Recommending assembly points, evacuation routes, and standard operating procedures for potential flooding due to reservoir dam failures: a case study of Gondang Reservoir, Lamongan, East Java

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Abstract. The failures of water-retaining structures, such as reservoirs and lakes, may cause massive flooding. Located in the Gondanglor village, Lamongan, East Java, the Gondang reservoir is approximately 30 years old. Currently, the village does not have an official evacuation Standard Operating Procedure (SOP), a guide needed during disaster emergency responses, including the risk of reservoir failures. The absence of the SOP means that the community members have not prepared themselves to face any hazard that threatens their safety. This research aims to recommend assembly points, evacuation routes, and Standard Operating Procedures (SOP) as inputs for the preparedness of reservoir dam failures. Criteria used to determine the assembly point locations are the minimum space per person, accessibility of private vehicles, access to safer places, either a street or open space, minimum distance from buildings, accessibility of disaster response vehicles, safe from falls, and other hazards. The evacuation routes consider road networks and conditions, movement directions, and distance between starting and assembly points. The evacuation SOP focuses on communication flows. Community members and Gondang reservoir's officers are interviewed, and studies related to evacuation procedures are reviewed to help accomplish the research aim. This study has successfully recommended assembly points, evacuation routes, and SOPs for evacuating villagers when the potential of Gondang reservoir failures is identified. Community members and village officers of Gondanglor were involved in the designing of assembly points, evacuation routes, and the SOP. The study has suggested five assembly points and the shortest possible routes to reach the points from varying locations in the village. SOP suggested communication flows during varying emergency stages, including the "Abnormal" (Level 1), "Alert" (Level 2), "Alert" (Level 3), or "Warning" (Level 4) status. The results are expected to increase the preparedness level of village members to reservoir dam failures.

Keywords: reservoir dam failure, Gondang reservoir, Standard Operating Procedure, evacuation route, assembly point

1. Introduction
Gondanglor village is located right below the Gondang reservoir dam (Figure 1). Currently, the Gondang reservoir is approximately 33 years old. President Suharto performed the inauguration of this reservoir in 1987 (Disbudpar, 2021). The reservoir area is 6.60 hectares with a depth of about 29 meters. The dam is a homogeneous landfill with a length of 903 m and a height of 27 meters. The water supply in this
reservoir comes from rainwater. Gondang Reservoir is used for irrigating rice fields (approximately 6,200 hectares) in Lamongan Regency during the dry season. Also, this reservoir is used as a tourist attraction to increase the local community’s economy. Even though the reservoir is still in good condition, the sediment level at the bottom of the reservoir had increased significantly so that the reservoir’s water capacity is no longer what it was when it was built. Climate change can affect increasing the intensity and frequency of rainfall and does not rule out the possibility of increasing the volume of water entering the Gondang reservoir. Furthermore, the Gondang Reservoir age, which is more than 30 years old, increasing the risk of dam failures. The villagers need to be prepared for the potential collapse of the Gondang reservoir considering the infrastructure age and the village location. Villagers need to know actions performed when the reservoir status endangers their safety.

An evacuation SOP (Standard Operating Procedures) is a guideline containing a series of written information regarding the procedures that need to perform to ensure the community's safety when a dangerous situation occurs. An evacuation SOP is needed to organize effective and efficient emergency responses. The situations may be due to natural, non-natural, and social factors. The SOP is one of the community preparedness in facing disaster risk. Therefore, SOPs need to be made in a language and format that is easy for users to understand. For example, an evacuation SOP may need to be presented in audio format or Braille to make it accessible to persons with disabilities. Moreover, the SOP that considers environmental and socio-demographic aspects and locally available technology can improve evacuation time and communication among stakeholders. Some information provided in an evacuation SOP includes gathering places, evacuation routes, communications and information flows, emergency numbers, the person in charge, and necessary equipment. Other important information can be added to increase the legibility and readability of the evacuation SOP.

Assembly points are relatively safe places to gather after the disaster evacuation process (PUPR, 2017). According to Safrina et al. (2015), the topography of assembly points terrain should be flat, not slippery, and not bumpy. The assembly points should be easily accessible to everyone, including children and people with special needs in routine and emergency conditions (Safrina et al., 2015).

Evacuation routes secure people from a disaster location to safer locations/assembly points (Pratama, 2016). Evacuation routes are determined based on several considerations, including the road network availability, the meeting point location, and the evacuation route length (NFPA, 2000; Pratama, 2016; Safrina et al., 2015; Pamungkas, 2020). According to Wijaya & Koswara (2016), evacuation routes are influenced by transportation directions and road conditions. Also, Safrina & Hermansyah (2015) mentioned that the distance traveled by victims from the initial location to the assembly points needs to be considered. With a short evacuation distance, fatigue during the evacuation process, especially in the absence of vehicles, can be avoided. With the evacuation route, it is expected that the evacuation process can be carried out more effectively.

Many organizations have developed evacuation SOPs to deal with dam failures. These evacuation SOPs provide various information that can improve quality, such as the most affected areas based on flood modeling, communication flow during emergency response, and activities at each level of emergency (CDEAP, 2020). These SOPs are generally integrated into water storage documents, for example, reservoirs, dams, or lakes (GCAP, 2018). Unfortunately, these various SOPs have not detailed the location of the gathering points, evacuation routes, and communication channels that can be followed by village officials and the local community where the water reservoir is located (GOI, 2016; TG, 2019).

Currently, Gondanglor village does not have an official evacuation SOP for accommodating the risk of Gondang reservoir dam failures. Gondanglor village has also not agreed on assembly points, evacuation routes, and communication flows when the Gondang reservoir dam fails. In emergency times, people tend to panic and move spontaneously, which is likely to exacerbate the disaster impacts. The evacuation procedure is needed so that community members can perceive actions needed to secure themselves during emergency responses. Further, Gondanglor has a low to high flood hazard, according to the Inarisk data (BNPB, 2020) (Figure 2). Areas with moderate to high flood hazards are in the northern part and areas with low hazard level is on the southern side of the village. It is worth mentioning that the Inarisk data has not incorporated the potential of flooding due to the reservoir dam failures.
This study aims to recommend assembly points, evacuation routes, and an SOP for evacuating villagers when the potential of Gondang reservoir failures is identified. Specifically, the SOP focuses on the communication flow during the emergency response stages. Although it is unlikely that the Gondang reservoir dam may fail soon, the event is possible to occur to the landfill dam. Several dam failure events have occurred in many places (Latrubesse et al., 2018; Nabilah et al., 2020). Community members need to be prepared to face conditions when the dangers from the reservoir are imminent. This study supports the preparedness stage in the disaster management phase and supports village officers to coordinate and organize resources to improve community safety.

Figure 1. (A) Delineation of Gondanglor village; (B) Settlements located below Gondang Reservoir; (C) Reservoir functions as a tourism spot (Google Maps, 2020, Author, 2020)
Figure 2. Flood hazard index in Gondanglor village. Green, yellow, and red colors show low, moderate, and high flood hazard levels, respectively (BNPB, 2020)

2. Method

2.1. Data Collection

Data used in this study include primary data and secondary data. Primary data collection was performed using in-depth interviews and field observations. Interviews were conducted to explore community perceptions regarding the assembly points, evacuation routes, and emergency management when the potential of Gondang reservoir failures is identified. Semi-structured interviews were conducted with villages and village officers using questionnaires. Furthermore, field observations were also carried out to obtain information regarding locations that could be used as assembly points, the direction of evacuation routes, activity centers (starting points), and the locations prone to flooding due to reservoir dam failures.

Secondary data were also collected to obtain a general overview of Gondanglor. The secondary data are village statistics, videos, maps, and literature studies related to the research goal. Village statistics include administrative boundaries, population profiles, vulnerable communities (elderly, children, disabilities), village institutions, community activities profiles, agricultural activities, tourism visit figures, and road network maps.

2.2. Data Analysis

2.2.1. Assembly points

Eight criteria are used to determine the suitability of assembly points, including the minimum space per person, accessible by vehicles, access to safer places, either a street or open space, minimum distance from buildings, accessible by disaster response vehicles, safe from falls, and other hazards (NFPA, 2000; Pratama, 2016; Wijaya & Koswara, 2016; Wiwaha et al., 2016; PUPR, 2017; Pamungkas et al., 2020). If the meeting point's condition is following the literature, it is marked with the value "1" and "0" otherwise. A location is determined suitable as assembly points when the score is at least seven. Next,
evacuation routes consider road networks and conditions, movement directions, and distance between starting and assembly points.

The present study distinguishes between temporary assembly points (TES) and final assembly points (TEA). The assumption is that villagers will evacuate from various activity centers to temporary assembly points (TES) when an alarm siren sounds. The temporary assembly points are transit points. If the threat is still under control, the villagers do not need to gather at the final assembly points. However, should the Gondang reservoir situation be unmanageable, the villagers need to go to the final evacuation to be transported outside Gondanglor with the evacuation vehicles.

2.2. Evacuation routes

Evacuation routes are determined using network analysis. The analysis solves the shortest path between stops on a topological road network (Chang, 2019). The data used in this analysis is road network data consisting of geometry and attribute data. So, distance is the only main factor used to determine the shortest routes to reach assembly points.

Overlay techniques were also used to assess the suitability of assembly points and evacuation routes. The overlay analysis uses a geographic information system to combine at least two spatial data (Chang, 2019). The input overlay analysis is the data generated from the primary and secondary surveys. For example, the land use and road network data are superimposed to determine the possible route between starting points and assembly points.

2.2.3. Evacuation SOP

The community members, village officers, and Gondang reservoir's officers are interviewed to provide inputs to the proposed evacuation SOP. Also, reports and studies related to evacuation procedures for dam failures are reviewed. Information related to the communication flows and persons in charge is incorporated in the SOP. The present study differentiates the danger level associated with the reservoir dam failures into four stages, including the "Abnormal" (Level 1), "Alert" (Level 2), "Alert" (Level 3), or "Warning" (Level 4) status. The communication flows vary during the danger level. The findings are elaborated qualitatively using a flowchart. Descriptive analysis is conducted to describe research subjects based on the data obtained (Aulia & Yulianti, 2019).

3. Study area

Gondanglor is one of the villages in Sugio District, Lamongan Regency, East Java. The village is located ~4 km from the sub-district capital Sugio and ~17 km from the district capital Lamongan. This village is located at 7°20'03'' LS and 112°26'58'' BT. Gondanglor has six hamlets, 7 RW, and 16 RT (BPS, 2020). The hamlets in Gondanglor are Biting, Gondang, Jadrisari, Ngingkrang, Randu Bolong, and Rejosari. Gondanglor has an area of approximately 5.16 km² and is located at an altitude of 38 masl. The Bengawan Solo river passes part of this village, and there is a Gondang Reservoir. Gondanglor is bordered by Karang Sambipilih village and Kedung Banjar village in the north, Sidorejo village in the west, Nearagung village in the East, and Kalitengah village to Sambeng district in the south. The total population in Gondanglor in 2019 is 4,224 people, or 1,096 households (BPS, 2020). Based on gender, Gondanglor has a population of 2070 men and 2,115 women in 2019. Figure 3 shows that the largest population in 2019 is in the 45-49 age group. In contrast, the lowest number is in the 60-64 year age group. At least 500 elderly and 850 children live in Gondanglor.
4. Results and Discussion

4.1. Evacuation starting points, assembly points, and evacuation routes

4.1.1. Evacuation starting points

The activity centers of people in Gondanglor are residential, tourism, and trade and service areas (Figure 4). The activity centers attract many people to Gondanglor and are determined as the evacuation starting points. The settlement pattern in Gondanglor follows the road network, which can be considered an advantage in the evacuation process. The center of tourism activities in Gondanglor is the Gondang reservoir. The reservoir attracts many people to Gondanglor. The trade and services activities are performed mainly through shops and markets.

Figure 4. Landuse map in the study area. Settlements showed in yellow color; Trade and service areas showed in orange color; Tourism areas mainly located near reservoir dams (Author, 2020)
4.1.2. Assembly points

Figure 5 shows locations that meet the criteria as assembly points. The recommended assembly points are the field in Jaledriasri hamlet, the Kacangan - Balongwangi Street, the field at RW 6 Ngingkrang hamlet, the field of SDN Gondanglor II at the Ronggo Hadi street, and the Ronggo Hadi street. The field in Jaledriasri hamlet is adjacent to the Gondanglor village office. The point is assigned as the final assembly point (TEA) because it has a vast field area, good street conditions, accessible by disaster response vehicles, and close to the village office. Villagers and visitors are assumed familiar with the village office. The other four assembly points are temporary evacuation points (TES). It is worth mentioning that the Kacangan – Balongwangi street and the field of elementary school Gondanglor II at the Ronggo Hadi street No 152 do not meet one of the criteria that is the minimum distance of 6.1 meters from potential falls (e.g., trees, electric poles) and other hazards (NFPA, 2000; Pratama, 2016; Wiwaha et al., 2016). These assembly points might need modifications to ensure the villagers’ safety during emergencies. The complete assessment can be seen in Table 1.

Table 1. Assembly point assessment

| Criteria                                                                 | Field in RW 6 Ngingkrang hamlet | Field in Jaledriasri hamlet | Kacangan - Balongwangi street | Field of elementary school Gondang Lor II at the Ronggo Hadi street No 152 | Ronggo Hadi Street |
|-------------------------------------------------------------------------|---------------------------------|----------------------------|-------------------------------|--------------------------------------------------------------------------------|-------------------|
| The minimum distance from the building is 20 m (PUPR, 2017)             | 1                               | 1                          | 1                             | 1                                                                              | 1                 |
| The gathering point can be either a street or an open space (PUPR, 2017)| 1                               | 1                          | 1                             | 1                                                                              | 1                 |
| The location does not obstruct disaster response vehicle movements (Wijaya & Koswara, 2016) | 1                               | 1                          | 1                             | 1                                                                              | 1                 |
| Have access to a safer place (NFPA, 2000; Pratama, 2016; Wiwaha et al., 2016; Wijaya & Koswara, 2016) | 1                               | 1                          | 1                             | 1                                                                              | 1                 |
| Have unobstructed access and are easily accessible by vehicles (Pamungkas et al., 2020; Wijaya & Koswara, 2016) | 1                               | 1                          | 1                             | 1                                                                              | 1                 |
| Has easy access to the medical team (Pamungkas et al., 2020)            | 1                               | 1                          | 1                             | 1                                                                              | 1                 |
| Provide a space of 0.3 m² / person with a minimum                       | 1                               | 1                          | 1                             | 1                                                                              | 1                 |
### Criteria

| Criteria                                                                 | Field in RW 6 Ngingkrang hamlet | Field in Jaledriasri hamlet | Kacangan - Balongwangi street | Field of elementary school Gondang Lor II at the Ronggo Hadi street No 152 | Ronggo Hadi Street |
|--------------------------------------------------------------------------|----------------------------------|------------------------------|-------------------------------|-------------------------------------------------------------------------|---------------------|
| height of 200 cm or more (minimum area = population x 0.3 m² / person) (NFPA, 2000) | 1                                | 1                            | 0                             | 0                                                                       | 1                   |
| The minimum distance of the gathering point to be safe from falls and other hazards is 6.1 meters (NFPA, 2000; Pratama, 2016; Wiwaha et al., 2016) | 1                                | 1                            | 0                             | 0                                                                       | 1                   |
| Total                                                                    | 8                                | 8                            | 7                             | 7                                                                       | 8                   |

**Conclusion**

Suitable

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**Figure 5.** (A) Village office. Recommended assembly points: (B) Field di Dusun Jaledriasri (adjacent to village Office); (C) Street of Kacangan – Balongwangi; (D) Field in RW 6 Dusun Ngingkrang; (E) Field of Elementary School at the Ronggo Hadi street; (F) Ronggo Hadi street (Google map, 2020; Google street view, 2020; Author, 2020)

### 4.1.3. Evacuation routes

Evacuation routes in Gondanglor Village are designed using the existing road network. The analysis in determining the evacuation route is as follows.

a. Road networks and conditions.

The road network status in Gondanglor consists of local or main streets and residential streets (Figure 6). Local streets are the street of Kedungpring-Sugio, Waduk Gondang, Kacangan-Balongwangi, Kedungpring - Mantup and, Ronggo Hadi. Further, the residential streets serve short-distance trips and are used by vehicles with low average speeds.
Most streets in Gondanglor are relatively in good condition. The examples can be seen in Figure 6. The street surface in the village is asphalt and pavements. The pavements are paving block and macadam soil. Asphalt roads are local or main roads. The paving street is scattered on neighborhood roads near people's houses. Macadam roads are primarily scattered in locations near rice fields and plantations.

![Figure 6. Road networks and road conditions in Gondanglor. (Google Street View, accessed April 2021; Author, 2020)](image)

b. Movement direction
Movements of people and goods in Gondanglor were influenced by the land use pattern (Figure 4). The activity sizes influence the number of movements. Figure 7 shows the overview of movement directions in Gondanglor. From the north side, the movements are from Karangsambigalih village, Sugio, and Lamongan Kota Districts. From the west side, the transportations enter the village from the village of Sidorejo, Sugio District. While from the East, the movements come from Deketagung Village.
c. The distance from starting points to assembly points
The evacuation starting points are residential, tourism, and trade and services areas, and the evacuation endpoints are designated assembly points. The distance between the starting points and the assembly points needs to be designed as short as possible. The shortest distance between the starting points and the assembly points can be obtained from overlaying the maps of assembly points, starting points, and the existing road networks. The shortest distance is measured from starting points to assembly points via the existing road networks. Evacuation routes proposed considering the location of the starting points, assembly points, and distance between the two are presented in Figure 8.
Figure 8. Gondanglor evacuation route map. Blue circle: final assembly point; Green rectangle: temporary assembly points; Orange lines with arrows: evacuation routes to final assembly points; Magenta lines with arrows: evacuation routes to temporary assembly points (Author, 2020).

4.2. Standard Operating Procedures (SOP) for evacuation
SOP for evacuation is one of the preparedness efforts for disasters. The SOP contains a series of activities and is designed in a flowchart form. The compiled SOP can answer questions related to "who does what," "what information is needed," and "when." Figure 9-12 shows a recommendation for communication flow during varying emergency response statuses. The status in increasing intensities is "Abnormal" (Level 1), "Waspada" (Level 2), "Siaga" (Level 3), and "Awas" (Level 4). The "Abnormal" status is a condition when several indications of emergency/damage to the reservoir are detected. The "Waspada" status is an indication of a critical condition. If the reservoir is in danger, its status will increase to "Siaga" or "Awas" when the surrounding community needs to evacuate. The SOP lists a
range of activities, communication flows, the information needed, and stakeholders involved during emergencies to ensure population safety and reduce potential damages.

A range of activities and stakeholders need to be performed during the "Abnormal" (Level 1) status. First, the reservoir operators need to continuously monitor the water depth and physical reservoir conditions and report the monitoring results to the local office head. Experts and technical teams can perform analyses to predict the potential events or fix the damages.

An "Abnormal" status may develop into a "Waspada" (Level 2) status. In this case, the local reservoir head office may report the updated situation to the river basin office (BBWS) head, and the latter could increase the "Abnormal" status to the "Waspada" status. Simultaneously, the local head office deploys experts and technical teams to monitor and predict reservoir conditions and fix damages—the river basin office head reports a situation to the National Directorate General of Water Resource. After declaring the Level 2 situation, the new status will be informed to the East Java and Lamongan water resource offices. Next, Lamongan water resource offices will inform the Lamongan disaster management agency (BPBD). BPBD informs the updated situation to the city mayor.

A "Waspada" status may develop to a "Siaga" (Level 3) status. The river basin office may deploy experts and technical teams to assess the reservoir condition. At the same team, a national team will also be deployed to assess the situation. The office of the Gondang reservoir will activate the alarm as a warning system. An information relay sequence will flow from the local reservoir office to stakeholders at the national, provincial, and regency levels. The information will also be delivered to sub-district and village offices to evacuate citizens to the assembly points and later to evacuation shelters.

Finally, a "Siaga" status may develop to an "Awas" (Level 4) status. During this stage, the disaster emergency office warns villagers that the Gondang reservoir will collapse. The head of the disaster management agency informs the head of the sub-district office, and the latter instructs the village leaders to evacuate all villagers to designated evacuation shelters.

5. Conclusion
While the likelihood of the Gondang reservoir dam failing soon is low, the event is possible to occur to the landfill dam. Community members need to be prepared to face conditions when the dangers from the reservoir are imminent. This research has successfully recommended assembly points, evacuation routes, and Standard Operating Procedures (SOP) for evacuation when the Gondang reservoir dam fails. This study has suggested at least five assembly points and evacuation routes to assembly points. The assembly points and evacuation routes are mapped so that villagers know where to gather during emergencies. The SOP for evacuation charts communication flows among stakeholders and information needed to improve coordination among stakeholders during emergencies. Provided regular disaster simulations, the study's results are likely to enhance the village's preparedness levels for potential disasters due to Gondang reservoir failures.

Further, this research is not without limitations. This research has not included flood modeling in determining the areas most affected when the dam fails. Next, the present study emphasizes communication channels among stakeholders when the Gondang reservoir condition increasingly endangers residents. Comprehensive evacuation SOP at a community level may need other information, such as early warning systems and supporting equipment or emergency vehicles. Next, the present study has not discussed the person in charge of each assembly point, although, culturally, neighborhood leaders will take the leading positions in coordinating villagers. Further, information on the socio-demographic condition of the community can increase the effectiveness of the evacuation process during the emergency response period. For example, persons with disabilities, pregnant women, and children need to be treated. Adjustments to the present research findings are suggested when more new data (i.e., flood simulations) are identified or whenever potential improvements are found during evacuation drills.
**Figure 9.** SOP for "Abnormal" status (Level 1)

**Figure 10.** SOP for "Status Awas" (Level 4)
Figure 11. SOP for “Waspada” status (Level 2)
Figure 12. SOP for "Siaga" status (Level 3)
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