A Simulation of the Irshalwadi Landslide using RAMMS DebrisFlow

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Abstract

Landslides are common in hilly areas, especially during monsoons, and pose a significant risk to nearby communities. The objective is to build preventive and safety measures to protect the communities. A recent landslide near Matheran was simulated to obtain friction parameters for the area and the flow velocities. The insights should help build dams to protect the communities from landslides.

1 Introduction

The landslide occurred on 19th July 2023, around 21:30, in the remote village of Irshalwadi, approximately 60km from Mumbai. Landslides are typically triggered by factors such as intense rainfall, earthquakes, volcanic activity, or human activities like deforestation and construction. There was a spell of anomalously heavy rainfall from the 17th to the 19th of July. There is also evidence of excess deforestation at the base of the landslide site. Moreover, after talking with locals, it was understood that the earth was dug from near the base of the landslide site to make bricks. The landslide likely occurred from a combination of these events.
The landslide was split into two lobes and wiped almost the whole village. Such events are standard during monsoons throughout the Western Ghats and cause an immense loss of life. We can get data on building dams to protect such villages using simulations. We start with a pre-event DEM of the area and modify it to include necessary features with a significant impact on the debris flow that occurred, then run simulations iteratively until the simulated deposition resembles the observed deposition in spread, height and volume.

2 Method

We run the simulation using RAMMS DebrisFlow, a flow model based on the Voellmy fluid friction model. The Voellmy model calculates the frictional resistance as a combination of two components: 1. Dry-Coulomb type friction (μ), represents the friction between the solid particles similar to a block sliding down the slope. 2. Viscous-turbulent friction (ξ), represents the friction due to the interaction of the fluid particles in a turbulent flow. The equation for the Voellmy-fluid friction model is given as:

$$S = \mu N + \frac{\rho g u^2}{\xi} \tag{1}$$

where:

- μ: Dry-Coulomb type friction coefficient
- N: Normal stress on the running surface (Pa), calculated as: $N = \rho h g \cos(\phi)$
  - ρ: Bulk density of the debris flow (kg/m^3)
  - h: Flow height (m)
  - g: Gravitational acceleration (m/s^2)
  - ϕ: Slope angle (degrees)
- ξ: Viscous-turbulent friction coefficient
- u: Flow velocity vector, $u = (u_x, u_y)^T$ (m/s)
  - u_x: Flow velocity in the x-direction
  - u_y: Flow velocity in the y-direction

The data input is in the form of the digital elevation model(DEM) of the domain of the landslide, the release area of the debris as a shapefile and the calibrated parameters, μ and ξ.
The first part is the estimation of the initial release area, which involves marking the area from where the debris started flowing followed by the depth at various points. Images taken post-landslide at the site, along with Google Earth imagery, have been used to estimate this.

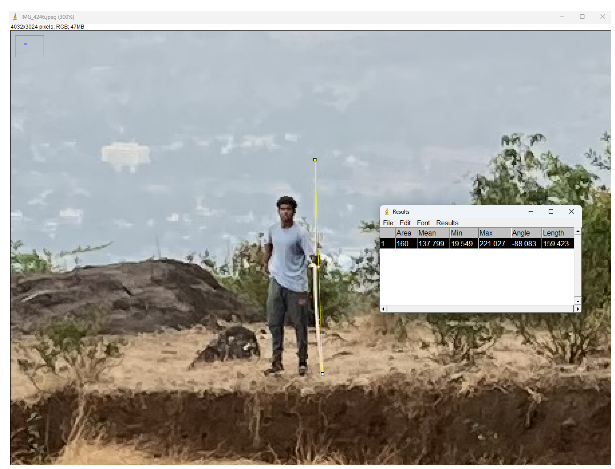

Figure 1: Image with reference stick

By taking the ratio of pixels for the height at each point with the height of the reference stick measured at 159 pixels, we charted the depth of the release area at various points along the release. We then further referenced other images with the same points to map a significant portion of the depth at the edge.

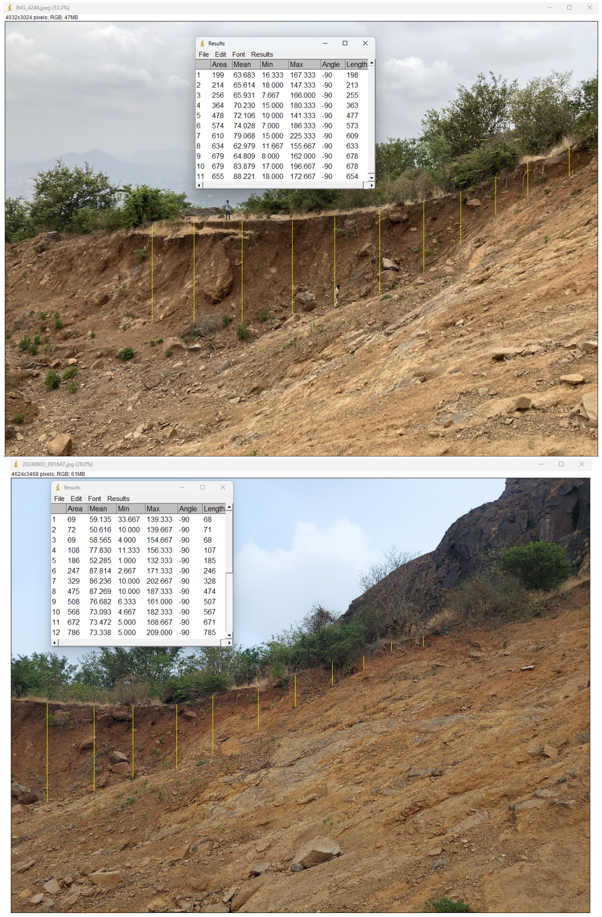

Figure 2: Note the 11th point in the second image matches with the 6th point in the first image

Length in pixels(l)	Height in m
198	1.2
213	1.3
255	1.6
363	2.3
477	3
573	3.6
609	3.8
633	4
678	4.3
678	4.3
654	4.1

Length in pixels(l)	Height in m
68	0.36
71	0.38
68	0.36
107	0.57
185	1
246	1.3
328	1.8
474	2.5
507	2.7
567	3
671	3.6
785	4.2

This covers the first 30m of the release area. Beyond this, the depth is approximately 4.5m till the end. The Google Earth image was used to mark the area by going around the areas without new vegetation.
When a simulation was run with this information directly on the DEM with the default parameters, we observed a mound obstructing the debris flow and causing it to split into two branches. Upon closer inspection, the Google Earth image revealed a small group of large trees.

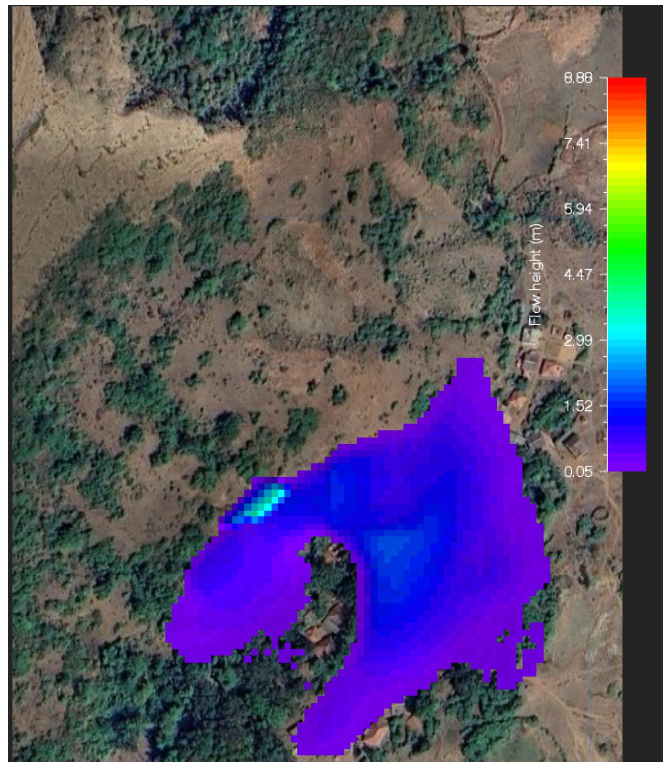

Figure 3: Simulation with unaltered DEM

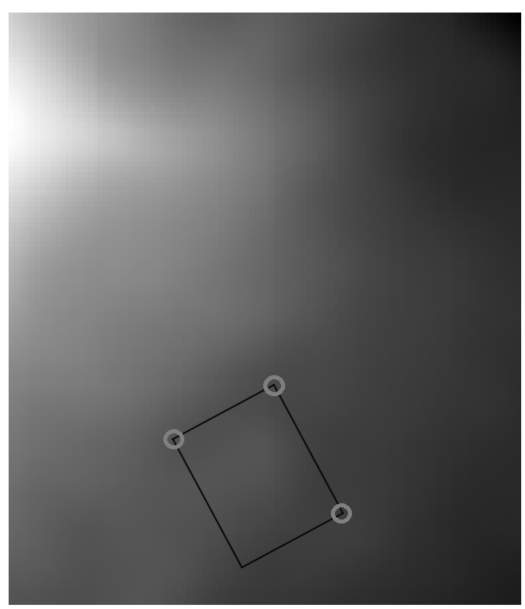

Figure 4: Points used to make plane to remove mound

For the mound formed due to trees, we made a box covering the whole mound and then chose the top and bottom right corners to define a plane and basically cut through the mound for the defined box. Another thing we found was from some drone imagery of the area, which revealed a seasonal stream flowing through the right bank. A post-event inspection of the site confirmed the presence of the stream and estimated its depth to be roughly 5m. We collected GPS points along the bank of the river, and that, combined with the Google Earth image, was used to mark the stream. After this, we applied Gaussian smoothing to the DEM to get rid of the sharp edges that had formed due to the editing.

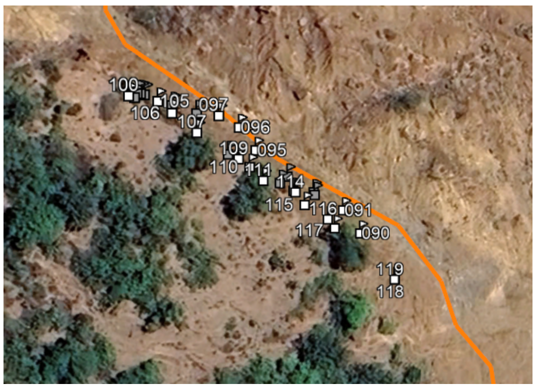

Figure 5: GPS point recorded and the stream dug in the DEM

Another observation at the site was that the trees on the right bank had fallen and, along with more trees, had formed a dam stopping the flow from flowing further. This dam was also erected in the DEM.

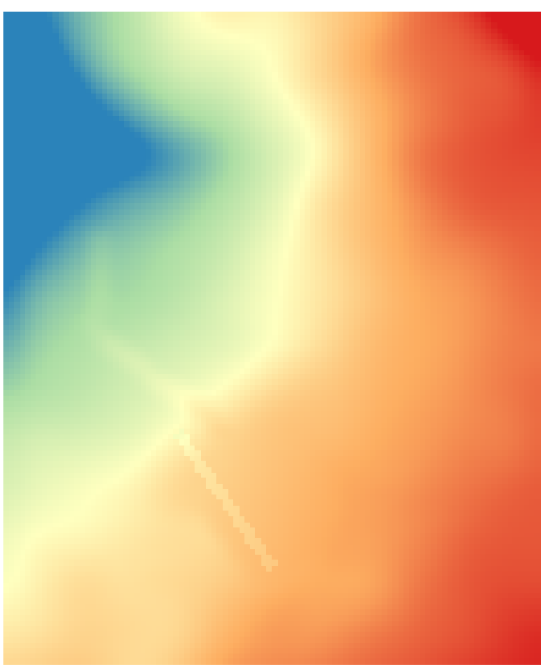

Figure 6: Final DEM after all edits

3 Result

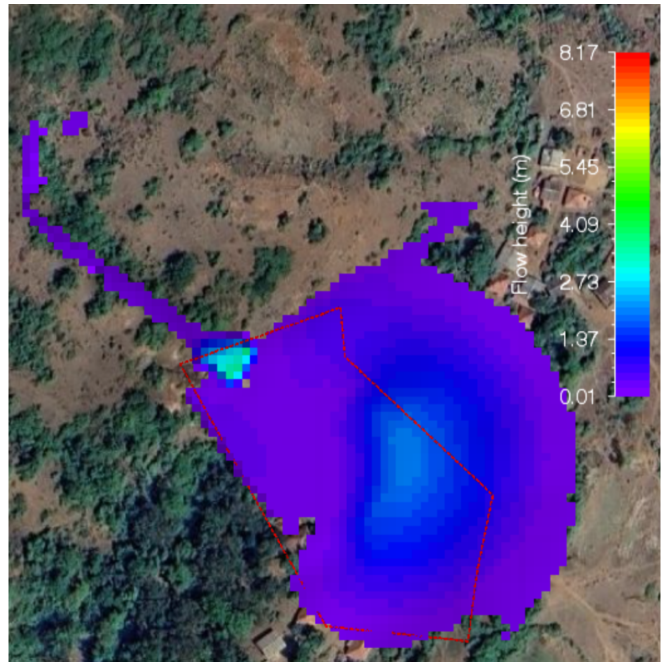

Figure 7: Max flow height (red polygon is actual deposition)

There is a large overflow of debris beyond the observed area. This is likely due to a dam similar to the one on the right side of the flow, as the flow stops along the side of a path, but we could not find any photos giving solid evidence of this. The deposition height is slightly more than 2m at the highest points, roughly matching the observed height.

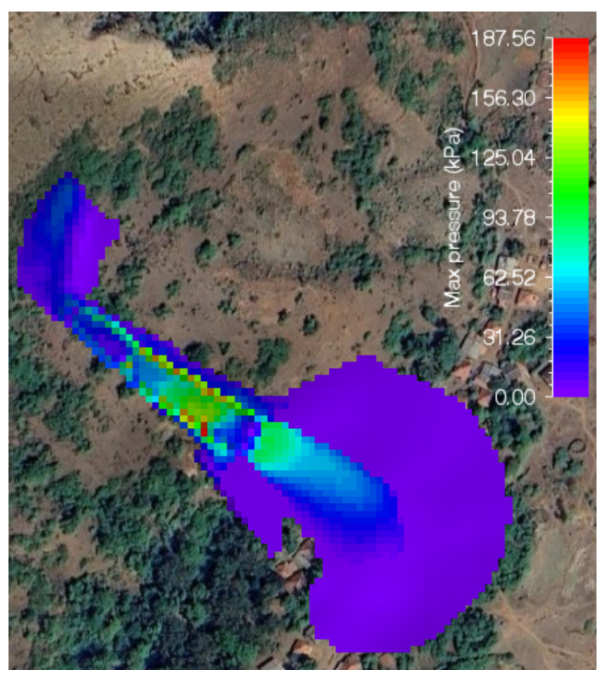

Figure 8: Max flow pressure

The value of μ is 0.2, and that of ξ is $100 m/s^2$ as obtained from the simulation. The maximum pressure reached was $187.56 kPa$, and the highest velocity obtained by the flow was $8.66 m/s$. The total volume of the deposition was $10144.8 m^3$. A 16m tall dam was able to stop the flow from flowing into the village. The reason for the tall dam is the short distance between the release area and the village.

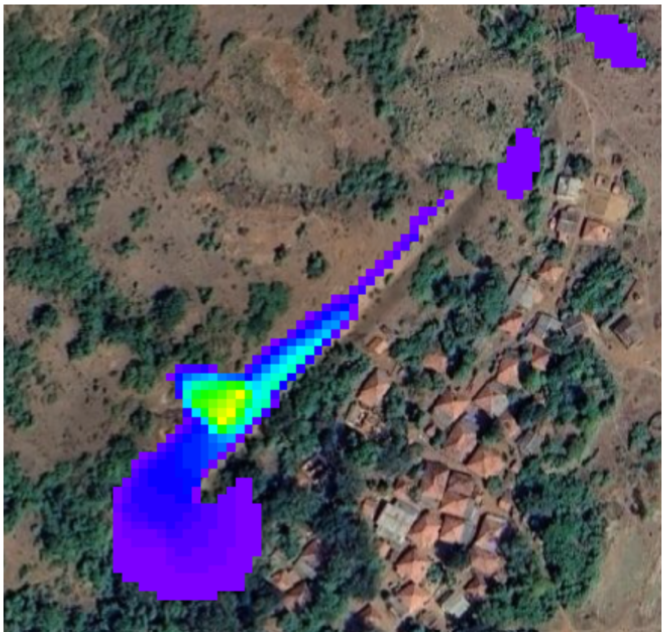

Figure 9: Simulation with dam

4 Discussion

- If there is a slope, a landslide is bound to happen, and there is a threshold where a slow-creeping landslide transitions into a fast flow of debris. Events like rain cause this threshold to fall; hence, many landslides happen during monsoon. So, there is a heightened need to protect the communities in landslide-prone areas.

- The μN in the equation represents the dry static friction similar to the friction experienced by a block sliding on a slope. It determines the spread of the deposition after reaching the deposition area. A higher value results in a smaller deposition spread while a lower value in a larger spread. The second term, $\frac{\rho g u^2}{\xi}$ can be understood as a drag due to the velocity of the flow. It determines how far the deposition area will be from the release area. A larger value of ξ means a lower value for the second term and hence the deposition area would be further down the slope while a smaller value would correspond to the deposition area being closer to the release area. So, a smaller value for a more rocky landslide and a larger value for a more muddy, fluid-like landslide. At the beginning of the landslide the second term plays a bigger role because the velocity is higher in the initial phase. In the second part when the deposition happens the first term determines how much the debris spreads out.

- The effect of adding erosion or a delay in the different sections of the landslide was negligible. Erosion caused the deposition volume to increase compared to the initial release area which can be used to account for the higher deposition volume compared to the release volume that were observed. It also increased the spread area of the deposition.

- The delay in different landslides on the other hand caused no change to the simulation other than a little delay in the landslide reaching the village. The final deposition area remained the same.

- Despite the overall height of the flow not being very high, the dam needed to protect the village would have needed to be double the highest flow height. This is because the village is located very close to the deposition area. If the village was located just 50m further down, a 7m dam also would have been sufficient to stop the debris from reaching the village.

- Another major observation is there is a clear difference between the release area and the deposition area similar to a glacier.

- Building dams is one of the ways the communities living near such places can be protected from damage by landslides. Further research can be based on stopping the flow by digging wells instead of building dams or a combination of the two. Consecutive smaller dams could also be successful in stopping the flow.