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Keywords: *debris flow, DEM, hazard, landslide and RAMMS.*

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Md Moniruzzaman [α] & Shovan L. Chattoraj [σ]

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I. Introduction

Landslide is collapse of earth, rock or debris from mountain or hill cliff down a slope. And defined as costly interruption of functioning a society/community causing extensive human, economic, social, material and environmental losses that goes beyond the ability of affected community. Landslide is the most significant geological hazards that contribute to natural disasters in hilly terrain of Chittagong, Bangladesh due to triggering influences e.g. heavy rainstorms, earthquakes, cloudbursts, geo-engineering setting, population intensification, indiscriminate hill cutting, unauthorized settlements, unplanned human activities, deforestation etc. [1-9]. The landslide is resultant by the effects of gravity and landform from the sliding movement of rock, soil, and organic materials under [10]. Landslide has become a frequent phenomenon for parts of Chittagong which brutally affects life, livelihood and property of the inhabitants blooming on every day trip, tourism and agriculture [5,7,11]. Physiographically, 18% of Bangladesh is hilly area and more of floodplain [12]. It has been found that over 0.5 million insolvent people are living on the lethal foothills of Chittagong [13,14]. Nearly 235 people died due to landslides in several informal settlements during 1997 in Chittagong and its contiguous urban fringes [15].

Debris flows and debris rushes have become a major natural hazard process in hilly regions which are complex, gravity-driven, water and sediments with extreme moveable capacity [16-23]. Modeling debris flow is a dynamic research arena and can play substantial role in disaster mitigation and management [24-26]. In this study, evolved Rapid Mass Movements Software (RAMMS) as an art of mathematical simulation model to forecast motion of stirring mass declining naturally from relief area (head) to base area via 3D/2D. Digital elevation model (DEM), the Voellmy rheological inputs and secondary ground data i.e. geotechnical parameters are fundamental prerequisites for RAMMS [9, 27-31].

a) Study area

The study undertaken is mostly surrounded in Bandarban district and a small part of south-eastern Rangamati district. The study area is approximately in-between 92.230282 decimal degrees (dd) to 92.594080 dd east longitude and 22.211499 dd to 21.850400 dd north latitude (Figure-1). Both Bandarban and Rangamati are the two hill districts among there of Bangladesh. The Tahjindong (1280m) Mowdok Mual (1052m), and Keokradong (883m) are the height hill peaks of Bangladesh including newly reported Saka Haphong (1063.1424m). The Sangu River (also known as Sangpo or Shankha), Matamuhuri and Bakkhali are the major river in Bandarban district [32]. The Rangamati district shares international border with India (Tripura state to the north and Mizoram state to the east) and Myanmar (Chin State to the east) comprising of 1292 km2 is riverine and 4825 km2 is under forest vegetation [33].

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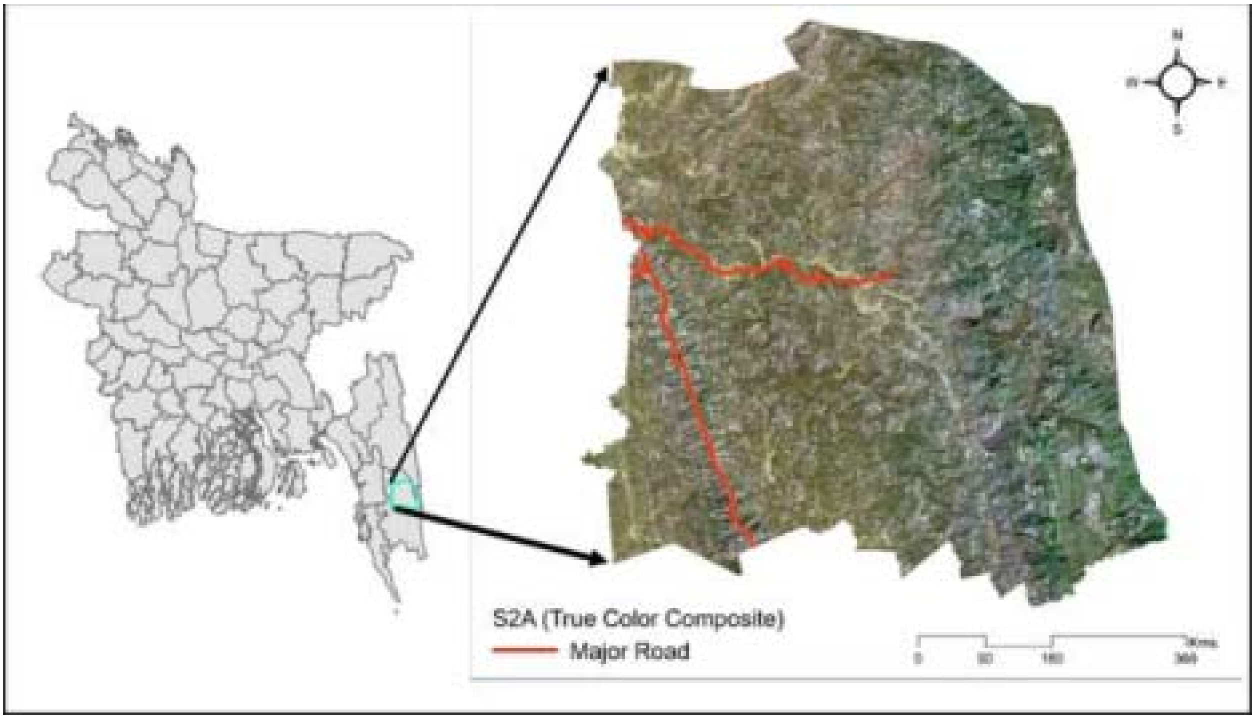

Figure 1: Study area showing in parts of Bandarban and Rangamati district

II. Methods and Materials

a) *Satellite Data Used*

European Space Agency (ESA) operated Sentinel 2A (S2A) multispectral remote sensing data acquired for the study. In the present study 10 m spatial resolution bands used (bands specifications are shown in table-1). At first cloud-free, orthorectified and radiometrically corrected S2A scenes acquired in 10 March 2018 was retrieved from Copernicus Sentinel Scientific Data Hub [34]. The S2 A data was processed using ESA SNAP 6.0 platform.

Table 1: Used Sentinel 2A data details

Used S2A Bands	Central Wavelength (µm)	Resolution (m)
Band 2 - Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 - Red	0.665	10
Band 8 - NIR	0.842	10

The Advanced Land Observing Satellite-1 (ALOS), the Phased Array type L-band Synthetic Aperture Radar (PALSAR) ALOS-PALSAR 12.5 m spatial resolution open source and freely available DEM used in this research. The elevation of the study area varies 4 meters to 980 meters (Figure-2a). Figure-2a also denoted 10 primary samples and 3 selected samples from total of 13 samples on which the simulation model run. In figure-2b aspects details and in figure-2c the slope have shown where slope is categorized into four classes and found maximum slope in the hilly terrain in-between 31.9-77.5.

b) *Model Input Data*

i. *Digital Elevation Model*

The fundamental pre-requisite datasets for RAMMS model are digital elevation model (DEM) release area and mass along with friction properties and others associated geo-engineering parameters. Topographic settings is an initial input for simulation model of debris flow because the movement of flows will be determined, directed and dominated by elevation. Hence, high resolution precise DEM is required to define release area. The present study used ALOS-PALSAR 12.5m DEM. Two must needed inputs were given in debris flow modeling (i) Release/block release; and (ii) hydrograph. In this study, block release was favored due to its applicability.

Generally, RAMMS model usually follow unchannelized debris flow state particularly for superficial landslides and hill-slope debris flows. The designed model flow path was validated via satellite imagery. An important fact is the release area, for small unchannelized debris flows by a known initial height

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which will be released as a block [35]. The release areas and approximate corresponding calculation domains had been identified and demarcated over the DEM (Figure-2a).

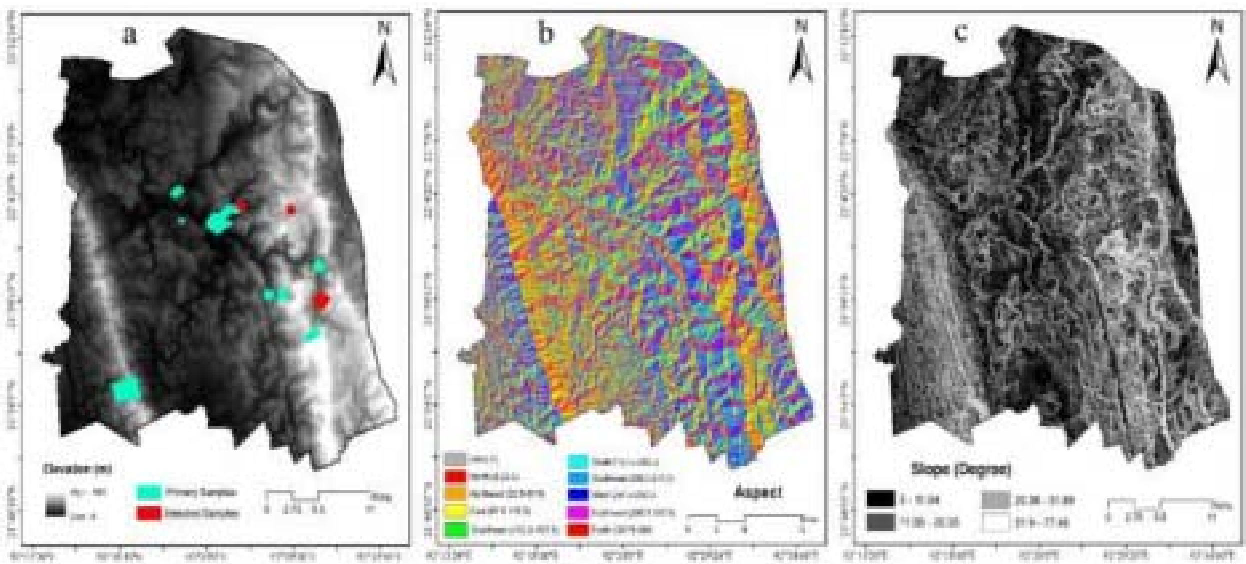

Figure 2: Elevation distribution throughout the study area (a); Aspect details (b); And slope variations

ii. *Others parameters and model calibration*

The rheological features and shear strength factors of slope is fundamental for RAMMS simulation model. The RAMMS physical model follows the Voellmy friction law [36] and (i) Dry-coulomb friction (μ); and (ii) Viscous-turbulent friction (ξ) are frictional resistance. The equation to calculate total frictional resistance (S) in Pa unit is as following

$$S= \mu\rho Hg\cos(\varphi) + (\rho gU2)/\xi$$

Assuming, g -gravitational acceleration, H -flow height, ρ -density of the debris, φ -slope angle, and U -initial flow velocity.

The collected samples were analyzed at the Indian Institute of Remote Sensing (IIRS), Dehradun at various capacity levels using shear testing electronic tools (Model No. AIM 104-2kN, Make Aimil Ltd, New Delhi). Samples were tested at 0.25, 0.50 and 1 kgf/cm2 regular load and subsequent shear strength factors at failure were determined.

RAMMS uses a single-phase model which is difficult for flow simulation with higher variety of debris flow materials. If the debris flow events are known the friction factors should vary to follow observed flow pathways so the simulation model ran multiple times to get desire results. Afterwards the best fit simulation outcomes were collected for further investigation [37]. A range of friction values used (e.g. dry friction 0.05-0.2) to fix optimal values and turbulent flow as 100-2000 m/s2 [37]. Others input factors e.g. release height, materials density, momentum and lambda (coefficient) were eventually retained constant. At the time *simulation* model flow found nearly 90% matched compare to real event the parameters frozen immediately. Among all typical outputs of RAMMS, momentum is relative. Momentum is measured in m^2/s unit, furthermore multiplied by density of debris and area under consideration to derive actual momentum in (kg*m/s).

III. Results and Discussions

a) *Interpretation of simulation*

Generally, RAMMS simulation provides four fundamental outputs are height, momentum, pressure and velocity. In addition, specific information of any point, line profile, run-out longitudinal profile are also possible to visualize in 2D and 3D format. The major concerns of ebris flow are height, velocity and momentum. The high expenses of clearing huge debris and the detachment of roads for the large quantity debris eventually interrupt the local inhabitant's daily life. Thereafter velocity and momentum plays vital role to signify remedial specifications (by type, magnitude and nature) to stop debris flow movement and damage reduction. The dynamic physical parameters of RAMMS simulations are narrated as following:

b) *Mendrui Para*

Debris flow-1 (Figure-3a) Mendrui Para, is beside Raikkhiyang Lake in the Eastern part of Bandarban. On the foot of the small hill local inhabitants occupied entire hazardous area by building human settlements. A small divergence into all branches observed from top to downwards. The simulated maximum flow height was 6.15m and maximum velocity 23.15m/s for flow-1. The debris flow-2 (Figure-3b) is slightly and flow-2 respectively. Comparatively debris flow-2 was little extensive than flow-1 with longer flow height (6.44m) and velocity (35.58m/s). The debris flow-

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1 seems to be more dynamic as to velocity, pressure and thickness. The momentum was identified concentrated in the centre for flow-1 and surrounded for flow-2 proportionally following 59.59m^2/s and 113.96 m^2/s respectively. The distribution of pressure along the entrainment path was found 160.72kPa and 317.909kPa separately for flow-1 and flow 2.

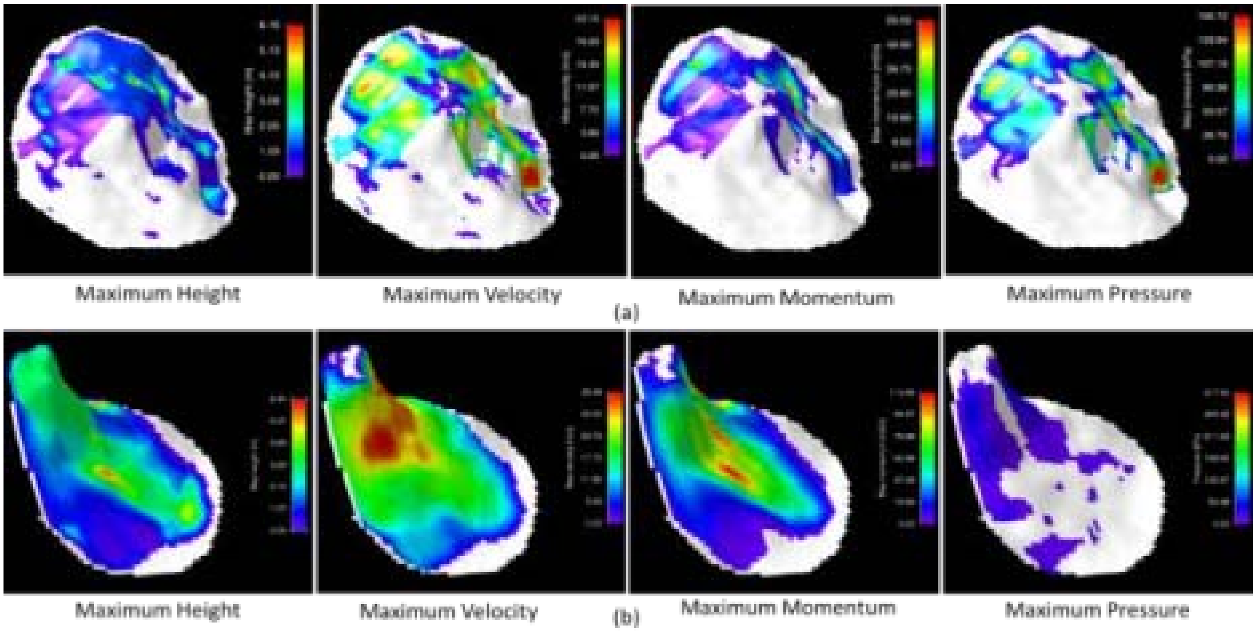

Figure 3: Simulation outputs of debris flow at Mendrui Para. (a) 3-D spatial variation of height, velocity, momentum and pressure along with run out path way of debris flow-1; (b) 3-D spatial variation of height, velocity, momentum and pressure along with run out path way of debris flow-2

c) *Prangsha Para*

Prangsha Para is basically settlement area and nearby western part of Rangamati district. A small channel goes to downstream of the hill foot. The simulated debris flow (Figure-4) model provides maximum flow height 1.11m and velocity 7.02m/s at the initial zone and gets surrounded afterwards. The height pressure recorded in the model 120.80kPa and the maximum momentum of 5.85m^2/s was observed at the primary zone.

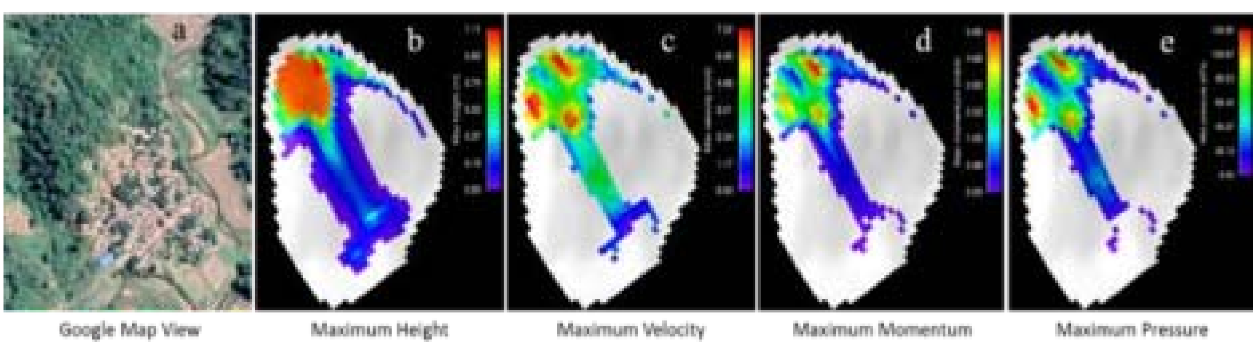

Figure 4: Google map view of present settlement status at Prangsha Para (a); 3-D spatial variation of maximum height, velocity, momentum and pressure along with run out path way of debris flow (b-e)

d) *Dadru Khyong*

Bottom of the selected hill human settlement found in hazardous situation at Dadru Khyong area. The debris flow simulated model (Figure-5) of the selected area was recorded 4.75m maximum height at the centroid. Model result show that maximum velocity of 22.78m/s at the centroid. Maximum momentum was found 54.09m^2/s.

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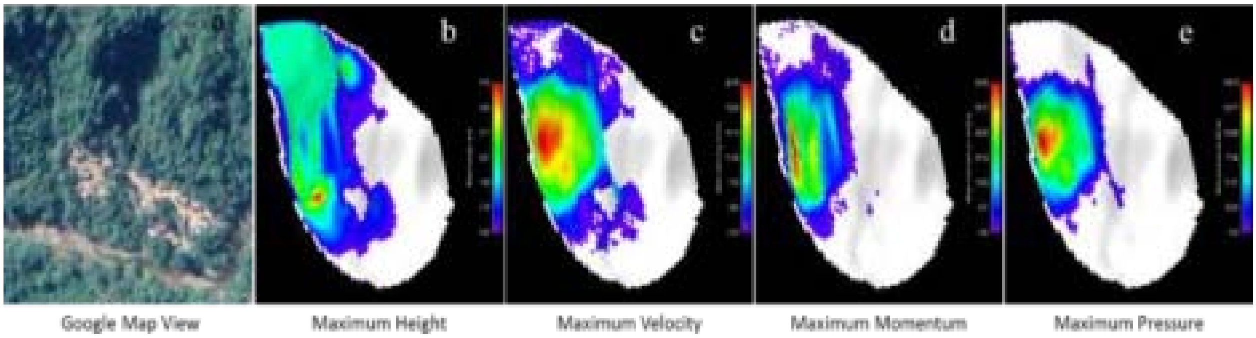

Figure 5: Google map view of present settlement status at Dadru Khyong area (a); 3-D spatial variation of maximum height, velocity, momentum and pressure along with run out path way of debris flow (b-e).

Overall, figure-6 describes the vertical profile of the three selected defies flow simulation area. The first one (Figure-6a) is showing the flow height and distance travel by the debris of *Mendrui Para* area which touches to 4.0m and suddenly slow down till the bottom. It has destructive impact on the local inhabitants due to the altitude variation tops to 350m. The second one (Figure-6b) is describing the maximum height relationship with distance covered by debris at *Prangsha Para* area which has a clear indication of rush flow over the settlement as the lowest altitude over 400m. And the third one (Figure-6c) is showing the maximum sheer stress varies and a sudden pick denotes extreme situation raising altitude till 200m.

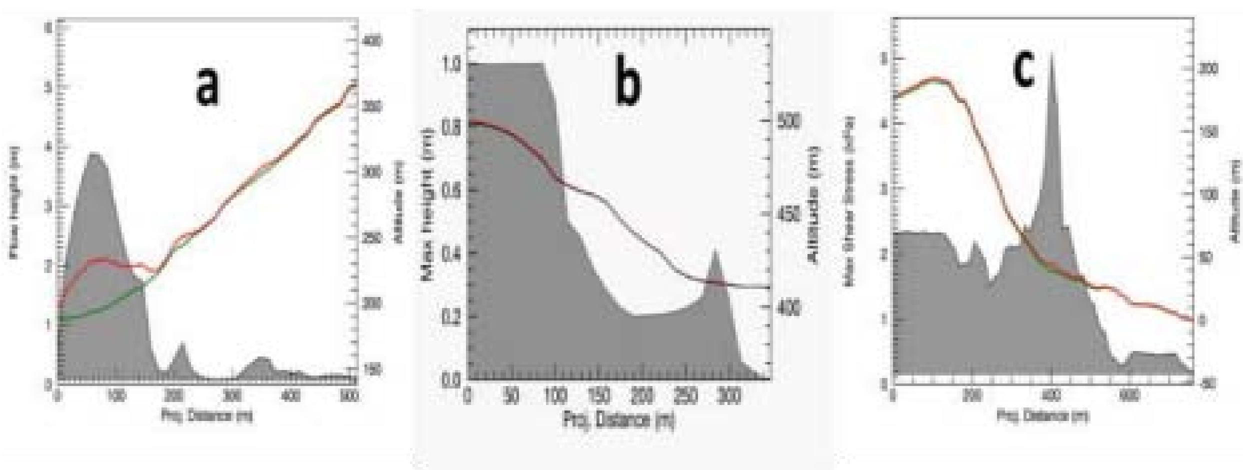

Figure 6: Vertical profile of the debris flow simulation. (a) *Mendrui Para* area flow height and covered distance relationship; (b) *Prangsha Para* area maximum height and covered distance relationship; (c) *Dadru Khyong* area Maximum sheer stress and covered distance relationship; And all the three have a common secondary axis altitude

IV. Conclusion

Overall the study concludes the following remarks:

- Dynamic physical flow parameters can be calculated using numerical simulation and flow modeling to aid mitigation, like height of check dams can be determined to digest initial thrust of the flow
- Collateral damage due to obstruction of rivers pathway and possible alteration resulting inundation can be assessed by knowing the velocity, height, pressure and momentum of modeled debris flow.
- Predictive modeling can be helpful in possible debris flows with little or no variation of geo mechanical properties at adjacent susceptible localities.

Conflicts of Interest: The authors declare no conflict of interest.

Authors' Contributions: M.M. proposed the topic. M.M. and S.L.C. commanded the research design, data processing, analysis, and wrote the manuscript.

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