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Rapid response to a slope disaster with a web-based debris flow model: an interactive example of visualizing and evaluating sediment transportation at Yusui Creek

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Keywords: rapid response, slope disaster, web-based debris flow model, interactive system, sediment transportation, Yusui Creek

1. Introduction

Tropical Storm Lupit, combined with seasonal southwesterly winds, brought more than 2,700 mm of rain from August 1 to 9, 2021, caused destructive floods, landslides, as well as the catastrophic collapse of Minbaklu Bridge in Taoyuan District. Rapid responses were conducted immediately to collect the aftermath images from various satellites and unmanned aerial vehicles, with the intention to assess and mitigate the damages, as well as to clarify and eliminate the cause of disaster. All geospatial data were integrated and shared through the Big Geospatial Information System (BigGIS) (https://gis.swcb.gov.tw/), which facilitates the exports, scholars, government officials and general publics to gain a better understanding of the disaster and make the best of these geospatial data in a timely manner.

Based on the experiences acquired in this event, one of the most powerful and crucial tools to support the rapid response of disaster is a numerical model of debris flow driven by the *in situ* observation of landslides and validated by the most updated ranges of alluvial fan. This requires (1) a flexible input that can digest the geospatial data collected from various platforms; (2) an accurate and efficient simulation that can be accomplished and repeated in a short period of time; (3) a sound function to visualize the result that can be adjusted several times to optimize the required parameters; as well as (4) a purpose-oriented output to estimate the amount of sediment transportation. This paper reports the web-based simple debris flow (SDF) model that has been implemented in BigGIS and gives an interactive example of visualizing and evaluating sediment transportation at Yusui Creek.

2. Materials and Methods

The SDF model is simplified from the fully developed laminar flow model proposed by (Hunt 1994) to simulate the movement of debris flow. It assumes that the water and sediment are well-mixed and the water content is saturated. The Newtonian Fluid is formed and gradually transited to the Bingham Fluid, and then the Non-Newtonian Fluid. This fluid moves along the river channel governed by the equation of motion. Some simplifications are introduced to increase the efficiency of simulation (Chiang 2010). Assuming both the riverbed and air-fluid interface are free surface with zero shear stress, the velocity profile of debris flow can be expressed as (Chen et al. 2018; Hunt 1994)

$$u_M(z) = \frac{g sin\theta}{2\nu}[h_M^2 - (h_M - z)^2], \qquad (1\text{-}1)$$

where u_M is the velocity of debris flow [m s^{-1}]; z is the vertical position [m]; h_M is the depth of debris flow [m]; ν is the kinematic viscosity [m^2 s^{-1}] that can be specified by the sediment size with a suggested range of 0.23–5.35 m^2 s^{-1}; g is the gravitational acceleration [m s^{-2}]; θ is the slope of riverbed [°], as illustrated in Figure 1. Note that the initial conditions required for running the SDF model are the digital elevation model, sediment source, kinematic viscosity, equilibrium concentration, and simulation time step. They can be specified interactively through the graphic user interface of BigGIS.

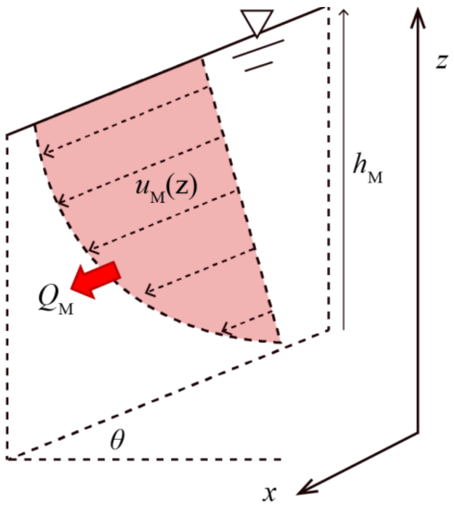
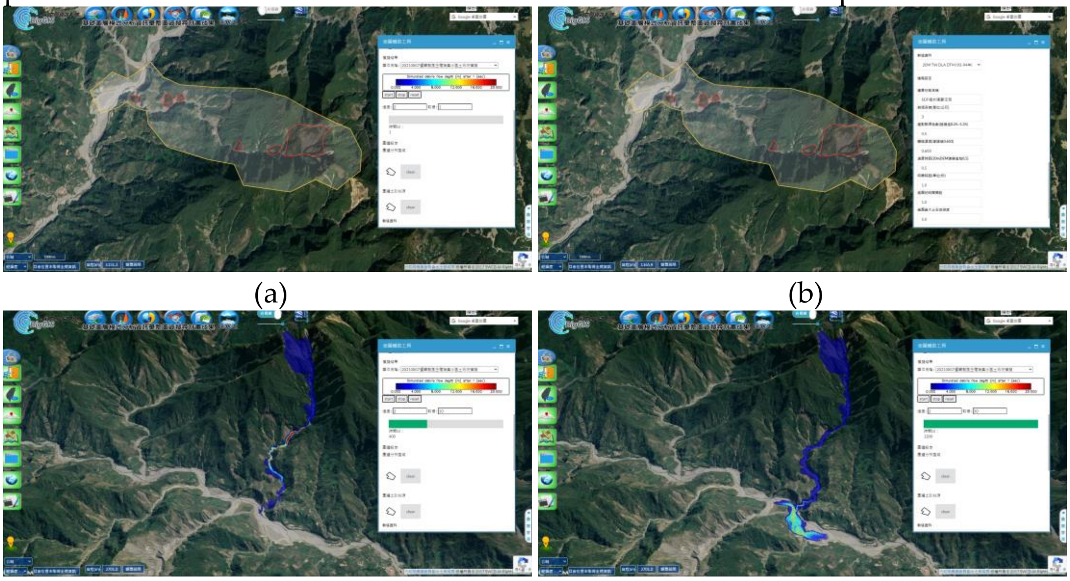


Figure 1. Illustration of the velocity profile of debris flow and related parameters. (Chiang 2010)

3. Results and Discussion

Figure 2 gives an interactive example of visualizing and evaluating sediment transportation at Yusui Creek during the Tropical Storm Lupit in August 2021. Both the region of interest (watershed of Yusui Creek) and the region of sediment source (new or expanded landslides) can be delineated on the aftermath imagery at its full resolution displayed in BigGIS (Figure 2a). All required parameters (initial conditions) can be specified in the pop-up dialog (Figure 2b). Note that the suggested value has been included and explained in the dialog as default value for each parameter. Since the SDF is rather efficient, it can be executed online and the result from each time step can be visualized in 3D mode in real time (Figure 2c). A total of 1,200 time-step is specified in this simulation and the final result of alluvial fan can be visualized in 3D mode and compared to the aftermath imagery as well (Figure 2d). The simulation can be repeated several times with different combination of parameters until the simulated alluvial fan matches the observation. The optimized parameters can be used to visualize and evaluate sediment transportation.



(a) (b) (c) (d)

Figure 2. Example of visualizing and evaluating sediment transportation at Yusui Creek during the Tropical Storm Lupit in August 2021. (a) Delineate the region of interest (watershed of Yusui Creek) and the region of sediment source (new or expanded landslides) on the aftermath imagery; (b) Specify all required parameters (initial conditions) ; (c) Execute the SDF model and visualize the result of each time step in 3D mode online; (d) Examine and compare the final result of alluvial fan to the aftermath imagery.

4. Conclusions

High-spatial-resolution orthophotos and LiDAR derived elevation models are two photogrammetry products that are mostly and immediately collected after a major disaster, with the intention to assess and mitigate the damages, as well as to clarify and eliminate the cause of disaster. Apart from providing a web-based platform to integrate and share these important data through internet, BigGIS takes a further step to implement the SDF model that retrieves the crucial information of sediment transportation to support the rapid response of slope disaster. Limited by the well-mixed assumption of water and sediment, as well as the fixed-bed assumption of no entrainment effect, the SDF model does not intent to make a detailed and accurate simulation of the slope disaster, but instead to provide an interactive tool of visualizing and evaluating sediment transportation.

References

1. Hunt, B. (1994). Newtonian fluid mechanics treatment of debris flows and avalanches. Journal of Hydraulic Engineering, 120, 1350-1363
2. Chiang, S.-H. (2010). Modeling Multi-Hazard: Landslide Initiation and Debris Flow. Ph.D. Thesis, Department of Geography, National Taiwan University, 1-134
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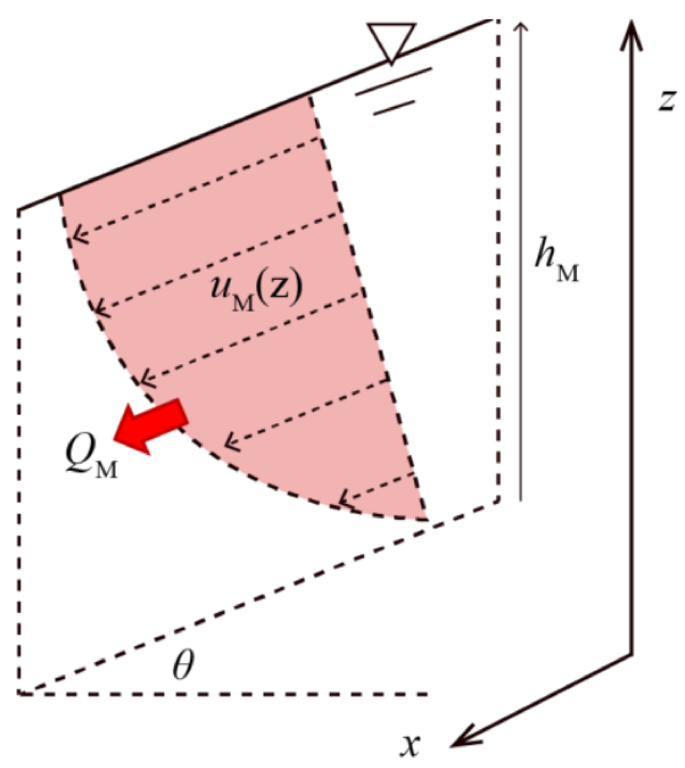

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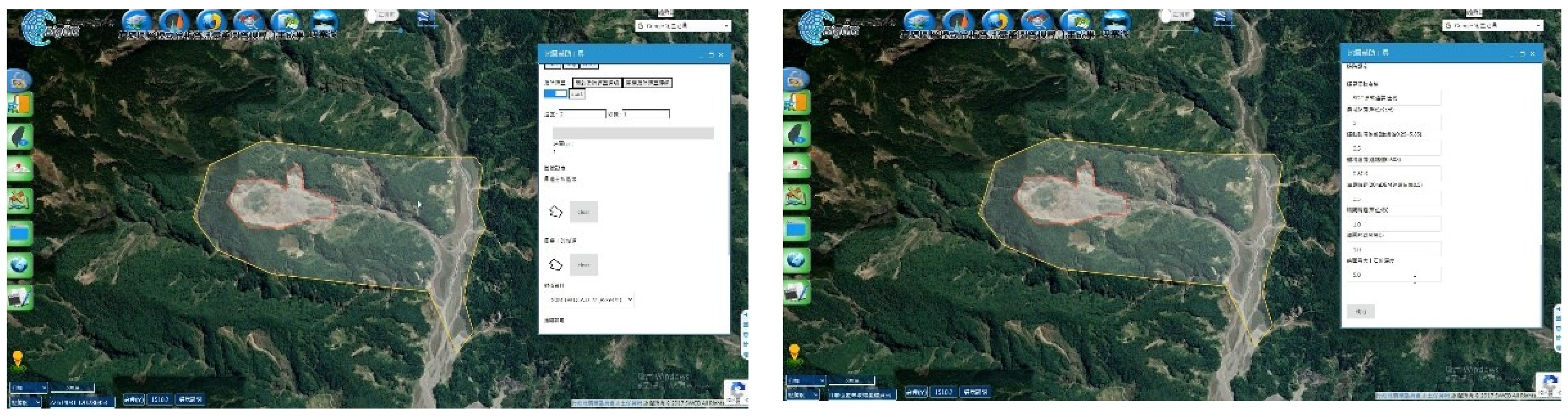

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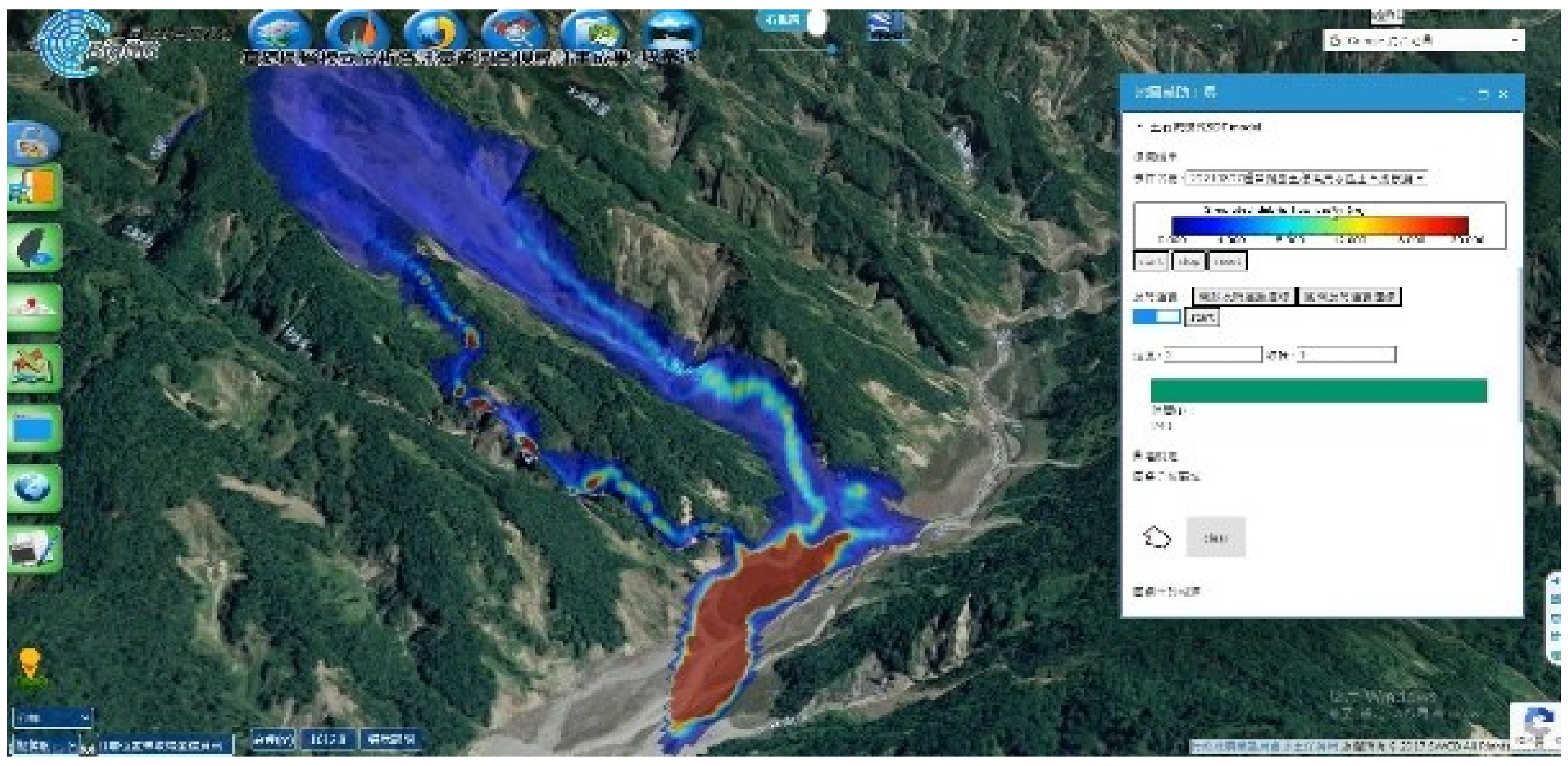

Figure 3. Example of visualizing and evaluating sediment transportation at Yusui Creek during the Tropical Storm Lupit in August 2021. Examine and compare the final result of alluvial fan to the aftermath imagery.

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