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The Emerging Widespread Debris Flow Disasters in Tropical Terrain of Peninsular Malaysia: Understanding the Risk and Policy Intervention

Abd Rasid Jaapar[1*], *Mohamad Faruq Syahmi* Md Aripin[2], *Ibrahim* Komoo[3], *Che Aziz* Ali[4], *Zamri* Ramli[5], *Abd Rahim* Harun[5], *James* Bachat[2], *Zakaria* Mohamad[2], *Rohayu Che* Omar[6], Khamarrul *Azahari* Razak[7] and *Choun Sian* Lim[8]

[1]Institute of Geology Malaysia, 43600 UKM, Bandar Baru Bangi, Malaysia
[2]Geomapping Technology Sdn Bhd, 43000 Kajang, Malaysia
[3]Academy of Professors Malaysia, 62000 Putrajaya, Malaysia
[4]Geopark & Geotourism Creative Solutions Sdn Bhd, 43000 Kajang, Malaysia
[5]Department of Mineral and Geoscience Malaysia, 62000 Putrajaya, Malaysia
[6]Universiti Tenaga Nasional, Institute of Energy Infrastructure (IEI), 43000 Kajang, Malaysia
[7]Universiti Teknologi Malaysia, Disaster Preparedness and Prevention Centre (DPPC), Malaysia-Japan International Institute of Technology, 54000 Kuala Lumpur, Malaysia
[8]Universiti Kebangsaan Malaysia, Institute for Environment and Development (LESTARI), 43600 Bandar Baru Bangi, Malaysia

Abstract. Several widespread debris flow disasters stroke Peninsular Malaysia in between 2021 and 2022, scattered across the country. It was the first time for this hazard being nationally recognised as a type of geological disaster in the country. Debris flow disaster is not a new phenomenon. It had been recorded since 1995, however, in the past they were isolated incidents and did not attract much attention. The recent widespread debris flow disasters started in Gunung Jerai, Kedah on 18 August 2021; followed by similar incidents but in 3 different states concurrently in (1) Bentong, Pahang, (2) Hulu Langat, Selangor, and (3) Jelebu, Negeri Sembilan on 18 December 2021; Kenyir, Terengganu on 27 February 2022; and finally at Gunung Inas, Kedah on 4 July 2022. These disasters sparked numerous technical and social issues where heated debates on whether they were purely due to natural processes or caused anthropogenic activities. Previously, debris flow phenomena in Malaysia were so rare, that the term 'debris flow' was not familiar to the lay public. The term of "debris flow" was often disregard or used interchangeable with 'water surge' phenomena by the media and public, especially for sudden sediment water surge from hilly upstream after intense rainfall at hillside river catchment areas, normally occurs during the monsoon season. The ordinary water surge has significantly lesser level of destruction and momentum as compared to a debris flow with higher debris-type sediments. This paper discusses the emerging issues of debris flow in Malaysia and some initiatives being carried out in in facing the geohazard. The Department of Mineral and Geoscience Malaysia and a team of local geohazard experts have taken the lead to carry out studies to understand the sudden emergence of widespread and cascading debris flow events in Malaysia. As a result, proposal on policy intervention was put forward to the relevant government ministries; post-disaster programme has been continuously carried out to educate the communities on the geological disaster risks through community-based disaster risk management (CBDRM).

1 Introduction

It is a general misconception by the lay public that channelized fast flowing landslide or debris flow events occur at the hillside river catchment is being considered as ordinary riverine water surges from upstream headwaters after a heavy rain. During the debris flow disaster in Gunung Jerai, the event was termed as 'river water surge phenomenon' by the communities and mass media. The water surge phenomenon commonly occurs at the foot of mountainous region or hillside river catchment after extreme rainfall events in the upstream, causing the rapid increase of river water level creating torrent flows rapidly to the downstream. However, this process does not carry debris materials and the water rarely overflows over the riverbanks. Due to the misconception and lack of knowledge, the communities at risk are getting false information and taking incorrect countermeasures.

In the recent years, this country had observed multiple events of debris flow occurred at the same time with varying degree of destruction where communities were badly affected, socially and economically. The Department of Mineral and Geoscience Malaysia, the government agencies responsible geological hazards, has structured multiple initiatives to communicate the understanding of hazards and risks of debris flow, as well as strengthening the communities through policy intervention and localised community-based programme in the disaster prone areas.

* Corresponding author: arjaapar@gmail.com

1.1 Debris Flow Events in Malaysia

The earliest record of debris flow in Malaysia pointed to the Genting Sempah Debris Flow in 1995, which killed 20 people and 3 were still missing. A year later, 'Pos Dipang Mud Flood' and 'Keningau Greg Tropical Storm' occurred three months later which killed 44 people and 303 people, respectively.

Between the years 2000 to 2015, approximately 20 debris flow disasters occurred throughout the country. However, most of these events were not recognised as debris flows but commonly being treated or labelled as mud floods, floods and some with landslide connotation which were perceived as slumping type landslides at the crown areas instead of the overall debris flows. Table 1 shows the list of some debris flow events in Malaysia after re-examining past disaster events.

In 2021, the first major debris flow disaster occurred in Gunung Jerai, Kedah caused major destructions and damages to most of its district of Yan and 5 were killed. Four months later, the debris flows occurred concurrently at least 3 States in Peninsular Malaysia, in Bentong, Pahang; Hulu Langat, Selangor; and Jelebu, Negeri Sembilan; consequently 23 lives perished in total and major disturbance with economic loss of near RM1.0B (USD210M). Four months later, another debris flow disaster occurred at Kenyir, Terengganu without any fatality but had disrupted the operation of the hydroelectrical dam. Lastly, on 4 July 2022, the Gunung Inas, Kedah debris flow disaster with run-out distance approximately a few kilometres. It caused 3 fatalities and the cascading impact of debris and mud flood inundated up to 20 km at the downstream.

Table 1. List of major debris flow events, its distribution and fatality count in Malaysia (modified from [1]).

No	Date	Location	Fatalities
1	30 June 1995	KM 38.6 Kuala Lumpur–Karak Highway, Genting Sempah, Selangor	20
2	29 Aug 1996	Pos Dipang, Kampar, Perak	44
3	26 Dec 1996	Keningau, Sabah	300
4	4 Jan 2000	Cameron Highland, Pahang	6
5	22 Sept 2001	Kampung Chinchin, Gombak, Selangor	1
6	28 Dec 2001	Pulai River, Gunung Pulai, Johor	5
7	28 Jan 2002	Ruan Changkul, Simunjan, Sarawak	16
8	8 Nov 2002	Taman Hillview, Hulu Kelang, Selangor	8
9	7 Aug 2011	Sungai Ruil, Cameron Highlands, Pahang	7
10	23 Oct 2013	Bertam Valley, Cameron Highland, Pahang	1
11	18 Aug 2021	Gunung Jerai, Yan, Kedah	5
12	18 Dec 2021	Bentong, Pahang, Hulu Langat, Selangor and Negeri Sembilan	23
13	27 Feb 2022	Hulu Terengganu, Terengganu	-
14	4 July 2022	Gunung Inas (Sungai Kupang, Baling), Kedah	3
Total fatalities			442

1.1.1 Gunung Jerai Debris Flow

Debris flow disaster in Gunung Jerai was the turning point of debris flow study in Malaysia. The level of destruction and disruption had never been seen before in this area or even the country. The concern was heightened by whether the hazard might affect the status and integrity of current Gunung Jerai as both the National Geopark and archaeological heritage site.

The debris flow disaster was reported triggered by an extreme rainfall (281 mm in 6 hours) [2]. This had caused multiple landslides to occur on the steep slopes of this isolated mountain (1,217m). Residents described the 'water surge' carries rock boulders as big as one-storey house along with uprooted trees, sand and mud. Signs of temporary dam bursting can also be observed at the upstream where these dams accumulated loads and burst. The energy carried by the debris flow also scoured and widened the river channel up to 5-7 times in width than its original size. As the new debris scoured and eroding the riverbanks, it also exposed the evidence of old debris-flow colluvial deposit horizons. The exposed old colluvium suggested there were possibilities of larger debris flow events in the past before this incident. This evidence was an eyes opener of researchers that this area might has undergone more than one debris flow event and it was never recorded.

1.1.2 Bentong Debris Flow/Hulu Langat Debris Flow/Jelebu Debris Flow

These events occurred three months after Gunung Jerai Debris Flow in the same year. There were consecutive heavy rain events for three days due to regional tropical depression meteorological phenomenon. As a result, hundreds of landslides occurred on the Main Range of Peninsular Malaysia (Titiwangsa Range) and fell into the main tributaries and rivers flowing into three different states of the country. The water level in the major rivers in the areas, among them the Kerau River rose above critical level [3]. Aerial observation found that hundreds of landslide scars spreading across the mountainous range including the mountain primary forest areas. The extreme rain and water surge had swept through the landslide debris 'avalanche' to downstream carrying uprooted trees and sediments. The debris were then deposited in the narrow rivers at the downstream and clogged the water flow causing mud flood as well as destroying houses in the low-lying settlement areas.

1.1.3 Kenyir Debris Flow

Kenyir debris flow occurred on 27 February 2022. There is no casualty reported for this event. However, this area is located at one of the most important hydroelectric dam and power plant in Peninsular Malaysia. The debris flow not only deposited in the dam's reservoir but also destroyed multiple transmission towers, parts of power plant, accessibility roads and jeopardised the dam integrity.

The source of the debris flow was mainly due to rockslides of granitic rocks (weathering grade III-IV) [4]. The sliding blocks were huge and massive in size measuring up to 30 m in length. These rockfalls of large boulders can also be observed at the site and simulation was carried out to understand the force and kinetic energy of the rock fall. The Limit Equilibrium Method (LEM) analysis found the blocks were sliding at an extreme condition where the water infiltrate the joint opening at 100% filled.

1.1.4 Gunung Inas Debris Flow

The most recent incident that occurred was on 4 July 2022 causing 3 fatalities, destroying 17 residential houses, affecting 3,546 residents, and costing approximately RM25.9 million of economic losses. This event was very controversial due to the appearance and believes of logging and plantation activities at the hillside since 2010 could be related.

The disaster was triggered by heavy rains, causing the landslides to occur at the hillside in the upstream followed by debris flows that carry all the debris materials along the river channels and then deposited at the nearby villages. Weather satellite images showed the rate of rainfall at the mountainous area during the events was as high as 150 mm/hr. There was a bridge at the downstream acted as temporary dam where the bursting of this temporary dam, resulted in wider spread of debris flood and mud flood at the downstream of the main river channel and plain areas [5]. The logging and plantation activities in the past were among the public suspicion as the culprit to this tragedy even though their activities had ceased for years, however the activities might had contributed a fraction of the debris materials from accelerated erosion and siltation.

Investigation report by government agencies estimated the total volume of debris deposits about 7.3 million m^3, where 0.3 million m^3 was from landslide, 2.6 million m^3 from the debris flow processes, 3.3 million m^3 from debris flood, and 1.1 million m^3 from mud flood. Comparing to that volume of soil loss via erosion and siltation by the logging activities (since 2010) only contribute about 1.5 million m^3. Hence, the geological hazard process alone could cause the major destruction without the existence of the human activities.

1.2 Lack of Research and Knowledge

Four recent debris flow incidents taught us that research and understanding on debris flow in Malaysia is still at infancy stage. The failure to identify the correct terminologies and processes could lead to improper and incomplete database of event reporting, ultimately keeping track of past disasters. On the other hand, there were constraints to conduct analysis of the current events when the infrastructures including sensors for data measuring such as rain gauges were not available at the disaster areas and many highland areas in general.

In addition to that, proper knowledge on understanding the mechanisms of the process is very important in order to structure the best approach for any mitigation works. This can only be obtained if all the involved parties such as government technical agencies, research institutions, stakeholders, communities, and private consultation firms are ready to work in cooperation for the sake of public concerns.

2 Understanding the Hazards and Risks

2.1 Cascading Geological Events and Major Causal Factors

It is important to understand the debris flow processes, as well as the impacts of that processes in order to understand the risks. Recent debris flow events showed that the occurrence were due to the cascading geological events which triggered by extreme and prolonged rainfalls. Cascading Geological Processes is a term coined to educate the communities on the compounding and transitioning of geological processes from landslide to debris flow, subsequently debris flood and mud flood (Fig. 1). In the context of geomorphology, the mountainous or hillside catchment, they are the terrain conditions that susceptible to the debris flow events. The communities need to understand the geological processes and environment in order to be resilient and safe.

This large-scale disaster starts as landslips or landslides that triggered by rainfalls. When the rain prolonged and the volume of water increases, the debris will start to move rapidly downstream and destroying anything in its path, or known as debris flow. Reaching to the foot of the mountain, the slope gradient becomes gentler and the velocity decreasing as the debris mixes with water thus depositing the heavy debris to the surrounding area and causing flood (this phenomenon is called debris flood). The water continues to flow downstream to the main river carrying mostly sand and silt materials which at the same time flooding the area in the vicinity of the river (mud flood).

Fig. 1. Cascading geological processes starting from (a) a landslide or many landslides; (b) debris flow; (c) debris flood; and (d) mud flood.

2.2 Public vs Scientific Understanding

Public often relates the debris flow disaster with anthropogenic activities such as unsustainable logging, mining and quarrying, and uncontrolled hillside development. This is probably due to the public usually only had experienced the flooding part of the whole process, i.e. debris flood and mud flood. Hence, the perception was on land erosion and logging activities. The recent debris flow phenomena were extraordinary and have never happened before in their lifetime.

Public perception is sometime based on hearsay, experiential learning and observation, sometime could be skewed away from the actual scientific understanding. On top of the extreme rainfall as the triggering factor, natural elements such as geological, geomorphological, and hydrological processes are the main causing factors leads to debris flow disasters, where a debris flow can be originated from a natural landslide in the highlands. In many cases, anthropogenic activities might only contribute a fraction, either positively or negatively, to the impact of the disaster. Public awareness on debris flow hazard is a natural processes that can repeat within certain period of time is very crucial.

3 Policy Intervention

Following the Gunung Inas debris flow tragedy, proactive measures have been taken by the government technical agencies and authorities to structure a policy to recognize debris flow as a major geological hazard in the country that could occur more frequently in view of current trends of climate extreme and variability. Short-term and long-term measures are being planned to improve the technical knowledge, disaster risk management and public awareness.

3.1 Short-Term Actions

These sets of actions were proposed to understand the mechanisms of the geological process and development of mitigation measures on the currently affected areas. Some of the suggestion includes:

- Detailed geological hazard mapping.
- Installation of early warning system.
- Adaptation and mitigation measures for disaster risk reduction.
- Capacity building and outreach via public forum.

3.2 Long-Term Actions

The long-term actions were proposed to develop the geological hazard database, through governance to institutionalize expert groups and infra-/info-structures of integrated system for prevention and mitigation measures. The suggestions are as listed below:

- Establishment of National Research Centre for Geological Hazards.
- Mapping programme on potential debris flow in high risk areas based on river sub-basins.
- Networks of devices for detection and Early Warning System (EWS) on mountainous areas.
- Integrated geological disaster mitigation measures.

3.3 Community-Based Disaster Risk Management for Debris Flow Disaster

One of the first action planned by the government was the development Community-Based Disaster Risk Management (CBDRM) modules for all affected area and debris flow prone areas. The CBDRM programme was designed and developed to address the aspects of disaster education, awareness, preparedness and resilience. Effective high impact CBDRM programme can only realise when it was co-designed, co-developed, and co-implemented by empowering local knowledge, understanding the local disaster risks (coupled with technical/scientific information), and its cascading impacts to the social, economic, and environment.

The CBDRM program emphasised on the strategies in communicating risk information or ‘knowledge transfer’, by sharing the relevant technical information about cascading geological processes (landslides, debris flow, debris flood, and mud flood) as part of understanding the risks. The evacuation route should be identified, evacuation centre should be made known to the local communities. It is important to empower the local stakeholders on their roles and responsibilities as well as special attention to vulnerable communities in building disaster resilient in local stakeholders and communities. The risk nature of debris flow is of high-impact (if it occurs) and low-frequency in occurrence, hence regular and continuous drills and awareness programmes should be practiced.

4 Future Planning and Way Forward

Malaysia is still in the infancy stage of understanding hazards especially geohazards, managing disasters, and developing the mitigation measures. However, with close cooperation between government technical agencies, research institutions, stakeholders, communities, and private consultation firms, the rate of understanding can be improved significantly to be on par with other countries that have experienced this disaster on yearly events.

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