and pyroclastic flow. The other hazard (secondary) can be in the form of lahar and volcanic-tsunamis. A small island with dense population and all kinds of limitations will be more susceptible to eruption. The potential strategy that must be developed for volcanic risk management on a small island is the sister island concept. This concept is a networking system between communities on disaster-prone islands and communities on other islands that are safe to prepare evacuation procedures to avoid chaos in a volcanic crisis.

Keywords: Gamalama volcano; Ternate Island; Sister Islands; Small Island Management

1. INTRODUCTION

Indonesia has 17,504 islands [1], and most of them are small islands. According to the definition stated in Law No. 1 of 2014 concerning Coastal Areas and Small Islands Management, small island means an island along with its ecosystems which has an area smaller than or equal to 2000 km^2. The small island has several characteristics and often poses obstacles in regional development. The characteristics of the small island include location reachability problems, limited development space, limited natural resources, susceptible to damage to ecosystems, limited transportation and communication, limited internet network, limited market, limited clean water supply, and high dependency for supplies from outside [2].

Despite many such limitations, the fact remains that small islands are still attractive to many people for activities such as traveling, working, and even residing. It is statistically evident that there is an increasing trend for the number of inhabitants living in Indonesia small islands due to birth and migration. Those automatically also increases the number of private assets and public facilities that support their lives.

One of the interesting issues relating to small island management is disaster risk management. The issue is certainly related to various limitations, as mentioned earlier. Such limitations make small islands vulnerable to natural disasters [2] and disasters due to climate change [3]. Natural hazards such as earthquakes, tsunamis, volcanic eruptions, and hazard threats due to hydro-meteorological factors such as floods, high waves, extreme weather, land fires, and drought threaten some small islands in Indonesia. If those threats meet human and environmental factors along with the limitations of small islands, the risk of disaster will increase.

One of the hazards faced by people living in volcanic islands is the eruption. This threat is especially present in small volcanic island areas with active volcanoes. Out of the thousands of small islands in Indonesia, more than 20 islands are small volcanic islands with volcanoes that erupted in the Holocene era. Moreover, most of them are still active until the present time. One of the phenomenal eruptions on the volcanic island in Indonesia was the 1883 eruption of Krakatoa. The pyroclastic flow of the Krakatoa eruption reached the sea and triggered a tsunami as high as 41 meters, causing 36,000 deaths [4 – 8].

This research aims to reveal eruption hazards on small volcanic islands with rapidly developing settlements and to seek potential solutions to reduce the risk of catastrophic eruptions on small volcanic islands. This research undertook a case study on Ternate Island (Fig. 1), one of the small volcanic

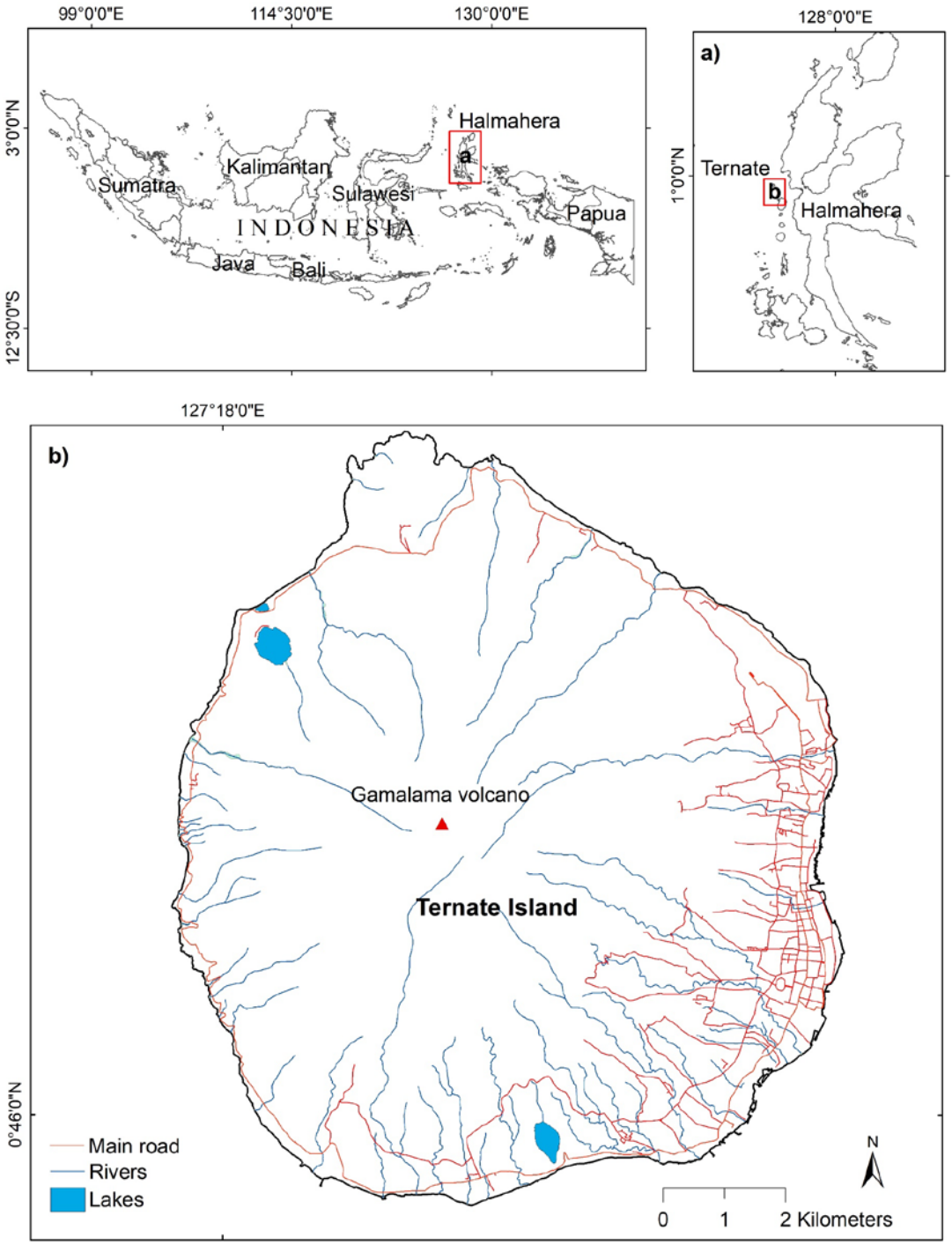

Fig.1 Research location in Ternate Island, North Maluku, Indonesia

islands with an active volcano and a rapidly developing settlement in the administrative area of Ternate City, North Maluku Province (Fig. 2).

2. METHODS

This research is exploratory. The potential for eruption hazards on the small volcanic island of Ternate was explored using eruption event data including eruption type and eruption impact which were collected from various official and trusted sources. Data sources consisted of a database of the Center for Volcanology and Geological Hazard Mitigation [9]; Eruption database of the Global Volcanism Programs [10]; scientific publications about Gamalama Volcano [11]; Map of Gamalama Volcano Eruption-Prone Areas [12]; Geological Map of Gamalama Volcano, Ternate [13].

Potential solutions for reducing risks of an eruption on Ternate Island were analyzed from

potential hazards and characteristics of Ternate Island as well as from past experiences of the people which were explored through in-depth interviews. Some selected key-persons were the Head of Emergency and Logistics Division of Ternate Regional Disaster Management Agency, the Head of Alertness Division of Ternate Regional Disaster Management Agency, the Head of Alertness Section of Regional Disaster Management Agency of Ternate City, Researchers from the Center for Disaster Studies of Universitas Khairun, Representatives of Volunteers from the Indonesian Red Cross of Ternate Chapter, and Some Traditional Leaders and Village Heads in Ternate City.

3. RESULTS AND DISCUSSION

3.1 Ternate Island

Ternate Island is a small volcanic island formed in the subduction zone of 3 tectonic plates, namely Indo-Australian, Eurasian and Pacific plates. In addition to Ternate Island, other volcanic islands also emerge in the collision zone between the plates, including Tidore Island, Moti Island, Makian Island, Sangihe Island and Mare Island. Ternate Island is an island that has been developing and is one of the centers of economic, shipping and aviation activities in the North Maluku region.

Administratively, it is part of Ternate City. Economic centers are growing rapidly in the East - Southeast part of Ternate Island (Fig. 2). Ahmad Yani Port, the main port, becomes a strategic point of shipping lanes in eastern Indonesia, which serves national shipping routes to various regions in Indonesia. Air transportation is served by Sultan Baabullah Ternate International Airport, which is the main gate to and from the Ternate Island and other areas in North Maluku.

Fig. 2 Existing settlement on the southern flank of Gamalama volcano, Ternate Island in 2018. (photo by Ilham)

3.2 Gamalama Volcano Eruption History

Gamalama Volcano is a nearly perfect cone-shaped stratovolcano with a radius of 5.8 km and an area of approximately 105 km^2 [12]. The peak is at an altitude of 1,715 meters above sea level [10]. It has erupted 77 times since it was recorded in 1510 for the first time. The eruption products include pyroclastic flow, lava flow, lahar, and various types of tephra including ash, sand, gravel, and blocks. The eruption materials were gradually deposited, forming the Ternate Island as it is present.

The repose period after the eruption varies greatly from 1 year (even less than one year) to 50 years. In general, after a long period of rest (more than ten years), major eruptions will occur and have a significant impact. For example, the eruption occurred after a 50-year rest from 1687-1737, producing a lava flow westward reaching the sea. Another example is the eruption after an 18-year rest from 1962 - 1980, resulting in a massive explosion that produced a new crater and the ashes covered the entire Ternate island with a thickness of 10-15 cm. The social impact arising from the 1980 eruption was an evacuation of around 40,000 people to other islands around Ternate Island, such as Tidore Island, Hiri Island and Halmahera Island.

On the other hand, a short repose period does not always mean small eruption and insignificant impacts. For example, the eruption which took place after a 1-year rest (1770 – 1771), or the eruption in 1771 – 1772, produced a lava flow that killed 40 people. The following eruption was also phenomenal, with a 1-year rest (1774 – 1775), which was the 1775 parasitic eruption, producing a maar with a diameter of 700 meters (upper part) and 350 meters of the lower part as deep as 40-50 meters around Soela Takome village, resulting in 141 missing people. The 1840 eruption was also preceded by a period of only one-year rest (1839-1840) and caused a tsunami on Halmahera Island [14, 15].

3.3 The Characteristics of Gamalama Volcano

Gamalama volcano activities have been well recorded since the beginning of the 16th century. The records indicate that the eruptions of Gamalama ejected volcanic materials from ash until block-sized and were often followed by volcanic bombs [12]. Some eruptions were followed by lava flow and pyroclastic flow [11]. The eruptions followed by lava flow occurred 15 times, in 1653, 1687, 1737, 1739, 1763, 1771-1772, 1773-1774, 1839, 1840, 1843, 1844, 1847, 1864-1865, 1871 and 1907 [9,10,12]. The eruptions followed by pyroclastic flow occurred three times, in 1991, 1993, and 2003 [11].

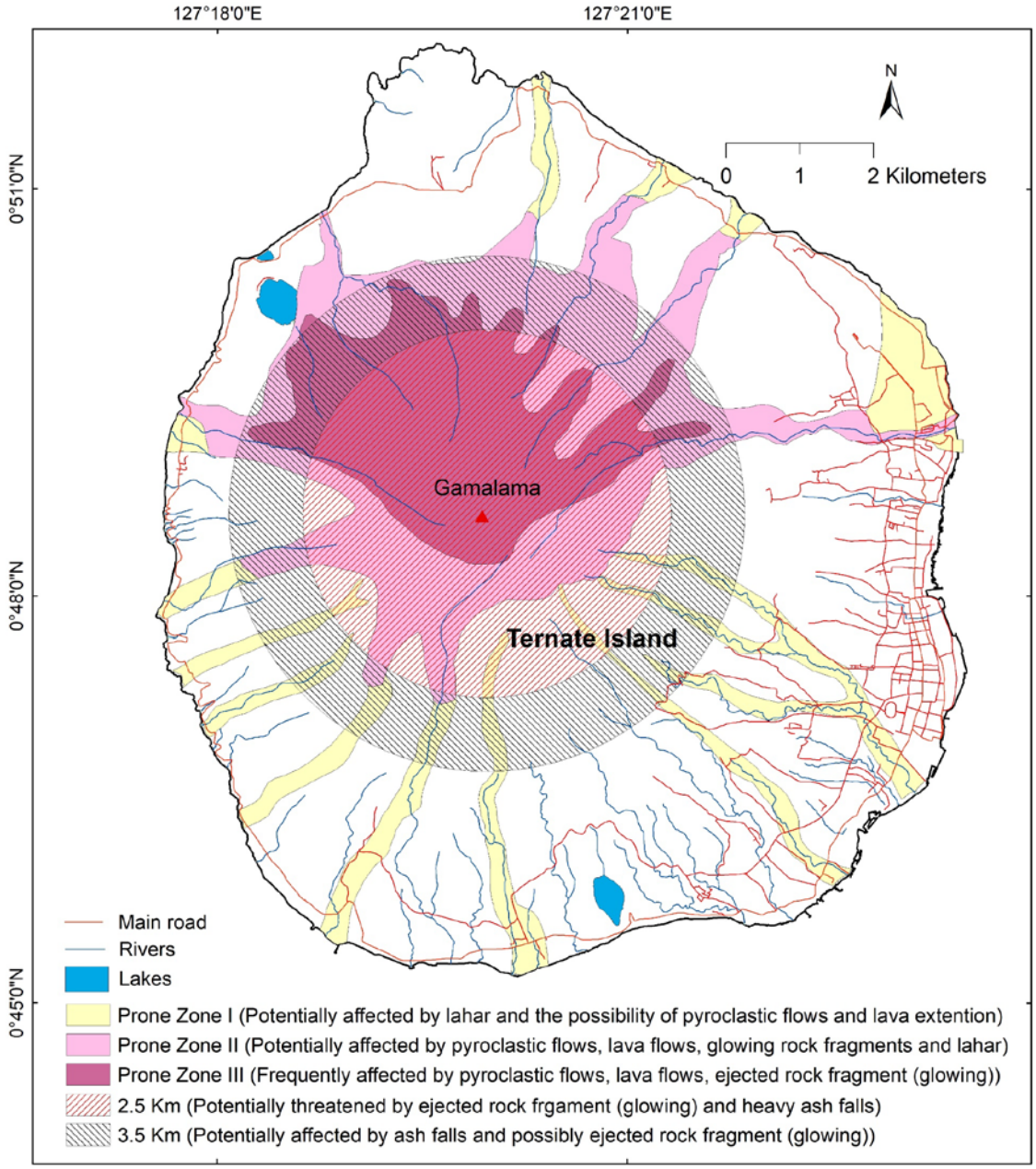

Fig. 3 Disaster prone zone map of Gamalama volcano in Ternate Island [12]

Another characteristic is parasitic eruptions as in 1561 and 1775. The eruption in 1775 produced large Maar Tolire and small Maar Tolire. According to Bronto et al. [13], Maar Tolire was formed due to the phreatomagmatic eruption process, which is an interaction between magma and groundwater that occurs below the surface. The parasitic eruption of Gamalama Volcano is controlled by the alignment of the structure that cuts its peak in a relatively northwest-southeast direction [11].

Another interesting point to observe from the characteristics of Gamalama Volcano is the correlations between the Gamalama eruption and tectonic earthquakes before the eruption. The earthquakes shake around Ternate, and the eruption before or after the quake was recorded by De Clerc [15] who mentioned that an earthquake occurred close to the 1840 Gamalama eruption. Older than De Clerc's record, Maar Tolire formed in 1775 was allegedly due to land subsidence caused by an earthquake [9]. Another more recent record of the earthquakes taking place a few days before the eruption was 1980, 1983, and 1993. A tectonic earthquake with a magnitude of 5.8 Richter Scale occurred before the 1993 eruption. Tectonic earthquakes with a magnitude of more than 4 Richter Scale have the potential to activate fluid reservoir that can be by a volcanic earthquake before the eruption [11].

3.4 Eruption hazard potentials on Ternate Island

The eruption hazard potentials of Gamalama Volcano on Ternate Island are enormous. Hazard potentials can be identified from past events recorded in history or the literature. Primary eruption hazard potentials include ejection and incandescent materials (such as volcanic ash, sand, gravel, and blocks), lava flow, and pyroclastic flow. The secondary hazards from the volcanic eruption are volcanic tsunamis and lahars (Fig. 3).

Volcanic materials in volcanological terms are also known as tephra. Tephra is a general term for volcanic rock fragments released into the air by volcanic explosions and carried upward by hot gas in the eruption column. It is classified based on its size, namely volcanic ash (fragments of less than 2 mm); lapilli (fragments between 2 and 64 mm); blocks (angular fragments greater than 64 mm); bombs (round fragments larger than 64 mm). Large-sized Tephra (bombs or blocks) will usually fall not far from the crater hole, and smaller sized tephra (lapilli) will fall farther from the crater hole, even for the very small-sized tephra or so-called volcanic ash can be carried by winds reaching hundreds to thousands of kilometers [16].

Tephra can spread from tens to hundreds of kilometers from its source and can have an impact on humans and environment such as: harming the health of humans and pet animals, curbing flight activities and destroying the important infrastructure (transportation, telecommunications, water installation, and drainage system), buildings, and agricultural land and commodities. Thick volcanic ash can damage housing infrastructure and clog irrigation channels. Bomb and block-sized tephra have the potential to land more than 10 km from the crater hole but usually, land within 5 km. The most damaging consequences of large-sized tephra are direct impacts such as making holes in the roof, killing people or livestock and causing serious damage to plants [16].

Lava is molten rocks with temperatures from 600°C to 1000°C released by volcanoes during eruptions [12]. It can flow from less than 1 km to several tens of kilometers depending on the chemistry, temperature, effusion rate, viscosity, and topography. Lava flow velocity also varies from a few meters to several tens of km/h before it cools and hardens.

Pyroclastic flow or better known as Pyroclastic Density Currents is a material flow phenomenon in the form of a mixture of fragmented volcanic gas and volcanic rock moving down the slopes of volcanoes at speeds of tens to hundreds of kilometers per hour, and reaching a temperature of more than 700 ° C [16].

A lahar is a hydro-volcanic event occurring during eruption and after eruption indicated with a large debit flow with high sediment concentration and poor sortation [11, 18]. Lahar formed during an eruption is often referred to as primary or syn-eruptive lahar and lahar formed after the eruption ends often referred to as secondary or post-eruptive lahar. The slopes of the stratovolcano in the volcanic island, such as Ternate Island, are generally steep and contain less compact material, making it easier for lahar to form. Besides, wet tropical climate conditions with high rainfall make an ideal condition for forming lahar. As a result of the limited area of the volcanic island, the risk of fatalities and infrastructure damage due to lahar can be higher.

Volcanic earthquakes occur due to magma movement. The magma movement changes pressure on the rock around the magma so that at a certain point, the rock can break (triggering an earthquake) or move aseismically (through creep motion) [16]. Ternate Island, like other volcanic islands, is a volcanic building that results from a rapid deposition of magmatic products in a limited area. As a consequence of this relatively rapid construction, any volcanic construction with a significant height (≥1000 m) is a fragile structure. Volcanic earthquakes can trigger sector collapse, rock falls, and avalanches, which are gravitational movement from some portion of volcano slopes [16]. Moreover, the sector collapse and landslide occurring in the sea can trigger volcanic tsunamis.

Tsunamis are waves or a series of long-period water waves generated by an inevitable disturbance in the sea or lake environment and can affect the coastal environment [19]. Such inevitable disturbances can be underwater earthquakes, underwater landslides, underwater volcanic eruptions, seafloor collapse, bombs, or fall of meteors in the sea. Several eruption mechanisms can trigger tsunamis such as an underwater explosion, airwaves generated by volcanic blasts, pyroclastic flows or lahars entering the sea, the collapse of the underwater caldera, subaerial failure, and submarine failure [14].

3.5 Settlements and residents potentially exposed eruption hazards

Settlements on Ternate Island have developed since the golden age of the Sultanates of Ternate, Tidore, Jailolo, and Bacan. The development of settlements continues until the present time, especially on the southern flank of Gamalama Volcano (Fig. 2). Besides, the settlement is also growing on the north and west flanks. Because the settlements are close to the main crater, there is considerable potential for the entire population on Ternate Island exposed to eruption hazards, not to mention the potential exposure to parasitic eruptions as happened in 1775.

Based on assessments from the Global Volcanism Program, the population living around Gamalama Volcano is distinguished by distance from the main crater. The population living within a radius of 5 km from the main crater is 103,429 people, living within a radius of 10 km is 204,820 people and living within a radius of 30 km is 308,691 people [10]. Spatially, the distribution of building blocks (public facilities and settlement) on Ternate Island can be seen in Fig. 4.

3.6 Challenges in volcanic crisis management on a small volcanic island

Volcanic crisis management on a small volcanic island has many challenges. In terms of hazard, it might not be significantly different from the hazard on a large island. However, in terms of vulnerability, small islands are more vulnerable due to various limitations, as stated by Wilkinson et al. 2016. Eruption hazards of Gamalama Volcano such as lava flow and pyroclastic flow in the past generally did not cause casualties because at that time the population was not as dense now. The growth of the population and settlements existing around Gamalama Volcano can increase the risk of disasters. Similar to the hazards in the past, the potentials of populations and settlements for exposition can increase.

The eruption on 4 September 1980 could be a valuable lesson for mitigation efforts in the future. At that time, the number of people living in Ternate was 42,000 based on the 1976 population census [20]. In 1980 there was an eruption making the entire Ternate Island covered with volcanic ash with a thickness of 10 – 15 cm so that 40,000 people fled to Tidore and other islands around Ternate [10]. According to this data, the majority of people on

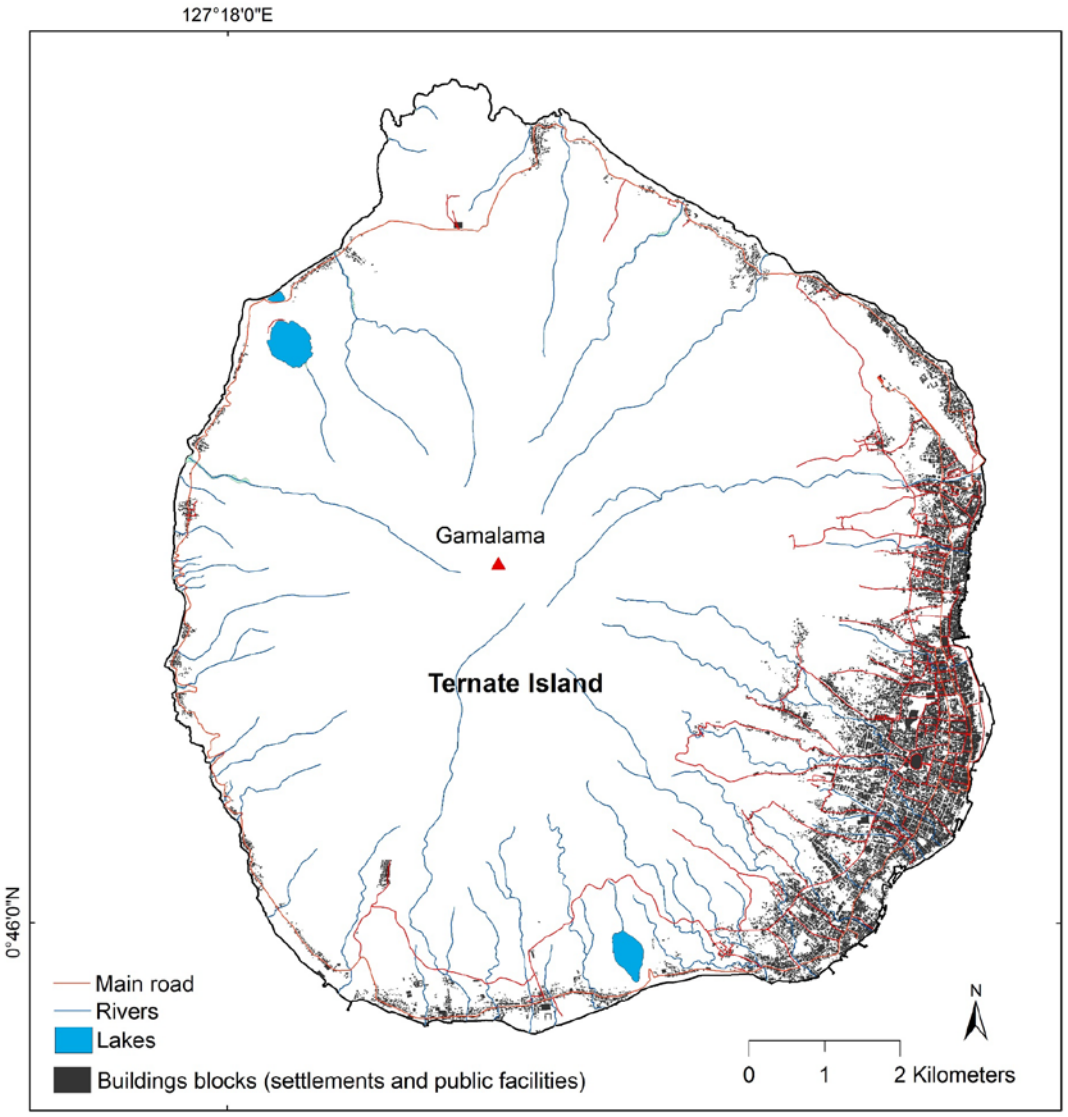

Fig. 4 Spatial distribution of building blocks (public facilities and settlement) on Ternate Island, North Maluku, Indonesia

Ternate were displaced due to volcanic ash from the 1980 Gamalama eruption.

In 2017, the population on Ternate Island (consisting of 4 subdistricts: Central Ternate, South Ternate, North Ternate, and Ternate Island) was 211,937 people [21]. Using the population of Ternate in 1976 as preliminary data, the current population is five times that of 1976. If the eruption hazard similar to that in 1980 with a volcanic ash deposit of 10 – 15 cm attacks Ternate Island and requires the evacuation of 80 % of the population, approximately 169,550 people must be evacuated.

The challenge is the readiness of the infrastructure for determining evacuation location, type of transportation to use, location of assembly point, port location, evacuation duration, and readiness of evacuation location as well as the readiness of the parties involved in disaster management.

Considering the eruption hazard, geographical condition, population density, distribution of settlements, and community experiences in dealing with eruptions, one of the potential solutions that can be proposed is the concept of sister islands. The concept of sister islands is a system of networking/brotherhood relations established between communities on disaster-prone islands and communities on other safe islands for preparing evacuation procedures to avoid chaos in crisis situations. The network can be started by developing mutual awareness of communities and regional government to find solutions to the problems of eruption threat on Ternate Island. The information regarding eruption hazards must be disseminated so that people on Ternate Island are ready if they must evacuate outside the island at any time.

Disaster management stakeholders in Ternate can communicate with disaster management stakeholders on nearby islands that have the potential for refugee locations. Regarding the proximity of Ternate Island, there are several potential islands for final evacuation, namely Tidore Island, Hiri Island, Maitara Island, and Halmahera Island (Sidangoli). Administratively, Hiri Island is part of Ternate City. Tidore and Maitara Islands and a part of Halmahera Island belong to Tidore Islands City. Sidangoli (Halmahera Island) belongs to the administrative area of West Halmahera Regency.

The technical development for the concept of sister islands involving the aforementioned islands involves at least three regional governments (Ternate City, Tidore Islands City, and West Halmahera Regency). Regional Disaster Management Agency (BPBD) was established in the three regional governments and North Maluku Province. In terms of authority, if a disaster impacts more than two regions, the authority belongs to the BPBD at the provincial level. Therefore, BPBD of North Maluku Province has a great task in preparing technical cross-regency/city contingency plans for the eruption hazard of Gamalama Volcano.

4. CONCLUSION

Ternate Island is a small volcanic island that was formed gradually from the deposition of materials from the eruption of Gamalama Volcano. Living on a volcanic island with an active volcano, the population has a number of eruption threats such as ejection of tephra, lava flow, pyroclastic flow, lahar, and volcanic tsunami. By taking eruption hazards, geographical conditions, population, distribution of settlements, and community experiences in dealing with eruptions into consideration, one of the potential solutions that can be proposed is the concept of sister islands. It is expected that, when there is an eruption, the government and the communities living around Gamalama Volcano are ready to make an evacuation effort outside the island if it is no longer possible to stay on Ternate Island or just avoid the hazard for some time.

The technical concept of sister islands is indeed complicated and requires a long process because it involves many parties, both the government and communities living on Ternate Island. Therefore, regional disaster management stakeholders, the BPBD, must immediately take an initiative to start discussing the concept and thinking about its implementation strategies so that everything is ready when an eruption occurs.

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