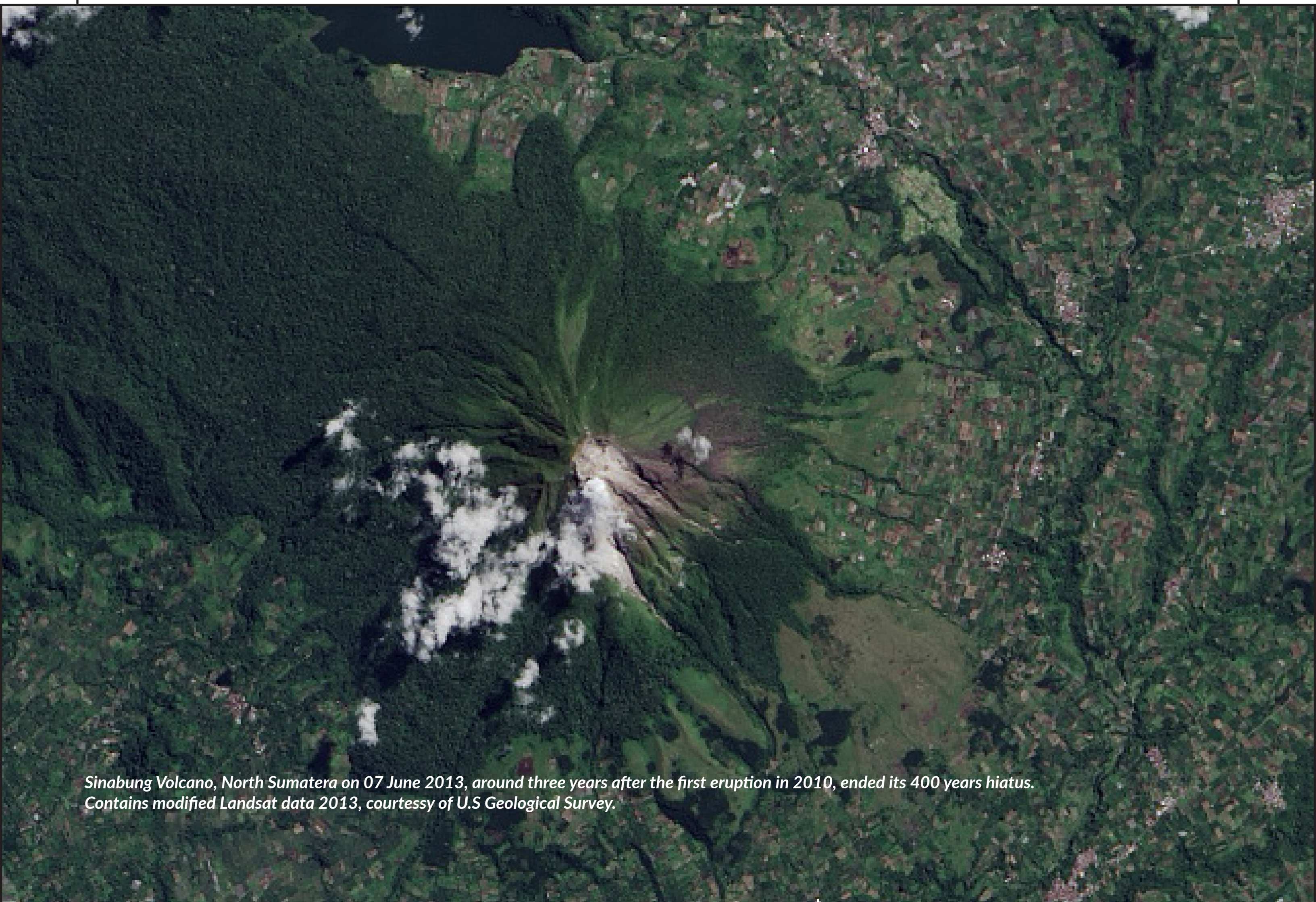
Resilience Development Initiative

British Geological Survey

# Understanding Geological Hazards to Support Disaster Risk Assessment in Indonesia:

## A report on a collaborative workshop between Resilience Development Initiative and the British Geological Survey

## 24-25 January 2022



*Sinabung Volcano, North Sumatera on 07 June 2013, around three years after the first eruption in 2010, ended its 400 years hiatus. Contains modified Landsat data 2013, courtessy of U.S Geological Survey.*

# Understanding Geological Hazards to Support Disaster Risk Assessment in Indonesia:

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| | |
|---|---|
| BIG | Geospatial National Agency of Indonesia *(Badan Informasi Geospasial)* |
| BGS | British Geological Survey |
| BMKG | Meteorology, Climatology, and Geophysics National Agency of Indonesia *(Badan Meteorologi, Klimatologi, dan Geofisika)* |
| BNPB | National Agency for Disaster Management of Indonesia *(Badan Nasional Penanggulangan Bencana)* |
| BRIN | Research and Innovation National Agency of Indonesia *(Badan Riset dan Inovasi Nasional)* |
| CVGHM or PVMBG | Centre for Volcanology and Geological Hazard Mitigation of Indonesia *(Pusat Vulkanologi dan Mitigasi Bencana Geologi)* |
| DRR | Disaster Risk Reduction |
| EWS | Early Warning System |
| ITB | Institut Teknologi Bandung |
| LAPAN | National Institute of Aeronautics and Space of Indonesia *(Lembaga Penerbangan dan Antariksa Nasional)* |
| MAGMA Indonesia | Multiplatform Application for Geohazard Mitigation and Assessment in Indonesia |
| LIPI | *Lembaga Ilmu Pengetahuan Indonesia* (Indonesian Institute of Sciences, superseded by BRIN) |
| NERC | Natural Environmental Council of United Kingdom |
| RDI | Resilience Development Initiative |
| RBPA | Risk-Based Planning Approach |
| SADEWA-LAPAN | Satellite-based Disaster Early Warning System by LAPAN |
| UKRI | United Kingdom Research and Innovation |
| UN | United Nations |
| UNPAD | University of Padjajaran |
| VONA | Volcano Observatory Notice for Aviation |

# EXECUTIVE SUMMARY

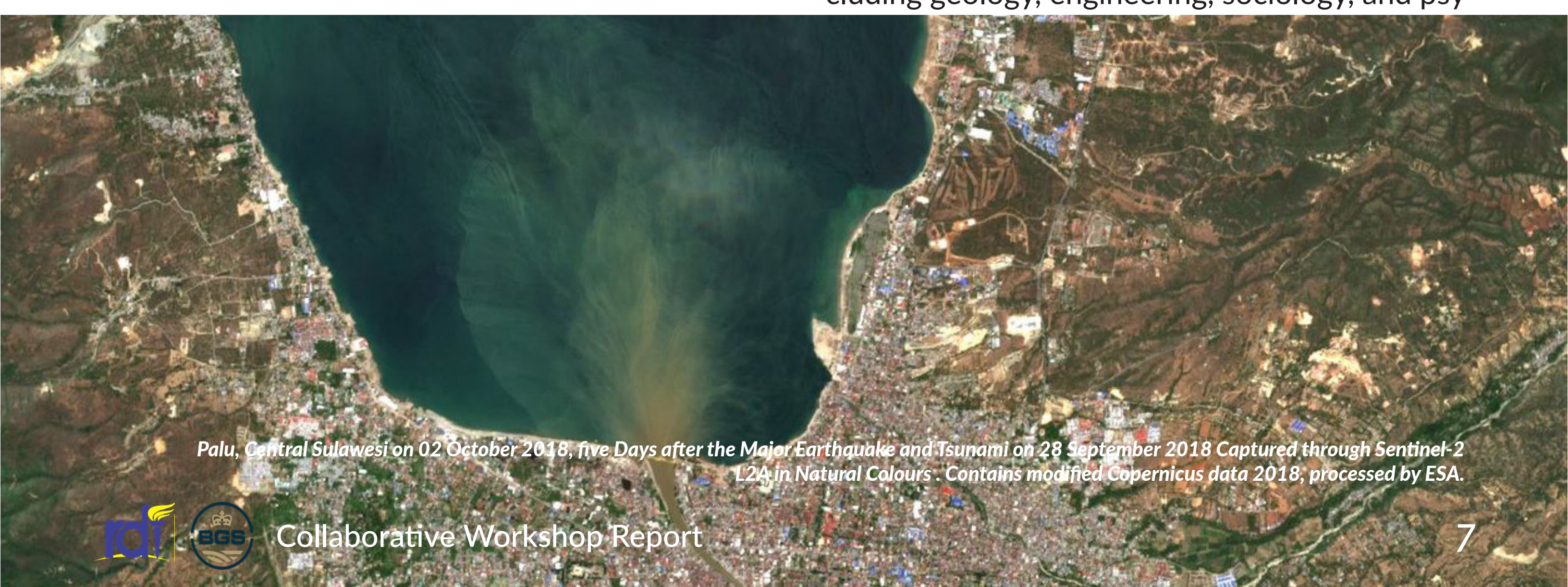
Indonesia encompasses one of the most active tectonic regions on Earth. Geological hazards in the country are a potent threat to a large and vulnerable population. It is therefore important that decisions made by disaster managers are informed by the best available earth science. However, large areas remain unstudied, with limited knowledge of past behaviour impacting understanding of future hazards and risks.

To understand the challenges and research opportunities related to natural hazards in Indonesia, the Resilience Development Initiative (RDI) and British Geological Survey (BGS) organised a collaborative workshop over two days in January 2022. The workshop provided an opportunity to bring together key stakeholders in disaster risk science and management in Indonesia. The workshop aimed to discuss and offer a forum to explore research needs in terms of understanding, measuring, mitigating, and modelling geological hazards in Indonesia, with a specific focus on earthquakes, landslides, volcanoes and tsunamis. The main findings from this exercise are summarised below.

**Fundamental hazard assessment.** A common theme across the four geological hazards discussed was the need to improve fundamental hazard assessments. For earthquakes, this involves improving the understanding of crustal faults at the local level and feeding this into national hazard assessment exercises. For landslides, a significant challenge raised was the resolution of susceptibility maps. There is a need to produce local hazard assessments considering local geological and environmental conditions. For volcanoes, the challenges were around understanding how past activity can be used to inform understanding of future hazards. However, participants agreed that it is difficult to understand the potential range of activity at infrequently active volcanoes, making hazard assessment more challenging. The main challenge for tsunamis was understanding the relative importance of various tsunami mechanisms. Earthquake-triggered tsunamis are relatively well understood compared to tsunamis triggered by volcanic eruptions and sediment movement.

**Baseline geological data.** High-quality, up-to-date, and complete data are the foundation of the best quality science. It is therefore imperative to collect and manage baseline data. For hazard assessments, there is a clear need for geological data to provide knowledge of past events and understand the possible future activity. Key points were raised around data availability and accessibility, where datasets are stored and who is responsible for storing, maintaining, and sharing data. An important first step to improving knowledge of hazards is to first determine how much data exists and where there are data gaps that can be filled through collaborative research.

**Collaboration and interdisciplinary working.** Disaster Risk Reduction (DRR) challenges require a holistic approach to hazard research and management. Common across all hazards is the need to work across different groups, from researchers to stakeholders and local communities, and across disciplines of science and education, including geology, engineering, sociology, and psy-



*Palu, Central Sulawesi on 02 October 2018, five Days after the Major Earthquake and Tsunami on 28 September 2018 Captured through Sentinel-2 L2A in Natural Colours . Contains modified Copernicus data 2018, processed by ESA.*

chology, among others. Collaboration in every aspect of geological hazard monitoring in Indonesia is crucial among stakeholders. Integration between researchers, government, community and media is needed to close the gap between geological hazards research and community risk perception.

**Community and culture.** Indonesia is a vast country with different communities and cultures. In some communities, there may be a tendency for people to trust local beliefs over official sources such as local scientists or the government. Researchers need to understand and respect the different structures that exist in different communities and find appropriate ways of communicating that are sensitive to these dynamics. Involving communities in the scientific process is a critical way of embedding a safety culture into communities. Transient populations such as displaced peoples, tourists and migrants were identified as particularly vulnerable to geological hazards. Understanding how to reduce the risk to these populations is an important research gap.

**Communication and engagement.** Communication could be improved by involving communities in the scientific process, co-developing outreach and education programs for schools and communities, and through the use of citizen science tools. Additionally, exploring the use of storytelling through traditional art, poems, songs, stories, and films can be a way of raising awareness of hazards and remembering and learning from past events.

**Institutional responsibilities.** The DRR lifecycle from hazard monitoring to crisis response requires precise coordination, collaboration, and division of responsibilities. Making progress on hazard science requires an understanding of institutional roles and responsibilities, and clarity on mandates and relationships between different government organisations and research institutions.

*Landsat 8 Satellite Image of Mount Anak Krakatau on 01-11-2018 in Natural color. Image courtesy of the U.S. Geological Survey.*

# 1. Introduction

## 1.1. Background

The Indonesian archipelago is located at the intersection of 3 active tectonic plates (Indo-Australian Plate, Pacific Plate, and Eurasian Plate). The complex tectonic conditions make the area prone to a range of geological hazards, with varying spatial scales. The occurrence of disasters associated with natural events in Indonesia is distinctively high, with the total number of disasters in 2020 reaching 2,952, including 16 destructive earthquakes, 7 volcanic eruptions, and 577 landslides. These events either caused fatalities or affected livelihoods (BNPB 2021). Hazards in Indonesia are often closely connected, for example: landslides resulting from earthquakes, tsunamis associated with volcanic eruptions, and other cascading hazard phenomena. One of the most significant geological disasters to have occurred in the last five years was the 2018 Sulawesi event, when a 7.4 magnitude earthquake triggered landslides and liquefaction in multiple areas around Palu (CNN Indonesia, 2021). The combined effects of the earthquake, landslides and tsunami led to the deaths of at least 4,340 people and displaced a further 172,635 (Bateson et al., 2020; Schambach et., 2021). It resulted in losses of Rp 2.89 trillion that caused damage amounting to Rp 15.58 trillion (BNPB, 2019). Despite the high profile of destructive events such as the Sulawesi event, landslides are the most common geological hazard in Indonesia. These can have dramatic impacts on lives and livelihood. In 2021 a landslide near Cihanjuang Village, Cimanggung District, West Java, resulted in 40 casualties, 25 people injured, 26 heavily damaged housing units, and 1,126 displaced people (CNN Indonesia, 2021).

With 127 active volcanoes, Indonesia faces a significant threat from volcanic activity. These volcanoes cover a wide range of behaviour from lava dome growth, instability and subsequent collapse to highly explosive eruptions. Volcanic hazards associated with eruptions include ash clouds (for aviation), tephra fall, ballistics, pyroclastic density currents, gas and aerosol emissions, lava flows, volcanic earthquakes, tsunamis, lahars and acid rain. Volcanic hazards may occur before an eruption (e.g., volcanic earthquakes), at the time of the eruption, or many years after an eruption has ceased (e.g., lahars and resuspended volcanic ash). On 4 December 2021, heavy rainfall triggered the collapse of the lava dome at the summit of Mount Semeru, East Java. The dome collapse led to an eruption, which generated pyroclastic density currents and rain-triggered lahars. This multi-hazard event impacted several villages and caused at least 34 casualties (BNPB, 2021).

The high intensity of volcanic and tectonic activity, in combination with long stretches of coastline, makes Indonesia vulnerable to tsunamis. The most destructive event ever recorded globally was the 2004 earthquake tsunami which led to over 230,000 fatalities in the Indian Ocean, of which ~160,000 were on the coasts of Sumatra, especially in the city of Banda Aceh, which was devastated by the flooding. The eruption of the Krakatau volcano in 1883 resulted in 36,000 fatalities. In December 2018, the collapse of the Anak Krakatau volcano produced a tsunami that flooded the coastal areas around the Sunda Strait, resulting in 437 fatalities (Novellino et al., 2020; Hunt et al., 2021; IFRC, 2021; Priyanto et al., 2021).

## 1.2. Objectives

Indonesia's pronounced tectonic activity and resulting geohazards pose a grave threat to its large and often vulnerable population. It is therefore important that decisions made by disaster managers and resilience planners be informed by the best available science. With the increasing exposure of populations to hazard events in Indonesia, there is an urgent need to improve the understanding of geological multi-hazard processes to better manage these often-complex events. Multi-hazards are defined as (1) the selection of multiple major hazards that the country faces and (2) the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects (UNISDR 2017).

We have an opportunity now to exploit a comprehensive suite of new technologies, data streams and analysis techniques to help address some of the knowledge gaps in multi-hazards science. These could provide improved insight into the occurrence of hazardous phenomena and their impacts. For example, studies have demonstrated the potential of deep learning techniques to analyse geological hazard data effectively. This technique has been used in landslide susceptibility assessment, seismic data interpolation and denoising, along with earthquake detection and localisation (Ma & Mei, 2021). The last two decades have seen an explosion in the availability of large volumes of satellite data acquired routinely over much of the world. Innovative machine learning methods are being developed to help analyse these big datasets to extract information relevant to natural hazard processes, e.g., volcanic unrest (Bountos et al. 2022).

As geological hazards are difficult to forecast, there is a need to establish risk reduction technologies based on the identification, analysis, and assessment of potential geohazards and any multi-hazard processes (be they independent, cascading, compound, creating change conditions or mutually exclusive). Therefore, developing tools and techniques to quantify uncertainties and identify management methods are required to advance risk assessment.

This collaborative workshop coordinated by the Resilience Development Initiative (RDI) and British Geological Survey (BGS) provided an opportunity to bring together the key stakeholders in disaster risk reduction (DRR) in Indonesia. The main aim of the workshop was to learn, discuss and offer a forum to explore research needs in terms of understanding, measuring, mitigating, and modelling of multi-geological hazards in Indonesia. During the workshop, participants discussed the key geological hazards that impact Indonesia (earthquakes, tsunamis, landslides and volcanic activity), the assessment methods used to monitor and understand these processes, hazard communication, and disaster risk reduction policies and their implementation. Besides aiming to stimulate the key actors and public understanding and awareness of various hazards, the workshop presented case studies to encourage the implementation and continuity of previous research and explore new approaches for addressing catastrophic disasters or potential impactful hazards that are still not well-assessed.

We hope the outputs recorded in this workshop report will help prioritise and focus research efforts in understanding the range and scope of existing data and will support government and agencies at the national and local level, communities, experts from relevant organisations, including but not limited to, IABI (Indonesian experts in disaster management), HAGI (Indonesian expert in geophysics), IAGI (Indonesian experts in geology), IATsi (Indonesian experts in tsunami), universities, and all relevant stakeholders, to ensure each entity can contribute to the discussion on emerging issues related to geological hazards and their mitigation to strengthen Indonesia's resilience in the future.

In Sections 1.3 and 1.4 of this report, we detail the workshop format and provide a simple demographic breakdown of the participants. In Section 2, we provide summaries of all the invited presentations delivered at the workshop. There were two presentations for each hazard (earthquakes, volcanoes, landslides and tsunamis). In Section 3, we provide summaries of the breakout discussions for each hazard. Finally, in section 4, we synthesise the key actions into next steps.

## 1.3. Workshop format

The virtual workshop was held in two three-hour sessions on 24th and 25th January 2022, with presentations and discussions in English. While the workshop focused on understanding geological hazards in Indonesia, we also took the opportunity to explore potential research collaboration among Indonesia and UK research agencies. Each type of geological hazard has its own characteristics and issues. Therefore, to delve further into each hazard type, the workshop sessions were organised into two days; the first day of the workshop focused on earthquake and landslide hazards, while the second day focused on volcanic and tsunami hazards. The workshop session on each day was arranged into two parts:

A) **An overview of the geological hazard in Indonesia.** Each day began with a keynote presentation from a senior official or scientist representing a disaster management organisation in Indonesia. These presentations summarised the broader hazard context in Indonesia. The keynotes were followed by invited presentations on specific hazards with presenters from relevant Indonesian agencies, RDI senior fellows, and BGS researchers. The presentations covered aspects of previous and ongoing projects from each institution such as applied technologies and methods. The Padlet Q&As for the talks are given in ANNEX 1 at the end of this report.

B) **Mapping challenges, opportunities, and research gaps for each type of geological hazard.** In this session, participants were divided into three groups. Each group was led by a facilitator to discuss the recent state of hazard mitigation in Indonesia, exploring possible technologies to strengthen the monitoring process and research gaps based on applied methods and actual conditions. Participants then regrouped for a short feedback session where the facilitator of each group delivered an overview of the discussion. The Padlet comments and questions for breakout rooms are given in ANNEX 2 at the end of this report.


*Figure 1. Workshop Format*

## 1.4. Participants

Across the two-day workshop, 66 participants attended the first day, and 69 participants attended the second day. Stakeholder representatives for each geological hazard were formally invited to the workshop. Most participants were researchers and practitioners from government agencies, local communities, practitioners, academia, and other related organisations involved in geological hazard monitoring and mitigation in Indonesia (Figure 2). Most participants who attended the workshop were men (68%), with 32% of attendees being female.

Figure 2. RDI x BGS Workshop Participant breakdown by profession


*Figure 2. Workshop Participants breakdown by profession*


*Lake Toba and its proximity with Sinabung Volcano, North Sumatera, captured through Sentinel-2 L2A on Natural Colour, 02 July 2021. Contains modified Copernicus data 2021, processed by ESA.*

# 2. Workshop Presentations

Below is an overview of the key points raised in each presentation, including a summary of the discussion sessions following the talk.

## 2.1. Hazard and Risk Assessment for Earthquakes and Landslides

### 2.1.1. Keynote Speaker: Overview of landslides and earthquake hazards management and monitoring by Dr. Yoga Andriana Sendjaja M.Sc, Padjadjaran University


*Figure 3. Overview of landslides and earthquake hazards management and monitoring by Dr. Yoga Andriana Sendjaja M.Sc*

The first day of the workshop focused on the Preparedness and Mitigation phases of geological hazards management with a focus on landslides and earthquakes. Dr Sendjaja emphasised that since Indonesia often experiences landslides, especially in West Java, homes cannot be built without first assessing the landslide hazard. Landslides are not only caused by varying soil types or extreme weather events but also by the climate. Indonesia has the SADEWA LAPAN (https://sadewa.sains.lapan.go.id) platform or dashboard that combines rainfall with land cover maps to improve landslide hazard mapping and prediction for early action. This platform also provides land use data, predicts albedo, rainfall, and affected areas, and evaluates hydro-meteorological hazards. Given the tectonic setting of Indonesia, earthquakes are a reality the country needs to live with. Indonesia has developed several Earthquake Zonation Maps (Peta Zonasi Gempa), or probabilistic seismic hazard maps, with 2% and 10% ground shaking exceedance probabilities in 50 years (both 1 and 0.2 sec). After the Palu earthquake, Indonesia developed a Disaster-Prone Zone scale to be used in detailed spatial planning. However, there remain significant data gaps in many regions.  With improved data, including geological mapping, Indonesia can enhance landslide and earthquake management plans.

### 2.1.2. Knowledge and Implementation Gaps in Disaster Risk Reduction and Spatial Planning in Indonesia by Dr. Saut Sagala, ITB and RDI


*Figure 4. Knowledge and Implementation Gaps in Disaster Risk Reduction and Spatial Planning in Indonesia by Dr. Saut Sagala*

Dr Sagala noted that the impacts of natural hazards in Indonesia are becoming more severe and costly and emphasised that spatial planning is an essential element in reducing disaster risk. Dr Sagala explained the various stages of a Risk-Based Planning Approach (RBPA), illustrating the points with his experience in the aftermath of the Palu earthquake. The RBPA approach consists of five stages:

***1) Know the hazard:*** The first stage of RBPA involves the periodic and systematic collection of data and information about the geological hazards, including regular hazard assessments and appropriate stakeholder identification. Historical data is important but can also be unreliable/incomplete for certain hazards. For example, we know that landslides are an important geological hazard in Palu, Sigi, and Donggala, in addition to tsunamis, floods, and earthquakes. However, in historical data catalogues, only earthquakes and tsunamis are mentioned.

***2) Understand the consequences:*** This stage involves validating hazard information and assessing the consequences of each hazard that threatens the planning area. The Palu Spatial Plan[1] 2010-2030 did not have appropriate scenario assessments for potential hazards. Understanding historical data and past events and how they might affect planning decisions today is important in this regard.

***3) Evaluate likelihoods:*** This stage focuses on the possibility of single or cumulative hazards occurences. In the Palu case, the assessment of the likelihood of liquefaction and the possibility of an earthquake was known, but there was a gap in implementation.

***4) Take a risk-based approach:*** Determining the level of risk that will be considered in formulating policies and DRR options. These require careful collaboration and co-development. The Palu Spatial Plan (2010-2030) was developed unilaterally without proper collaborations or consultations.

***5) Monitor and evaluate:*** We need to work together to assess the effectiveness of spatial planning and DRR intervention measures.

The RBPA method requires collaborative knowledge collection and creation by all relevant stakeholders, including communities, researchers and DRR professionals. Adequate scientific information is essential to conduct complete and adequate hazard assessments, which are inputs for formulating long-term and appropriate DRR strategies. But this is not possible where there are data and knowledge gaps. Therefore, strengthening geological hazard research in spatial planning is of critical importance. Alongside scientific information, local knowledge and participation are required to increase awareness and improve community resilience.

1 Palu's spatial plan or Rencana Tata Ruang Wilayah (RTRW) accessed on: https://jdihn.go.id/search/daerah/detail/303092

### 2.1.3. Interseismic strain on the Lembang fault, Bandung by Dr. Ekbal Hussain, BGS

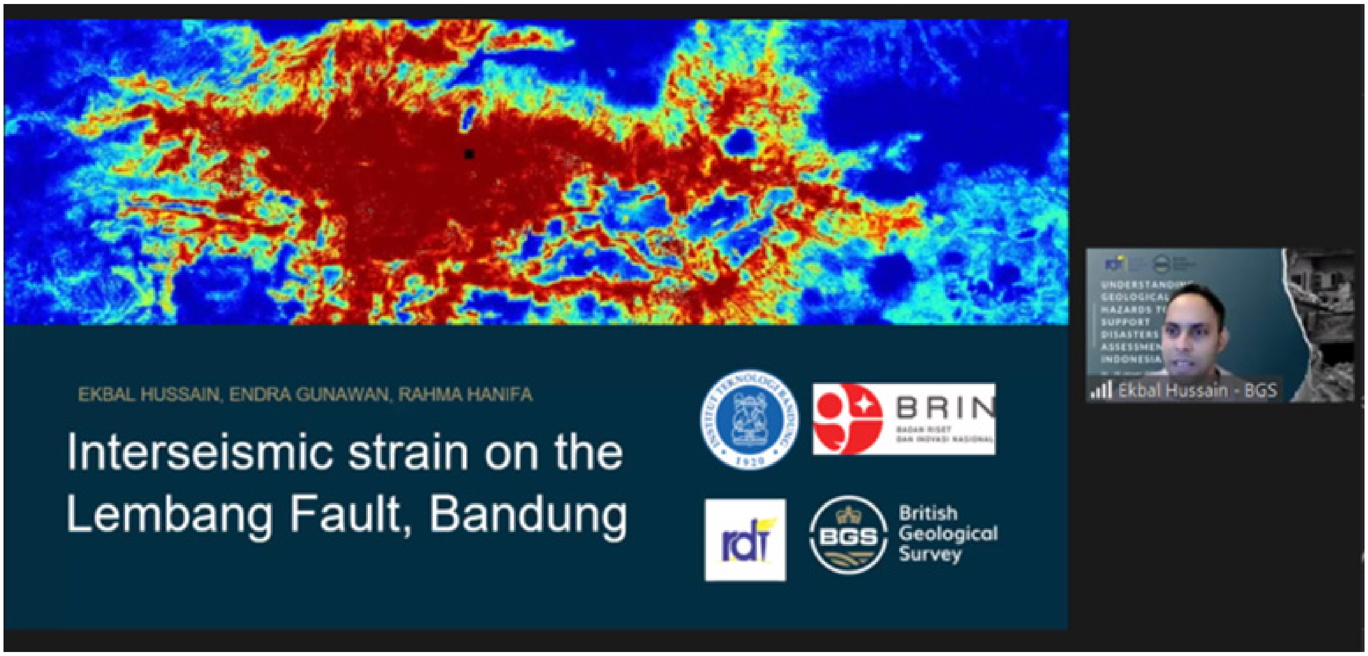



*Figure 5. Interseismic strain on the Lembang fault, Bandung by Dr. Ekbal Hussain*

Dr. Hussain presented a project working with Dr Endra Gunawan (ITB) and Dr Rahma Hanif (BRIN) using satellite radar data to measure the ground movements around the Lembang Fault. They found that the Lembang Fault has a geodetic slip rate of around 4.7 mm/year, less than the 6 mm/year estimated by Meilano et al. (2012). The new rate is higher than the geological slip rates of 1.95 – 3.45 mm/year estimated by Daryono et al. (2019). Paleoseismic trenches across the fault show clear evidence of large earthquakes equivalent to magnitude 6.5-7 events. Using the newly measured slip rate, they estimate that the fault has enough accumulated strain to produce a magnitude 6.8 – 7.2 earthquake. There is evidence for shallow creep on the fault at a rate nearly half that of the total slip rate (2.2 mm/year). The estimated locking depth of 3.3 km is shallower than expected for a crustal fault. But this could be affected by the trade-off between the slip rate and the locking depth.

The satellite data also shows a dramatic pattern of land subsidence in the Bandung basin. There are likely multiple sources of localised high rates of subsidence (>10 cm/year) due to building loads and a broader pattern (4-6 cm/year) related to groundwater extraction. Multi-hazard scenarios can be used for dynamic risk. Dr Hussain showed how, using the method of Gill and Malamud (2014), hazard interactions can be mapped into a matrix, which can be used for anticipating multi-hazard cascades.

### 2.1.4. Landslide mapping, technological advancement, and modelling in Indonesia by Dr. Dicky Muslim, Padjadjaran University


*Figure 6. Landslide mapping, technological advancement, and modelling in Indonesia by Dr. Dicky Muslim*

Dr Dicky Muslim highlighted that landslides are both geological and hydrometeorological hazards. From a business point of view, for example, in mining industries, it can also be categorised as a geotechnical hazard. Indonesia is experiencing a rising trend of landslide disasters. Landslide hazard management belongs to two groups, namely CVGHM and BMKG, which can result in confusion and duplication of efforts in research or response. Then, there is the centralised management of emergencies and decentralised management of mitigation. Furthermore, landslide disaster management in Indonesia generally focuses on geological studies and non-structural interventions.

Landslide sources and impacts can differ geographically across Indonesia. Detailed inventories of these sources and impacts exist, but the issue with keeping them up to date is lack of resources and time. There is a strong need for more detailed maps and collaborations to better use the inventories for hazard understanding. This is particularly relevant for spatial planning needs.

A case study of the Citanduy watershed showed a strong correlation between large landslide occurrence with geological conditions. In Cisolok, landslides occurred in paddy fields whereas in Cimanggung poor spatial planning and land use activities resulted in increased landslide occurrences. These examples show a correlation between human activities and poor land use with slope instability events. Ideally, spatial planning discussions should therefore involve geologists.

### 2.1.5. Landslide Database and Geomorphological Inventory by Dr. Christian Arnhardt, BGS


*Figure 7. Landslide Database and Geomorphological Inventory by Dr. Christian Arnhardt*

Dr Christian Arnhardt presented on landslide data collection. Landslides are complex natural phenomena. Variations in speed, runout, and kinematics result in different types of landslides, from long-travel landslides to short-travel landslides. There are numerous triggers of landslides: ground conditions, geomorphological processes, physical processes/triggers, and man-made processes. The key information needed to be recorded in a landslide database, in order of importance, are:

1) *Location:* coordinates, relative position, relative to landmarks
2) *Occurrence*: date, time relative information
3) *Attributes:* type, size, geometry, material
4) *Cause/trigger*: rainfall, earthquake
5) *Damage and impact:* impact on infrastructure, buildings, and fatalities
6) *Photos*

There are numerous ways of collecting landslide information, for example by using a paper form (Proforma) that includes the relevant landslide information. In the UK, such kinds of proforma were used by experts for landslide mapping in the past, which included questions about location, shape, mechanism, cause, slope, damage, geology, notes, and sources. A more modern version exists now in the form of the System for Integrated Geoscience Mapping (SIGMA) mobile kit, developed by BGS. It is designed for digital data capture and mapping directly into a GIS in the field using a ruggedised tablet PC.

An advantage of SIGMA mobile is that a wide variety of geological information, photographs, sketches and comments are easily collected through the use of tailor-made data-entry forms, which are stored in a fully relational database linked to a spatially referenced location point in the GIS.

In the frame of the LANDSLIP PROJECT in India, an app was developed that allows the collection of landslide information. The main idea behind this was to have an understandable and easy-to-use tool, that will enable people with minimal training to collect landslide information. Questions in the app include information around landslide source area, date/time, location, type, material, trigger, damage/impact, notes and photos.

Additional data can be obtained from various resources, including field mapping and remote sensing, the public, and social media. A database should include all the relevant fields and information defined in the data collection tool (e.g., proforma). It should also allow the connection with other information, like ground conditions and morphological aspects. The archiving and visualisation can happen in a multi-stage approach with various levels of input, but also linking across different departments and organisations.

## 2.2. Hazard and Risk Assessment for Volcanoes and Tsunamis

### 2.2.1. Keynote Speaker: Overview of Geological Hazard and Mitigation in Indonesia by Ir. Andiani, M.T., CVGHM


*Figure 8. Overview of Geological Hazard and Mitigation in Indonesia by Ir. Andiani, M.T.*

Ir. Andiani, M.T., as the head of the Centre for Volcanology and Geological Hazard Mitigation (CVGHM), delivered an overview of the volcano and tsunami monitoring system and hazard management in Indonesia. Indonesia is located above four active tectonic plates giving the region its complex geology. One of the effects of this is the existence of 127 active volcanoes that are categorised based on their recent activity into types A (77 volcanoes that have had historical eruptions since 1600 AD), B (29 volcanoes that have had historical eruptions before 1600 AD), and C (21 volcanoes that have no record of historical eruption but show signs of activity such as fumaroles). Indonesia also has more than 280 active faults making Indonesia prone to experience both tectonic and non-tectonic (volcanoes and landslides) tsunamis. As a centre under the Geological Agency of the Ministry of Energy and Mineral Resource, CVGHM is tasked to carry out research, field investigations, engineering and services in volcanology and other geological hazard mitigation, including, earthquake, tsunami and landslides.

On volcano monitoring and mitigation, CVGHM has at least 194 seismometers, 35 CCTV, 59 GPS, 38 tiltmeter, 12 EDM, two CTD, six multigas sensors, eight DOAS, and 74 observatory posts routinely monitoring 69 active volcanoes. With these assets, CVGHM can provide volcanic hazard mitigation in the form of a) volcano early warning system (EWS) that consists of four alert levels (I, II, III, IV) where each level is related to lists of actions formalised in the form of standard operating procedures, b) volcanic hazard-prone area mapping, and c) technical recommendations according to volcanic activities. Whereas, on tsunami mitigation, CVGHM's service covers a) quick response and post Investigation of earthquake/tsunami, b) mapping of tsunami deposit and hazard, c) dissemination of earthquake/ tsunami information, and d) giving technical recommendations for earthquake/ tsunami hazard impact mitigation. Based on historical records since 1629, there were 31 tsunami events triggered by earthquakes, 10 tsunamis triggered by volcanoes, and 5 by landslides. Although CVGHM plays a prominent role in hazard monitoring and mitigation, this effort is still a joint work of all parties, including government, academic, private sector, media, and society. The collaboration among the parties will determine the success of mitigating future geological disasters.

### 2.2.2. Volcano Monitoring System Development in Indonesia by Dr. Devy Kamil Syahbana, CVGHM

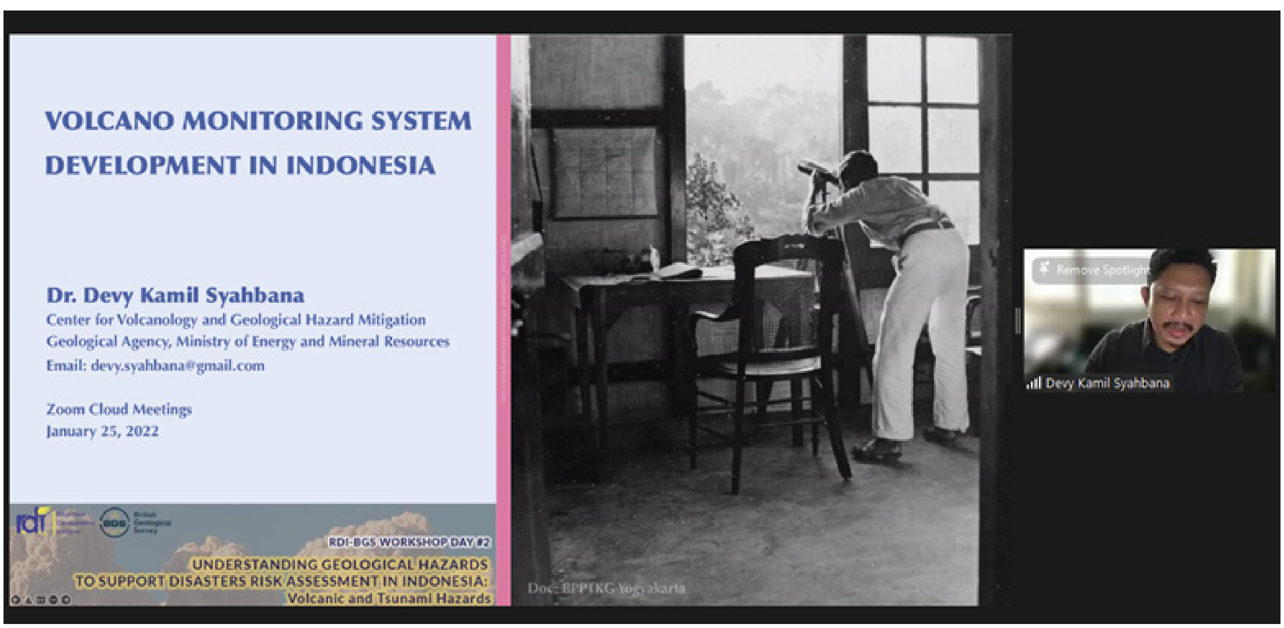



*Figure 9. Volcano Monitoring System Development in Indonesia by Dr. Devy Kamil Syahbana*

Dr. Syahbana began his presentation with a summary of historical volcanic events and their impacts in Indonesia, followed by a discussion on current volcano monitoring activities led by CVGHM. Indonesia has 127 active volcanoes, of which 79 erupted in the last 10,000 years, 42 volcanoes caused fatalities, and at least 7 to 12 volcanoes erupt yearly or around two volcanoes every day. Based on historical data, the most frequent volcanic hazards associated with fatalities are lahars and pyroclastic density currents. However, the largest number of fatalities are caused by secondary hazards that occur least often, such as famine (e.g., Tambora 1815), disease and tsunamis (e.g., Krakatoa 1883).

In volcano monitoring systems, there are four components which consist of a) regulation, b) equipment, c) human resources, and d) cooperation with institutions.

Historically, CVGHM originated as an institution of volcano monitoring systems during the Dutch era. After independence, the volcano monitoring duties were carried out by the Government of Indonesia under the Ministry of Energy and Mineral Resources. Several regulations have been released under the Ministry of Energy and Mineral Resources, including (1) Volcanic, Landslides, Earthquakes, and Tsunami Mitigation Guidelines and (2) Guidelines for Determining Geological Disaster-Prone Areas. To support its hazard monitoring service, CVGHM is supported by more than 300 volcano monitoring stations (visual, seismic, deformation, and geochemistry), radio and satellite telemetry, database and information systems and 74 volcano observatories monitoring 69 volcanoes. In terms of dissemination systems, CVGHM established MAGMA Indonesia (https://magma.esdm.go.id), a quasi-real-time information system for volcano, earthquake, and landslide hazards (warnings, incident reports, and technical recommendations). Alert levels, hazard maps, some open-access monitoring data, information streams, and specific notices for aviation activities, known as VONA (Volcano Observatory Notice for Aviation), are also provided by CVGHM.

Real-time monitoring is extremely resource-intensive. Each observatory has two to four volcano observers working to cover 24 hours of monitoring. There are 200 volcano observers around Indonesia who are trained local technicians and not scientists. CVGHM is headquartered in Bandung with around 40 staff, including geophysicists, geochemists, geodesists, geographers, and technicians. CVGHM collaborates with several partners, both internationally and nationally, to strengthen its role and services. Output from such a collaboration is the Agung and Batur Volcano Monitoring Networks Map developed jointly between Indonesia and the US. In conclusion, hazard warnings are not the only thing to strive for. An early warning and monitoring system should consist of four components, the first is risk knowledge, the second is hazard monitoring and warning, the third is communication and information dissemination, and the fourth is response capability.

Dr. Syahbana noted that Indonesia's geographical scale and diversity make communicating hazard information difficult. Something that may work in one region may not work in another. Therefore, there is a need to understand local culture/traditions and how communities perceive hazard information. Finally, volcanoes are not the exclusive domain for volcanologists or certain institutions but a shared domain that needs to be worked on together.

### 2.2.3. Volcanology at the British Geological Survey by Dr. Samantha Engwell, BGS


*Figure 10. Volcanology at the British Geological Survey by Dr. Samantha Engwell*

Volcanology is one of the research focuses at BGS. BGS uses science to address problems associated with a) volcanic environments and hazards, b) volcanic products and magmatism, c) eruption processes, and d) science for decision-making and policy. The BGS Volcanology team has particular interests in volcanic islands, using deposits to build an understanding of eruptive history, behaviour, and hazard. The team has developed approaches for low-data environments using analysis of field data to estimate eruption source parameters (eruption size, plume height, etc.) to inform the application of numerical modelling techniques for hazard assessment. BGS, together with LIPI (now BRIN), ITB, and other institutions, has conducted studies using multi-hazard approaches to better understand the 1883 Krakatau Eruption through a Natural Environment Research Centre (NERC) funded project using information from seismic surveys, analysis of volcanic and tsunami deposits, and numerical modelling of pyroclastic density currents and tsunamis to identify mechanisms for tsunami formation from volcanic eruptions.

The BGS volcanology also has several projects on volcanic environments and society. Examples include, citizen science projects: myHAZ-VCT (https://vct.myhaz.app) and the EUROVOLC citizen science tool (https://eurovolc.bgs.ac.uk); and a volcanoes-tourism project. The myHAZ-VCT is a multi-hazard application for collecting and sharing observations of natural hazards and their effects in near real-time. The EUROVOLC tool collates observations collected through other volcanic citizen science tools available across Europe, emphasising transboundary hazards. The volcanoes-tourism project focused on the phenomenon of international tourists as a transient population that may not understand the potential risks associated with their environment due to a lack of awareness, preparedness, or language barriers. The risk drivers that can influence the vulnerability of tourists to natural hazards include access to resources, communication methods by authorities in-country, preparedness and awareness of tourists, and exposure.

### 2.2.4. Tsunami hazard management and mitigation in Indonesia by Dr. Abdul Muhari, S.Si., M.T, BNPB


*Figure 11. Tsunami hazard management and mitigation in Indonesia by Dr. Abdul Muhari, S.Si., M.T*

Dr Muhari presented an overview of earthquake-driven tsunami hazards in Indonesia. Indonesia is well known for large megathrust earthquakes, some of which have produced large damaging tsunamis. There appears to be a sizeable seismic gap on the Java portion of the subduction zone. If this is released together, it could result in an Mw 9 earthquake and generate tsunami heights over 20m.

To enable better mitigation efforts, Indonesia has produced tsunami height calculations and models for 100-, 500-, and 2500-year period tsunamis. These models predict tsunami inundation based on wave height hitting the coastline. The hazard intensity (tsunami run-up and inundation height) and return period should be considered when designing appropriate mitigation. Lessons could be learnt from the 2011 Japanese earthquake and tsunami and different tsunami preparedness levels created: Level I and Level II, reflecting return periods of 50-200 years and >200 years, respectively. Each of these levels could be presented by associated hazard maps showing maximum inundation lines. There have been previous attempts at implementing this in Indonesia, e.g., Muhari et al, 2014.

Dr. Muhari noted that there are two different ways to mitigate the damage from tsunamis, the green and the grey approaches. The green approach, such as nature-based solutions, can protect from multiple hazards (both rapid and slow onset disaster), has various co-benefit, low cost, and stronger protection over time, but this green approach is vulnerable to extreme events, and requires more space and time for the benefits to be realised. Meanwhile, the grey approach can be applied with the help of specific expertise, such as civil engineer, hazard modeller, and this approach can deliver immediate results and require less space and time. Therefore, both approaches have their benefits and drawbacks. Thus, integrating green and grey approaches in coastal land-use planning for multifunctional landscape and mitigation functions may be the most appropriate action (Muhari 2018). Indonesia needs integrated studies including coastal biology, coastal dynamics, civil engineering and socio-anthropological studies for more diverse mitigation measures; for example, coastal forest should be developed on non-elevated (coastal dykes) to allow roots to penetrate deeper for a better endurance against waves and abiotic stress.

### 2.2.5. Assessment of potential Tsunami hazard from Indonesian volcanoes by Prof. David Tappin,

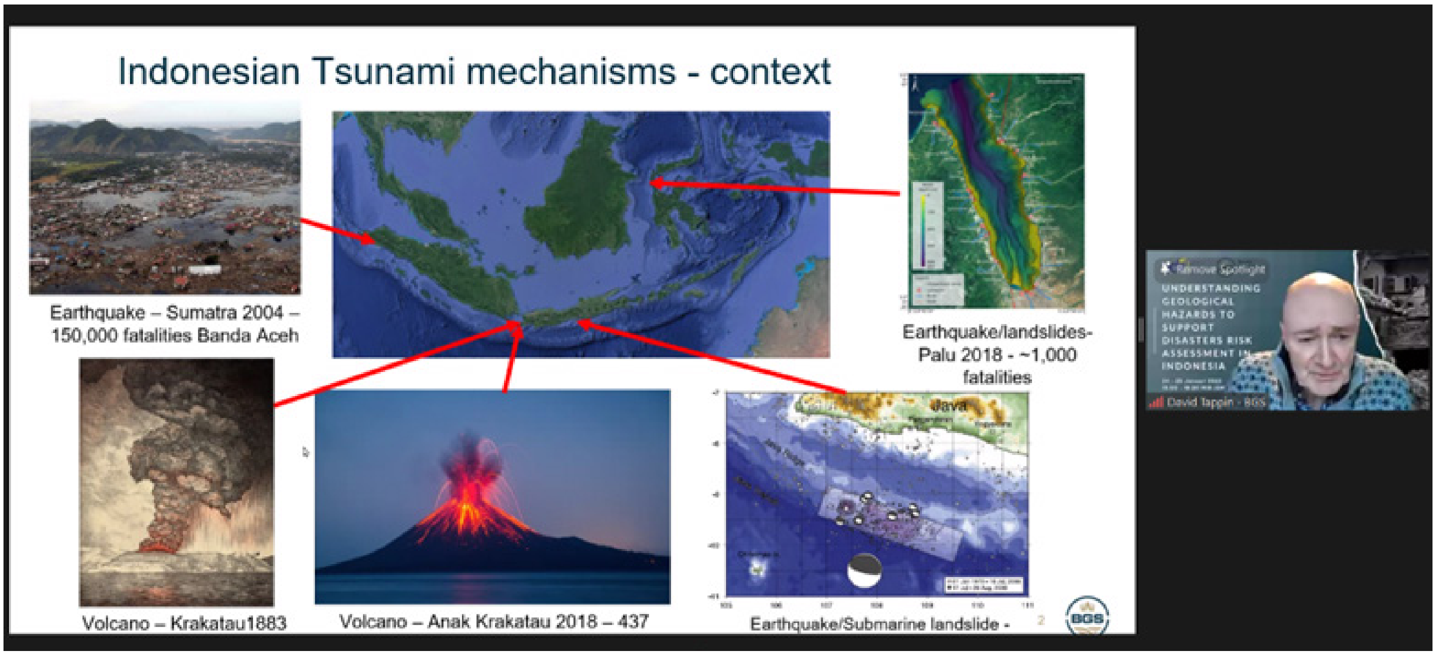



*Figure 12. Assessment of potential Tsunami hazard from Indonesian volcanoes by Prof. David Tappin*

Prof. Tappin, in his talk, provided a detailed discussion on the subset of Indonesian tsunamis that were generated by volcanic eruptions. Indonesia has various conditions that might trigger a tsunami such as tectonic earthquakes, volcano eruptions, and earthquakes followed by submarine landslides. The earliest known volcanic tsunamis in Indonesia occurred in 416 (Krakatau). Historically there have been 25 volcanic tsunamis following eruptions at Krakatau, Gamalama, Teon, Gamkonora, Peuet Sague, Soputan, Awu, Ruang, Banua Wuhu, Paluweh, Agung, Iliwerung, and Anak Krakatau. Several eruption related tsunamis resulted in fatalities: Awu volcano in Sangihe Island (1856), Ruang in North Sulawesi (1871), Krakatau in South Lampung (1883), Paluweh Island in Flores Sea (1927), and Anak Krakatau in South Lampung (2018).

The most devastating volcanic tsunami was in 1883, when the eruption of Krakatau generated a tsunami of up to 40 metres in the Sunda Strait, resulting in 33,000 fatalities. The most recent volcanic eruption-induced tsunami was Anak Krakatau in 2018, which caused up to 9-metre run-ups on the coasts of Java and Sumatra and 437 fatalities. The tsunami occurred due to the collapse of the volcano's southwest flank. For volcanic-induced tsunamis, there is a need for a baseline assessment on a) information on active volcanoes near the ocean and preliminary identification of potential hazards, b) volcano activity monitoring, and c) an understanding of volcanic tsunami mechanisms. It is essential to understand that the initiation mechanism for volcanogenic tsunamis differs from that for earthquakes. The volcanic tsunami mechanism is locally generated and has a concise warning time. Attempts to mitigate tsunami hazard requires local community action, building on education to increase hazard awareness. It is also important to start developing warning systems for both volcanic activities and related tsunamis, acknowledging that this could be relatively expensive to install and maintain.

# 3. Discussion: Opportunities, Challenges, and Gaps

In this section, we summarise discussions arising from three breakout rooms for each of the four main hazards: earthquakes, landslides, volcanic eruptions, and tsunamis. In each room, participants were given 35 minutes to discuss three questions:

**1) What are the opportunities that can be optimised further in monitoring and [hazard type] hazard assessment in Indonesia?**
**2) What are the challenges faced in monitoring and [hazard type] hazard assessment in Indonesia?**
**3) What are the research gaps that can be identified in monitoring and [hazard type] hazard assessment in Indonesia?**

To enable wider participation, participants were encouraged to take part in free-flowing discussion in English managed by a facilitator and/or contribute ideas and thoughts to a pre-set Padlet in their language of choice. At the end of each session, one member of each group was given 5 minutes to report on the discussion in plenary. Below is a summary of the themed discussions.

## 3.1. Earthquake Hazard

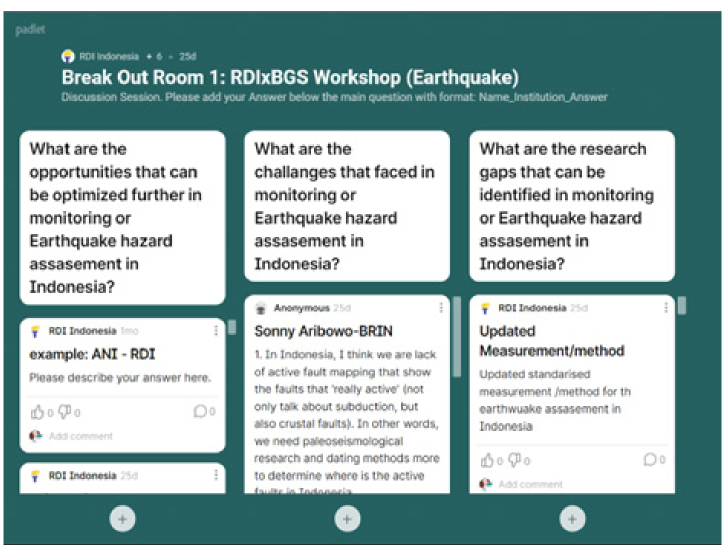



*Figure 13. Example of the Padlet setup for the earthquake breakout rooms*

**Hazard assessment:** Participants discussed the availability of earthquake hazards maps in Indonesia. It was noted that existing earthquake-prone zone maps (Peta Kawasan Rawan Bencana Gempa Bumi) lack sufficient active crustal fault information. Additionally, earthquake hazard maps are only available at a coarse resolution (1:50.000-1:5.000.000) whereas more detailed resolution maps (1:25.000 or more) are needed to enable better spatial planning. One participant mentioned that knowledge of active faults varies across the country, with faults in West Java currently getting more focus because of the large population density in the region. However, in comparison, active faults in Sumatra are poorly understood. Another participant mentioned an increasing awareness of hazard cascades in Indonesia, such as the sequence of hazards following the Palu earthquake. They suggested a need for more local-level earthquake hazard mapping, including the areas likely to be prone to secondary/cascading hazards, conducted in a participatory manner and verified by the official authorities.

**Data:** Participants discussed some factors hindering earthquake mapping such as data availability, human resources, and technology. One researcher suggested that Indonesia needs better paleo-seismological research and dating methods to identify active faults in Indonesia. For now, active fault monitoring is only conducted on the Lembang and Opak faults. To tackle limited data availability, Indonesian researchers could develop an open-access database. Participants agreed that more collaboration is needed between Indonesian and international researchers and practitioners to increase earthquake research and data collection.

**Equipment:** A few participants spoke about the challenges with the management of monitoring equipment. In Indonesia, earthquake monitoring and EWSs can be installed by several stakeholders, including central governments (CVGHM, BNPB, and BRIN), local governments, and universities. Regarding the earthquake EWS, due to the nature of earthquake events that cannot be predicted, some universities and research institutions implement the EWS by accelerating the delivery of information about earthquake events to the potentially impacted population. This system works by receiving a signal from central government stakeholders and delivering it as a siren signal to remote and rural areas where mass, electronic, or social media information is inaccessible. This requires a joint collaboration among stakeholders. However, there is no clear coordination between these institutions to maintain the equipment or to collaborate further. A participant mentioned that equipment can also be prone to theft and suggested that this might reflect on the gap between scientific research and local perception. Thus, capacity enhancement on the natural hazard-related technology to the community prone to those natural hazards needs to be frequently conducted.

**Disaster preparedness:** Participants noted that Bandung city does not have a local disaster management agency. This is a challenge because a local mechanism to raise the profile of hazards to authorities does not exist. There is considerable wealth exposure to earthquake hazard proximal to the Lembang fault. Additionally, it was mentioned that many buildings are not prepared for high levels of ground shaking and that even new buildings are not built to earthquake resistant standards or utilized standardised building code. In the event of a disaster, a participant noted that the role and responsibilities are unclear. The emergency management group appears to be different for each event/region, showing that there is a lack of clarity regarding roles and responsibilities.

**Communication:** Participants engaged in discussions around the use of social media for communication before, during and after hazardous events. However, it was noted that social media users need to understand language sensitivities, particularly in a large, culturally diverse country like Indonesia. A participant indicated that Twitter has been a successful way of disseminating guidance and information through official government Twitter handles (e.g. @BNPB_Indonesia). A participant suggested that there is an opportunity to include local communities in the data collection process through social media and citizen science approaches. Participants agreed that greater collaboration with experts from social sciences would be essential to develop innovative and inclusive methods of communicating hazard/risk information. A participant noted emphasised the need to include social scientists to help bridge the gap between the technical analysis and local stakeholders if we want to improve resilience in the community.

## 3.2. Landslide Hazard

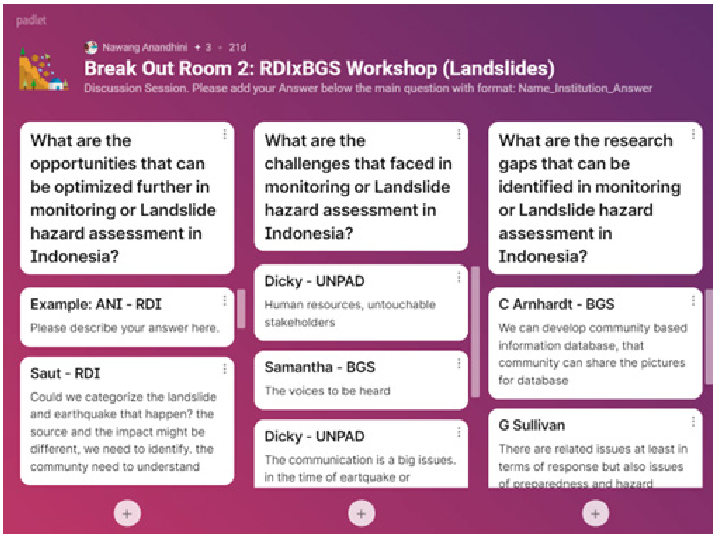



*Figure 14. Example of the Padlet setup for the landslide breakout rooms*

**Landslide hazard maps:** Participants were concerned with the lack of detailed landslide hazard maps (*Peta Kawasan Rawan Bencana Gerakan Tanah)* in Indonesia (>1:50.000), despite landslides being very localised hazards. Landslide occurrence depends on various parameters, including geological conditions, climate, land cover, and land use. One participant noted that due to Indonesia's diverse geological and geographical characteristics, producing detailed landslide-prone zone maps is challenging but not impossible. However, it requires human resources, equipment on the ground, and a maintenance plan. All of which have significant cost considerations. Participants were unsure to what extent hazard assessments had been completed/ conducted at the site for the new capital. If this has not been done yet, perhaps it is an opportunity to engage in a meaningful project.

**Physical and social vulnerability:** It was noted that most of Indonesia's current building construction regulations are adopted from other developed countries, which are not precisely applicable in the region, considering the soil and geographic condition. Another participant noted that there are opportunities for research into building construction materials and structure and how construction can be adapted for different hazards. There is much information for earthquake hazards, but less for volcanic, landslides, and hydrometeorological hazards.

It was also noted that vulnerability maps are needed to help identify areas of high risk. This would need to consider a range of vulnerability factors, including physical (e.g. built environment) and social vulnerability (e.g., wealth, demographics of the population) combined with hazard exposure.

**Landslide processes:** Participants discussed the knowledge gaps regarding landslide mechanics and were clear that understanding different landslide drivers and processes (causal and triggering factors) is essential as this allows the development of meaningful landslide hazard products, such as landslide susceptibility or hazard maps. However, knowing the limitations and gaps in these products is also essential and must be communicated to users and stakeholders comprehensively.

Participants agreed that remote sensing technologies could help in landslide mapping. There is an opportunity to investigate the correlation between the remotely sensed transformation of land use and landslide hazards; for example, does certain vegetation strengthen or weaken the soil? Natural landslide hazards can be exacerbated by anthropogenic activity such as deforestation, farming and irrigation practices, fires etc. These influences need to be better understood and incorporated into hazard mapping. A participant summarised this point: "*Geological condition can't be changed. But the way people "do" things matters. Geologists need to be involved in infrastructure planning. City planning needs to be based on the geological conditions.*"

**Early warning systems (EWS):** Participants engaged in a lengthy discussion about EWS. Although a system currently exists, it is unclear to what extent this is used. There is a need for local but integrated EWS. Participants were also clear that warnings should be inclusive and conscious of disabilities, perhaps through a multi-sensual warning system, e.g., sound and light.

**Communication and engagement:** Participants discussed the importance of having multi-disciplinary teams, including geologists and other geo-scientists together with social scientists to transfer the more technical output of maps and models into something understandable and meaningful for stakeholders and communities. Additionally, the input and feedback from affected communities and people on the ground is essential to improve the developed tools and test their accuracy / suitability. Participants were clear that engaging people and communities in the entire process from the beginning is an important aspect of developing useful, usable, and used and trusted products, outputs and tools in the end.

**Landslide database:** A participant noted that Indonesia already has a standard reporting system, but not many people use it. Developing a community-based information database is another opportunity. Indonesia has MAGMA Indonesia (https://magma.esdm.go.id), a multi-platform application consisting of geological disaster information and recommendations for landslides. Participants discussed whether this existing system could be enhanced to enable community and local government (non-geologist) to participate in data entry. Such entries could enrich the database and educate people and the government, which could help develop a sense of ownership. The database might also include landslide types, sources, and other necessary characteristics.

*Aerial Photograph of Landslide at Cimanggu District, Sumedang Regency on 11 January 2021. Courtessy of Dept. Geological Engineering of Padjadjaran University.*

## 3.3. Volcano Hazard

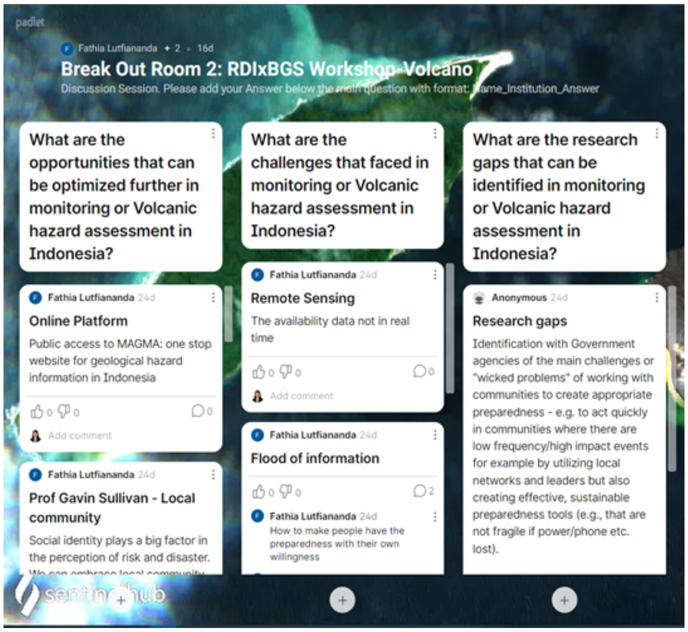


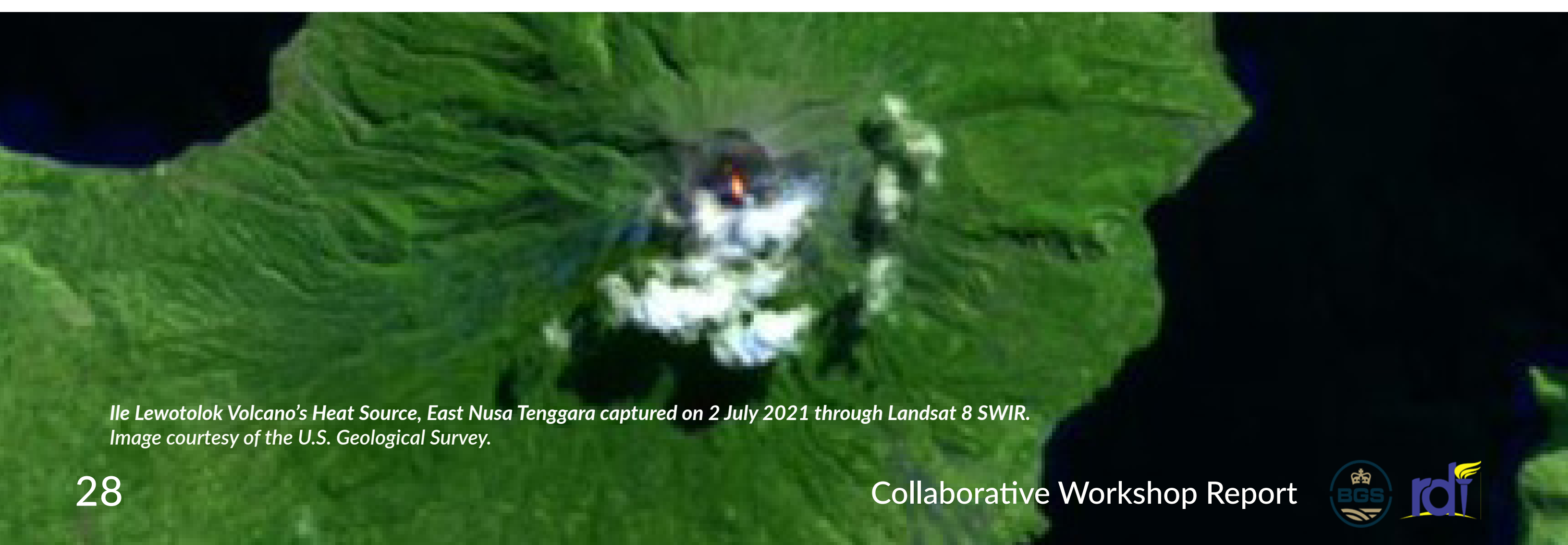

*Figure 15. Example of the Padlet setup for the volcano breakout rooms*

**Hazard assessment:** Many volcanic areas in Indonesia are densely populated. Participants agreed that some of Indonesia's volcanoes are very active, frequently erupting, while others appear to be doing very little. Therefore, there are differences between communities that are used to living with volcanoes that erupt frequently and communities that are not. A participant noted that: "*We live between the past disasters and future disaster*", and noted that it is more difficult to maintain sustainability for preparedness in communities who live near volcanoes that do not erupt over longer time intervals.

Participants agreed that it is more difficult to understand the potential range of activity at volcanoes that are not frequently active, making hazard assessment more challenging. There is a need for geological field mapping of volcanic environments to gather data on past events, to better understand the behaviour of the volcanoes and potential future activity.

Volcanoes as multi-hazard environments: Participants agreed that more work needs to be done to better understand multi-hazard relationships, which include coincident, cascading and cumulative hazards and impacts from an eruption and from independent hazards, for example, extreme weather. This can be built and strengthened from past event information. Participants mentioned that the division of responsibility is not clear for multi-hazard events (e.g., volcanic eruption triggered tsunami) that potentially cross the boundaries between managing agencies.

Volcano monitoring and warnings: A participant noted that volcano observatories in Indonesia have different levels of monitoring capability. A lack of equipment is an issue with existing instruments prone to theft. Another participant suggested that regarding information dissemination, the current problem may be too much information. Sometimes there is information overload with many WhatsApp groups that are flooded by hazard information on a regular basis, which may desensitise people to the information when



***Ile Lewotolok Volcano's Heat Source, East Nusa Tenggara captured on 2 July 2021 through Landsat 8 SWIR. Image courtesy of the U.S. Geological Survey.***

it matters. There is a need to understand how these systems can empower people. People tend to want data only when the crisis is happening, e.g., during an eruption.

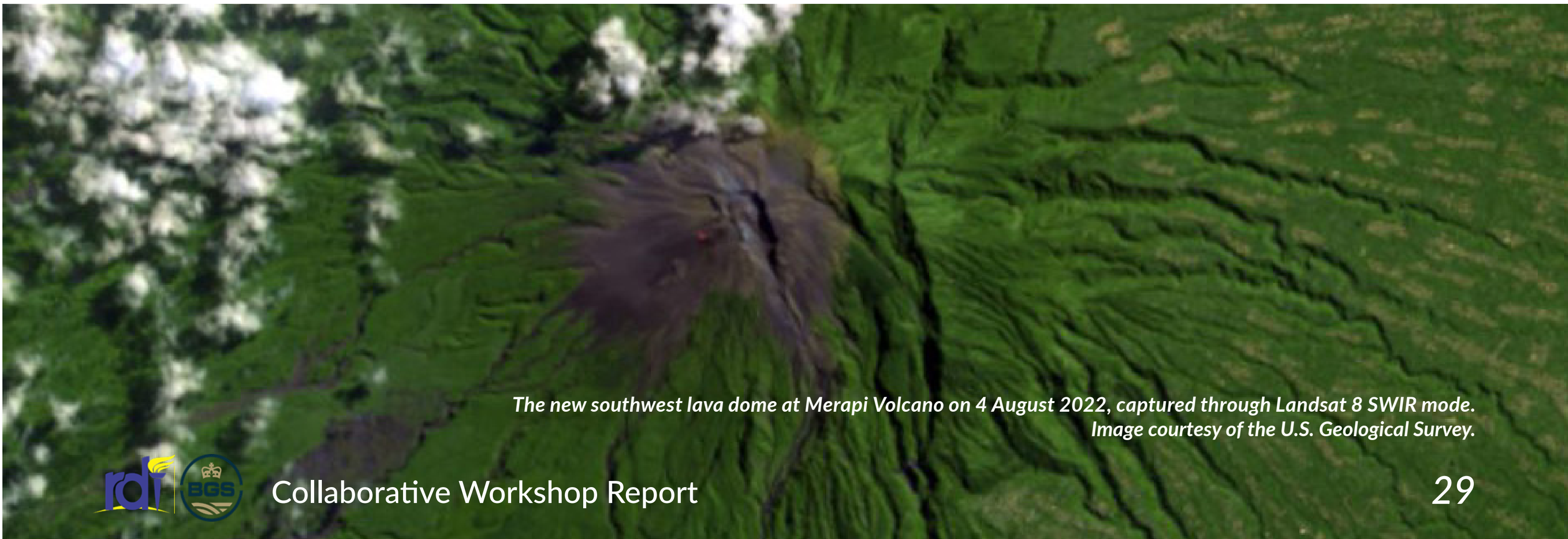
Participants discussed how we can sustainably conduct preparedness activities. They agreed that the best system is one that is promoted by local people and is used by them. A participant noted that for regions around infrequently erupting volcanoes local leaders are more effective than technological based interventions. This presupposes that local leaders are open to the warnings provided by the authorities and so it is crucial that these systems work well together.

**Community and culture:** Indonesia is a vast country with different communities and cultures. Participants noted that in some communities there may be a tendency for people to trust local beliefs instead of the official sources such as local scientists or the government. Researchers need to understand and respect the different structures that exist in different communities and find appropriate ways of communicating that is sensitive to these dynamics. Given this challenge participants discussed how we can embed a culture of safety into communities, such as involving communities in the scientific process.

There is the possibility of developing and applying citizen science tools, such as the BGS myHaz app, to involve communities in making observations. Another possibility discussed was to include communities in mapping activities and developing communication tools. Thus, they will have a sense of ownership of the data and the act of mapping may help them understand hazard maps better. A participant noted that social identity plays a big role. Who the information comes from matters. Alternative communication tools or methods such as art, stories, poems, and films can also be used effectively to learn and communicate past volcanic (and other hazard) activity.

**Transient populations:** Indonesian volcanoes are popular tourist attractions. Participants agreed that tourist hotspots and activities located near volcanoes need to be identified to determine risk drivers, formulate hazard communication, and propose mitigation action that can be taken to reduce tourists' vulnerability. This is also relevant for submarine volcanoes, some of which have become diving spots for tourists (e.g., Banua Wuhu, North Sulawesi).

**Submarine volcanism:** It was noted that submarine volcanoes also need consideration. Globally, there is a gap in understanding and monitoring of submarine volcanic activity. This gap could be reduced by satellite monitoring and using hydrophones. Assessing submarine volcanoes with potential for hazardous eruption could be the starting point in addressing this hazard since a submarine volcano located less than 500 metres from the sea surface has a higher possibility to produce greater impact.



*The new southwest lava dome at Merapi Volcano on 4 August 2022, captured through Landsat 8 SWIR mode. Image courtesy of the U.S. Geological Survey.*

## 3.4. Tsunami Hazard

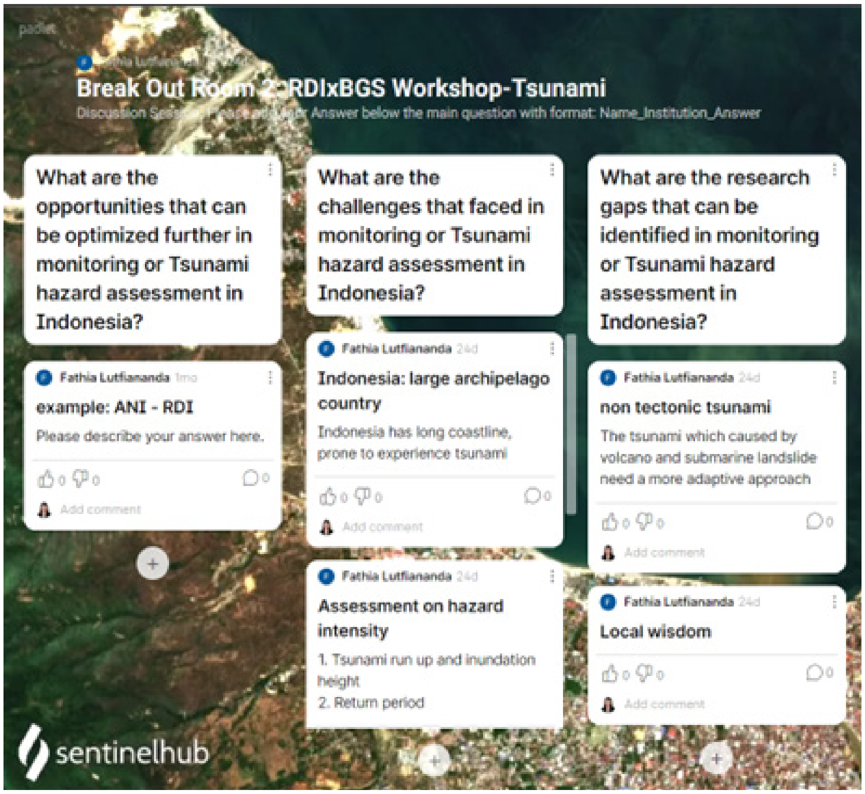



*Figure 16. Example of the Padlet setup for the tsunami breakout rooms*

**Tsunami mechanisms:** Participants discussed the various mechanisms that have generated tsunamis in Indonesia. A major challenge is Indonesia's very long coastline in a tectonically dynamic region, which has resulted in a high exposure to tsunami hazards. The most common triggers are earthquakes but historically there have been significant tsunamis generated from volcanic eruptions. Participants agreed that further work needs to be done to understand non-tectonic tsunami-generating processes, such as volcanic eruptions and subaerial landslides. Before 1990, at least 13 volcanoes in Indonesia caused tsunamis, and 12 of them are in-land, including Krakatau, South Lampung; Gamalama, Ternate Island; Teon or Sarawerna, Banda Sea; Gamkonora, Halmahera ; Gamalama, Ternate Island; Tambora, Sumbawa Island; Peut Sagoe, Banda ; Aceh; Soputan, Celebes Sea; Awu, Sangihe Island; Ruang, North Sulawesi; Paluweh or Rokatenda, Flores Sea; Agung, Bali; and Ili Werung, Lembata. The only submarine volcano that triggered a tsunami is Banua Wuhu, Sangihe Island (Mutaqin et al., 2019). Tsunamis caused by volcanic activity might be rare but have historically been impactful. Participants highlighted a need to better understand which volcanoes in Indonesia could induce a tsunami. Additionally, a participant identified the eastern regions of Papua and Maluku as areas with a known tsunami hazard but few detailed data collection and research investigations.

**Monitoring:** Participants discussed the various monitoring instruments in place around Indonesia. BMKG are working on developing a GNSS network but the data from this is currently not available in real-time. As with other monitoring equipment, participants highlighted the ongoing issue with vandalism and theft, for example solar panels often get stolen.

There are well developed systems for monitoring tectonic tsunamis but globally the hazard from non-tectonic tsunamis, such as from volcanoes and submarine landslides, is not yet understood. An inclusive monitoring and EWS for non-tectonic tsunami is needed because these events have a very short warning time and a complex mechanism. Participants discussed how modern GNSS and other geodetic datasets are being used to monitor tectonic strain and to identify areas with 'seismic gaps', which could be prone to tsunamigenic earthquakes. There remains an opportunity to expand this network as the coverage is variable across Indonesia.

**Institutional responsibilities:** The public awareness of tsunami hazards increased dramatically after the massively destructive event of 2004. A participant informed that the government is also taking this hazard seriously. A 2019 presidential regulation mandated the management of tsunami hazard through key government institutions. However, the collaboration and coordination between these institutions could be better. Another participant noted that the division of responsibility is sometimes unclear. Local authorities want the national government to maintain and manage equipment/infrastructure, while the national government wants the local government to manage them. One of the challenges participants discussed was the confusion around the roles and responsibilities during a crisis, such as the Krakatau eruption and tsunami. During a multi-hazard event, it is unclear which is the responsible organisation.

**Early warning systems (EWS):** A participant informed that Indonesia's tsunami EWS for earthquake events was set up in 2008 and has improved dramatically. The system is now operational in real-time mode in all relevant provinces. The EWS siren setup is managed by BMKG and BNPB, and maintained by local government with the sirens tested on the 26th of every month. They noted that despite the overall increased awareness regarding tsunami hazards, especially since 2004, progress has been variable from area to area. People are starting to rebuild in hazard prone areas, and some schools have good education programmes while others do not. Participants discussed the increased appetite for locally developed technologies for hazard monitoring, and various new technologies being developed to aid in tsunami hazard monitoring and early warning, including the ongoing development of a buoy that can be used by fisherman.

**Tsunami readiness:** Participants questioned the efficacy of large-scale risk assessments and highlighted the need to produce tailored assessments, including details of local topography, demography and exposure. Communities need to be engaged with these in a culturally sensitive, non-technical way. A participant noted the difficulty in maintaining long-term preparedness of communities and highlighted the need to increase the capacities of local government and communities. Moreover, simulation exercises (e.g., tabletop exercises) are important to inform and change hazard governance. Participants agreed that experience from past disasters could and should be used to inform planning for potential future events. An opportunity highlighted was the timeliness of aligning with existing national and international programmes, for example, the United Nations "Tsunami Ready" (UNESCO 2022) initiative as part of its Decade for Ocean programme and the BMKG-BRIN tsunami readiness plans.

Participants discussed a major challenge regarding tsunami readiness of tourists who will not have a full awareness of the tsunami hazard and risk and knowledge of how to respond when there is an event. This was reflected in the 2018 Sunda Strait Tsunami, which struck the popular tourist destination of Anyer. With appropriate knowledge and resources, tourists can be better prepared and evacuate themselves safely.

# 4. Next Steps

Several common themes emerged in the breakout groups across the four hazards) which are summarised below.

1. **Public awareness of hazards.** Indonesia has high population exposure to multi-hazards. There is a need to raise awareness of hazards, both in local communities and transient populations, such as tourists, internally displaced people and migrants. Indonesia is multi-cultural; therefore, communication can be challenging. Some suggestions for communication include:

a. Involving communities in developing innovative methods and tools

b. Exploring the use of story-telling through traditional art, poems, songs, stories and films as a way of raising awareness of hazards and remembering past events

c. Developing outreach and education programs for schools/communities

d. The use of citizen science tools, such as a system to collect observations (e.g., adapting the BGS myHAZ-VCT app or plugins to the MAGMA platform) to involve local communities in data collection, thereby increasing their understanding of hazards and potential impacts

f. The development and promotion of existing resources targeted at international tourists to raise their awareness and enable them to be better prepared in case of a hazard event, such as a tsunami.

2. **Community based DRR.** Involving communities and all relevant stakeholders in knowledge creation will engender a sense of ownership of the data and products. This approach should help localise community-based DRR measures and ensure sustainability.

3. **Baseline geological data.** For hazard assessments, there is a clear need for geological data to provide knowledge of past events and understand the potential future activity. Some key points were raised about data availability and accessibility, where datasets are stored and who are the organisations responsible for storing, maintaining and sharing data. Mapping these aspectss is a crucial next step. We also discussed data standardisation and data sharing across all hazards.

4. **Hazard interrelationships.** There is a need to better understand coincident, compound, cascading and cumulative hazards and impacts.

5. **Interdisciplinary working.** A need to work across different groups, from researchers to stakeholders and local communities, and across disciplines of science and education including geology, engineering, sociology and psychology, among others is common toall hazards.

6. **Applying research in planning.** There is a need to work with authorities and stakeholders to use science to inform decision-making and planning. This includes land use, building construction, and building codes.

7. **Knowledge Transfer.** Collaboration, developing, and strengthening the skills of early-career researchers and students is key to improving future resilience to hazard. Early career researchers (including Masters and PhD students) are invaluable partners for addressing scientific problems. They have the time to dedicate themselves to scientific problems. Engaging students have the added benefit of training and capacity building of young researchers, some of whom will build research careers of their own.

Collaboration in every aspect of geological hazard monitoring in Indonesia is crucial among stakeholders (Penta Helix). Integration between researchers, government, community, business and media is needed to close the gap between geological hazard research and community risk perception. In addition to improving community capability, increasing government capacity is also required. This increased capacity is required across several aspects including technical research, spatial planning, policy, etc. The technical aspect covers data collection, database development and maintenance, and methodology standardisation (standard operating procedures). Spatial planning comprises leveraging geological information for spatial and development planning (including the new capital city). The policy aspect encompasses using scientific evidence to formulate local and national policies.

This workshop attempted to build further collaboration and improve networks across several institutions that are essential in assessing and managing geological hazards in Indonesia, including the Centre for Volcanology and Geological Hazard Mitigation (CVGHM), National Disaster Management Authority (BNPB), National Research and Innovation Agency (BRIN), Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG), Geological Agency of the Ministry of Energy and Mineral Resources, Geo-Spatial Information Agency (BIG), National Institute of Aeronautics and Space (LAPAN), Indonesian Association of Geologists (IAGI), Indonesian Disaster Expert Association (IABI), University Forum for Disaster Risk Reduction, Geological Department Association of University in Indonesia, and other related institutions and communities.

Following this workshop and its findings, a step forward is to explore how Indonesia and the UK can learn from each other to improve hazard information and products and enhance their understanding of multi-hazard processes. For this, further meetings and workshops will be planned with key stakeholders and hazard-specific experts. This future work will include analysing available hazard information and products in Indonesia and the UK. We will discuss what has already been done, what is required and challenges to progress in both countries. This discussion will be about data availability, baseline data (geology, land use data etc.), data collection and data management. Furthermore, finding gaps and missing information in the context of hazard information and products and management and policy in both countries are interesting and important aspects that will be included in the conversation. Also, achievements and successes, together with key findings of experts and stakeholders are important to understand what has worked in the respective countries. A clear and vital message highlighted in this workshop was that we need a better way of stakeholder communication and involvement. Thus, future workshops will include a specific session on effective stakeholder engagement and communication.

For this, we will conduct a stakeholder mapping exercise to find out who is dealing with the hazards I) before they happen, ii) during a (multi-) hazard event, and iii) after the (multi-)hazard event. Based on these three simple scenarios, key institutes and organisations will be identified that are dealing with various aspects of hazard management such as data collection, hazard analysis, risk assessment, legacy and policy etc. Based on the findings and results from this mapping, a potential workflow can be developed that could be tested in other countries as well, for example, in India, Malaysia, and the Philippines, where RDI and BGS have existing projects and partnerships.

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# ANNEX 1: Presentation Q&A Padlets

# Workshop Presentations Q&A: Day 1

## I. Keynote: Dr.Sc Yoga Andriana Sendjaja: Overview of landslide and earthquake hazards management and monitoring in Indonesia

### Ekbal Hussain - BGS
### Data

Are there nationally managed databases for hazard occurrences?

*Sometimes, we have to gather the data by provinces, regencies. But actually, we have national agency that might have an inventory about the data. — NAWANG ANANDHINI*

### Christian Arnhardt - BGS
### Landslide Early Warning Systems

Thank you very much for the nice presentation.

1.) You mentioned Early Warning Systems for landslides. Is this a more local or a more regional system(s)?

2.) Is it correct that the EWS focuses on rainfall induced landslides? Or are there also ideas to look at earthquake induced landslides?

### Susilohadi - P3GL to Dr. Saut Sagala and Dr. Yoga

Is there any national level program that evaluate every potential disaster spot in Indonesia? It seems that people and local government on those spots always seen unprepared when a disaster occurs.

### Julia Crummy - BGS

Interesting presentation. You mentioned about growing tea plants strengthening the soil, and changing to growing other plats has made the soil more fragile and therefore, more susceptible to landslides. Is there a reason for this change in crop growth?

## II. Dr. Saut Sagala: Knowledge and implementation gaps in disaster risk reduction and spatial planning in Indonesia

### Julia Crummy - BGS

Are there building/planning regulations that have to be followed specific for hazards, for example, buildings that can withstand shaking? Or roof strengths to withstand tephra loads?

*Yes there are Julia, but the implementations are still limited. The guideline is at national level where implementation is monitored by local governments. This is where knowledge gap exists. — ANONYMOUS*

### Rahma Hanifa - BRIN

Thank you for your great presentation Dr Saut! You mentioned that have historical record is important as a basis to incorporate risk knowledge to spatial planning. How about places that don't have good historical record, especially earthquakes recurrence can be hundreds of years with lack of written historical record. while paleoseismology study is also very limited

What are the key driven factor enabling risk-based approach in such places. e.g. in Bandung City, which is quite prone to Lembang Fault earthquake and the megathrust. thank you

*Thanks Dr. Rahma. For a place where historical record does not exist, we need could still rely on earthquake scenarios that scientists could build. Use this scenario as something that can be translated into popular vocabularies where communities and local governments could understand. Therefore, they are still able to understand potential disasters. This is where scientists (natural, social), media, community initiatives should work together.*
*— ANONYMOUS*

## III. Dr. Ekbal Hussain: Monitoring on active faults and earthquake hazard assessment

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### Rahma Hanifa - BRIN

Impressive presentation Ekbal thank you! and the matrix is a good way to think systematically on possible cascading risk. Can it also be use to understanding potential systemic risk? or are there other recommended method to future plausible understand systemic risk?

### Fathia Lutfiananda - RDI

**To: Dr Ekbal Hussain**

What do we have to prepare in an attempt to monitor active faults by using InSAR? Is it possible to monitor as many as a possible recognized fault by using this method? Despite the fault located in the densely populated or vegetated area?

*Yes, this theoretically it would be possible to monitor all faults. But as you mentioned, InSAR struggles in areas with a lot of vegetation. Densely populated areas are better for InSAR.*
*— EKBAL HUSSAIN*

### Bambang Sidharta - Geological Agency

Dr. Hussain,

1. Land subsidence in Bandung is not only due to the groundwater extraction only, but also due to the physical and mechanical properties of the soils, including soft soil since Bandung Basin is comprised of the lake and volcanic deposits. Does this factor also include?
2. Have you mapped the liquefaction area that could be triggered by the Lembang Fault?

*2. we haven't mapped for liquefaction. but we open for collaboration to do that — NAWANG ANANDHINI*

### Nur Khoirullah - UNPAD

Thank you, Dr. Ekbal, for the excellent presentation. I think the potential earthquake of the Lembang fault will create multiple catastrophic events such as landslides, floods, liquefaction, as you presented. During the rainy season, floods and landslides often occur in the greater Bandung area. We need to anticipate the worst scenario by creating a landslide model potential map in greater Bandung using the PGA mentioned before. the 0.7 PGA is massive enough to induce a great landslide on the upstream river and induce a flood and liquefaction in soft soil in Bandung city

*Thank you. You are absolutely right. We need to understand the full multi-hazard consequences of certain scenarios. This needs broader collaboration between different scientists.*
*— EKBAL HUSSAIN*

## IV. Dr. Ir., Dicky Muslim, M.Sc: Landslide mapping, technological advancement, and modelling in Indonesia

### Saut Sagala - RDI
With the large-scale areas that need to be mapped for landslide mapping in Indonesia, do you have a quick win or some steps that we can do to cover and use so that we will be able to inform the communities about the potential landslides.

### Julia Crummy - BGS
Really interesting presentation Dicky, thank you. You raised a really key point that geology underpins DRR - having that baseline geological data enables us to understand the hazard and processes and mechanisms that leads to them. Field work is essential!

### Ekbal Hussain - BGS
### Updating maps
Thanks very much Dicky. The pace of change in some parts of Indonesia is really fast so hazard maps quickly go out of date. What provisions are there to update existing hazard/susceptibility maps?

### Fachriey Mungkasa
### Dewi Gentana
Dr. Dicky Muslim, based on your experiences yang what is the best and accurate method to determining the landslide area that can describe the landslide zoning of the area? Thank You

## V. Dr Christian Arnhardt: Landslide database and geomorphological inventory

### Fathia Lutfiananda - RDI
Thank you for the comprehensive presentation Dr. Arnhardt. Regarding the landslide data inventory/reporting with certain technology you mentioned earlier, what kind of infrastructure needs to be prepared in an attempt to implement those kinds of reporting systems?

### Nur Khoirullah - UNPAD
Excellent presentation Dr. Christian. I have several questions,

1. How much influence of the landslide inventory in the UK have on the landslide potential prediction to upcoming landslide hazards?
2. On-site analysis, I often analysed landslides based on soil and rock mechanics data however it is still complex and requires a lot of field data, laboratory analysis and funding. Maybe you have suggestions?

# Workshop Presentations Q&A: Day 2

## I. Keynote: Ir. Andiani, M.T: Overview of volcanic and tsunami hazards management and monitoring in Indonesia

### Saut Sagala - RDI

Thanks Bu Andiani for sharing the overview. What are key areas that need to be strengthened in regards to the collaborations with various stakeholders nationally and internationally?

## II. Dr. Devy Kamil Syahbana: Advancement of Volcano Monitoring System in Indonesia

### Julia Crummy - BGS

Thank you for a really interesting talk. You mentioned you have around 200 volcano observers across Indonesia. Are these all scientists or are people living in communities near volcanoes also volcano observers?

*Generally, they are local people whom we recruit and train to be able to install and maintain volcano monitoring equipment. They are trained to be able to visually monitor crater activity anomalies, they are also trained to be able to classify the types of earthquakes recorded in volcanoes. — DEVY KAMIL SYAHBANA*

### Dissemination of volcanic hazards information

There are lots of vulnerability maps of volcanic eruption based on updated database from observation station. How the DRR activities are conducted by CVGHM, especially for the inhabitants around volcano?

*We have completed geological mapping and published hazard maps of more than 90 percent of Indonesia's active volcanoes. At present, the most important thing is that these maps are used as a primary reference for local governments in spatial planning and in the preparation of regional contingency plans. The CVGHM also participates in delivering information on volcanic hazards to the public through seminars, workshops, and even simulations. — DEVY KAMIL SYAHBANA*

### Ekbal Hussain - BGS
### Submarine volcanoes

Thank you very for that excellent overview Dr Devy. What sort of monitoring provisions do you have for submarine volcanoes?

Also, are satellite-based data included in your datasets too?

*Currently, the CVGHM monitors 10 of 12 volcanoes that historically have caused tsunamis. One of them is a submarine volcano called Hobal in the east of Flores Island. Another submarine volcano, Banua Wuhu in North Sulawesi will be monitored continuously starting this year. We have at least four other submarine volcanoes, but due to their location in the deep sea (>2000 meters below sea level), we do not monitor them continuously as the impact is likely to be small due to excessive hydrostatic pressure at that depth. Currently, we prioritize volcanoes that pose the greatest risk to the community. — DEVY KAMIL SYAHBANA*

### Julia Crummy - BGS

This is related to the question above - following a volcanic eruption, do you map the impacts and level of damage of buildings for example?

*I find this as an important point. I think PVMBG needs to collaborate with other stakeholders, since damage / impacts would be able to be mapped by other stakeholders too, including research centres, local governments, etc — SAUT SAGALA*

*Julia: Absolutely. This is something I am really interested in. There are some tools / apps available for collecting impact data. We are developing a tool for collecting building exposure and post-event damage data for multi-hazard environments. So, if anyone here is interested, I would love to talk more! — ANONYMOUS*

*Usually, this is coordinated by the BNPB (National Agency for Disaster Management) as well as BPBD (Local Government Agency for Disaster Management), and even other agencies. — ANONYMOUS*

## III. Dr. Samantha Engwell: Understanding and communicating volcanic hazard

### Community as 1 stakeholder

Thank you, Sam, for comprehensive presentation. How do BGS communicate the hazard maps and information to pentahelix stakeholders (academic-business-government-communities- media / ABG-CM) for a possible event of eruption, especially for community (as non-scientist society)? any reports for those issues?

### Bambang Sidharta, ST, PMEG

Volcanoes and tourism is a good approach to disseminate the volcanoes science and also a good campaign to rise the awareness of the community

### Saut Sagala - RDI

It is interesting to hear your presentation Sam about how Citizen Science and Tourisms are part of the concerns. These are areas that we could explore more in Indonesia. I wonder if we need to divide the approach / tools based on the characteristics of the volcanoes.

In addition to that, if also we also could hear from you on any available tools related to the citizen science and tourisms and what areas we still need to improve on these tools and we could apply in Indonesian context, perhaps.

*This is a link to the tools we have https: www.bgs.ac.uk/geology-projects/volcanoes/citizen-science-for-multi-hazards — JULIA CRUMMY*

*We haven't developed any tools specific to tourists, but this is definitely something we can talk about. I am interested in the dynamic vulnerability of tourists as they move around, seasonality of visitors etc. — JULIA CRUMMY*

*In addition to the link Julia has shared above, I will reshare the link the Eurovolc tool as it's not currently in the website above https: /eurovolc.bgs.ac.uk. It was an interesting project as it brought together different tools across Europe and included a data entry component. It allows someone who might not be familiar with the tools local to different countries (e.g., a tourist) to make an observation, but we still need to think about how to encourage this type of update, as well as add other tools across Europe. Happy to also talk about myHAZ-VCT more. The intention with myHAZ is always to make it available to other places if it would be useful. — MELANIE DUNCAN (BGS)*

## IV. Dr. Abdul Muhari, S.Si., M.T: Tsunami hazard management and mitigation in Indonesia

### Saut Sagala - RDI

Thank you Dr. Muhari. You highlighted important points on your conclusions. I wonder if you could say something about how have the integrated studies that you mentioned been developed in Indonesia? And if you could share your opinions on areas to be improved in the integrated studies.

### Ekbal Hussain - BGS

### New capital

Thank you for a fascinating talk Dr Muhari. Has such analysis been completed for potential tsunami hazards for the new capital?

## V. Prof. Dr. David Tappin: Assessment on potential hazard of tsunami

### Education

What are the aspects that we must cover when it comes to educating children about tsunamis?

# ANNEX 2: Breakout Room Padlets

The Padlet responses detailed below were amalgamated from three different breakout rooms for each hazard.

# Earthquake Breakout Rooms

## What are the opportunities that can be optimized further in monitoring or earthquake hazard assessment in Indonesia?

**Aria Mariany - RDI**
Resource, data dissemination

**Anonymous**
collaboration

**Julia Crummy - BGS**
Is there an agreement for data sharing across Indonesian institutions?

*for several data, we need no agreement. The data is available. But, for earthquake hazard assessment, which usually only is had by researchers from university or government research institution, a little bit difficult to get — ANONYMOUS*

**Gabby - RDI**
Education

**Kartika_Balai Pelestarian Cagar Budaya Provinsi Jawa Tengah**
Perlu kerjasama lintas sektoral,masyarakat dan pemerintah, perlu menggali dan mempelajari kearifan lokal masyarakat setempat dalam mengenali tanda2 alam di sekitarnya

**Julia Crummy - BGS**
Citizen science?

**Julia Crummy - BGS**
Outreach / education programs

**Kay Smith - BGS**
Is there a clear understanding of roles and responsibilities from National level to Regional or Local levels for earthquake measurement and/or monitoring and/or technology maintenance long-term?

**David Tappin - BGS**
The power of social media to call the scientific organisation interest

**Christian Arnhardt - BGS**
India has already tried to apply social media, but languages might still become the problem. Each country might use different languages

**Fathia Lutfiananda - RDI**
We need to include people from social science to improve the perception of the message

**Luke Bateson - BGS**
Exposure, vulnerability of the earthquake

**Annie Winson - BGS**
Having the historic baselines, information, assessment. We should have enough data to start.

**Sam Engwell - BGS**
Identification of what datasets available, where these are held, who is responsible for them and what further data is needed and could be collected.

**Luke Bateson - BGS**
Importance of communicating the hazards (exposure, vulnerability) to the people who are at risk. What is the best method of communicating the information to people?

**Rahma Hanifa - BRIN**
Invitation to collaborate building Lembang Fault Observatory with BRIN: Lembang fault monitoring with GPS, Seismometer, and other Geo data, also people observation and education, bridging the research and knowledge to local government and community, finding key driven factor to enable risk-informed planning in Bandung. To be replicate in other area

## What are the challenges that are faced in monitoring or earthquake hazard assessment in Indonesia?

**Sonny Aribowo - BRIN**
1. In Indonesia, I think we are lack of active fault mapping that show the faults that 'really active' (not only talk about subduction, but also crustal faults). In other words, we need paleoseismological research and dating methods more to determine where is the active faults in Indonesia

**Kay Smith - BGS**
Is there a standardised measurement and/or processing methodology for seismic monitoring in Indonesia?

**Ekbal Hussain - BGS**
Many volcanoes not all of them have observatories

**Yoga Sendjaja - UNPAD**
Super populated area which located in an active fault. How to mitigate that?

*People perception regarding hazard still low — FATHIA LUTFIANANDA*

**Dicky Muslim – UNPAD**
Bandung city does not have a local disaster management agency. This is a challenge because a local mechanism to raise the profile of hazards to authorities does not exist

*Many rich people live in the hills near the Lembang Fault – wealth exposure to the earthquake hazard — EKBAL HUSSAIN*

**Anonymous**
Challenges are limitless to "educate" all stakeholders about EQ. But, sadly to say that among hundreds of cities & municipalities, Bandung City has no BPBD (local disaster management agency)

**Rahma Hanifa - BRIN**
We observed many local effect and cascading hazard in Indonesia, such as the Palu earthquake. We need more effort for detail - local earthquake hazard mapping assessment, including its secondary/cascading hazard, and conducted in a participatory manner, verified by the official authority. For monitoring, we also have a good progress with more instrumentation, but for detail monitoring, we still limited.

## What are the research gaps that can be identified in monitoring or earthquake hazard assessment in Indonesia?

**Updated Measurement/method**
Updated standardised measurement /method for the earthquake assessment in Indonesia

**Sonny Ariwibowo - BRIN**
The Risk communication need to be further developed. Thus, the community be more accepted in the earthquake hazard assessment.

**Gabby - RDI**
Talking generally, the problem in involving a more advanced tech relies on the maintenance. Sometimes there have been guidance or manuals regarding on how to utilise the tools but still lack of the guidance or workshop to build the capacity on tools maintenance

**Kartika - BPCB Provinsi Jateng**
It is necessary to socialize the results of the research and applications in people's lives

**Aria Mariany - RDI**
Is it need to more clear role of stakeholder in earthquake hazard assessment, what organization or institution can be used as source of the data used or the information of eq can be referred for development?

**Julia Crummy - BGS**
Data sharing and data collection need to be more accessible for the public

**Kay Smith - BGS**
Data sharing within institution

**Julia Crummy - BGS**
Can I add Citizen Science here? This can be super useful to engage the public, and collect observations of hazards and impacts

**Anonymous**
We cannot prevent the earthquake, we only can reduce the potential risk when it happens. the gap is very wide, especially to save the people

**Fathia Lutfiananda - RDI**
We can start to assess the active fault in the highly populated areas. And we need to involve people to monitor this hazard.

**Saut Sagala - RDI**
Detailed data of earthquake for high and dense populations. Next is how to produce the hazard maps based on the earthquake data

**Rahma Hanifa - BRIN**
Offshore earthquake source and hazard. And we have a lot of them, e.g., the recent Flores earthquake in December 2021, Maluku earthquake 2021, complexity in Sunda Strait, Pelabuhan Ratu Bay, etc.

**Bambang Sidharta, ST, PMEG**
The major problem is how we communicate the disaster issue especially earthquake to the local community and how the research can be applied to the regional planning (authorities and stakeholders) especially in the prone areas (including building code, etc.)

**Gavin Sullivan – IPU Berlin**
Culture, sociological, psychological aspect

**Luke Bateson - BGS**
What the hazards are and when the hazards come. People quickly forget. It's the battle to keep people memories.

**Sam Engwell - BGS**
Videos that remind people of past events. Approach of case study.

**Saut Sagala - RDI**
They could learn for another places/countries. Given the wide and population. There is difficulty in distributing videos.

**Luke Bateson - BGS**

How much knowledge in the head of people, the kind of information that know by people that affected by tsunamis

**Gavin Sullivan – IPU Berlin**

Funding, communities' networks. We should have communications between two countries. About prioritizing communities' issues. There's a need of information.

**Annie Winson - BGS**

Scientist (volcanologist, earthquake) and the psychologist, sociologist, to view from broader area. Innovation, ways to communicating, how is been created and delivered. Video games to help to train

**Annie Winson - BGS**

Involving communities in the development of innovative and inclusive methods of communicating hazard / risk assessments

# Landslide Breakout Rooms

## What are the opportunities that can be optimized further in monitoring or landslide hazard assessment in Indonesia?

### Julia Crummy - BGS
Remote sensing mapping - for geology and vegetation and population?

### Kay Smith - BGS
Very similar considerations as for earthquake discussions about the open availability of data, data standardisation, collaborations, understanding roles and responsibilities for national, regional and local landslide hazard monitoring and mapping

### Christian Arnhardt - BGS
You mentioned Early Warning Systems for landslides. Is this more local or a more regional system(s)?

*Dr. Yoga: localized system, but we have to integrate it — FATHIA LUTFIANANDA*

### Social science
We need to involve people from social science to talk to people to capture landslide information thoroughly

### Fathia Lutfiananda – RDI
### Remote sensing
It is possible to identify landslide hazard in a vast area by using remote sensing approach. At least we need information regarding slope, geological map, land use and rain.

### Saut Sagala - RDI
Could we categorize the landslide and earthquake that happen? The source and the impact might be different, we need to identify. the community need to understand

### Christian Arnhardt - BGS
Yes, I agree. how we did this is we have specific and ground conditions. then people can realize what is it. I agree focusing on different types, different area, different landslide

### Dicky Muslim – Uni Pad
To build something that called "LIDIA" a database, the problem is in the human resources. It's not as easy to spread information. The opportunities: we could build the national level but it need go to the downstream

In India, we have some level. with this app you can touch the community, the apps that ask people easier or complicated question related to earthquake or landslide that looks like this or this.

### Dicky Muslim – Uni Pad
To educate people, but in the gov it just to have continuous project and yet not save people. Not just technical issues, but political too its different when local people talk to govt than foreign people

### Dicky Muslim – Uni Pad
Disseminate technical findings but we should define what is the goal, to be used by them

## What are the challenges that are faced in monitoring or landslide hazard assessment in Indonesia?

**Aria Mariany - RDI**
Limited capacity and detailed scale of the landslide map

**Iyan Haryanto**
Various geological structure in Indonesia.

**Kay Smith - BGS**
Technology - is there equipment needed on the ground, maintenance plan (and safety) of equipment and cost consideration

**Christian Arnhardt - BGS**
Is it correct that the EWS focuses on rainfall-induced landslides? Or are there also ideas to look at earthquake-induced landslides?

*Many mechanisms might trigger a landslide.*
*— FATHIA LUTFIANANDA*

**Landslide location**
Some of landslide in Indonesia located in remote area

**Standard reporting on landslide**
Indonesia already has a standard reporting system, unfortunately not many people understand

**Ekbal Hussain - BGS**
Human activity can change the landslide hazard

**Dicky Muslim – Uni Pad**
Human resources, untouchable stakeholder

**Samantha Engwell - BGS**
The voices to be heard

**Dicky Muslim – Uni Pad**
The communication is a big issue. In the time of earthquake or volcanos the technical things such as internet connection didn't work. It's just analogue

**Samantha Engwell - BGS**
Ensuring the voices of local scientists are heard

## What are the research gaps that can be identified in monitoring or landslide hazard assessment in Indonesia?

**Julia Crummy - BGS**
Mapping the land use for the landslide hazard. Transformation of land use

**Gabby - RDI**
Building construction -> most of Indonesian current building construction regulations are adopted from other developed countries which are not precisely applicable in the region, considering the soil and geographic condition

*Interesting comment - I think there are opportunities for research into building construction materials and structure, and how construction can be adapted for different hazards. There is a lot of information for earthquake hazards, but less so for volcanic, landslides, hydromet hazards — JULIA CRUMMY*

**Julia Crummy - BGS**
Social vulnerability assessments - wealth, demographics of population etc., and combining with exposure and hazard to understand where high risk areas are

**Fathia Lutfiananda – RDI**
**New Capital City**

Geological information needs to be delivered detailed into what potential hazard might happen to the area

**Christian Arnhardt - BGS**

We can develop a community-based information database, that community can share the pictures for database

**Gavin Sullivan – IPU Berlin**

There are related issues at least in terms of response but also issues of preparedness and hazard assessment that there are top-down and bottom-up (community-led & empowering) approaches-interventions. Also, there are bigger issues also about how strengthening etc. efforts are targeted once hazards are identified (e.g., a comparable issue to having programmes to retrofit buildings to increase earthquake resilience).

# Volcano Breakout Rooms

## What are the opportunities that can be optimized further in monitoring or volcano hazard assessment in Indonesia?

### Integrated new methods
New updated and modernized monitoring

### Anonymous
Perlu ditunjang dengan adanya peralatanterbaru, meingkat kan sumber dayamanusianya dengan dilakukan diklat atausebgainya

*(need to enhance the latest equipment and improve human resources by training) — ANONYMOUS*

### Online platform
Public access to MAGMA: one stop website for geological hazard information in Indonesia

### Gavin Sullivan – IPU Berlin
### MAGMA
Great to see this website - I'm interested to know how many people access this or subscribe. Do people rely on it or engage with it? How also do you counter mis or disinformation (which can be a problem with social media)?

*In research with Pak Saut in Sinabung we have explored these issues using social psychological models and qualitative research and also with Dr. Lusi Nuryanti on Merapi. — ANONYMOUS*

**Gavin Sullivan – IPU Berlin**

Social identity plays a big factor in the perception of risk and disaster. We can embrace local community to improve people's perception towards hazards

*It is important also to explore where DRR is community driven or community led ... also after raising awareness that people know about what they can do to respond with others in their local communities. — ANONYMOUS*

*We have tried also to explore how preparedness can be encouraged on the basis of culture-specific interventions rather than universal approaches and how to build this into everyday actions using local social capital (e.g., check on neighbours to evacuate etc.). Keen to do more work on this :-) — ANONYMOUS*

*Who gives the information to evacuate often needs to be a trusted or ingroup member - there are also issues of emotion and their denial. A focus on panic and reducing this doesn't help -empowering people about where to go and to look after each other is important. — ANONYMOUS*

### Anonymous
Is there a clear understanding of roles and responsibilities with regards to data provision, interpretation of the data and who passes on the information to the relevant authorities (whether that is to government, regional, local, community-level). Also is there a standardisation in the 'risk' level of the hazard

### Dicky Muslim – Uni Pad
Save the people, but geology in Indonesia is on the stream. So, the opportunities lie on how to connect geology study to community. Is there any BGS study regarding that?

**Julia Crummy - BGS**
Mapping is one of the opportunities. Some BGS works is mapping and going on with the locals. It helps the partners.

**Alessandro Novellino - BGS**
Training courses even the webinar is the start to increase assessment project, increasing volcano studies.

**Julia Crummy - BGS**
Understanding the vulnerability of tourists - where are the 'hotspots', when do they visit, how are hazards communicated to tourists? What are the risk drivers, and what mitigation actions can be taken to reduce tourists' vulnerability?

**Alessandro Novellino - BGS**
Everyone can access the data and the tools, there are lots of information that you can find online

**Julia Crummy - BGS**
Understanding the physical vulnerability of buildings -construction materials and structure, and understanding how volcanic hazards can damage buildings. Building design regulations.

## What are the challenges that are faced in monitoring or volcano hazard assessment in Indonesia?

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**Finding a different way to communicate the risk**
Especially Indonesia with various different culture

**Bambang Sidharta - Geological Agency**
It's a challenging on how to differentiate the active volcanoes and the dormant ones. Since a nonactive volcanoes can explode too.

**Anonymous**
The amount of information available of the vulcanic hazard

**Susilohadi**
The current system focuses on the only on volcano hazard not to the multi hazardous event

**Institutional responsibilities**
Institutional responsibilities and the challenge of these hazards that intersect operational responsibilities. This is a challenge shared by other places.

**Remote Sensing**
The availability data not in real time

**Flood of information**

*How to make people have the preparedness with their own willingness — FATHIA LUTFIANANDA*

*Give only the relevant information so people don't get overloaded — EKBAL HUSSAIN*

**Fathia Lutfiananda – RDI**
Inaccessibility of people in remote area to access the information

**Two types of hazards**
Low frequency of hazard but high impact, and high freq but low impact.

**Dicky Muslim – Uni Pad**
There are communities that can't read map.

**Saut Sagala - RDI**
Hard to monitor and do assessment on submarines volcanoes

**Syahwin - civil servant**
I think mobile application regarding monitoring or

volcanic hazard assessment much easier to bring people attention and awareness to participate

**Tantan – Geological Agency**

1. Lack of volcano monitoring equipment,
2. The existing tools were stolen by irresponsible persons

**Julia Crummy - BGS**

In response to Dicky's comment on communities being unable to read maps - perhaps there is an opportunity to design other communication tools. Outreach and education

## What are the research gaps that can be identified in monitoring or volcano hazard assessment in Indonesia?

**Submarine vulcano**

Dig deeper about the technology we need. Remote sensing

**Anonymous**

Multihazardous approach for vulcanic hazard assessment

**Vulcano past data availability**

Data availability can be understood for the vulcano

**Anonymous**

Identification with Government agencies of the main challenges or "wicked problems" of working with communities to create appropriate preparedness - e.g. to act quickly in communities where there are low frequency/high impact events for example by utilizing local networks and leaders but also creating effective, sustainable preparedness tools (e.g., that are not fragile if power/phone etc. lost).

*Change to a "culture of safety" is one issue long-term. — ANONYMOUS*

*Identification of novel solutions — ANONYMOUS*

**Alessandro Novellino - BGS**

Amount of data, it is common to use satellite data

**Julia Crummy - BGS**

Geological mapping. Alternative communication tools / methods - art, stories, poems, films. Translation of communication materials

# Tsunami Breakout Rooms

## What are the opportunities that can be optimized further in monitoring or tsunami hazard assessment in Indonesia?

### Public awareness of tsunami

After the Tsunami 2004, there are many strengthening on Tsunami Early Warning System, GIS methods, etc.

### Saut Sagala - RDI

The research is still limited. Such as Papua, Maluku. The record is still lacking.

What is the balance between accessing remote datasets (earth observation mapping) and field measurements (quantitative geophysical characteristics) post-event to build the understanding for potential mitigation?

### Samantha Engwell - BGS

There is lack of information regarding volcano-induced tsunami. We don't have necessary knowledge about the volcanos that can induce tsunami.

What are the challenges that are faced in monitoring or tsunami hazard assessment in Indonesia?

### Anonymous
### Post-Aceh tsunami infrastructure

Limited reply - there were some vertical evacuation towers made (this is my understanding) but people apparently were unlikely to use them - confirmation from Indonesian colleagues about this and other infrastructure would be great.

*There is a Tsunami museum also I think ... — ANONYMOUS*

*Don't know if it integrates new preparedness insights — ANONYMOUS*

*The maintenance of the Tsunami early warning system especially in the area who has been affected by the community (Like ACEH). — RDI INDONESIA*

*Was there also relocation away from the shoreline for communities and new guidelines on building etc.? — ANONYMOUS*

*Yes, there is tsunami museum and still there — ANONYMOUS*

### Coordination between stakeholder

For the management of tsunami hazard in Indonesia

### Limited data availability

More local and detailed data

### Indonesia: large archipelago country

Indonesia has long coastline, prone to experience tsunami

### Assessment on hazard intensity

1. Tsunami run up and inundation height
2. Return period

### Indonesia: geohazard capital of the world

Various mechanism that can trigger tsunami in Indonesia: tectonic, volcanic, and submarine landslide

*Start with earthquake: easier to identified — FATHIA LUTFIANANDA*

*Tsunami volcanogenic — FATHIA LUTFIANANDA*

**Saut Sagala - RDI**

We have good records regarding tsunami events in Indonesia, but from location and sources wise, the record is still lacking. Such as volcano or landslide-induced tsunami

**Saut Sagala - RDI**

Tourist didn't have any idea about the risk that might happen, it is reflected from Selat Sunda Tsunami. If the knowledge is enough, they can evacuate themselves better.

**Samantha Engwell - BGS**

Because it is more personal and individual so it hard maybe to increase the risk awareness.

**Kay Smith- BGS**

Rarely pick up on tsunami things when travelling.

## What are the research gaps that can be identified in monitoring or tsunami hazard assessment in Indonesia?

**Anonymous**

Low-Cost Technology Monitoring, Information and Dissemination

**Anonymous**

100% Tsunami Ready Coastal - UN Agenda by 2030 (UN decade for Ocean)

*How to? — ANONYMOUS*

*Localize this approach in each location in Indonesia. — RDI INDONESIA*

**Submarine Vulcano / Tsunami induced Volcano**

More than 80% eruption did not give impact to land. Need more knowledge on this topic.

**Anonymous**

More effective tsunami evacuation and mitigation, can we save people 100%?

**Short- and very long-term preparedness/ DRR**

Long-term strategies such as relocation, cultural change etc.

**Anonymous**

GPS network

**Non tectonic tsunami**

The tsunami which caused by volcano and submarine landslide need a more adaptive approach

**Fathia Lutfiananda - RDI**

Local wisdom

**Samantha Engwell - BGS**

We have to observe particular volcanoes first then can proceeded to tsunami monitoring, such as sea level

**Samantha Engwell - BGS**

Working with government to define tsunami, working out for contingency plan.

Resilience Development Initiative

British Geological Survey