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Morphometric and channel erosivity analysis of lateritic gully catchments using high resolution DTM and repeat survey Structure-from-Motion datasets

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Abstract— **Fine-scale gully catchment mapping is a prerequisite towards ascertaining any soil loss estimates from such areas. The use of high resolution Digital Terrain Models (DTM) has greatly facilitated extraction of minor gully features, but these remain essentially top-down views of the surface and do not capture erosional or morphological aspects formed on gully walls. However, Structure-from-Motion affords repeat survey capabilities that allow documentation and precise mapping of gully features and the main erosion channels, while also providing means of creating side-view looking 3-D models for documenting otherwise obscure features. Repeat such surveys provide the means for using a DEM differencing approach to quantify the amount of erosion and surface lowering in the gully catchment. Longitudinal profile analysis of the developed gully channels using standard hydraulic and steepness equations of the Detachment Limit Model also provide insights into the rill erosivity. The above methods have been used to analyze a lateritic badland tract in southwestern West Bengal in eastern India.**

I. Introduction

Gully research has often focused on quantifying their morphological parameters using erosion pins, total stations, laser profilometers and differential GPS[1], along with the use of remote sensing products and techniques, like very high resolution (VHR) satellite imageries and Digital Elevation Models (DEMs)[2,3,4]. The advent of airborne and terrestrial laser scanning[5] and image modeling through Structure-from-Motion & Multi-view Stereo (Sfm-MVS) technologies [6,7] now afford greater capability of using side-looking sensors to document gully wall morphological forms that were not always discernable from top-down satellite based sensor views. In the Indian context too, DEM generation from satellite stereo-data for terrain analysis[8] has been found especially suitable for demarcating and analyzing small catchments and gully fields[9].

The Gangani Tract, (locally known as *Ganganir Danga*, translated as *Land of Fire*, due to the deep ochre hues of the exposed rocks as a result of the presence of hydrated iron oxides), is situated near the small town of Garbeta ($22^{0}51'47''$ N, $87^{0}21'13''$ E) in Paschim Medinipur district, West Bengal, in eastern India. The area is part of the lateritic uplands situated in the northern and western portions of the district and is deeply gullied and riven by numerous channels that dissect the upper lateritic and lower elevation sandstone surfaces. Detailed mapping and morphometric characterization of the region is thus important for ascertaining the extent of rill and gully erosion occurring therein and the year-wise changes in the small gully catchments. Morphometric analysis of the incised channels developed on the exposed surfaces is also important to document their erosivity, that contributes directly towards the overall erosion occurring from the region.

II. Methods

A high resolution 2 meter Digital Terrain Model (DTM) obtained from JAXA (Figure 1), generated using the ALOS Daichi satellite has been used to analyze the terrain attributes of the area. This dataset was used to extract the various gully basins and the traditional morphometric parameters for each of them, like basin hypsometric integrals. Alongside this, specific locations have been surveyed repetitively during the last 3 years using the Structure-from-Motion (SfM) technique, leading to the generation of multiple DTM datasets, which could be subtracted from each other to obtain the surface elevation changes.

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Rebound RockSchmidt Hammer readings on the gully wall helped characterize the differential resistance of the surface lithologies to incision by overland flow. Longitudinal profile analysis of the formed gullies was done using the Detachment Limit Model[10] for characterizing erosion from bedrock channels, as per the following equations:

$$k_{sn} = \left({}^{e}/_{K}\right)^{1/n} \tag{1}$$

k_{sn}- Normalized steepness index, e- Erosion rate, K- stream power coefficient combining lithology-rainfall aspects

$$\tau = \rho g \left({}^{Q}/_{W}\right)^{0.6} S^{0.7} \tag{2}$$

Q- Discharge, W- Width, ρg- Specific weight of water, S- Slope, τ- shear stress generated by water flow in the gullies

III. Results and conclusions

Use of the 2m DTM enables extraction of various morphological features of the badland tract, especially the fingerlike projections of the numerous gully heads. The older gully fields are larger with more total volume loss. When normalized by area, smaller younger gullies are more seen to be more erosive, with higher hypsometric integrals (Figure 2). Due to their higher erosivity, these younger gullies had also expanded at higher rates.

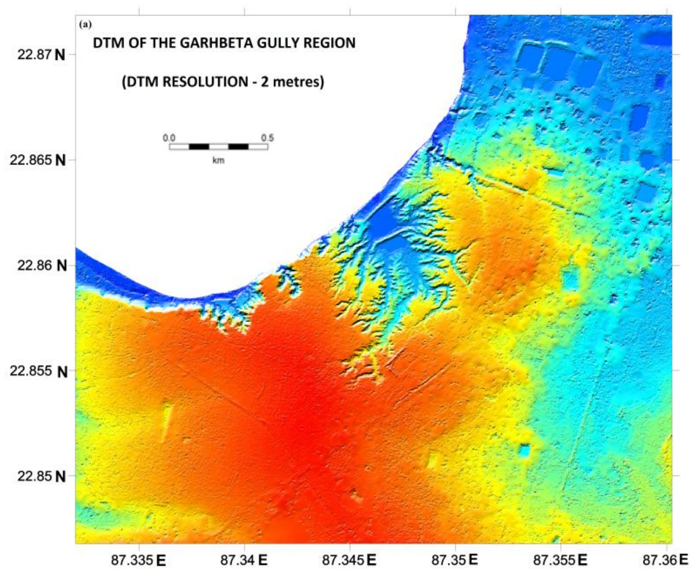

Figure 1. The 2 meter DTM of the Gangani Tract with the finger-like projections of the gullied landscape

The SfM method allowed creation of 3D representations of the gully wall and cave-forms (Figure 3), allowing their measurements, which would be otherwise impossible from spaceborne top-down images. Thus SfM-MVS provides a viable solution to not only represent them on screen but also the ability to view them interactively from all possible angles. Multi-temporal SfM datasets helped depict the micro-topographic changes in the dimensions of the rills and minor gully network and their rates of deepening were ascertained from DEM differencing such datasets.

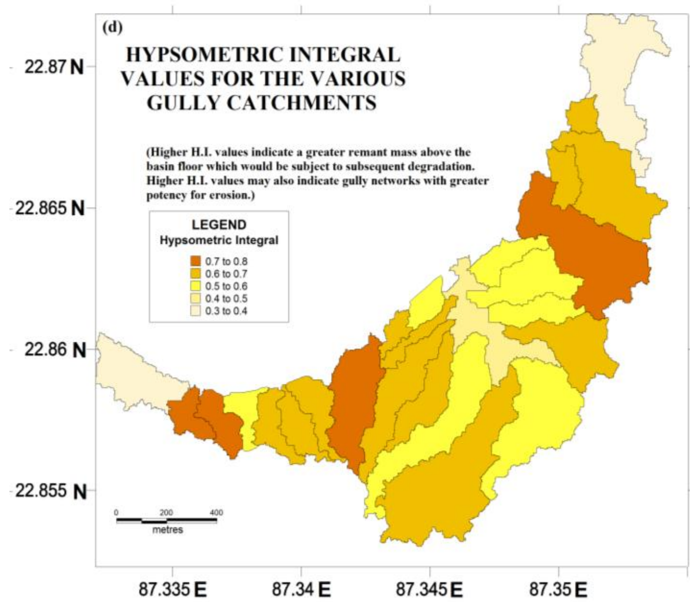

Figure 2. Hypsometric integral variations across the gully basins

Figure 3. SfM based 3-D model of a cave and earth pillar form [From Patel et al., 2020]

Extraction of the Ksn parameter and characterization of the channels on basis of their steepness values again revealed spatial variations, with the younger gullies in the western part of the Gangani Tract reporting the highest values and show marked breaks in their longitudinal profiles where the gully channel transitioned across different lithologies.

Plots of RockSchmidt hammer readings taken along the gully walls and floor show the lithological variations along the gully longitudinal profile and these could be correlated with the breaks and minor knickpoints seen along them, as ascertained from the Ksn analysis.

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