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Debris Flow in Peninsular Malaysia - Case Study on Sungai Kupang Debris Flow, Kedah

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Abstract

Kampung Iboi and several villages downstream of Sungai Kupang, Baling, Kedah were hit by a debris flow and mud flood on 04 July 2022. The disaster claimed the lives of three people, destroyed 17 houses and affected 3,546 residents with losses estimated at RM25.91 million. The flooding that hit Kampung Iboi had high destructive power became the main cause of death, and the bridge to be washed away with several houses completely destroyed along the route. With the calculated amount of debris dumped along the river channels, from landslides to mud flow area of 7.25 million m^3, the quantity of water capable of transporting debris is estimated at 11.23 million m^3. Considering the area of the sub-basin receiving high intensity rainfall of around 10 km^2, rainfall in mountainous areas is estimated at 290 mm/hour.

Result from site investigation show that the disaster area can be divided into four zones; namely the landslide zone, the debris flow zone, the debris flood zone and the mud flood zone. A total of 59 large (>5000 m^2), medium (1000-5000 m^2) and small (<1000 m^2) landslides were identified with a total landslide mass volume of 276,038 m^3. The landslides zone occurs on slopes with an average angle of 30°-35° in the upstream areas which is covered by secondary forest. In the debris flow zone, material consist of the rock blocks (2.0 m to 5.0 m), tree trunks, sand, silt and mud were deposited forming deposits with a thickness of 3.0 m and a cumulative volume of 2,589,021 m^3. The debris flood zone is characterized by materials such as tree trunks, sand, silt and mud that were deposited in areas which is less than 5º slope. The length of this zone reaches up to 6.0 km with an average thickness of debris of about 1.6 m and a volume of 3,275,467 m^3. Mud flood zone was occurred as far as 5.3 km away from the slope with flood height ranging from 0.2 m to 2 m, covering an area of 150 m to 680 m in width. It is estimated that the flood zone carried about volume of 1,111,178 m^3 consisting mainly of mud and silt. The Debris Flow Geological Hazard Map produced during the investigation has identified three post-disaster management zones, i.e. Destructive Zone, Hazard Zone and Safe Zone.

A team lead by Department of Mineral and Geoscience Malaysia (JMG) consists of experts from various department has been assigned to conduct a forensic study in order to understand the cause and effect of this catastrophic event. Several short-term and long-term mitigation measures have been proposed to address existing disasters and to face the threat of debris flow phenomenon throughout the country in the future. The strategy of reducing the risk of debris flow should be implemented holistically in order to improve more integrated disaster management.

Keywords: Debris Flow, Sungai Kupang, Debris Flow Geological Hazard Map

1. Introduction

The phenomenon of debris flow in Malaysia is one of the most feared events, following the high destructive power possessed along its route. Debris-flows is a natural phenomenon in mountainous and steep natural terrains, well-known as fast-moving landslides which generally occur during periods of heavy rainfall (Ghazali, 2013). They consist of loose soil, rocks, and tree trunks combined with water, forming slurry that flows downslope which can displace boulders, may carry away vehicles, houses, bridge and other objects due to their relatively high density and viscosity down the stream (Jimjali Ahmed, 2020). Records show that the landslide incidents including debris flow brought significant losses to the country resulting in more than 500 deaths (since 1961) and property destruction estimated at RM3 billion (1973 - 2007) and it is expected to increase by up to 17 billion in the next 25 years if no long-term mitigation plans are taken. The country is also facing various challenges due to the climate crisis which is changing the pattern, frequency and intensity of rainfall. Climate change has caused a cascading effect which involve landslides, debris flows, debris floods and mud floods. The disaster have recorded a high mortality rate in Malaysia with the total of 442 deaths in 27 years (1995-2022) and economic losses estimated at almost RM904.2 million. Apart from extreme weather, anthropogenic factors such as changes in land use for agricultural development in high degree slope areas can increase systemic risk rates, emerging hazards and geological disasters.

The earliest record in Malaysia explaining debris flow incident is at KM 38.6 Karak Highway-Genting Sempah, Selangor and Pahang on 30 June 1995 which claimed 20 lives, rammed and swept away by a stream of debris more than 50 m from the road to Genting Sempah. The largest debris flow occured on 26 December 1996 in Sungai Keningau, Sabah, killing 300 people and 5,000 houses along the river. The tragedy is well-known as Greg Typhoon due to heavy rains that cause the landslide and debris flow triggered by the tail of Greg Typhoon which began to lose energy when it reached the coast of Sabah. In the same year, another debris flow incident occurred on 26 August 1996 in Pos Dipang, Perak claimed 44 lives (Komoo, 1997). Three (3) large-scale landslides occurred on the steep slopes of high ridges triggered by heavy rains and the debris flowing into the river, destroyed more than 20 houses of Orang Asli. Since then, more than 25 debris flow incidents have been recorded including the Gunung Pulai Debris Flow, Johor on 28 December 2001 (killing 5 lives), Ruan Changkul Debris Flow, Sarawak on 28 January 2002 (killing 16 lives), Sungai Ruil Debris Flow, Pahang on 07 August 2011 (killing 7 lives), Sungai Lubok Panjang Debris Flow on 18 August 2021 (killing 6 lives), Sungai Lui Debris Flow, Selangor on 18 December 2021 (killing 3 lives), Sungai Telemung Debris Flow on 18 December 2021, killing 8 lives) and Sungai Kupang Debris Flow on 04 July 2022 (killing 3 lives). The complete list and its distribution are shown in Table 1.

Department of Mineral and Geoscience Malaysia (JMG) is taking the lead in the investigation of debris flow in Malaysia, has conducted forensic studies with the help and support by experts from various government agencies to find the cause of the incident and produce a comprehensive report to formulate recovery and mitigation plans for the benefit of the affected communities.

2. Case Study Area

Kampung Iboi, a Malay traditional village and several villages downstream which are located on the banks of Sungai Kupang, Baling, Kedah were hit by the debris and mud flood on 04 July 2022. The disaster claimed 3 people, destroyed 17 houses and affected 3,546 with losses estimated at RM 25.91 million. The disaster with a high destructive power is the main cause of death and destruction of many infrastructure (Fig. 1). This incident happened very quickly, starting around 4 pm and the flood receded only after the next few hours. The debris flow and flood in Kampung Iboi was caused by a combination of several geological processes in the upstream area of Sungai Kupang. Heavy rains have triggered

Table 1. List of Debris Flow Incidents in Malaysia

No	Date	Incident Name and Location	No of Deaths	Type of Disaster
1	30 June 1995	Debris Flow at KM 38.6 Lebuh raya Kuala Lumpur–Karak, Genting Sempah, Selangor	20	Debris flow
2	29 August 1996	Mud Flood at Kampung Orang Asli, Pos Dipang, Kampar, Perak	44	Debris flow, debris flood and mud flood
3	26 Dec 1996	Tropical Typhoon Greg at Keningau, Sabah	300	Debris flow, debris flood and mud flood
4	4 Jan 2000	Landslide at Cameron Highland, Pahang	6	Debris flow
5	22 Sep 2001	Landslide at Kampung Chinchin, Gombak, Selangor	1	Debris flow
6	28 Dis 2001	Debris Flow at Sungai Pulai, Gunung Pulai, Johor	5	Debris flow
7	28 Jan 2002	Landslide at Ruan Changkul, Simunjan, Sarawak	16	Debris flow
8	8 Nov 2002	Landslide at Taman Hillview, Hulu Kelang, Selangor	8	Debris flow
9	10 Nov 2003	Landslide at Seksyen 23.3 ke Seksyen 24.1, Kuala Kubu Baru, Selangor	0	Debris flow
10	2 Nov 2004	Debris Flow at KM 52.4, Lentang, Lebuhraya Kuala Lumpur–Karak, Pahang	0	Debris flow
11	10 Nov 2004	Landslide at KM 302, Lebuhraya Utara Selatan, Gunung Tempurung, Perak	0	Debris flow
12	12 Nov 2004	Landslide at Taman Harmonis, Gombak, Selangor	1	Debris flow
13	12 Apr 2005	Landslide at KM 33, Simpang Pulai, Cameron Highland, Pahang	0	Debris flow
14	15 Nov 2007	Landslide at KM 4 ke KM 5, Gap, Jalan Fraser's Hill, Pahang	0	Debris flow
15	15 Jan 2008	Debris Flow at Jalan Fraser's Hill, Pahang	0	Debris flow
16	3 Jan 2009	Landslide at Seksyen 62.4, Jalan Lojing-Gua Musang, Kelantan	0	Debris flow
17	7 Ogos 2011	Landslide at Kampung Orang Asli, Sungai Ruil, Cameron Highlands, Pahang	7	Debris flow and debris flood
18	23 Okt 2013	Landslide at Lembah Bertam, Cameron Highland, Pahang	1	Debris flow
19	5 Nov 2014	KM 28, Jalan Tamparuli, Ranau, Sabah	0	Debris flow
20	11 Jun 2015	Debris Flow at Jalan Fraser Hill's, Pahang	0	Debris flow
21	18 May 2015	Landslide at KM 38.80, Jalan Penampang Tambunan Dongongan, Sabah	0	Debris flow
22	15 Jun 2015	Debris Flow at Sungai Mesilau, Kundasang, Sabah	0	Debris flow
23	23 Ogos 2015	Debris Flow at Sungai Kedamaian dan Panataran, Kota Belud, Sabah	0	Debris flow
24	18 Ogos 2021	Flash Flood, Gunung Jerai, Yan, Kedah	5	Debris flow, debris flood and mud flood
25	18 Dis 2021	Flood di Bentong, Pahang, Hulu Langat, Selangor dan Negeri Sembilan	23	Debris flow, debris flood and mud flood
26	27 Feb 2022	Debris Flow at Empangan Kenyir, Terengganu		Debris flow
27	4 Jul 2022	Debris Flood at Sungai Kupang, Kedah	3	Debris flow, debris flood and mud flood
Total of Deaths			442	

dozens of landslides in the ridges and steep slopes. Material with high water saturation formed debris flow and consequently turned into a debris flood as the water content increased. The Kampung Iboi Bridge became a 'temporary dam' which caused the debris flood in the downstream area when it burst. After the debris was deposited, the leftover materials mainly consist of mud and silt formed the mud flood further downstream.

Fig. 1: Photo of Kampung Iboi, Sungai Kupang, Kedah (the most affected area)

3. Geology and Geomorphology

The entire Sungai Kupang Basin is underlain by three main rock units, namely Inas Granite in the upstream part of the basin with high topography (ranging from 200 m to more than 1450 m), Semanggol Formation in the middle and Kroh Formation which forms the low and undulating hills at the very downstream (Fig. 2). The Inas Granite in the upstream covers almost 70% of the rock distribution in the Sungai Kupang Basin area. The granite consists of medium- to coarse--grained porphyritic granite formed by quartz, feldspar and biotite minerals. The Semanggol Formation, which consists of laminated black mudstone and sandstone, forms the lowland that underlies almost 25% of the Sungai Kupang Basin area. This formation is separated from the granite by a major fault know as Bok Bak Fault. This fault has formed a clear topographic or slope change from steep in the granite area to very gentle land in Semanggol Formation. The Kroh Formation is exposed further downstream of the river which is occupies about 5% the basin area. Its consists of black shale, calcareous shale and limestone. Some of these rocks have been metamorphosed into slate, phyllite and hornfels that contact with granitic rocks.

The Bok Bak Fault is oriented in a direction of northwest-southeast (NW-SE) affects the downstream direction of Sungai Kupang. It also produced a shear zone that created a weak zone between the granitic and sedimentary rocks, producing minor faults (weak zones on the slope) as well as influencing the geomorphology of the Sungai Kupang catchment area.

The geomorphology of the Sungai Kupang Basin is dominated by the mountainous landscape of the Bintang Range which forms Mount Inas with a height of 1454 m and Mount Bok Bak with a height of 1199 m. The geomorphological characteristics of the upstream to low-lying area are controlled by the underlying rock and lithological units. Between the peaks and the lowlands, there are river channel with V-shaped that became the transport zones of debris. The dendritic drainage pattern upstream form four (4) sub-basins that eventually merge with the main river forming the Sungai Kupang Basin (Fig. 3).

4. Rainfall Distribution

In Malaysia most rain gauges are installed in lowland areas. In the Sungai Kupang Basin, only one (1) rain gauge station is installed in Kampung Iboi. On July 4, 2022, the rainfall reading in Kampung Iboi was around 36 mm within 3 hours. The rainfall intensity at gauging station is considered small and does not allow such a phenomenon to occur unless there are other influences such as heavy rainfall happened in the highlands of Mount Inas where there is no rain gauge to record it.

Based on the amount of debris dumped along the river channels, from landslides to mud flow area which is about 7.25 million m^3, the quantity of water capable of transporting debris is estimated at 11.23 million m^3. Considering the area of the sub-basin that receives high intensity rainfall of around 10 km^2, rainfall in mountainous areas is estimated at 290 mm/hour (KeTSA, 2022). Using the United State Geological Survey (USGS) Rainfall Calculating based on a sub-basin area of 10 km^2, rainfall for the same amount of debris is 200 mm/hour. Based on the estimated, the rainfall during landslides and debris flow is at least 200 mm/hour for 4 hours in Sungai Kupang Basin for the day of incident.

5. Erosion and Siltation

Based on satellite images released by the Malaysian Space Agency (MySA), 813 hectares in Compartment 8 were deforested in 2019, this has led to an erosion rate of 743,895 metric ton/year (Fig.4.A). For the first 6 months of 2022, the area has been deforested and turned into agriculture land with an area of 980 hectares and the annual erosion rate is 57,330 metric ton (Fig.4.B). The rate of erosion used for the calculation of the load rate that goes into the river channels based on soil erosion and siltation studies by Gharibreza et al. (2013). In summary, within 3 years from 2019 to 2022, the rate of erosion that goes into the river channels in Sungai Kupang Basin is estimated at 1,011,006 metric ton as shown in Table 2.

6. Site Investigation

Site investigation are carried out by walk-over survey along the affected river channels from 16-23 July 2022 and aerial survey conducted on 27 July 2022. Based on the site investigation, the disaster area can be divided into four zones; namely the landslide zone, the debris flow zone, the debris flood zone and the mud flood zone (Fig. 5).

a) Landslide Zone

A total of 59 large (>5000 m^2), medium (1000-5000 m^2) and small (<1000 m^2) landslides were identified with a total landslide mass volume of 276,038 m^3. The landslides occurred at an average angle of 30°-35° at upstream areas in secondary forest. Based on Varnes (1978) classification, landslides were dominated by the translational landslide (slides failure). The landslide is 3-5 m wide, 5-10 m long and is classified as shallow (depth of 1.5 m – 5 m). The landslide zone is 0.3 km long. Most landslides occur on the soil layer of the weathered granite, and the shallow sliding on the plane between weathering soil and fresh rocks.

b) Debris Flow Zone

Field surveys, satellite imagery and UAV analysis showing the debris flow in four (4) sub-basins sizing from 20 m width, flowing to the main stream of Sungai Kupang with an average size of 40 m. The length of debris flow is following the length of the river, and the longest debris flow is reaches to 5 km. The debris flow with thickness of 3.0 m transports the rock blocks (2.0 m to 5.0 m in diameter), tree trunks, sand, silt and mud along the stream with a cumulative volume of 2,589,021 m^3. Suspended silt and mud in the water can be

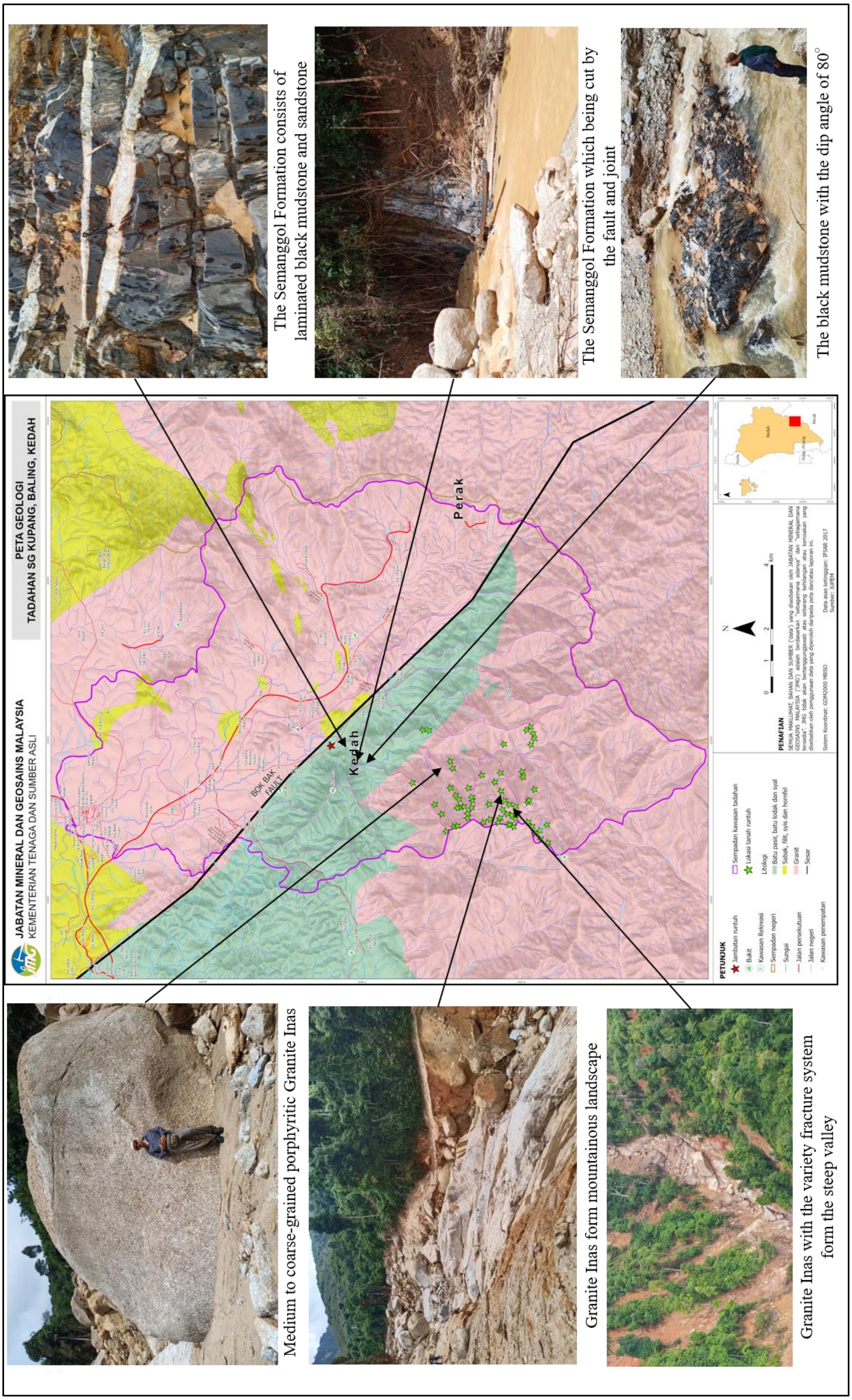


Fig 2: The Geology Map of the Sungai Kupang Basin (Source: JMG, 2022)

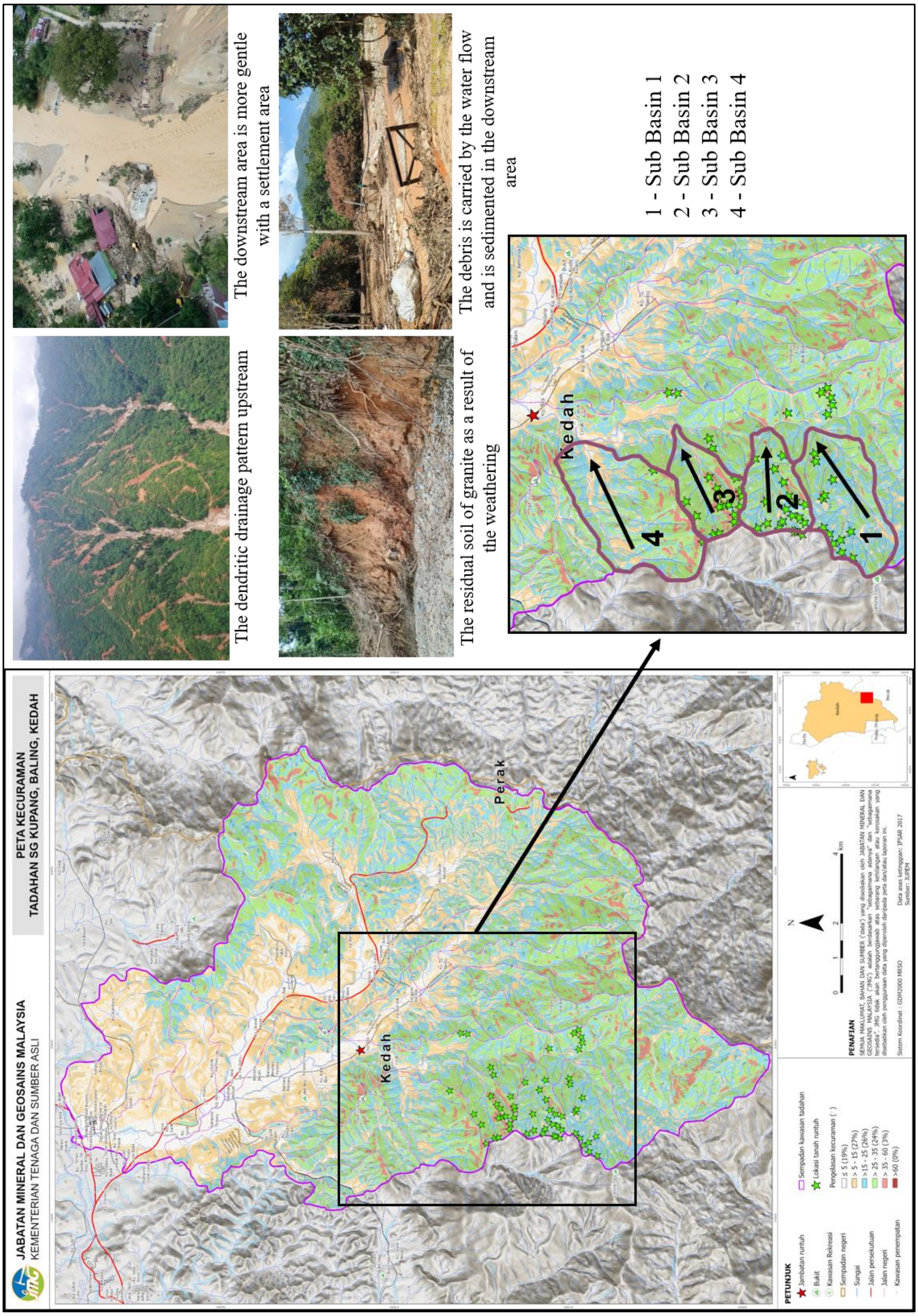
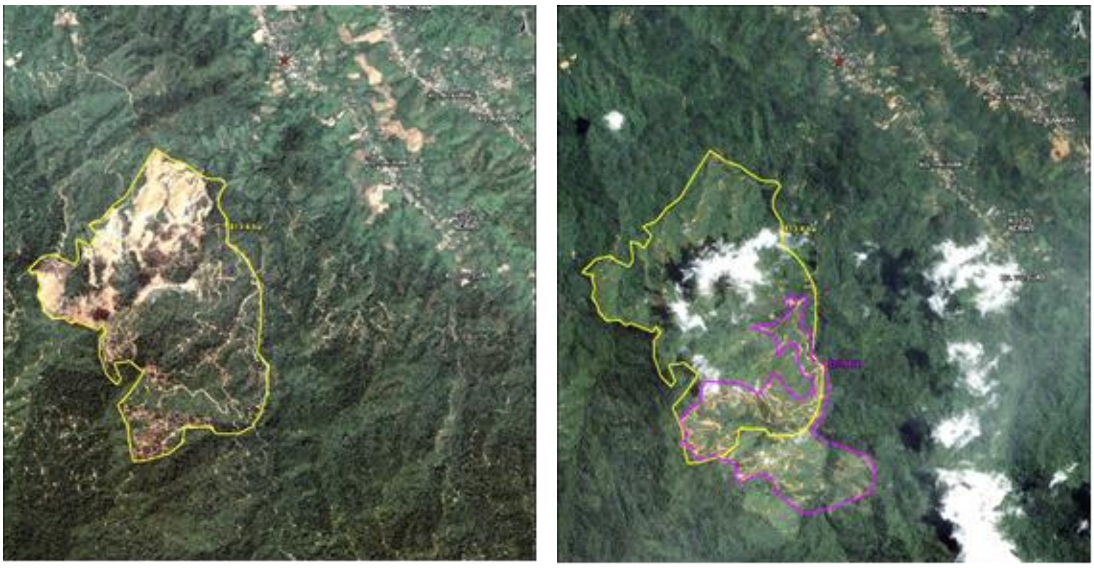


Fig. 3: The Geomorphology Map of the Sungai Kupang Basin (Source: JMG, 2022)



(A) (B)

Fig. 4. (A) Cleared Area (yellow line) in 18 Mac 2019 (813 hectares) (B) Cleared Area (yellow & purple line) in 02 July 2022 (980 hectares) (Source: MySA, 2022)

Table 2. The Erosion and Siltation Rate in Compartment 8 using Gharibreza et al., 2013.

Year	Area (Hectares)	Erosion Rate [Unit – metric ton per hectares annually]	Total [metric ton]
2019	813	915	743,895
2020	813	117	95,121
2021	980	117	114,660
2022 (Jan -Jun)	980	58.5	57,330

transported further downstream. Due to the medium gradient of rivers (15° to 35°), many rock blocks are stranded along the debris flow profile.

c) Debris Flood Zone

As the water content increases and a lot of debris is sedimented, the debris flow turns into a debris flood. The impact of the flooding began at the river mouth of Sungai Celak, about 1.2 km upstream of Kampung Iboi. Field findings show that Kampung Iboi received the main force from the impact of transported debris up to 800 m wide and weakened in the area of Kampung Hangus with a width of 450 m. The debris flood brought a lot of tree trunks, sand, silt and mud. Debris flood zone does not involve many geomorphological mechanisms (the slope angle is less than 5º), reaches up to 6.0 km with an average thickness of 1.6 m and volume of 3,275,467 m^3. Within this zone, a total of 4 bridges located between Lata Celak and Kampung Iboi have collapsed. Apart from that, infrastructure such as roads and some of the residents' houses were destroyed and badly damaged by the impact of debris and overflowing river water.

d) Mud Flood Zone

After the debris containing sand and tree trunks are stranded, the floodwater contains only high volume of silt material. Depending on the height of the water level, mud flood can overflow on the flood plains extensively. The recorded mud flood level ranges from 0.2 m to 2 m with the width ranges from 150 m to 680 m and estimated volume of 1,111,178 m^3. Mud flood zone was detected as far as 5.3 km from Kampung Hangus to Kampung Kuala Kupang and affected 36 villages along Sungai Kupang. The distribution of these zones is very wide and involves damage to public facilities and causes discomfort to the affected residents.

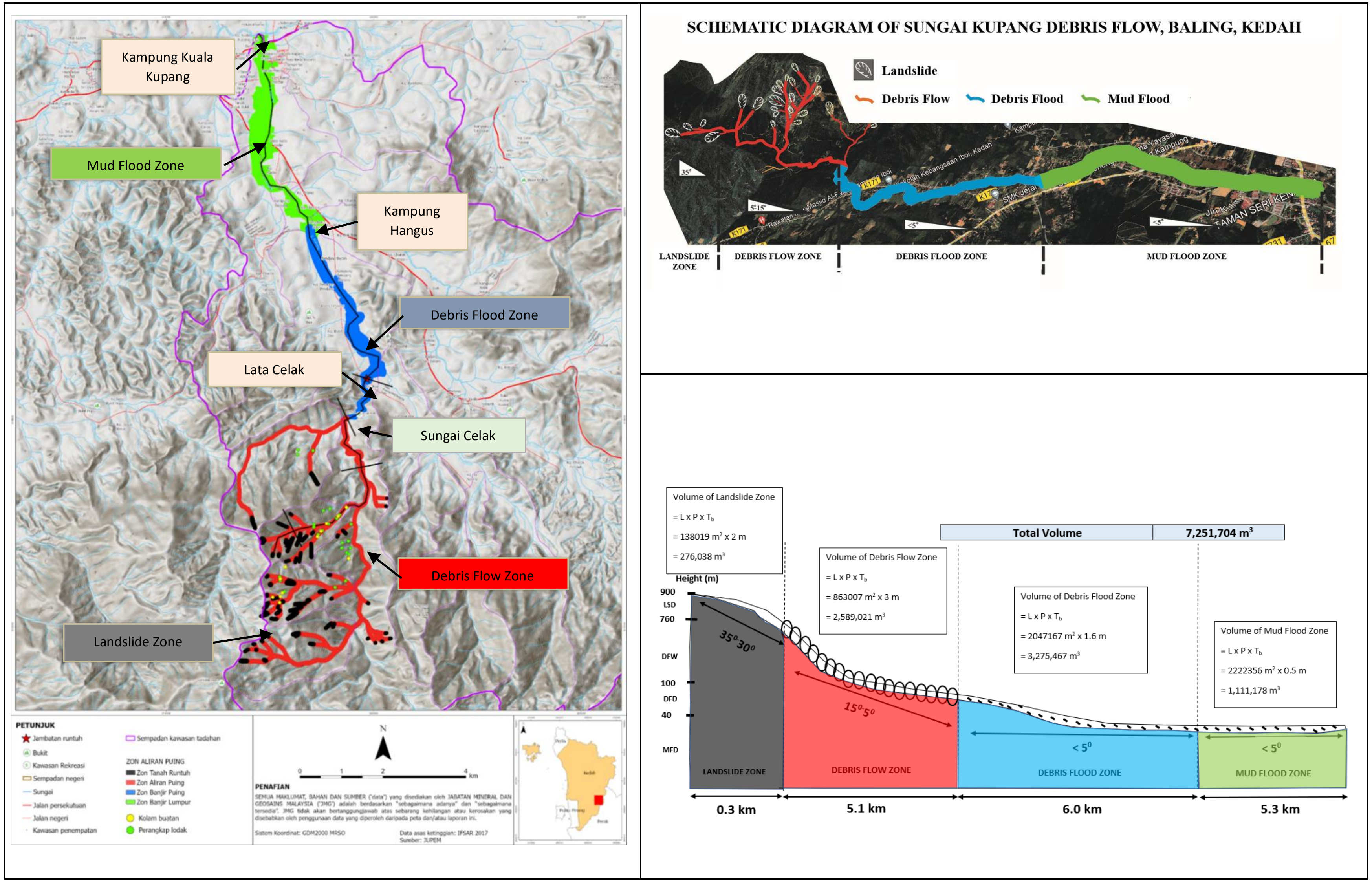


Fig. 5: Sungai Kupang Debris Flow Zone Map (Source: JMG, 2022) (Landslide Zone - Black), (Debris Flow Zone - Red), (Debris Flood Zone - Blue), (Mud Flood Zone - Green)

7. Debris Flow Geological Hazard Map

Based on field investigations and geomorphological analysis, a Debris Flow Geological Hazard Map is provided. This map is intended to be used as a post-disaster development planning guide in areas where the debris flow disaster has occurred. This hazard map takes an approach which the disasters that have occurred can recur in the future and the rebuilding process should take the current experience into account. For this hazard map, three post-disaster management zones were introduced, namely the Destroy Zone, the Hazard Zone and the Safe Zone (Fig. 6).

a) Destructive Zone

The Destructive Zone involves areas affected by landslides, debris flows and debris flood. Based on current surveys, any infrastructure in this zone can be destroyed if the repetitive debris flow occurs at the same intensity or more. Houses can be destroyed, while residents who are inside houses will be difficult to save. For disaster management purposes, all elements of infrastructure remain unsuitable for development in this zone and should be placed as a buffer zone, agricultural area or recreation site with an appropriate disaster early warning system.

b) Hazard Zone

The Hazard Zone involves areas affected by mud flood. Based on field surveys, most of these areas experienced mud flood at the level of waist-down (2 to 3 feet). Most losses involve property damage and discomfort, without building destruction or death. This zone can still be occupied or build permanent infrastructure, if risk factors and mitigation are considered in planning and construction.

c) Safe Zone

The Safe Zone in the basin is an area that is not affected with the debris flow at all and the repeating impending debris flow. This zone is suitable if reconstruction activities need to be carried out, in particular for the evacuation of houses or settlements that are severely affected by the debris flow. Safe zone is suitable area for the construction of schools, health centres and public buildings.

8. Mitigation

The investigation team has recommended short-term and long-term actions that can be implemented as mitigation measures to address existing disasters and to face the threat of debris flow phenomenon throughout the country in the future. Ministries, responder and technical agencies as well as local authorities should arrange the proposed work action based on recommended short-term action (within 2 years) and long-term action (within 5 years).

a) Short Term Action

i detail debris flow mapping within 6 months after the incident, collecting data for follow-up planning to reduce risks to local communities.

ii installation of early warning system including automatic rain gauge in real time. Rainfall information is crucial as the main 'early warning system' to reduce the risk of landslides, debris flows, debris floods or flash floods.

iii evacuation of residents from the Destroy Zone and Hazard Zone to a safe area. During these few months, the river water will remain murky, while flooding will be easier to happen due to shallow river conditions.

iv river deepening and continuous cleaning of debris to reduce the risk of post-disaster flooding.

v planting a deep rooting trees, shrubs, and ground cover plants in open areas to reduce the rate of erosion.

vi implementation of Community Empowerment Programs (C.E.P.) against the threat of landslides, debris flows and debris floods.

vii organising engagement sessions and geological hazard forums in Malaysia.

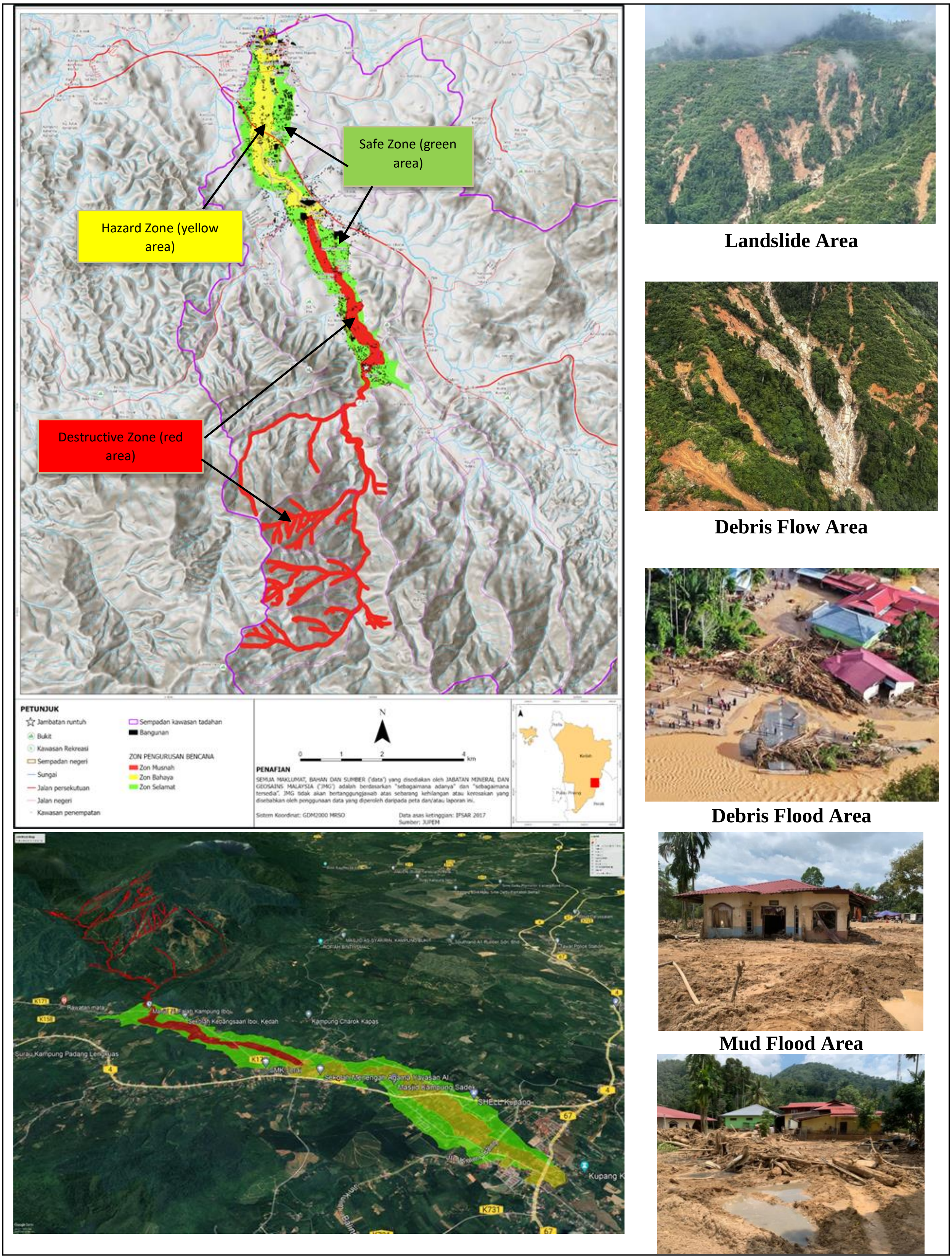


Fig. 6: Sungai Kupang Debris Flow Geological Hazard Map (Source: JMG, 2022) (Destructive Zone - Red), (Hazard Zone - Yellow), (Safe Zone - Green)

b) Long Term Action

i establishment of the National Geological Hazard Research Centre under the Department of Mineral and Geoscience Malaysia (JMG) as a geological hazard information reference centre to conduct forensic studies of geological hazard and strengthen the forecasting, monitoring and warning of national disasters.

ii initiation of the Debris Flow Risk Sub-Basin Mapping Program which use to map the hazard risk forecasts and conduct detailed studies of high-risk sub-basins.

iii the establishment of a geological hazard early warning systems network in the mountainous areas related to geological hazard and managed by the National Geological Hazard Research Centre to strengthen the geological hazard communication and effective announcements.

iv implementation of geological hazard risk mitigation based on structure for debris traps and various functions such as domestic and agricultural water resources, micro-hydro energy, eco-forest parks as well as recreational sites.

v empowerment strategic plan of the Integrated River Basin Management (IRBM) by introducing additional policies for Geological Hazard Management in Basin.

5. Conclusions

The debris flood is a rare event in a sub-basin, occurring when the water content increases and the mechanism of the flow of debris then turns into a debris flood. Debris flow and debris flood is not a common flood, but rather part of a geomorphological process that transports various types of debris material as a result of landslides and debris flows at the highland terrain to the downhill or valley area. It can result in loss of life, damage to infrastructure and destruction of property as well as impact discomfort to the affected communities.

The debris flow events have occurred more than 26 times since 1995 and claimed 442 lives with losses estimated at almost RM904.2 million. The debris flood in the Sungai Kupang Basin which happened on 4 July 2022 in Baling District, Kedah has affected 968 residential premises in 38 villages, resulting in 3 deaths, damage to 35 public infrastructure and have a double impact on survival and business due to damage to agricultural areas, animal farms, and affecting the tourism activities.

Therefore, the strategy of reducing the risk of debris flow should be implemented holistically in order to improve more integrated disaster management. This study is an integrated report based on several technical information of various departments and agencies. This report has recommended short-term and long-term actions that can be implemented as mitigation measures to address existing events and to counter the threat of debris flow across the country in the future.

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