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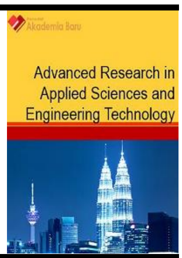

Debris Flow Risk Reduction in Malaysia: From Science-Policy to Multi-Stakeholder Actions

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ABSTRACT

Debris flows remained the deadliest and disastrous geological disasters in Malaysia. The two-decade records from 1995 until 2015 highlighted at least 23 events have occurred regardless of fatalities, and locations. The fatal event was induced by a typhoon recorded in Keningau, Sabah in 1996 with the highest human losses of 302, and economic losses of RM 458.9 million. To date, Malaysia has no dedicated national policy, framework, and standard operating procedure to address this sediment-related disaster in a holistic manner. Moreover, a dedicated, responsible government agency for managing debris flow risk reduction remained elusive. This study aims at providing insights for debris flow disaster risk reduction (DRR) by addressing risk governance, including multi-sectoral agencies roles and responsibilities for different triggering factors, i.e., earthquakes, and intense and prolonged rainfall, and DRR investment towards co-developing an integrated national action plan for reducing current risk, preventing future risk, and strengthening resilience. This study explores various methods to better understand local profiles and suitable methods to assess geological hazard risk processes, activities and impact towards redefining a comprehensive risk assessment method in Malaysia. A case study of recent event in Mesilau watershed induced by the earthquake and rainfall, as a result of 2015 Sabah Earthquake was selected for this study. This study elaborates the significance uses of scientific- and social-based study in promoting science-policy and multi-stakeholders action planning for reducing sediment-based disaster risk in the near future. This includes: (i) the mapping and characterizing the watershed area, (ii) modelling the past debris flow event, and (iii) engaging with the community and stakeholder to gather more local inputs.

Keywords:
Debris flows; disaster risk reduction; agencies; social-based study

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1. Introduction

Debris flows remained the deadliest, and disastrous geological disasters in Malaysia. The two-decade records from 1995 until 2015 highlighted at least 23 events have occurred regardless of fatalities, and locations. Majority of the events were induced by the intense and prolonged rainfall, and very few triggered by earthquake. To date, the typhoon-induced debris flow in Keningau, Sabah

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(1996) was reported as the fatal event in the history of Malaysia. The event has recorded the highest human losses of 302 people, and economic losses of RM 458.9 million [1-3]. Literature studies stated almost 96% of the events were induced by the rainfall, mainly due to the geographic locations of Malaysia that lies in the equator with tropical climates, and received abundant rainfall of 2,400 mm annually [4]. Thus, an intense and prolonged rainfall has become the major triggering factor for debris flow in Malaysia.

So far, Malaysia has no dedicated national policy, framework, and standard operating procedure to address this sediment-related disaster in a holistic manner. Moreover, a dedicated responsible government agency for managing debris flow risk remained elusive. Managing the disaster risk is crucial to reduce the impacts of current and future risk [5], and very significant to enhance the resilience of a community, and to achieve sustainable development [6]. Therefore, this study aims at providing insights for debris flow disaster risk reduction (DRR) by; (i) addressing risk governance, including multi-sectoral agencies, roles, and responsibilities for different triggering factors, i.e., earthquakes, and prolonged rainfall, and (ii) exploring risk investment towards co-developing an integrated national action plan for reducing current risk, preventing future risk, and strengthening resilience.

This study explores the suitable methods to assess the geological hazards, and local disaster risk processes, activities, and impacts towards redefining a comprehensive debris flow risk assessment in Malaysia. This study incorporates some steps, namely as; (i) the mapping and characterizing the watershed area, (ii) modelling the past event, and iii) engaging with the community and stakeholder to gather more DRR inputs, and improving the local awareness. A case study of Mesilau watershed induced by the earthquake and rainfall, as a result of 2015 Sabah earthquake was selected for this study.

2. Study Area

The selected site for this study was situated in Mesilau watershed, Kundasang, Sabah (Figure 1). The event was initiated on 15th of June 2015, 10 days after the 2015 Sabah earthquake on 5th of June 2015. The extensive ground shaking from the main earthquake has produced many earth materials accumulated on the upstream channel, and formed a temporary landslide dam. The following days of heavy rainfall has breached the temporary dam and remobilized the earth material as debris flow.

Geographically, three settlements were observed within the watershed area, namely as; Mesilau village, Naradau village, and Ranau town. From the three settlements, the Mesilau village posed the highest risk, as it is; (i) located closest to the foot slope of the mountain, (ii) closest living community near the river, and (iii) well-known as the touristic demanding areas with attractive remarks. Three of the well-reported impacts in Mesilau village were; the destroyed homestays in Mesilau Nature Resort (MNR), damaged agricultural lands, and destroyed connecting bridge to MNR [7].

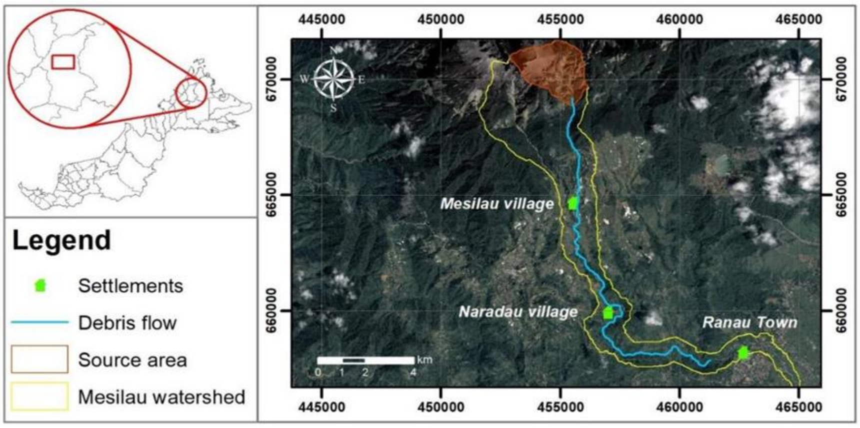


Fig. 1. The Mesilau watershed area highlighting the debris flow runout

3. Methods

The methodologies conducted in this study were divided into two different sections. The first section elaborated the science-based analysis, including; (i) mapping and characterizing the watershed area, and (ii) modelling the past debris flow event. The second section discussed the social-based analysis, such as; (iii) engaging with the community and stakeholder. The spatial datasets used in this study includes; the duo-temporal *Pleiades* satellite images, dated on February 2015 (before earthquake), and January 2016 (after earthquake), and the digital terrain model (DTM) of *Interferometric Synthetic Aperture Radar* (IFSAR) dated in 2008. For the social survey, the data collections were obtained by interviewing the local community, and distributing the people-centered survey.

3.1 Mapping and Characterizing the Watershed Area

Mapping and characterizing the watershed area was important for debris flow study as it helps to characterize the hydro-geomorphological causal factors, identify the initiation area, and determine the landslide areas. To perform the analysis, this study firstly delineated the watershed and sub-watershed of the source area using GIS-spatial analyst in ArcGIS 10.8, followed by performing the image analysis within the source area, and then, conducting a field observation to validate the findings. The overall flowchart for mapping and characterizing the watershed area is presented in Figure 2.

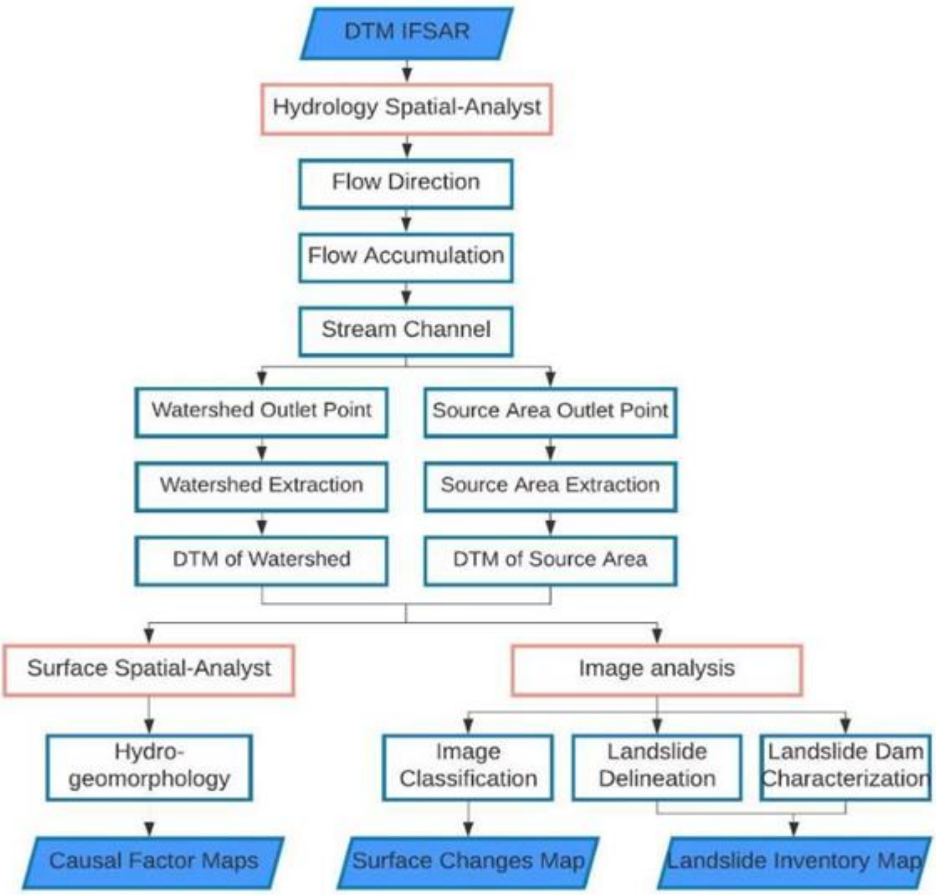
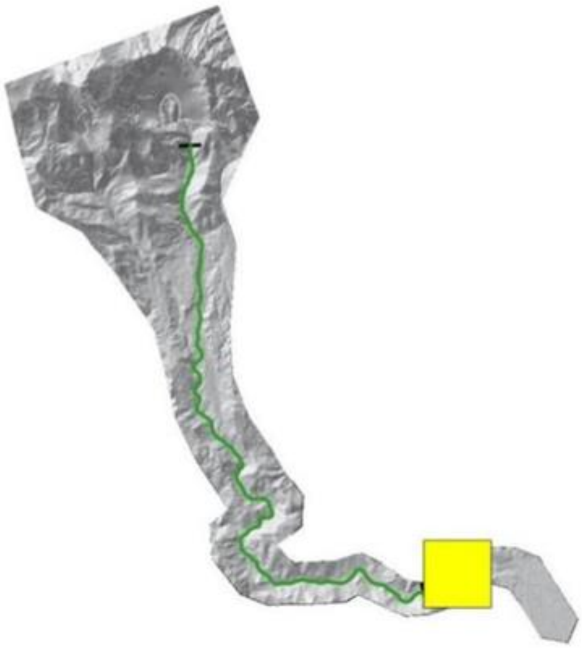


Fig. 2. The overall flowchart of mapping and characterizing the watershed area

3.2 Modelling the Past Debris Flow Event

Next, the methodology briefly discussed the significance of modelling the past event. This study used the HyperKANAKO modelling software, a user-friendly rainfall-based model developed by Nakatani *et al.,* [8]. This model represented an improvised version of Kanako-1D and Kanako-2D, and required two basic datasets, such as; the digital elevation model (DEM) and the hydrograph discharge. The user was first required to define the source of initiation (black line), and the depositional area (yellow square). Then, the user was required to calibrate the parameters within the LibreOffice5 software before performing the simulation. Figure 3(a) and Figure 3(b) highlighted the model setup and the calibrated parameters respectively.



(a)

Calculation parameters	
Item	Value
Version	2.06
Time interval of calculation(sec)	0.01
Mass density of sediment(kg/m^3) MKS	2650
Mass density of fluide phase(water and mud,silt)(kg/m^3) MKS	1000
Gravity acceleration(m/s^2)	9.8
Minimum flow depth(m)	0.01
Concentration of movable bed	0.65
Manning's roughness coefficient	0.03
Coefficient of erosion velocity	0.0007
Coefficient of deposition velocity	0.05
Coefficient of deposition velocity considering inertial force	0.9
Simulation continuance time(sec)	2400
Diameter of material(m)	0.2
pai	3.1415926536
Internal friction angle(deg)	37
Time interval of output hydrograph data(sec)	4
Time interval of output result data(sec)	1
Parameter using in 2D area; inflow direction(muki)(deg)	0
inflow center X axis in 2D area(jc)	0
inflow center Y axis in 2D area(jr)	41
Interval of 2D-x calculation points(m)	10
Interval of 2D-y calculation points(m)	10
Minimum depth at the front of debris flow in 2D(m)	0.01
Number of calculation points in 2D-x direction	172
Number of calculation points in 2D-y direction	173
Thickness of the 2D plane unstable sediment(m)	0.00
Side Bank Erosion Velocity	1.00
Side Bank Gradient(deg)	35.00
Processing mode : 0=To the two dimensions 1=Only the one dimension	0
Outflow Coefficient(a)	1425.00
Outflow Coefficient(b)	-1000000.00
Outflow Coefficient(c)	400000000
Result Q output : 0=No 1=Yes	1

(b)

Fig. 3. (a) The HyperKANAKO model setup; (b) The calibration of the model parameters

3.3 Engaging with Local Community and Stakeholder

Engaging with the local community and stakeholder played an important role in gathering more inputs related to the past event, and way forwards in DRR. Since the community was the first respondent to receive the impacts, therefore, the community engagements were very significant to deliver the knowledges, and react with the emergency responses [9]. To engage with the community and stakeholder, a nationally-supported and locally-led programs were co-designed to enhance the capacity of disaster managers for rapid-onset disaster. Moreover, the in-depth discussions with the local and international experts also gives the exposures to the communities towards the past impacts, as well as improving their preparedness for the future event. The examples of the locally-led DRR programs include; High-Impact Community-based Disaster Risk Reduction (HiCBDRR 2018), Science and Technology for Disaster Risk Reduction (STDRR 2019), International Workshop and Field on Disaster Risk Reduction (IDRM 2020), and Community-based Disaster Risk Management (CBDRM 2020).

Based on the aforementioned programs (Figure 4), this study has taken the opportunities to interview the local communities with the open-ended questions, and distribute the structured people-centered survey to the stakeholders. The people-centred survey was constructed by prioritizing the four inter-related elements known as; understanding local disaster risk, observation and monitoring, warning dissemination, and response capability. The formulation of the survey was designed together with the local and international experts, by adapting and adopting the global published surveys [10]. The final and revised survey was then distributed to the stakeholder who attended specifically the IDRM program in February 2020. The raw data collections were then transferred into the Statistical Package for Social Science (SPSS) software to process and interpret the findings using the descriptive and rank analysis.

Fig. 4. Engagements with the community and stakeholders; (a) On-site discussions with the international experts, (b) On-site discussions with local stakeholders, and (c) Local community engagements

4. Results and Discussions

4.1 Hydro-Geomorphological Derived Causal Factors

The first result was the hydro-geomorphological derived causal factors of the watershed area. The results were presented in four different maps as shown in Figures 5 and 6. Figure 5 highlighted the hydrological map of the watershed area, while Figure 6 presented the three surface maps of the source area. The hydrological extractions determined the watershed area was 38 km^2, sub-watershed of source area was 5.55 km^2, and the channel length was 18.6 km. Furthermore, the geomorphological extractions characterized the source area consists of the steep to very steep slopes, slope directions that converged towards the center of the channel, and majority of the slopes were relatively negative, showing a convex profile. Correlating the outputs together, the earth material was stripped off at the steep to very steep slopes, with high-speed velocity, and accumulated the earth material at the center of the channel. Thus, formed a temporary landslide dam.

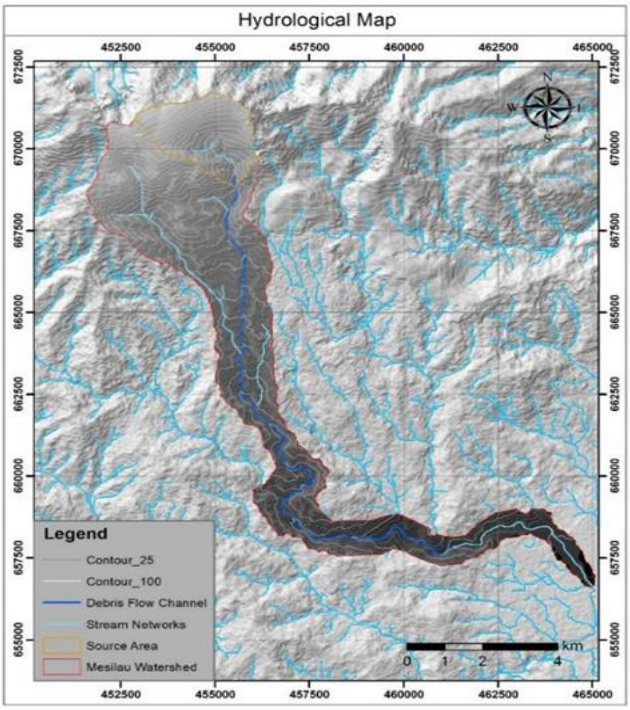


Fig. 5. The hydrological map of the watershed area

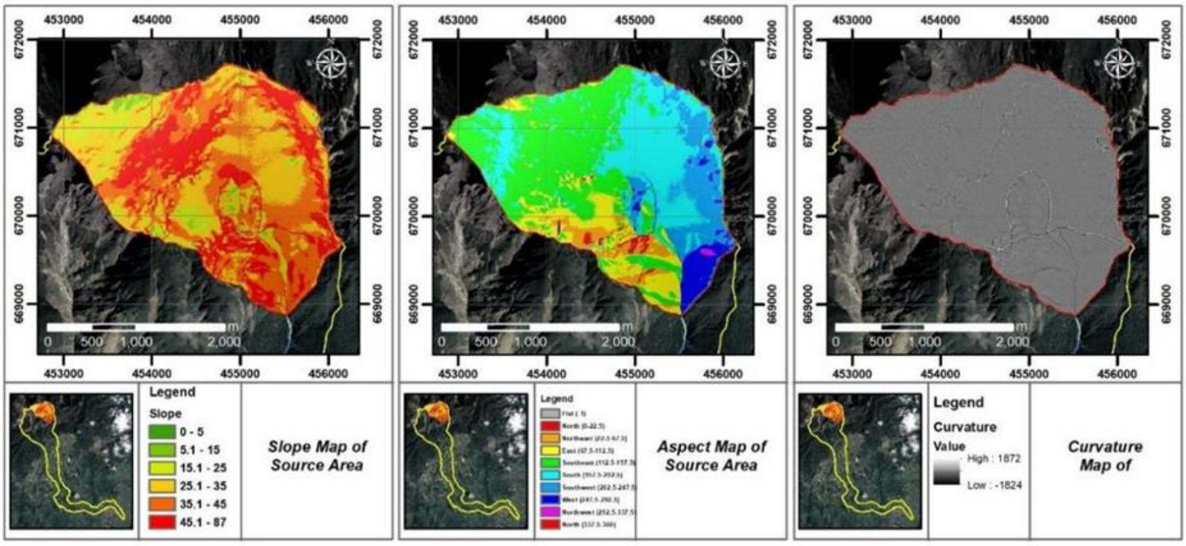


Fig. 6. The surface maps of the source area, (a) Slope; (b) Aspect; and (c) Curvature map

4.2 Image Analysis

The image analysis indicated that the landslide dam was located at the altitudes of 2,005 m from the mean sea level. The length was estimated at 190 m, while the width was approximately 120 m (Figure 7(a)). The overall landslides inventory based on the kinematic and diagnostic features determined at least 122 landslides were recorded regardless of the sizes and types (Figure 7(b)). [11] analyzes the stripped earth material resulting from the earthquake was 1.32 km^2 in average. Thus, contributed to the damming formation, and the long debris flow runout. Moreover, the estimated distance from the source of initiation to the Mesilau village was approximately; 4.0 km, Naradau village was 10.3 km, Lipasu road was 16.2 km, and Liwagu Dam was 18.6 km. The distance estimation was important to determine the time taken for the runout to reach the village.

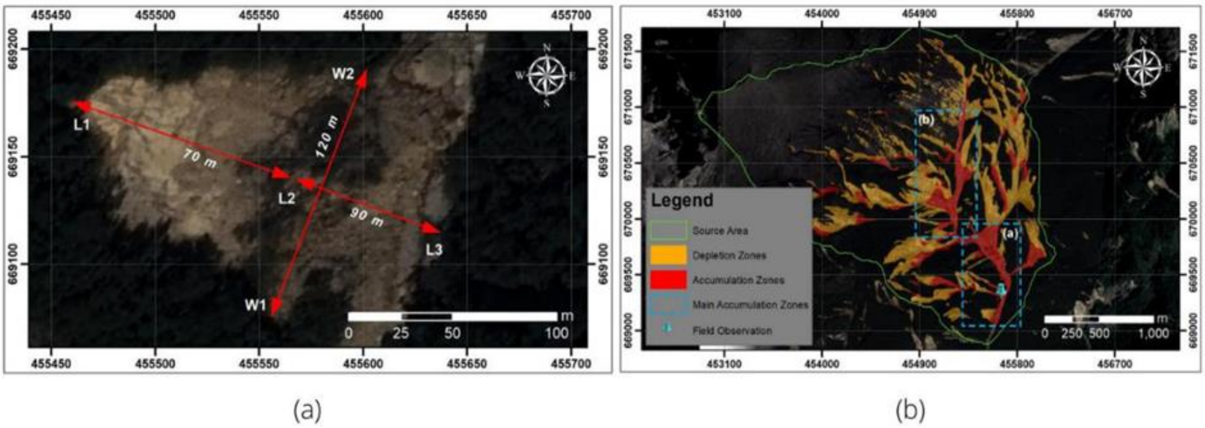


Fig. 7. (a) The characterized landslide dam within the upstream of Mesilau channel; (b) The digitized landslides based on the kinematic and diagnostic features of landslides

4.3 Field Observation

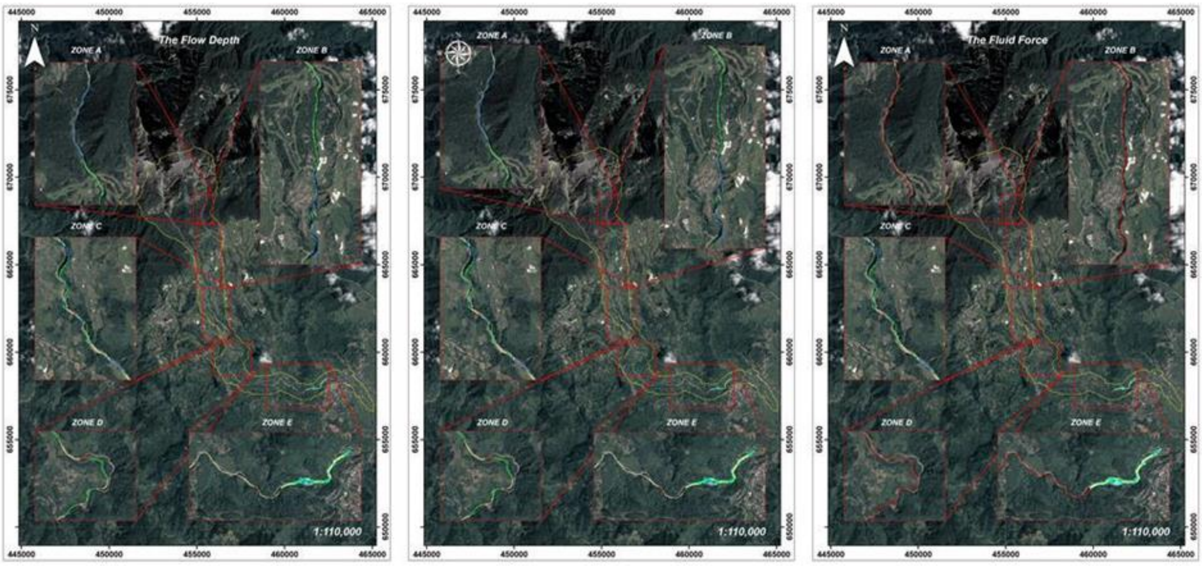
The field observation was conducted from 31st August until 06th September 2019, with the focus to validate the source area, and any potential damming area. As presented in Figure 8, many earth materials were identified along the river after the earthquake and debris flow. In addition, we identified many boulders were still hanging on the slope surfaces, and at least 3 post-damming areas that potentially trigger future geohazards.

(a) (b)

Fig. 8. (a) The determined boulders along the river and the slope surfaces; (b) The identified post damming area within the upstream channel

4.4 The Simulation Results

The simulation results were presented in three different outputs, including; (a) the flow depth, (b) the depositional thickness, and (c) the fluid force. The differences for every output were depending on the coloured line along the channel path. Based on the simulation results, we determined majority of the flow depth was ranging between 10 m to 14.9 m, the depositional thickness was up to 10 m, and the fluid force was approximately 3kN (Figure 9). These outputs were significant to support the decision-making processes in designing the suitable mitigation measures and reducing future risk.



(a) (b) (c)

Fig. 9. The simulation outputs using HyperKANAKO model, (a) The flow depth; (b) The depositional thickness; and (c) The fluid force

4.5 Social Survey

47 respondents with various backgrounds have responded to the survey consists of 51% respondents from the government agency, 25% from the Non-Governmental Organizations (NGOs), 16% from the academic, and 8% as retires. Majority of the respondents were graduated with the higher tertiary educations (degree, master, and PhD), and very few from the higher school background. In general, about 91% knew the existence of landslide and debris flow hazards after the earthquake, with 85% from them knew the occurrence of debris flow in Mesilau watershed. The disaster information was most retrieved through the experts (37.5%), newspaper (33.8%), and SMS (28.8%). Despite that, only 4.8% knew the EWS related to the debris flow. Thus, opening a gap for this study since the EWS for debris flow was limited. Based on their suggestion, the study area was in the very critical need for the EWS (64.0%), since the area was situated in a tectonic environment. Besides, the respondents also recommended both full-spec EWS by the government, and low-cost, community-based EWS to be developed and conducted in the study area, with the frequent local training for every six months (59.1%). The suggested programs include; community-based program (64%), and education (36%). In addition, 53% of the respondents also suggested that the information should be disseminated with the enhanced system, such as; the improvised siren speakers, phone call, and SMS.

The findings based on this study has highlighted the Mesilau watershed as an area that needs further attention towards the debris flow risk reduction strategies in the near future. The conducted analyses have justified that the upstream area is still consisting of many earth materials, and sediment that is still hanging, and at least three inundated areas are determined within the upstream area. The future dam breach could trigger either debris flow, mud flow, or flood. Coupled with the steepness of the slope gradients, the mobilization could travel at high-speed velocity and reach the element-at-risks within a short period. Thus, increasing the hazard and risk towards the downstream community. The simulation results portrayed as a good indicator to design a DRR strategic plan, especially in the high hazard areas to minimize the impacts. For examples, the channel areas that have a flow depth of 14.9 m, maximum depositional thickness of 10 m, and fluid force of 3kN. Based on the social survey, we concluded that the stakeholders agreed with both full-spec EWS, and low-cost, community-based EWS as the most suitable mitigation strategies in the area. The small investments by the government in co-designing the community program and disaster education for the vulnerable community is highly recommended.

5. Conclusions

This study demonstrated the local understanding of the past event of debris flow induced by 2015 Sabah earthquake, and also the way forwards in preventing future risk. This study also identified the challenges for the debris flow DRR in Malaysia, mainly due to the lack of understanding of past events, and predicting the future event, as well as the decision making for DRR in high-risk areas. Therefore, this study provides insights for the debris flow risk triggered by earthquake, mapping and characterizing the watershed area, modelling past event, and engaging with the community to better develop the risk reduction strategies in the near future. It is worth to mention that this study promotes science-policy to multi-stakeholder’s action planning to reduce the sediment-based disaster risk in the near future.

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