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The 2015 eruption of Gamalama volcano (Ternate Island–Indonesia): precursor, crisis management, and community response

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Abstract Gamalama is an active stratovolcano on Ternate, a small volcanic island in Maluku Utara, Indonesia. Since 1510, a total of 77 eruptions have been recorded, with various impacts on the population and environment on the island and its surroundings. In July 2015, Gamalama erupted after < 24 h of precursor signs. The seismic activity continued to increase until September 2015, as marked by three sudden eruptions that were not preceded by significant volcanic and tremor earthquakes. This research was intended to understand the chronology and impact of the 2015 Gamalama eruption, which is categorically unusual, and to learn how the government conducted relevant crisis management and in what manners the community affected by ejected materials reacted to it. The former was achieved by analyzing the data provided by the Gamalama volcano observatory. As for the latter, interviews with key stakeholders in volcanic disaster management and a questionnaire-based survey involving 85 respondents in the most affected areas were conducted. The results showed that despite the relatively small Volcanic Explosivity Index (VEI = 2), the 2015 eruption was rather unexpected to many parties because it began with a short-term precursor sign (less than a day). The impact included tephra deposits as thick as 2–6 mm was in the Loto, Togafo, and Takome Villages. A total of 1791 people was recorded evacuating to several locations, such as Afe Taduma village, the SMKN 2 camp, the SKB camp, and the Naval Base camp. After a rapid impact assessment and coordination with the Center for Volcanology and Geological Hazard Mitigation (CVGHM), the government issued a status of emergency and evacuation orders. In cases when eruptions are initiated with a short-term precursor, the large population size and geographic condition of Ternate Island create a particular challenge in the resultant evacuation. Nevertheless, with prior mitigation measures and evacuation drills in hazard zones, evacuation can be carried out effectively. Even when a large-scale Gamalama eruption requires an evacuation to neighboring islands, a properly implemented mitigation such as the establishment of sister islands can substantially facilitate volcanic crisis management activities on small islands.

Keywords Crisis management · Volcanic island · Gamalama volcano · Ternate Island · Indonesia

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Introduction

Historical and cultural context

Ternate is a small island located in the west of Halmahera Island (Fig. 1a). Administratively, it belongs to the City of Ternate, the Province of Maluku Utara. Ternate is a fertile volcanic island and is known by the world as the 'spice island'. Due to the spice factor, traders from various parts of the world came to this island, including traders from Europe in the early sixteenth century, making the Ternate as one of the busy trade routes in Asia (Taylor 1999; Ammari and Siokona 2003; Amal 2009; Daud 2012; KAPDKT 2015). One of the advantages of the busy trade routes at the beginning of the sixteenth century is the records of historical political, social, and natural disaster events on the island. Among the documented events are the eruptions of Gamalama volcano (Table 1). These data can at least describe eruption events in the

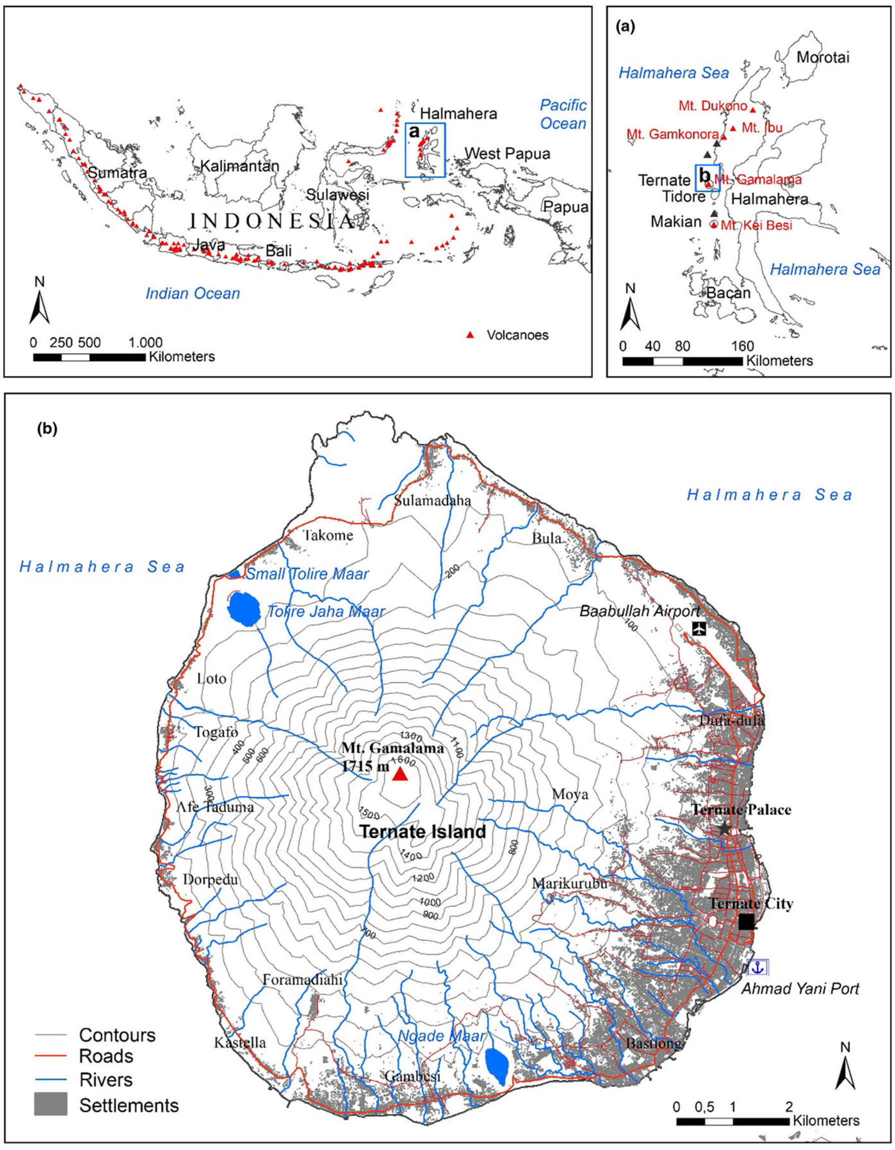

Fig. 1 **a** Five active volcanoes in Maluku Utara, Indonesia and **b** settlements and public facilities on the flank of Gamalama volcano on Ternate Island, Maluku Utara

Table 1 Gamalama volcano historic eruptions. *Sources*: De Clercq (1890), CVGHM (2011), Global Volcanism Program (2013), Paris et al. (2014) and NGDC/WDS (2019)

Years	Repose periods (years)	Descriptions
1510		VEI 3
1538	28	VEI 3
1551	13	Eruption from the central crater
1552	1	Eruption from the central crater
1561	9	December 31: VEI 2; parasitic eruption
1605	44	May: VEI 2; Eruption from the central crater
1608	3	July 18–19: VEI 3; Eruption from the central crater
1635	17	March 29: VEI 2; Eruption from the central crater
1643	8	June 15: VEI 2
1648	5	June 15–18: VEI 2
1653	5	December 31: VEI 3; Effusive eruption, lava flow
1659	6	June: VEI 2; Eruption from the central crater
1676	17	December 31: VEI 2; Eruption from the central crater
1686	10	September–October 13: VEI 2; Eruption from the central crater
1687	1	May 10–11: VEI 3; Lava flow to the west
1737	50	March 10–13: VEI 2; Lava flows to the west, reaching the sea
1739	2	VEI 2; Lava flow to the west
1763	24	VEI 2; Lava flow to the west
1770	7	July 6-December 9: VEI 3; Eruption from the central crater
1771–1772	1	August 28, 1771–October 9, 1772: VEI 3; Lava flow, 40 casualties
1773–1774	1	February 2–7: VEI 2; lava flow. October 21, 1773–January 22, 1774: VEI 2; Lava flows to the east
1775	1	August 20–November 6; VEI 3. On September 5–7, 1775, a maar was formed around Soela Takome village or 1.5 km southwest of today's Takome village. This maar had diameters of 700 m in the upper part and 350 m at the base and a depth of 40–50 m. This eruption resulted in 141 deaths
1811	36	February 1–May: VEI 2
1812	1	September 7: VEI 2
1814	2	November 27–28: VEI 2
1821	7	August 22: VEI 1
1831	10	May 27–June 27: VEI 2; Eruption from the central crater
1833	2	June 15: VEI 2; Eruption from the central crater
1835	2	January 4: VEI 2; Eruption from the central crater
1838	3	February 26–May: VEI 2; Eruption from the central crater, two people were injured
1839	1	January 29–March 26: VEI 2; Lava flows to the north
1840	1	February 2–September 29: VEI 3; Lava flows to the north; On February 14, the eruption triggered a tsunami on Halmahera
1841	1	March 30–November 20: VEI 1; Eruption from the central crater
1842	1	October 6–December 31: VEI 1; Eruption from the central crater
1843	1	April 10–May 27: VEI 2; Lava flows to the north
1844	1	March 24–November 14: VEI 1; Lava flows to the north
1845	1	April 23–September 3: VEI 1
1846	1	May 19: VEI 2
1847	1	February 7: VEI 2; Lava flows to the north; September 7: VEI (?)
1849–1850	2	November 27, 1849–November 19, 1850: VEI 2; Eruption from the central crater
1858–1859	8	November 1858–September 1859: VEI 1; Eruption from the central crater

Table 1 continued

Years	Repose periods (years)	Descriptions
1860	1	VEI 1; Eruption from the central crater
1862	2	July 15–October: VEI 2; Eruption from the central crater
1863	1	May 1–June: VEI 2; Eruption from the central crater
1864–1865	1	June 4–25, 1964: VEI 1; December 27, 1964–January 2, 1965: VEI 2; Lava flows to the northwest
1868–1869	3	March 13, 1968: VEI 1; November 13, 1968–February 10, 1969: VEI 2; Eruption from the central crater
1871	2	August 7-September 25: VEI 2; Lava flows to the northwest, one injury and one death
1884	13	May: VEI 2; Eruption from the central crater
1895	9	December 19: VEI 1; Eruption from the central crater
1896	1	August 3–4: VEI 1; Eruption from the central crater
1897	1	September 7–24: VEI 1; Eruption from the central crater
1898	1	Landsat 14–28 VEI 2; Eruption from the central crater
1900	2	May–June 4: VEI 1; Eruption from the central crater
1907	7	November 17–20: VEI 2; Lava flows to the northeast (known as "Batu Angus")
1911	4	September 2–6: VEI 1; Eruption from the central crater
1918	7	August–September 4: VEI 1
1923	5	April 13–May 6: VEI 2
1933	10	November 12–(?): VEI 2
1938	5	September 8: VEI 2; Eruption from the central crater
1962–1963	24	December 31, 1962–January 2, 1963: VEI 2; Eruption from the central crater
1980	18	Landsat 4–23 VEI 2; Eruptions from the central crater and new crater, 40,000 people were evacuated to Tidore, Hiri, and Halmahera Island
1983	3	August 9–12: VEI 3; Eruption from the central crater
1988	5	February 12–March 16: VEI 2; Eruption from the central crater
1990	2	April 25–26: VEI 3; Eruption from the central crater, followed by lava flow
1991	1	June 15: VEI 1; Eruption from the central crater
1993	2	May 6–21: VEI 2; Eruption from the central crater
1994	1	January 16–October 15: Eruption from the central crater, i.e., magmatic one time and phreatic three times
1996	2	July 2: VEI 2
2003	9	July 31–October 2: VEI 2; Eruption from the central crater, followed by pyroclastic flows
2007	4	August 23: VEI 1
2008	1	May 10: VEI 1
2011	3	December 5–23: VEI 2; Eruption from the central crater
2012	1	September 15–17: VEI 1; Eruption from the central crater
2014	2	December 18–25: VEI 2; Eruption from the central crater and the eastern fissure
2015	1	July 16–September 8: VEI 2; Eruption from the central crater and the northwest fissure; 1791 people were evacuated

past and provide lessons for current generations. Data on past eruptions are also beneficial to event reconstructions and can be used as the basis for hazard zoning to prevent fatalities in future volcanic disasters.

Ternate today has far developed in terms of population, culture, and social domain. This island indeed has a timeless attraction because it possesses high-potential resources, such as fertile soil for spice plantation and various public facilities that have been growing rapidly. These advantages create a pulling factor for many people to live on Ternate despite its relatively small area (111 km^2) and exposure to volcanic hazards. There are currently up to 204,820 people inhabiting the island (Global Volcanism Program 2013). For this reason, Ternate is unsurprisingly recorded as the most densely populated island in the Province of Maluku Utara. The majority of its residents live on the flank of Gamalama volcano and coastal areas (Fig. 1b). Most of the indigenous people earn a living as farmers of plantation commodities, e.g., cloves, nutmeg, and pepper. The life of the community is still more or less influenced by the Sultanate of Ternate, and this is mostly seen from the custom and culture practiced in the daily lives of the local people.

Eruptions and risk

Gamalama (1°48′ N, 127°19.5′ E) is one of five active volcanoes in the Province of Maluku Utara, aside from Dukono, Gamkonora, Ibu, and Keibesi volcanoes (Fig. 1a). Gamalama is an almost perfectly cone-shaped stratovolcano, with a width of 11.6 km and a height of 1715 m.a.s.l. (Pratomo et al. 2011). As collected from various sources, Gamalama is known to have a well-documented history of eruptions (Table 1). Since the first recorded volcanic event in 1510, it has erupted 77 times, 17 of which produced lava flows (Bacharudin et al. 1996). Generally, it erupts from the central crater (Pratomo et al. 2011), but in some instances, there were parasitic eruptions in 1737, 1763, 1770, and 1962–63. From time to time, the deposits of these eruptions formed a volcanic island known as Ternate Island (Hidayat et al. 2020).

On the other hand, the danger posed by Gamalama eruptions lingers as the absolute time of their occurrences and magnitude of impact can never be estimated. Based on the historical records (Table 1), the eruptions of Gamalama show an evolving trend from its first documented disastrous activity in 1510. With this detailed information, there are at least two major phases that can be identified from these eruptions. From 1510 up to 1770, the repose period was averagely longer than 10 years (Pratomo et al. 2011), but from 1771 to 2015, it became shorter, i.e., 1–2 years (Table 1). The impact of these eruptions included injuries, fatalities, homelessness, and evacuation. Eruptions generally occur from the central crater and are almost always magmatic—either with or without lava (Bacharudin et al. 1996; Pratomo et al. 2011); some are parasitic eruptions whose left marks are even visible until now, such as in Tolire Maar and Ngade Maar. In September 1980, an eruption significantly affected the lives of the people on Ternate Island as it led to the displacement of 40,000 people to neighboring islands (Global Volcanism Program 2013). At that time, the total population was merely 60,000 people.

The substantial growth in the population, starting from 1980, has raised a safety concern. It is unavoidable, given that today's inhabitants of Ternate Island are estimated at 204,820. At the same time, settlements have sprawled to the eruption hazard zone (Fig. 1b), elevating the disaster risk. An example includes the most recent VEI-2 eruption in 2011 that was followed by several hours of heavy rainfall and subsequent lahar. The incident resulted in the death of 7 people, injured 15 people, and damaged 577 houses (BPBD 2012). The constantly multiplying number of people living in the hazard zone is believed to elevate the potential adverse impact of the activities of the Gamalama volcano. In the last few years, the unrests of Gamalama have changed, specifically the precursor signs. Despite the relatively low VEI (in the range of 1–2), there is a trend of increasingly shorter signs of seismicity before eruptions. With a short precursor sign, the window of opportunity for residents to self-evacuate is also narrow. The 2015 Gamalama eruption was a shock as there were no signs that it would erupt very quickly, which was less than 24 h. Also, the duration of the eruption was relatively long, namely from July 16 to September 8, 2015.

Volcanic risk management in small island

A volcanic eruption is one of the most destructive and deadly natural phenomena (Bird et al. 2010; MIAVITA 2012). During the twentieth century, Witham (2005) estimated that 91,724 people were killed, and 291,457 people lost their homes due to eruption. The effects of eruptions on small volcanic islands are no less severe, for example, the Mount Pelee eruption in Martinique that killed 29,000 people (Gaudru 2005; Witham 2005) marks the highest death toll due to volcanic eruptions in the twentieth century. Therefore, volcanic risk management, especially on small islands, is of critical importance. This process can involve recognizing hazards and assessing the vulnerability and capacity of the local community. Monitoring of volcanic activities, including seismicity, fumarole, and ground deformation, is an attempt to identify related hazards and, consequently, increase community awareness and early warning systems. Besides, providing specific attention to the community as an attempt to increase capacity and reduce vulnerability is necessary. Vulnerability is the result of physical exposure to hazard coupled with human's ability to prepare for, mitigate, or bounce back from the negative impact of a disaster (Pelling and Uitto 2001). Accordingly, the magnitude of a disaster impact strongly depends on the community's degree of vulnerability to a hazard (Twigg 2004). In the case of small islands, all types of inherent limitations, such as narrow area bordered by seawater, low accessibility, and natural resource scarcity, expose their inhabitants to an increased risk of natural disasters (Komorowski et al. 2018).

Such communities are vulnerable to the impact of hazards because they are geographically marginalized (Gaillard et al. 2010). They have been forced by economic and social forces to live in places that are threatened by natural hazards. Rampengan et al. (2014) argue that isolated communities on small islands are often classified as vulnerable and marginalized groups. The small island size and accessibility problems are thought to be the causative factors of community vulnerability to both internal and external hazards (Pelling and Uitto 2001). One of the internal hazards is that of volcanic activities in the forms of ejection and incandescent tephra (volcanic ash, sand, gravel, and bomb), lava flow, pyroclastic flow, volcanic tsunamis, and lahars (Paris et al. 2014). Several studies have documented eruptions on small islands and the corresponding responses of the community (Smith 2011; Pyle et al. 2018; Cole et al. 2019), each of which is different from what generally happens in non-island regions. According to Witham (2005), records of the impact of volcanism on humans offer essential lessons for volcanic risk management.

Geographically, small islands are difficult to access, and their populations are generally classified as marginalized (Rampengan et al. 2014). Both problems weaken the capacity of the community in dealing with crises. Wisner et al. (2004) claim that the factors contributing to community marginalization on small islands are the absence of an early warning system and delays in self-evacuation and the distribution of basic life assistance by disaster management stakeholders. Experience in many developing countries shows that low accessibility diminishes the government's attention to small islands.

Moreover, in volcanic crisis management, translating information from scientists or experts in volcanic activity monitoring into appropriate and timely action is always a challenge (McGuire et al. 2009; Hidayat et al. 2020). Communication errors or information delays can be fatal for the people living in hazard zones on small islands. The 1985 Nevado del Ruiz eruption with 23,000 casualties is an example of the deadliest outcomes of a serious communication failure during a volcanic crisis (Witham 2005). As the population on small islands with eruption hazards multiplies, especially in developing countries like Indonesia, the impact is inevitably severe. Adversities may include failures to overcome communication problems during a crisis and, subsequently, a rise in fatalities (McGuire et al. 2009).

Considering these conditions, a concerted effort to find disaster risk reduction strategies at the technical level is paramount (Marzocchi et al. 2012). As an instance, volcano surveillance and monitoring of seismic activity are parts of ways to raise alertness. Carracedo et al. (2015) explain that seismic precursor signs allow early detection of magmatic activity and predict the eruption sites. In this way, early warning systems can operate smoothly and enable proper evacuation inside or outside the island. Human and livestock evacuation during a volcanic crisis is a vital component of volcanic risk management (Wilson et al. 2012a).

There have been various studies on volcanic crisis management in a broad spectrum and with diverse methodologies (e.g., Rivera et al. 2010; Procter et al. 2012; Marzocchi et al. 2012; De Bélizal et al. 2012; Mei et al. 2013; Hicks and Few 2015; Mutaqin et al. 2019), mostly not on small islands. Therefore, there is a lack of volcanic crisis management research in Indonesia despite the enormous threats on more than 20 small volcanic islands with active volcanoes (Hidayat et al. 2019). Because humans inhabit most of them, the risk of disaster is unavoidably high.

The objectives of the study are first to understand the chronology of the 2015 Gamalama eruption. Then we shall analyze how the impact and the authorities managed volcanic crisis with short precursor signs on small islands, and eventually how the affected community reacted to it. This paper highlights how eruptions with short precursors on small islands pose a distinctive challenge in their crisis management, in particular, the preparedness of the people living in hazard zones. This study and the described framework of crisis management on a small volcanic island are expected to be further developed as part of preparedness in dealing with future volcanic crises.

Methods

The secondary data included (1) relevant information on the Gamalama eruption events in July–September 2015, obtained from the Gamalama Volcano Observatory, and (2) details on crisis management, the number of evacuees, and evacuee camps from the Ternate disaster management agency (TDMA), while (3) the primary data were acquired by questionnaire-based surveys of the most affected community of the 2015 Gamalama eruption.

Data of eruption events

Historical data of Gamalama activities were compiled from various relevant literature (De Clercq 1890; Bronto et al. 1982; Bacharudin et al. 1996; CVGHM 2011; Pratomo et al. 2011; Global Volcanism Program 2013). The Gamalama Volcano Observatory (GVO) kindly provided recent data pertinent to the eruption process from the beginning of July to September 2015. The data in question included eruption chronology, seismic records, and volcanic ash distributions. Data on Gamalama activity was also obtained from the MAGMA Indonesia—Multiplatform Application for Geohazard Mitigation and Assessment—which was developed by the Center for Volcanology and Geological Hazard Mitigation (CVGHM). With this application, we can access quasi-real-time data about the alert-levels of Gamalama volcano (Table 2).

Evacuation chronology and crisis management

The Ternate Disaster Management Agency (Badan Penanggulangan Bencana Kota Ternate—BPBD) kindly allowed access to information on evacuation chronology and the number of displaced people recorded at three evacuee camp, namely the Ternate Naval Base camp, SMK N 2 camp and the SKB (Sanggar Kegiatan Belajar) camp. Also, there were some applicable data from Takome Village. The total number of evacuees at the end of the emergency response time was obtained from the National Disaster Management Agency (Badan Penanggulangan Bencana Nasional—BNPB). For data validation, interviews were conducted with disaster management stakeholders of Ternate City.

Questionnaire-based surveys of the affected community

The community response to the 2015 eruption was identified through questionnaire-based surveys with 13 question items. This method has been widely used in studies of disaster risk, resilience, crisis response, and preparedness (Millar et al. 2001; Carlino et al. 2008; Finnis et al. 2010; Mei and Lavigne 2012; De Bélizal et al. 2012; Mulyasari and Shaw 2013; Mei et al. 2013; Few et al. 2017). A questionnaire survey involved communities that were most affected by the 2015 eruptions on Ternate Island, i.e., Loto, Togafo, and Takome Village (Fig. 1b). Those villages lie on the west flank of Gamalama volcano, about 4 km from the crater wall that collapsed in the 2011 eruption. Based on the Statistical Bureau of Ternate, at the end of 2014, the population of the three villages was 2635 people (BPS 2015).

In the three most at-risk villages, this research sampled 85 people from the total population, which represented the distribution of sex, age, education, and occupation. These respondents were selected randomly and then interviewed using the predefined questions. Demographically, they were 47% male and 53% female, with the following age distribution: 13–25 years old (29%), 26–40 years old (38%), 41–55 years old (20%), and 56–70 years old (13%). The respondents had widely diverse occupations, namely self-employed workers (30%), farmers (27%), civil servants (7%), students (19%), homemakers (13%), and temporary employees (4%).

Although the collected data is a reliable illustration as to how the affected community views and thinks or feels toward eruptions, it does not generally reflect the entire population on the flanks of Gamalama volcano. Most of the villages on the southern flank had not, for decades, experienced eruptions. Besides, culturally,

Table 2 The alert-levels of volcanic activities in Indonesia. *Source*: The Multiplatform Application for Geo-Hazard Mitigation and Assessment for volcanic activities in Indonesia by the Volcanological Survey of Indonesia (VSI) https://magma.vsi.esdm.go.id

Levels	Names	Criteria	Implications
1	*Aktif normal* (normal)	There is no indication of increased volcanic activity, both visually and seismically	The community can carry out their normal activities, except in areas close to the volcanic crater
2	*Waspada* (advisory)	Elevated volcanic activities are observable, both visually and seismically. Eruptions threaten the High Danger Zone (KRB III)	Communities are prohibited from carrying out activities within the KRB III
3	*Siaga* (watch)	A significant increase in volcanic activities. Eruptions are most likely to occur, and these threats cover the Medium Danger Zone (KRB II)	The community is prohibited from carrying out activities within the KRB II
4	*Awas* (warning)	Large volcanic eruptions potentially occur. Evacuation of residents is paramount	Communities in KRB II and III must evacuate

the villagers in the south are predominantly immigrants and less strongly tied to the prevailing customs in Ternate. Relative to them, the communities in the north and west are culturally members of the Ternate Sultanate who are much more submissive and obedient to the Sultan of Ternate.

Results

The 2015 eruption

Eruptions with short precursor signs

A less significant escalation in seismicity was even recorded since July 15, 2015, at 11.04 A.M. (GMT + 9) (Fig. 2). At that time, the Gamalama volcano had the alert-level 2 (advisory). Significant volcanic and tremor earthquakes occurred at 03.04 P.M., and the tremor earthquakes continued with a maximum amplitude (6 mm) from 03.24 to 04.04 P.M. On July 16, 2015, at 09.58 A.M., an eruption took place in the northwest of the fissure, sending a thick white–grey ash plume into the sky (Fig. 3a) with medium pressure and a height of up to 1.5 km that drifted northward (Gamalama Volcano Observatory 2015a). This eruption was recorded as the biggest within the period of activity, i.e., from July to September. Several volcanic activities on July 17–19 resulted in grey–white ash plume columns as high as 300–800 m.a.s.l., drifting northwestward (Fig. 3b–d). On July 16–20, the Darwin Volcanic Ash Advisory Center reported that the ash plume of Lerobelong rose to an altitude of 2.1–5.5 km and drifted 20–130 km to the southwest, west, northwest, and northeast (Global Volcanism Program 2015). After July 20, the volcanic and tremor earthquake decreased until early August (Fig. 2).

On August 4 at 07.53 A.M., a low-intensity eruption began with one volcanic earthquake and three tremor earthquakes in the northwestern fissure. A thick grey ash plume came out of the crater, reaching a height of 800 m.a.s.l., and drifting toward the east and northeast (Gamalama Volcano Observatory 2015b). According to the Darwin Volcanic Ash Advisory Center, the ash plume of this eruption was drifted by winds up to more than 20 km to the northwest (Global Volcanism Program 2015). Afterward, the tremor earthquakes increased significantly until mid-August, and the volcanic earthquakes were heightened considerably on August 9. Although the seismicity elevated until the end of August, there was no eruption (Fig. 2). In contrast, a low eruption occurred on September 8 at 07.53 A.M. (Fig. 2) with only one volcanic earthquake and two tremor earthquakes (Gamalama Volcano Observatory 2015c).

The eruption on July 16 began with a short-term precursor (only 23 h after increased seismicity on July 15). There was also no significant increase in either volcanic or tremor earthquakes. Even for the eruptions on August 4 and September 8, they only started with a volcanic earthquake. Short precursors have forced the community and government to be exceptionally cautious because they allow only a short amount of time for evacuation.

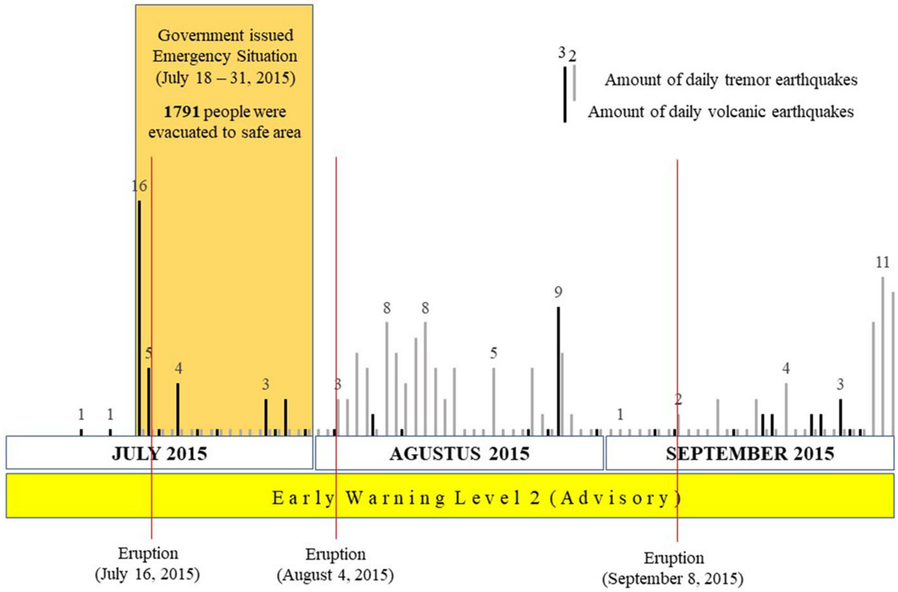

Fig. 2 Chronology of the 2015 Gamalama eruption (Seismicity data by Gamalama Volcano Observatory 2015a, b, c)

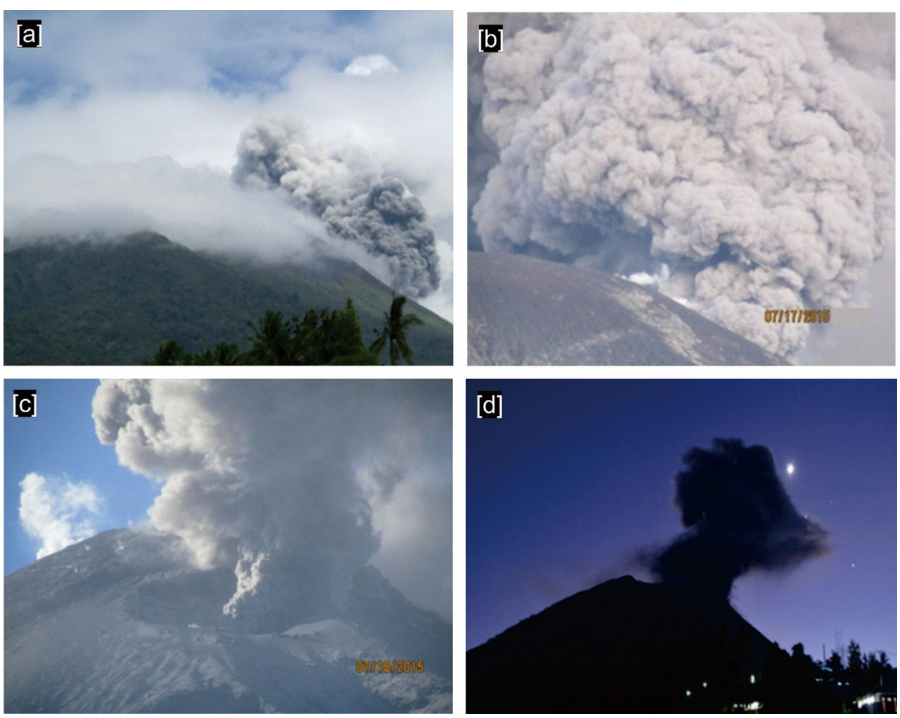

Fig. 3 The 2015 Gamalama eruptions: **a** an eruption on July 16 at 09.45 A.M. (GMT + 9), **b** grey-white ash plume on July 17 at 09.52 A.M., **c** grey-white ash plume reaching 800 m above the crater on July 18 at 08.43 A.M. and **d** ash plume drifted northwestward on July 19 at 07.11 P.M. *Source*: Gamalama Volcano Observatory (2015a)

Impact of eruption

The 2015 Gamalama eruption did not produce destructive hazards (i.e., pyroclastic flows, lava flows, ballistic blocks, sector collapses, and lahar) but volcanic ash. Volcanic ashfalls covered the north flank of Gamalama shortly after the eruption on July 16. On July 18–19, two volcanic activities occurred, generated volcanic ash plume, and drifted to the western flank, covering Loto, Togafo, and Takome villages (Fig. 4). Loto was the most severely affected by six mm-thick ashfalls (Fig. 5a). In Tagafo, a village located about 500 m south of Loto, the volcanic ash was up to 4 mm thick (Fig. 5b). Slight ashfall (1–2 mm) also covered Takome, a village located 1000 m north of Loto (Gamalama Volcano Observatory 2015a). Community activities and infrastructure in these three villages were disrupted. According to Wilson et al. (2012b), volcanic ash rarely endangers human life directly but can disrupt environmental health, critical infrastructure services, and aviation. Some airports are forced to close temporarily following even a few millimetres of volcanic ash (Guffanti et al. 2009), as was the Sultan Baabullah International Airport that was disabled momentarily due to the 2015 Gamalama eruption.

Volcanic Crisis Management

A top-down volcanic crisis management

Disaster management in Indonesia generally follows a top-down system. Indonesia has some major experiences in top-down volcanic crisis management, such as the 2006 and 2010 Merapi volcano eruptions (Mei et al. 2011, 2013), the 2007 Kelud volcano eruption (De Bélizal et al. 2012), and the 2010–2017 Sinabung volcano eruption (Wulandari et al. 2018). Top-down volcanic crisis management was also applied to the volcanic crisis during the Gamalama eruption in 2015. Either in an emergency or a normal situation, all Indonesia's active volcanoes are monitored by the Volcano Observatory Office, which is connected to the CVGHM head office in Bandung (Andreastuti et al. 2019). Monitoring the Gamalama volcano is the responsibility of the Gamalama Volcano Observatory (GVO). The recording and monitoring results are reported to the CVGHM Bandung and informed to the local government periodically. In a critical situation, alert-levels (Table 2) and hazard information have been disseminated through formal and informal communication to local government and regional disaster management agencies. In the 2015 Gamalama eruption, the crisis management system used this hierarchy (Fig. 6) to protect communities in disaster-prone areas.

The Gamalama Volcano Observatory (GVO) initiated intensive communication with regional disaster management authorities to manage a crisis after the eruption on July 16. Shortly after the eruption, the Fast Response Team of BPBD immediately went to the affected locations to distribute masks. On July 17, Gamalama erupted and left volcanic ash deposits over the main road and infrastructure on the northwest flank, potentially inhibiting access to affected sites due to poor vehicular traction and visibility problems (Wilson et al. 2012b). Also, on this day, the team from the BPBD, assisted by the Ternate Fire Brigade, cleaned the volcanic ash on the main roads and several public facilities on July 17. After receiving information from GVO that Gamalama's activities remained high on the third day (July 18), the Vice Mayor of Ternate as the ex-officio Head of the BPBD Ternate Office convened a coordination meeting with GVO and other agencies related to disaster management within the Ternate City to determine emergency response measures.

Following up on the results of this coordination, the Mayor of Ternate issued a Disaster Status due to the latest Gamalama Eruption with a Decree Number 124/III.13/KT/2015. Accordingly, the government set an emergency response status for 14 days, starting from July 18 to 31. Also, to overcome the disaster, the Government of Ternate formed the Emergency Response Team (Ternate Mayor's Decree Number: 126/III.13/KT/2015). These teams consist of many stakeholders (Fig. 7), led by the Incident Commander. They are tasked with (1) planning operations for emergency response handling, (2) submitting requests for assistance, (3) implementing and coordinating the deployment of resources for disaster response management quickly, accurately, efficiently, and effectively, (4) gathering information as a basis for planning emergency response commands, and (5) disseminating information about disaster events and their management to mass media and the broader community (BPBD 2015).

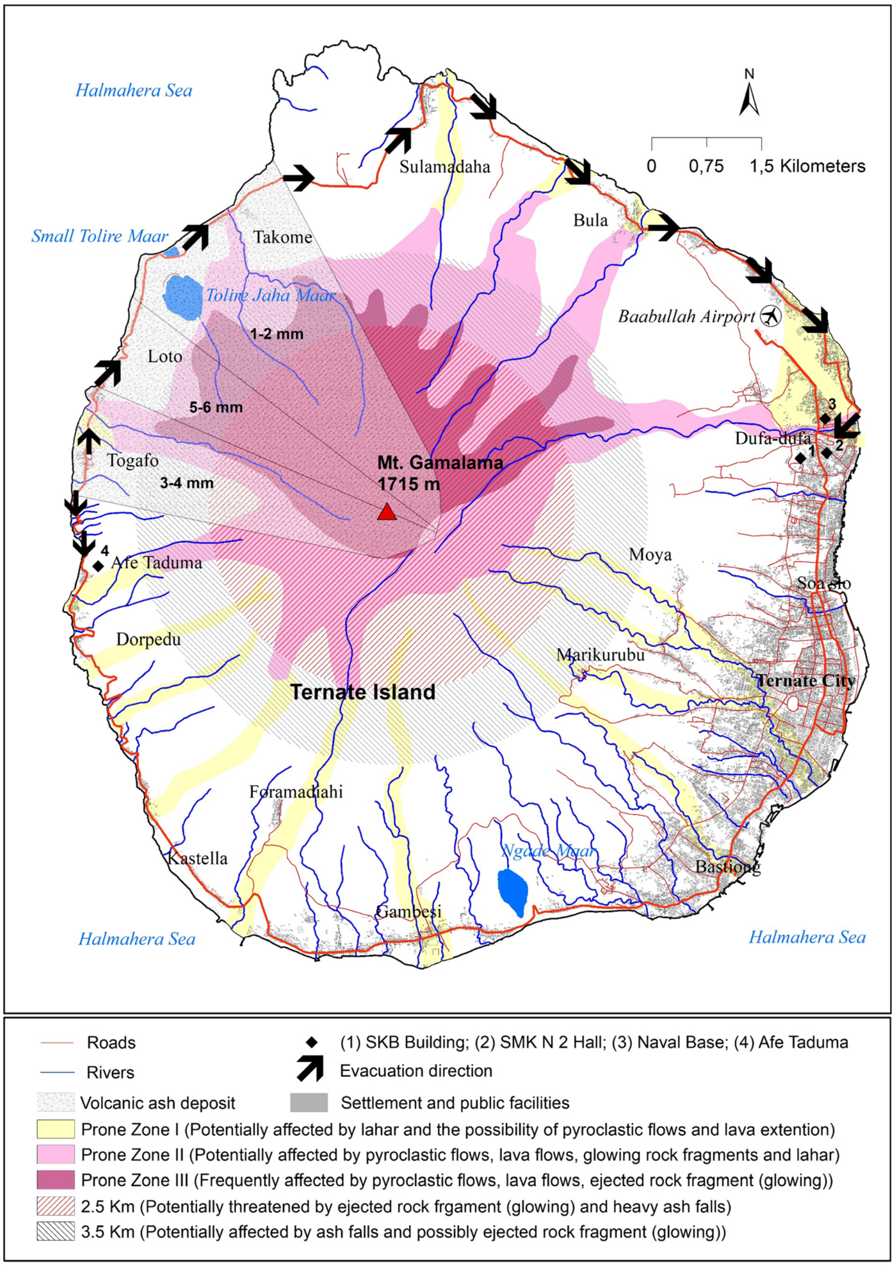

Fig. 4 Spatial distribution of volcanic ash deposit after the eruptions on July 16–18, the evacuation route, evacuee camp, and volcanic disaster-prone areas

The chronology and daily evolution of the number of evacuees

The community affected by volcanic ash was asked to evacuate on July 18 (Fig. 8). The emergency response team formed by the government immediately mobilized resources to evacuate the residents. On July 18, a total of 826 people moved to Afe Taduma (Fig. 8), a village approximately 2.5 km from Togafo (Fig. 4). They believed that Afe Taduma was safe from Gamalama volcanic hazard. Some of the evacuees had experienced the Gamalama eruption in 1980. An interview with the Head of Loto village revealed that Afe Taduma was considered a safe location because

Fig. 5 Impact of 2015 Gamalama eruption, **a** volcanic ash deposits in Loto village, the western flank of Gamalama volcano on July 18, **b** volcanic ash deposits in the street, near the bridge of Togafo village, on July 18 *Source*: Gamalama Volcano Observatory (2015a)

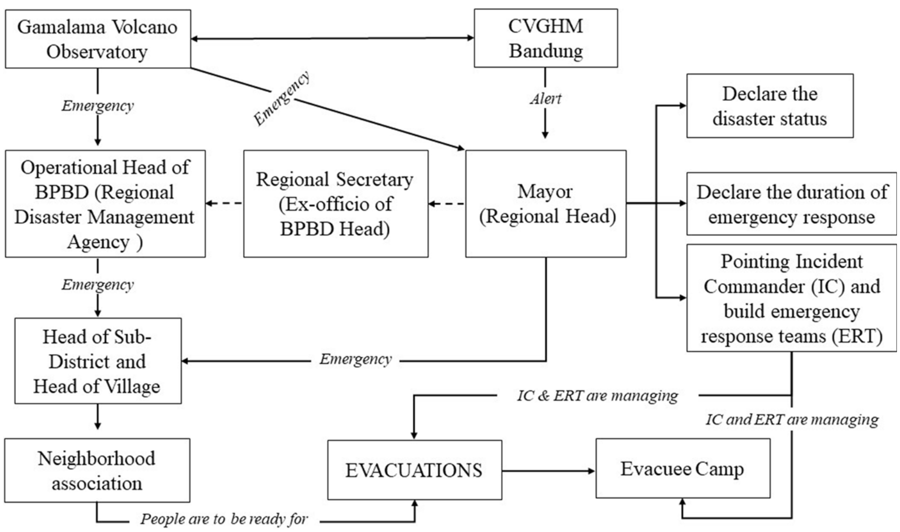

Fig. 6 The diagram of the volcanic crisis management in Ternate

geomorphologically the hill in the back of the village could block the pyroclastic flow and lahar from Gamalama. Besides Afe Taduma, the affected community also evacuated to the SKB camp and the Naval Base camp, evacuee camps approximately 15 km from Togafo and Loto (Fig. 4). On July 18, there were 327 people in the Naval Base camp and 377 people in the SKB camp (Fig. 8). The number of evacuees on the first-day evacuation (July 18) was 1530 people (BPBD 2015). On July 22, there were 756 people from Afe Taduma evacuated to SMK N 2 Camp (Fig. 8), an evacuee camp near the Naval Base camp (Fig. 4). By August 4, a total of 1791 people had been evacuated from the affected areas (Fig. 8).

Community response to the evacuation

The response of the volcanic eruption victims was analyzed based on the answered questionnaire items collected from the community in Loto, Togafo, and Takome. The results found that 76% of the respondents were displaced due to a volcanic eruption in July 2015, while the other 24% were not. Compared with the data from BPBD, only 68% of the total population in the three villages were displaced by the 2015 Gamalama eruption. The community was generally informed of the evacuation notice directly from the head of the village (39%), while others were from the loudspeaker announcements from the mosques (27%), the warning sirens (15%), other people who contacted them by telephone (12%), and neighbors (7%). This

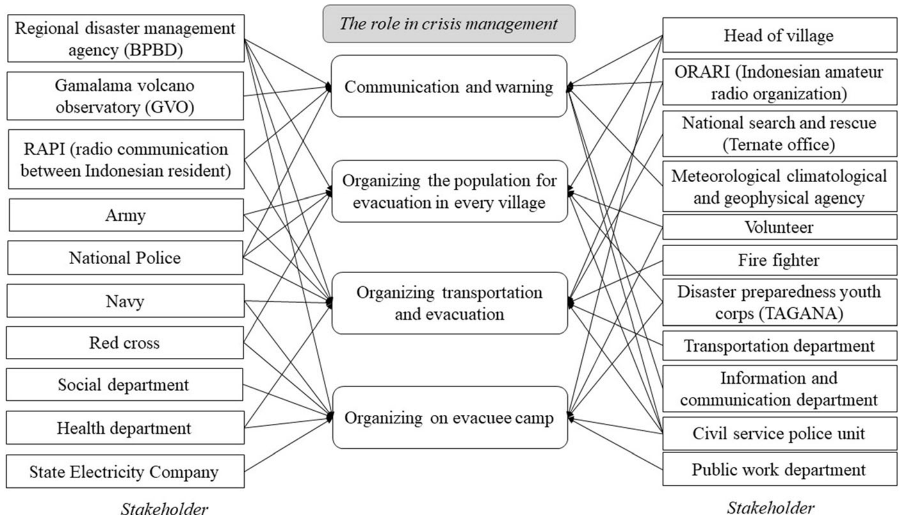

Fig. 7 The stakeholders involved and their role in the volcanic crisis management process

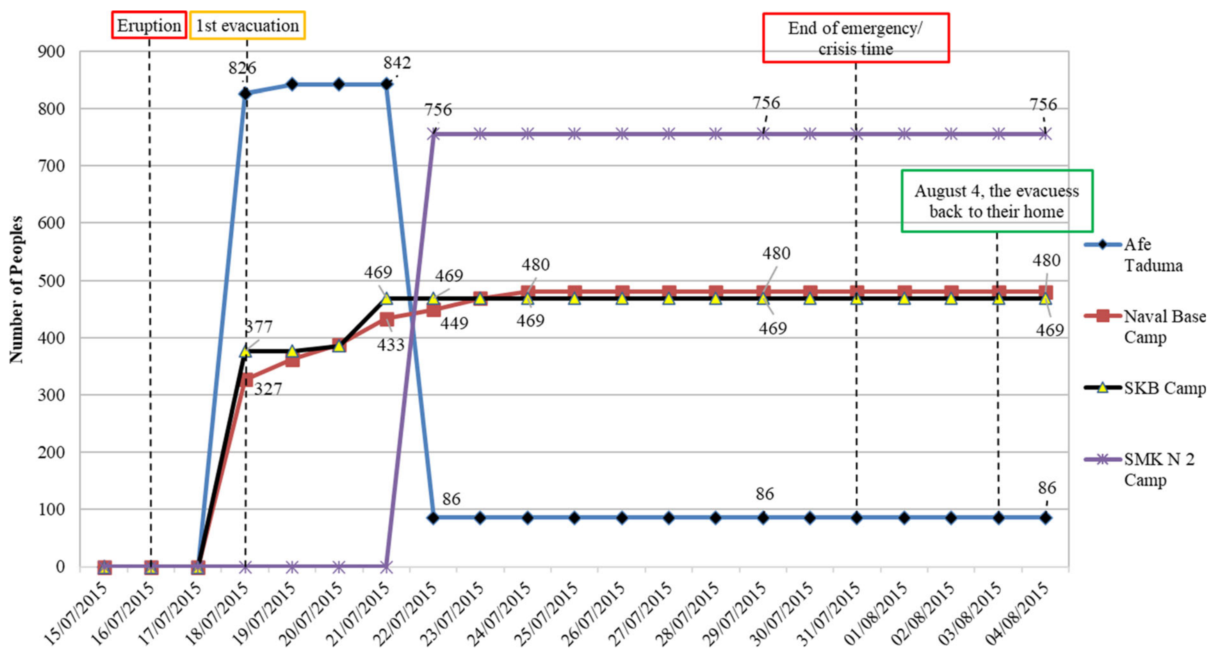

Fig. 8 The daily evolution of the number of evacuees between July 18 and August 4

condition was possible because in Ternate's culture, especially in the north and west flanks of Gamalama, the head of the village has a central position in various aspects of life. For example, in Loto Village, the Head is a customary figure who is highly respected and becomes a role model for the residents. Also, information from the village office was often announced using the mosque loudspeakers. Besides, in the three villages affected by the eruption, the settlement complex did not cover a wide area and had a pattern of clustering or along the right and left sides of the main road.

The majority of the respondents (60%) stated that they are willing to evacuate because they wanted to protect themselves from the destructive impacts of the eruption. Some complied with the government's recommendations to evacuate (15%), while only a few were forced (1%). Based on the results of the survey and field data collection, the residents in the affected areas evacuated to four different locations, namely the SKB camp, the Naval Base camp, SMK N 2 camp (vocational high school), and Afe Taduma Village. The survey revealed that the majority of them evacuated to the SKB Camp (42%) and the Ternate Naval Base camp (29%). Only 5% stated that they are evacuated to the SMK N 2 camp. The data collected in the survey and the real condition showed the different number of evacuees on the first day of evacuation (July 18) to Afe Taduma village as no respondents claimed to have been displaced to this village.

Regarding the evacuees in Afe Taduma, there is an indication that BPBD Ternate was not recorded the evacuees in more detail because they only stayed in Taduma to avoid the threats of ashfall and other volcanic hazards at night, while in the afternoon, they returned to their respective villages. For them, the evacuation was considered as a temporary instead of a long-term displacement at least throughout the eruption events and as a solution to avoiding any potential dangers during nighttime when the conditions were dark. Moreover, they believed that Afe Taduma was naturally protected by hills that could also shield them from pyroclastic flows and stones thrown out by the volcano. To evacuate, the evacuees used several modes of egress, which according to the survey, included vehicles provided by the navy, army, and BPBD (65%), private cars (4%), and private motorcycles (8%). These data showed that they generally did not evacuate independently. Many evacuees returned home during the crisis (41%) for several reasons, including assumptions that their homes would be safe (35%) and the need to feed their livestock (6%).

In crisis management, evacuees returning home during the emergency response time is an issue. During the day, they were assisted by their relatives who lived near the evacuee camps to reach their homes by motorcycles. Then, at night, they returned to the evacuation camp. The same situation also occurred during massive-scale evacuations during the 2010 Merapi eruption (Mei et al. 2013). The evacuees returned home for various purposes, such as feeding livestock, tending to crops in their plantations, and ensuring the safety of their houses.

Community willingness to evacuate often becomes an obstacle in emergencies. In the case of the 2015 Gamalama eruption, the victims in the three affected villages did not reject and were not coerced for evacuation. They even voluntarily gathered at strategic points on the side of the highway to wait for trucks to transport them to the evacuation sites. Such awareness cannot be separated from the participation of all parties in providing education to the villagers.

Now, the questions are, “What about the other villages that are also within the danger zone? Have they also received training or public dissemination about volcanic hazards and self-rescue simulations?” An interview with the Head of Disaster Mitigation in BPBD Ternate revealed that in the last few years, the government’s attention to the people in the danger zone had considerably increased. BNPB, BPBD Ternate, Provincial BPBD, NGOs, and universities have provided disaster education and increased community preparedness. BNPB has actualized the concept of a Disaster-Resilient Village in at least four hazardous villages. Besides, the idea of disaster resilience schools (Sekolah Madrasah Aman Bencana/SMAB) has been introduced and modeled in several schools. Furthermore, technical training relevant to disaster management has also been carried out, such as training in the use of radio communication during emergencies, map reading, and GPS application. All of these measures have been implemented in villages within the eruption-prone zones.

Discussion

Short-term precursors of eruption: a challenge to community evacuation on small islands

Eruptions threaten the population within the radius of hundreds of meters up to several tens of kilometers from their points of origin. By factoring in such distance in volcanic hazard assessment, Brown et al. (2017) found that small island communities constitute the most fatality count within the proximal distance up to 5 km from the source. This finding demonstrates the danger of living on small islands, especially small volcanic islands that have an active volcano, as in the case of Ternate (Hidayat et al. 2020). On the island, the settlements are found 4–7 km from the central crater, and the affected villages in the 2015 eruption (Loto, Togafo, and Takome) are 4.5 km from it. At such a close distance, eruptions, even with the smallest VEI, can endanger the communities. The 2015 disastrous event is an experience that proves the assertion that an eruption with the VEI-2 and short-term precursors (< 24 h) can create panic and disrupt the activities of the local population. The disruption is mainly attributable to volcanic ash deposits in the three affected villages and a relatively long duration of the eruption. In response to these situations, the government issued a status of emergency that lasted for 14 days and mandated evacuation from these villages. At the end of the emergency response period, there were a total of 1791 evacuees temporarily inhabiting evacuation camps and leaving their sources of livelihood.

In the case of short-term precursor, evacuation within the small-time window poses a number of challenges. (1) Limited time to disseminate the current status of volcanic activity prevents the community from receiving prior information that can function as a guide for rescue measures. (2) In the event when eruptions allow only a short amount of time for evacuation, both the population and rescue team must act more quickly to distance affected people from the threat. (3) There is only a limited time to prepare supporting facilities and infrastructure should an evacuation become necessary. All of these limitations multiply when a volcanic eruption occurs on a small island, that is, an area that already has various limiting circumstances in the first place, i.e., low reachability and suitability for development, natural resources scarcity, and insufficient telecommunication infrastructure (Wilkinson et al. 2016). These challenges are unlike the situations faced in evacuation on large islands, such as in the 2010 Merapi eruption (Mei et al. 2013) and the 2007 Kelud eruption (De Bélizal et al. 2012). A large area offers several advantages for evacuation. (1) There are more options for evacuation routes and locations to escape from hazardous volcanic activities. (2) The affected population in more extensive areas can distance themselves more flexibly from the epicenter of a volcanic disaster than the inhabitants of small islands, whose narrow lands are surrounded by vast waters, and every place is close to the disaster. (3) Many public buildings with adequate supporting facilities can be used as reliable evacuation shelters.

Various parties on Ternate Island, including the Head of Logistics and Emergency Affairs of BPBD Ternate, fear of a large-scale and long-term eruption that prompts the evacuation of most, if not the entire, population from the island. Such concern is not an exaggeration, given that in September of 1980 (around 40 years ago), the local people were faced with a heartbreaking incident of severe ashfall covering the entire island, which forced approximately 40,000 people to evacuate to the neighboring islands. Global Volcanism Programme (2013) recorded that the resultant ash deposit had a thickness of up to 15 cm. The evacuees had to leave their homes for a relatively long time (days to several weeks), and this affected their social and economic activities. Based on the 2015 and 1980 events, the social and economic impacts of volcanic ash can be very severe, and now is the right time for crisis management institutions on small islands with active volcanoes to take into account the adverse effects of volcanic ash in the development of evacuation scenarios.

Disaster mitigation and evacuation drills are the keys to a successful evacuation

There is a well-known fact that in various disastrous volcanic events, people refuse to evacuate, such as in the 2006 Merapi eruption (Mei and Lavigne 2012). Many reasons are believed to underlie this situation; for instance, when the influence of a kingdom or sultanate dominates a large share of the population, there is a common belief in the existence of supernatural powers that guard volcanoes and can be controlled by a caretaker (Donovan 2010). The same circumstance was found in the 2006 Merapi eruption when the people of Kinahrejo believing in Marijan, a *Juru Kunci* (caretaker) of Merapi volcano appointed by the Sultan of Yogyakarta, refused to evacuate (Donovan 2010; Mei and Lavigne 2012; Troll et al. 2015). On Ternate Island, the term *Juru Kunci* is known as *Kiemalaha Kie*, who is also appointed by the Sultan of Ternate. *Kiemalaha Kie* is responsible for performing traditional rituals as an attempt to guarantee the safety of the community from the threat of the Gamalama eruption. One of the rituals is running the *Kololie Kie*, which is a ritual around Gamalama volcano while visiting the sacred tombs on Ternate Island. (Syukur 2014; Ati 2018; Bodi 2019). Nevertheless, this role is not necessarily the primary source of people's confidence to evacuate in the event of an eruption. In an emergency, the Sultan has a significant influence on customary law communities in the Sultanate of Ternate that mainly reside in the northern part of the island. His role in dealing with Gamalama eruptions can be easily found in the form of word-of-mouth tales among the communities. The most heroic story tells how the Sultan of Ternate can chase away incandescent lava flow with his stick.

Ever since the demise of Sultan Mudafar Syah in February of 2015, concerns over safety and survival in the event of eruptions have arisen among the people. Stakeholders responsible for disaster management in the City of Ternate also continue to improve preparedness for any volcanic disasters. The 2015 eruption and its impact seem to be evidence of the importance of volcanic disaster mitigation. Mitigation measures and evacuation drills are among the keys to a successful evacuation. Community preparedness, especially in Loto and Togafo Villages, was the result of a long process of disaster mitigation activities carried out by the government, Non-Governmental Organizations (NGOs), and academics through community services before the recent unrest of Gamalama. The residents have been receiving attention from both NGOs and the government to improve their disaster mitigation measures because the three villages are within a close distance to the volcanic vent. Nowadays, Loto and Togafo are frequently used as target locations for public dissemination, training, capacity building, and other activities in the context of volcanic risk reduction. These findings need to be incorporated into learning materials for other small islands with active volcanoes to achieve fruitful disaster mitigation. Unfortunately, not every village in the hazard zone receives such a substantial amount of attention. Therefore, concerns about low community preparedness and what it potentially entails, should volcanic disasters reach these villages, persist. Most importantly, adversity is very likely to occur due to proximity to the source of the danger and past experiences in which volcanic activities hit locations that had been perceived as safe.

The sister island concept: a potential solution for volcanic crisis management on small islands

In principle, sister island is formulated from the implementation of the concept of co-existence with disaster risk (Yusup 2014; Cho et al. 2016). Living in harmony with disaster means that the local people are highly aware of the fact that they live in a hazard zone and that one day, they need to avoid the danger to save their lives (Yusup 2014). Conceptually, sister islands illustrate a collaboration between the inhabitants of at-risk islands and other more sheltered islands to prepare for everything that the former need in the event of life-threatening disasters (Hidayat et al. 2020). This concept can be developed on Ternate because it is a small island with volcanic hazards by factoring in its geographical and geomorphological conditions and the social and cultural aspects of the inhabitants of Ternate and the surrounding islands (i.e., Tidore, Hiri, and Halmahera).

The concept of 'sister' or 'twin' in volcanic disaster management has been previously introduced in Campania Region (Southern Italy), between Vesuvius municipalities and the Italian regions (Barberi et al. 2008). In Indonesia, its concept has been established in the form of sister villages between communities within the hazard zone of Merapi eruptions and the ones in safer areas (Mei et al. 2018). Sister villages are an ideal community-based approach to dealing with volcanic hazards on the flanks of Merapi. The direction and distance of pyroclastic flows are considered in the determination of a sister village, that is, a village that serves as a place for evacuation. The realization of the sister island concept is very relevant to small islands with high disaster risks. For instance, the 1980 Gamalama eruption was followed by heavy volcanic ash fall that led to 15 cm-thick of tephra deposits and the evacuation of 40,000 people, justifying the vital establishment of sister islands as a potential solution to volcanic crisis management issue on Ternate Island. For this reason, local disaster management stakeholders must prepare contingency plans for eruption hazards with scenarios of evacuation to the neighboring islands.

Conclusions

An increase in Gamalama activities in 2015, which involved several eruptions from July 16 to September 8, 2015, is the longest in the past 10 years. This unexpected turn of events was prompted by a short-term precursor (< 24 h) in the first eruption (July 16). Then, several eruptions occurred in the following days. Volcanic ash with a thickness of 2–6 mm covered the entire Loto, Togafo, and Takome Villages and, as a consequence, disrupted the daily activities of their inhabitants. After monitoring how the situations had developed in the field, the government of the City of Ternate issued an emergency status for 14 days (July 18–31, 2015). During the emergency response period, the government gave an order of evacuation to some predefined locations and formed teams of emergency response and volcanic disaster management consisting of relevant stakeholders in the City of Ternate. These teams are tasked with evacuating and providing services to evacuees during their stay at the camps.

The people of Togafo, Loto, and Takome were compliant with the evacuation order. Due to their awareness of the danger of eruption, they were willing to be evacuated to safer locations. This awareness is an interesting finding because, in some areas where customary systems are dominant, the communities tend to refuse on the grounds of obedience to the traditional leaders (similar to some villages on the flank of Merapi volcano). High awareness among the affected population is believed to be the result of mitigation activities that have long been carried out by the government, Non-Governmental Organizations (NGOs), and academics. Considering volcanic disasters that can occur at any time, it is imperative to implement mitigation measures in every area on Ternate Island, which generally has a close distance to the main crater (4–7 km). With properly implemented mitigation measures, the local population is expected to be more vigilant to any possibilities of small- and large-scale eruptions that may require them to evacuate to areas within the island or the neighboring islands.

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Author's contribution AH designed the study with input from MAM and DSH. The manuscript was written by AH with a contribution from MAM and DSH.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee of the Republic of Indonesia.

Informed consent Informed consent was obtained from all individual participants involved in the study.

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