Morphometric and Longitudinal Profile Analysis of Lateritic Gully Catchments using high resolution data and SfM

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Where are we looking for an example...

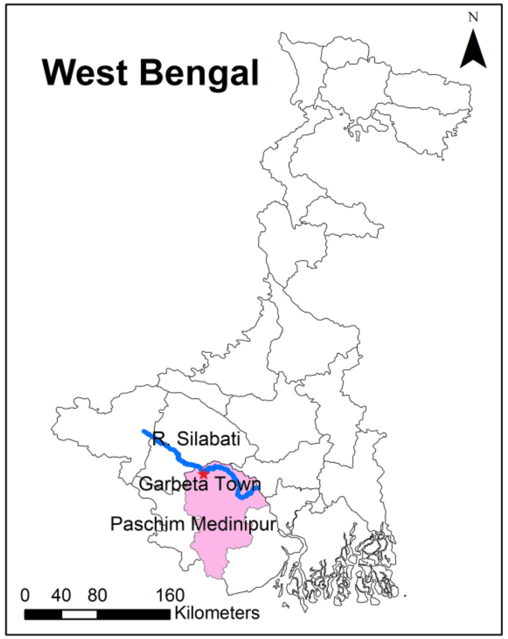
‘Ganganir Danga’ (*Land of Fire* due to ochre hues) at 22°51’-22°52’N, 87°20’-87°21’E), SW Bengal, c. 3 sq.km.

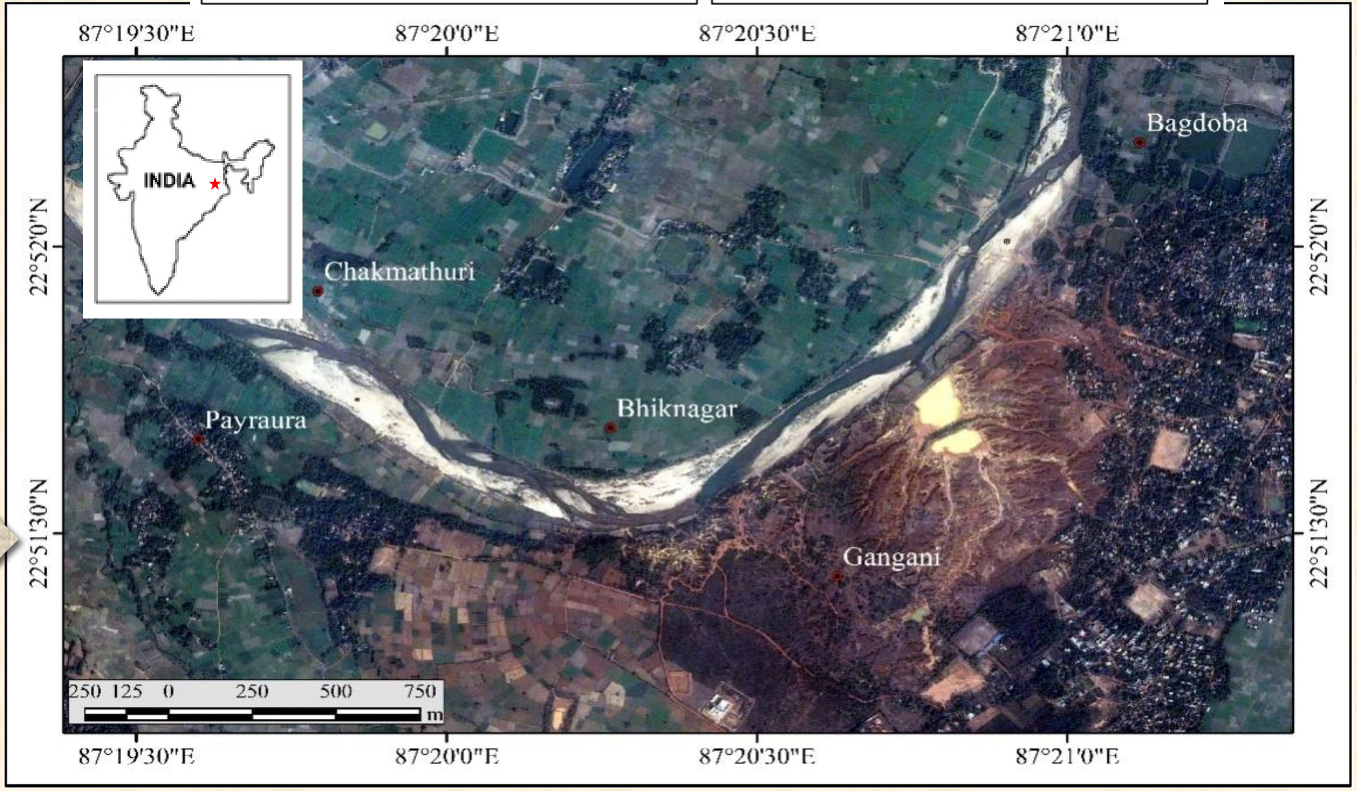
Avg. Temp. 35°C, Annual pptn: 1500mm - Humid badland (Gallart et al., 2013).

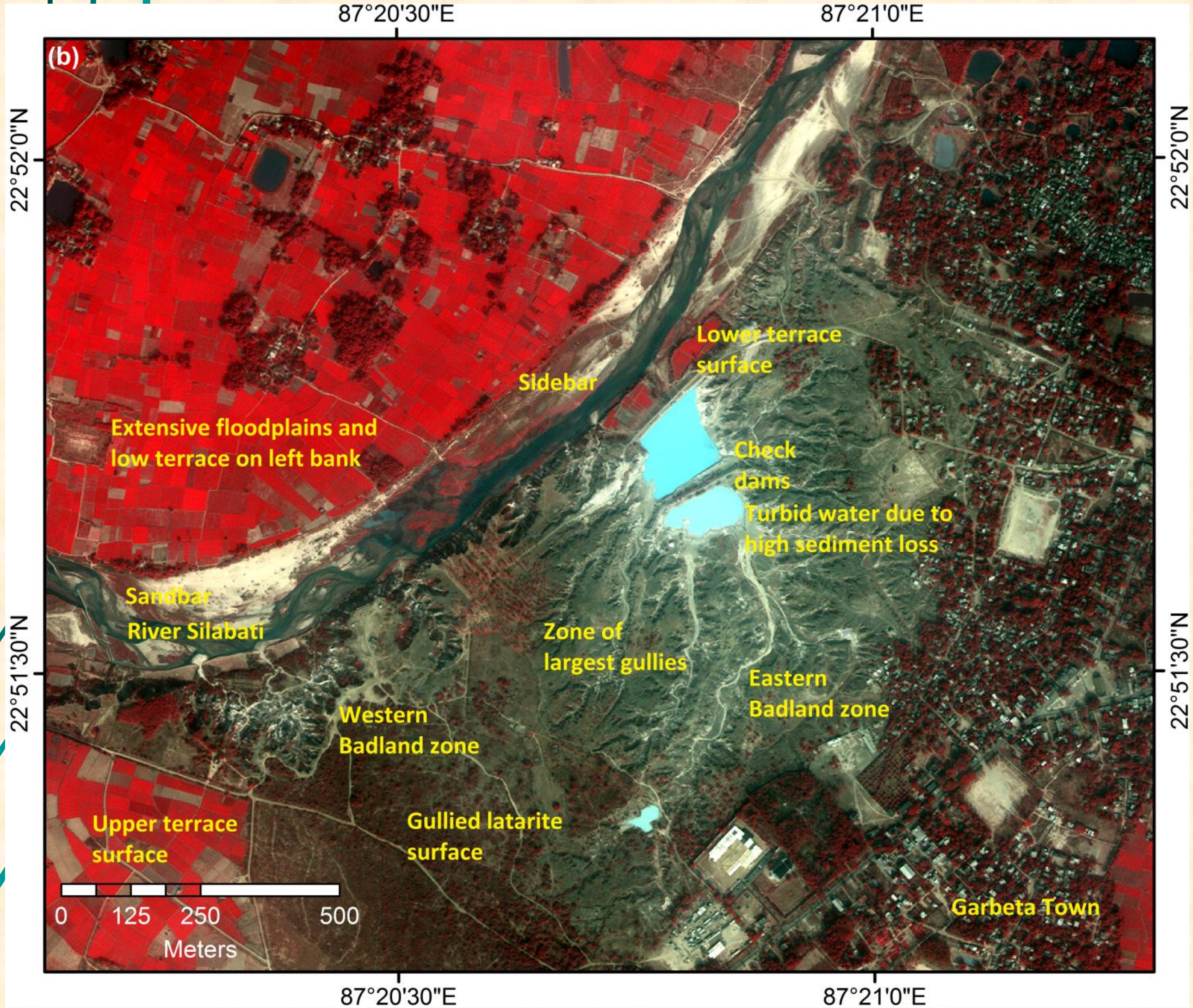
Cut into the lateritic Sijua Formation with two distinct surfaces (~15m diff.)

Intense rilling & gullying causing sediment loss.

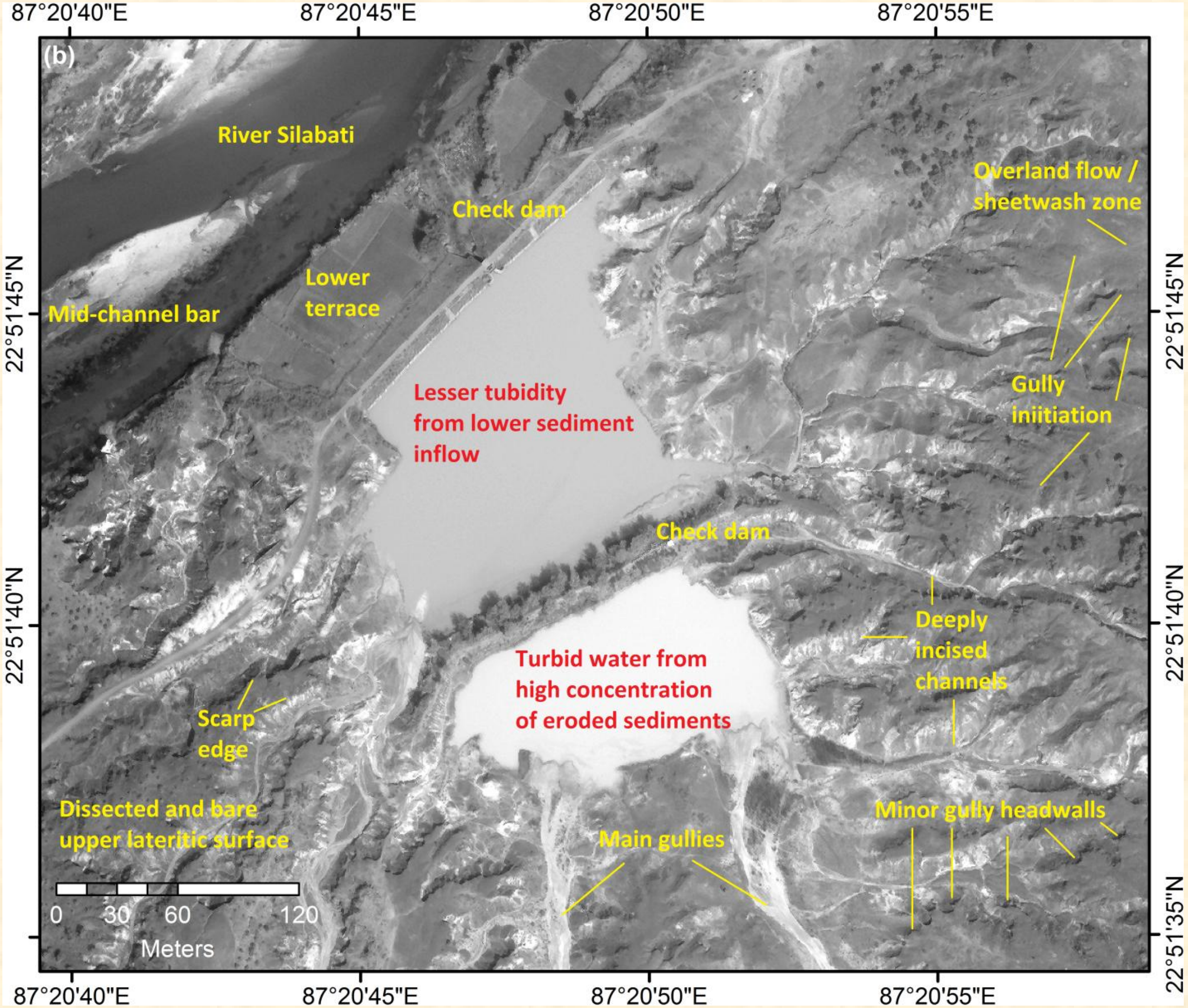
Inducted as a Geomophosite in Kale (ed.) 2017, *Geomorphosites in India*, making apparent its intrinsic, geologic, landscape and aesthetic value.







High resolution multispectral image (Worldview-2 4B multispectral bundle; spatial resolution: 1.84 metres; image date: 5 January 2011)



Very high resolution panchromatic image (Worldview-3 PAN; spatial resolution: 0.31 meters; image date: 12 November 2014)

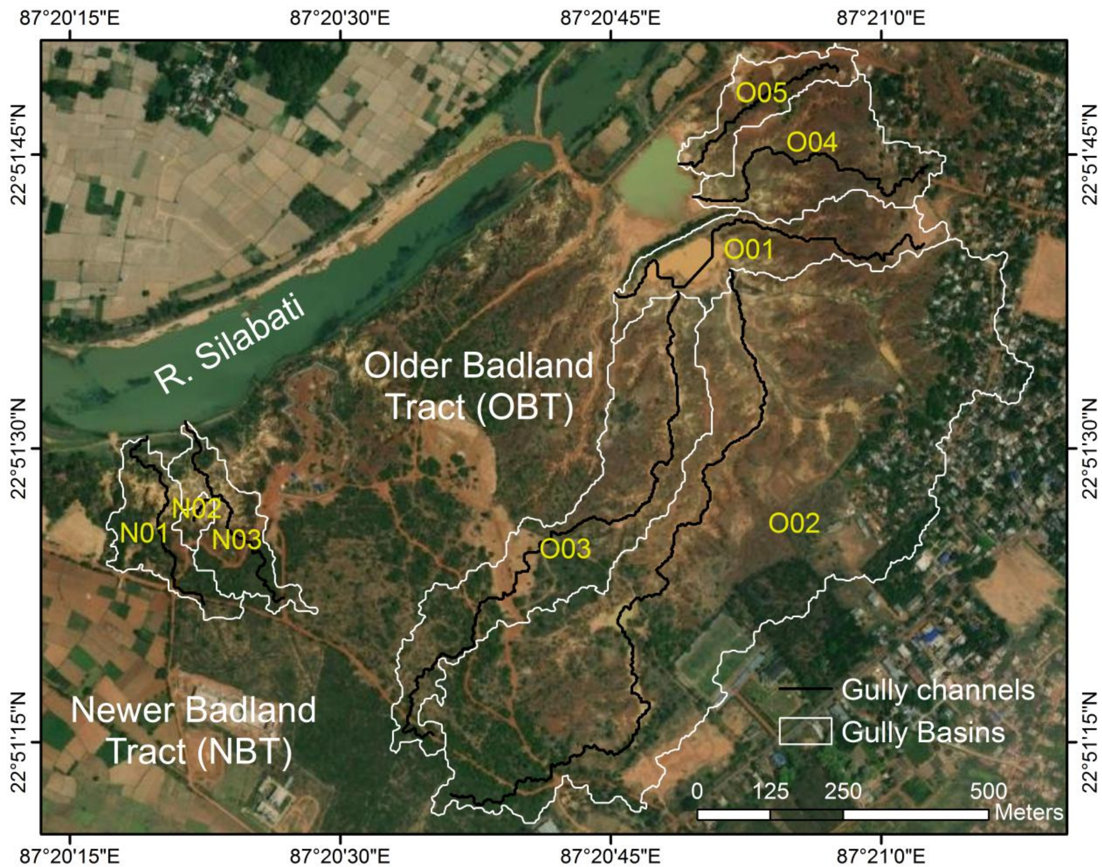
Typical Badland Features in Lateritic Terrain at Gangani











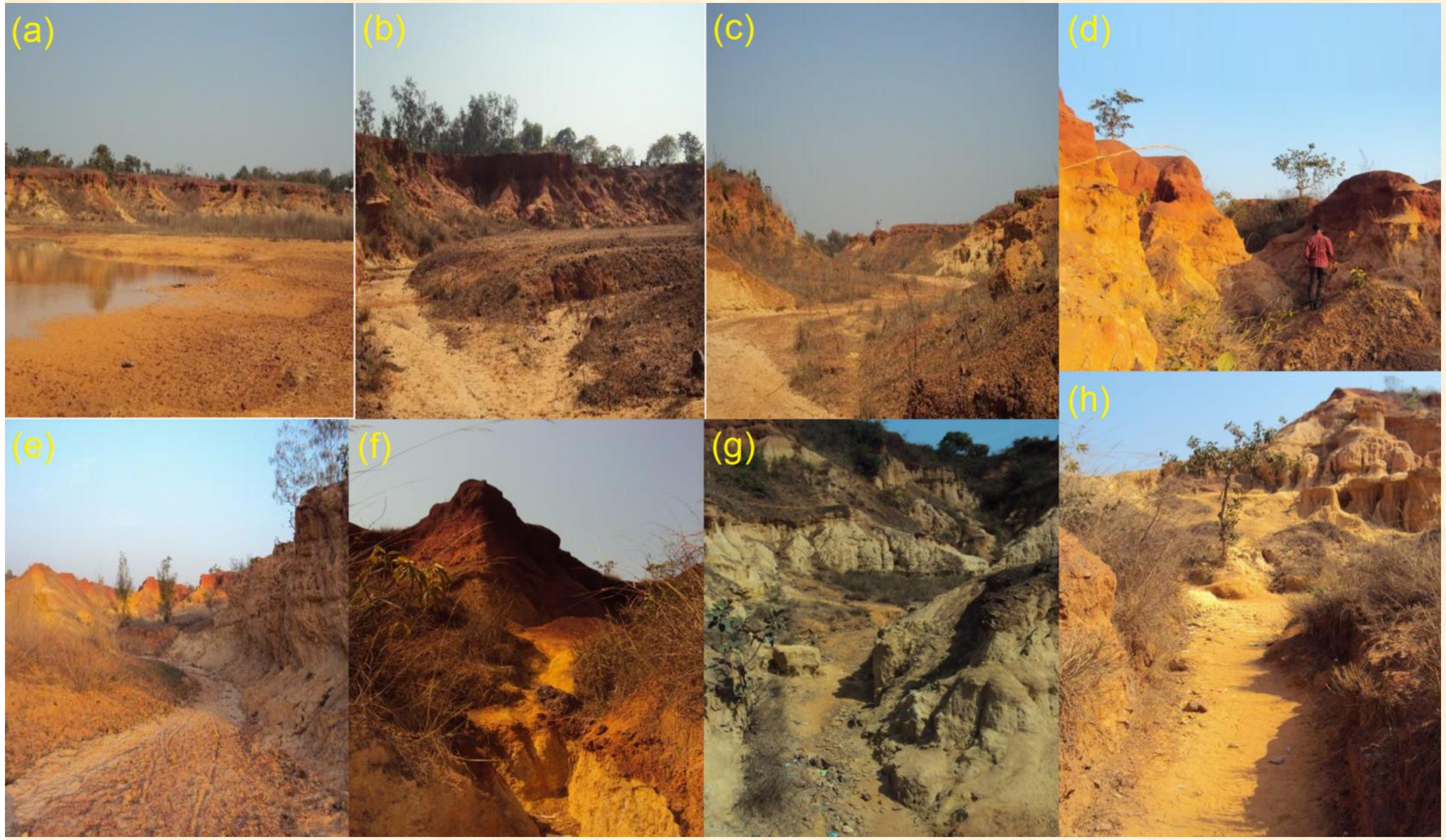
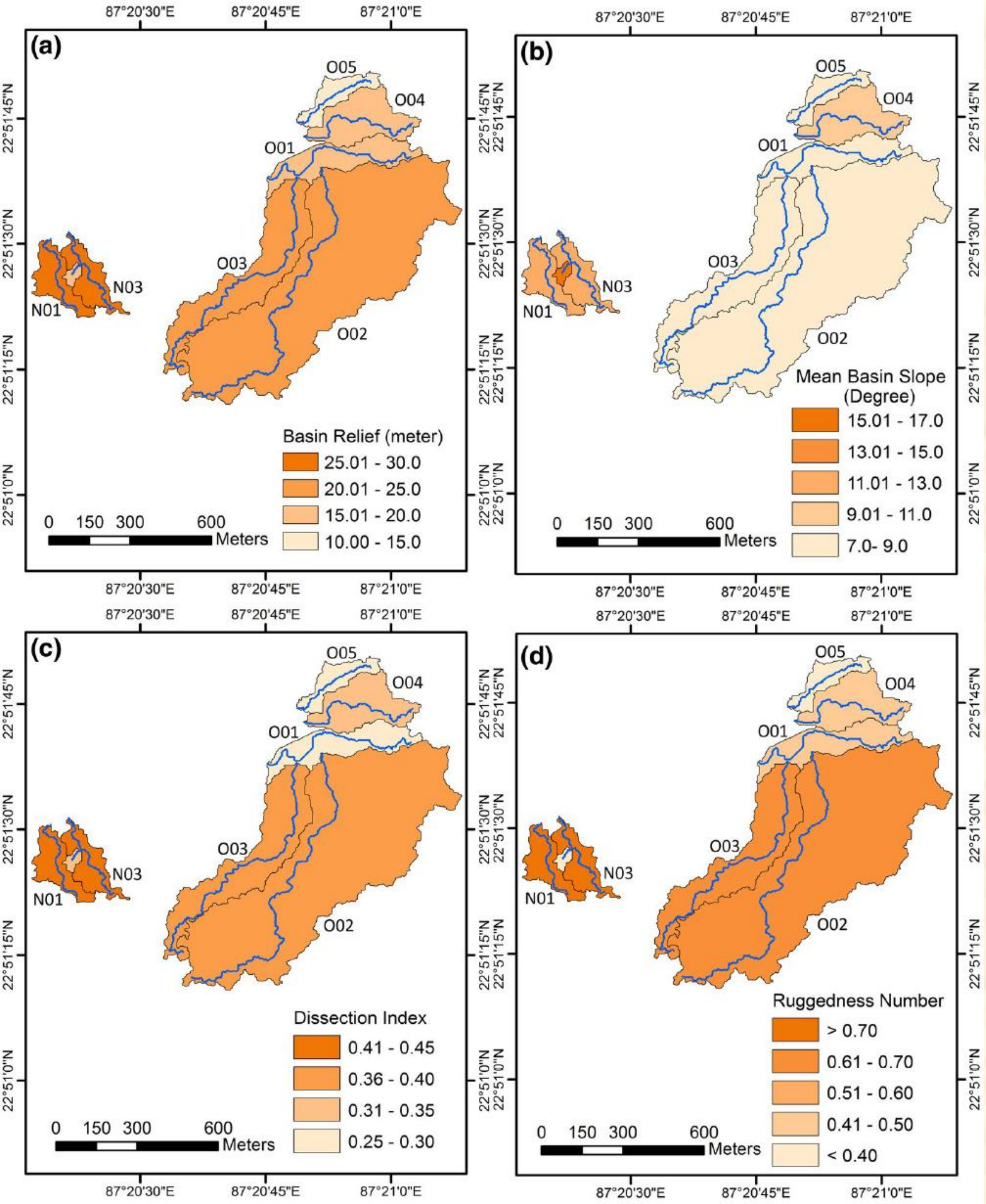
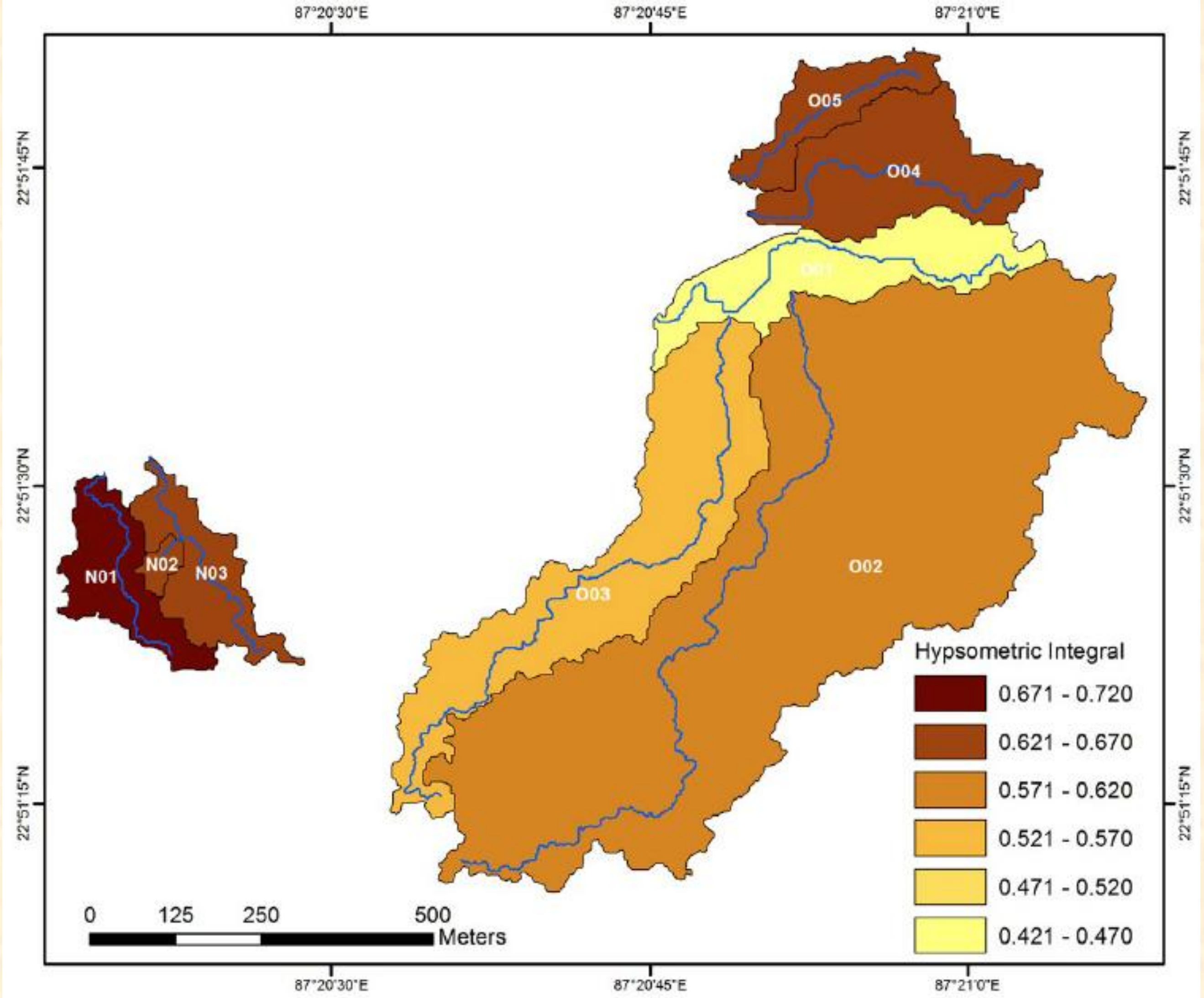


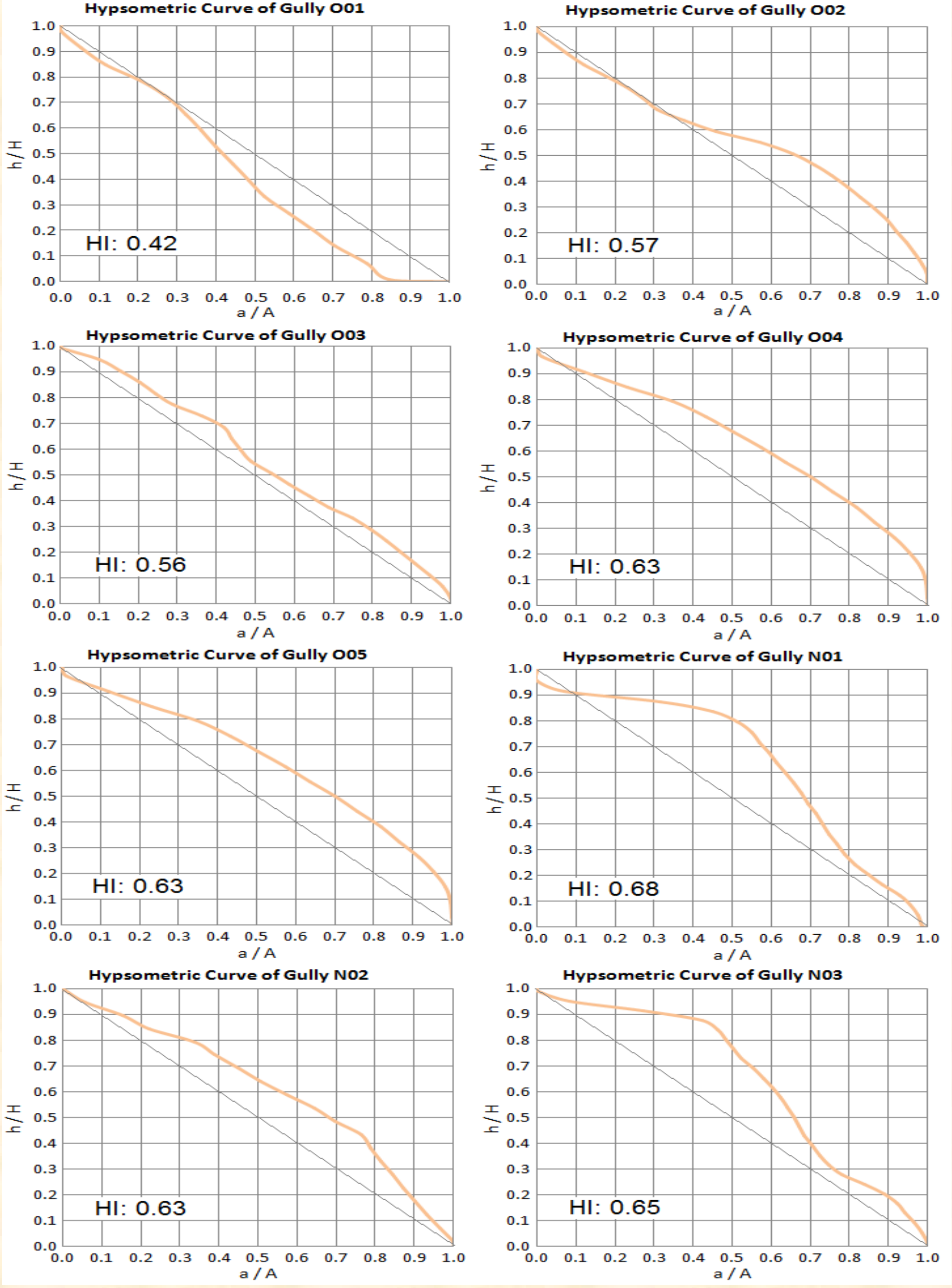
TABLE 1 Select morphometric parameters of the studied gully basins

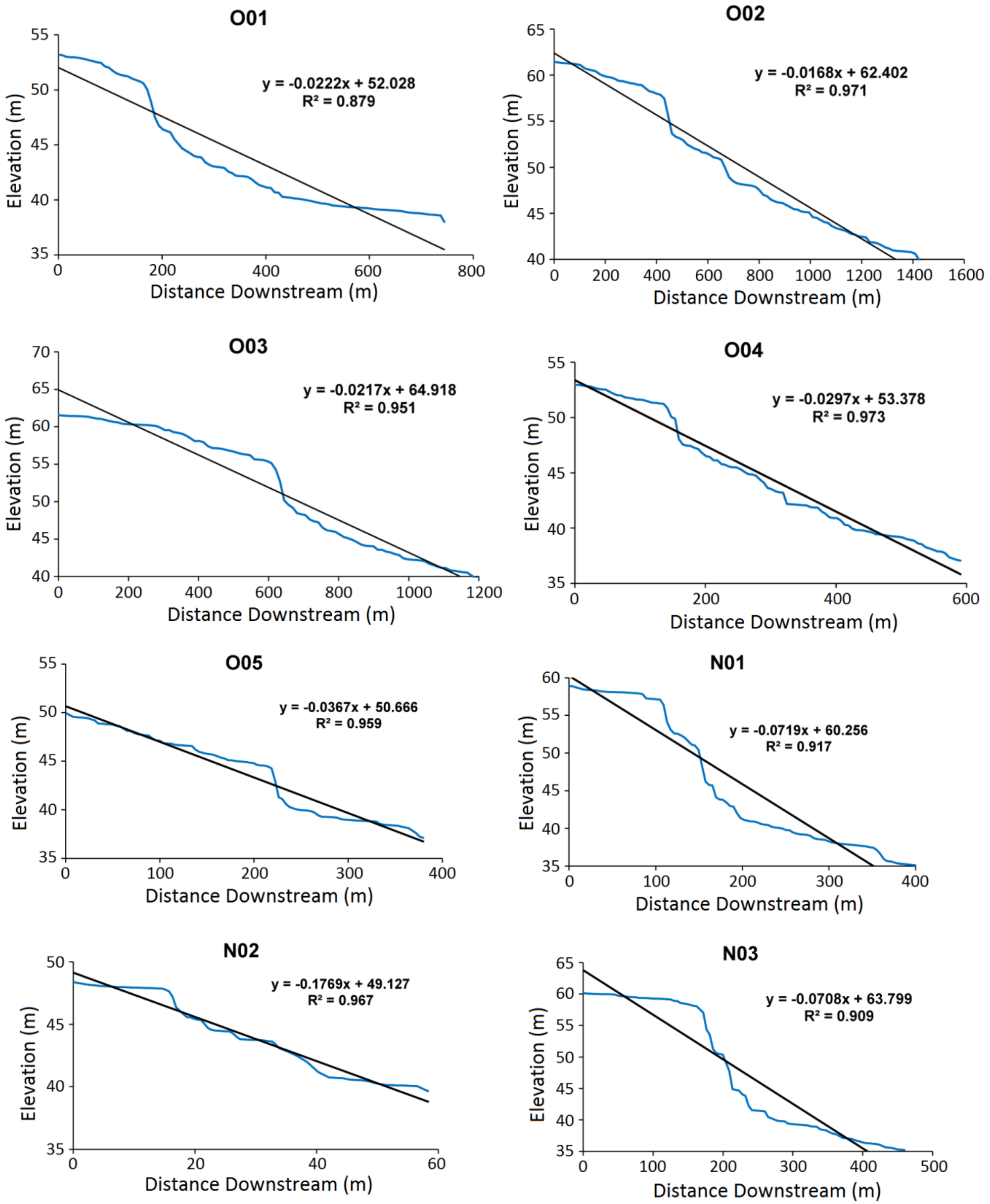
Gully basin	Area (m^2)	Perimeter (m)	Basin relief (m)	Mean slope (°)	Drainage density ($m/10{,}000\ m^2$)	Dissection index	Ruggedness number	Hypsometric integral
O01	46,731.669	1,582.354	15.48	8.57	293.655	0.285	0.455	0.422
O02	360,981.247	4,066.033	23.39	7.07	267.416	0.374	0.625	0.571
O03	97,693.815	2,566.339	22.87	7.73	283.007	0.367	0.647	0.556
O04	49,330.034	1,231.382	16.80	9.77	264.559	0.313	0.444	0.628
O05	20,803.732	961.614	13.72	7.22	244.963	0.268	0.336	0.633
N01	24,476.632	1,031.081	25.27	12.18	281.415	0.420	0.711	0.677
N02	3,184.300	274.161	18.68	16.98	184.979	0.320	0.346	0.633
N03	24,385.686	1,166.690	26.80	11.25	303.785	0.437	0.814	0.645

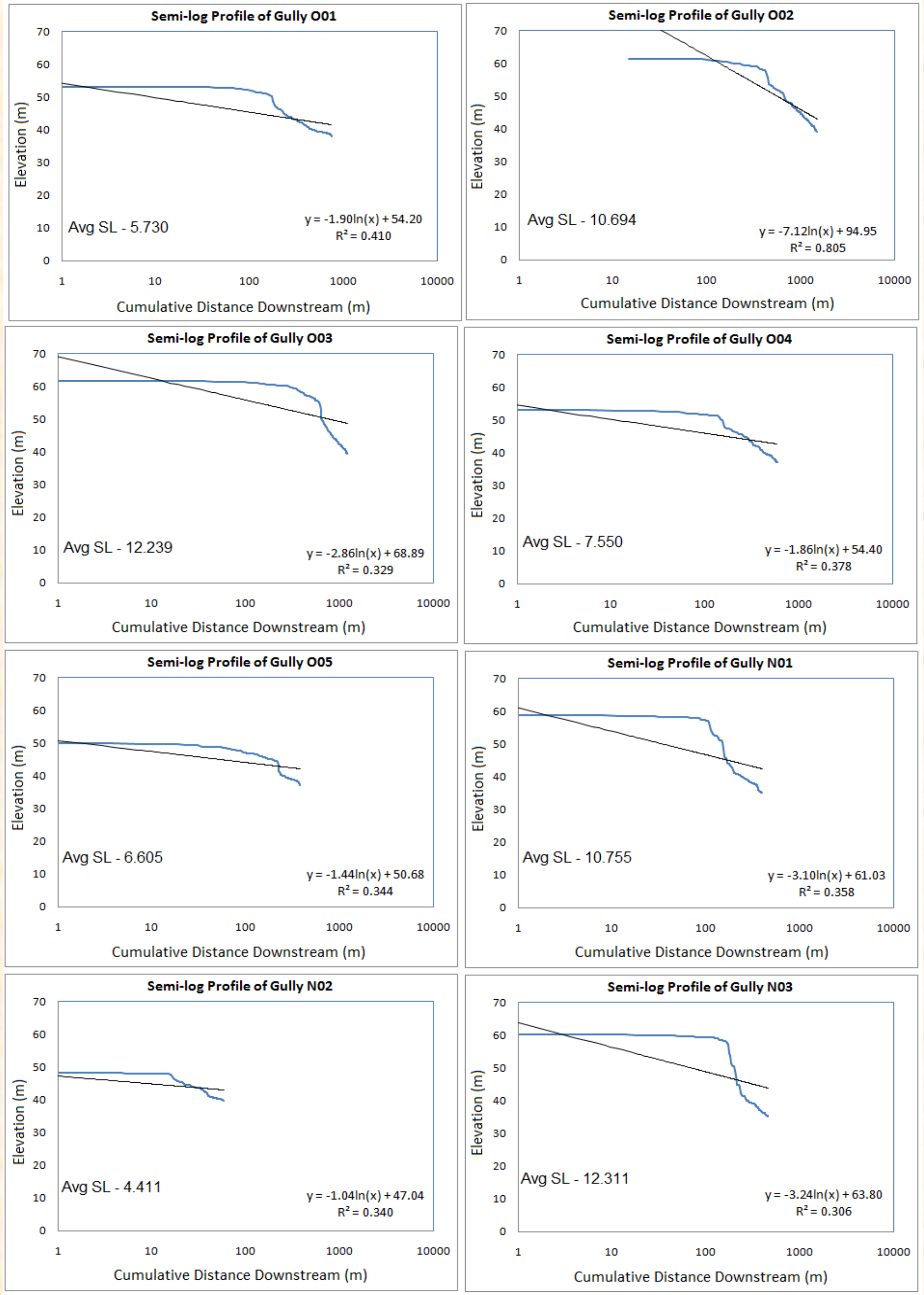


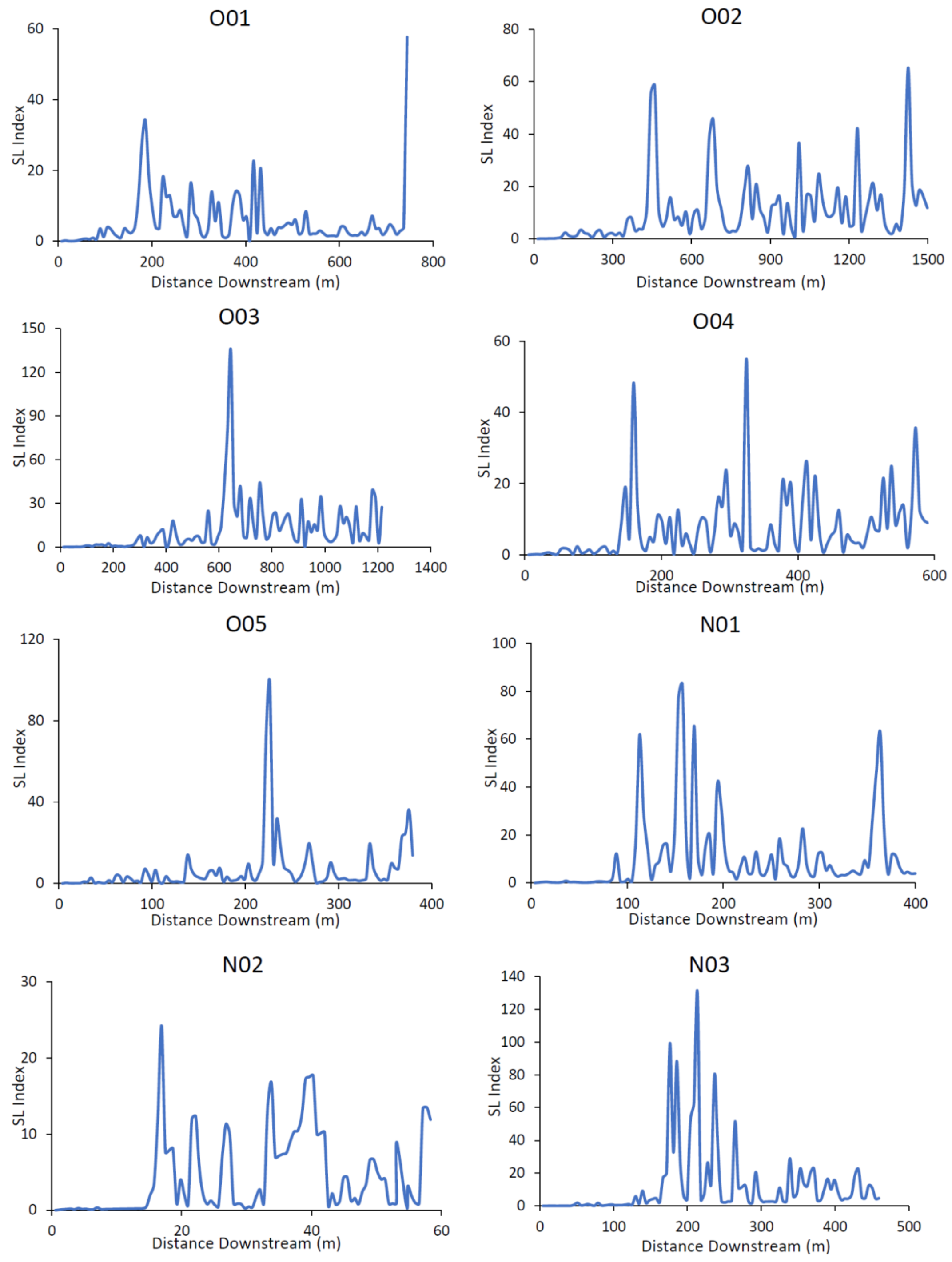


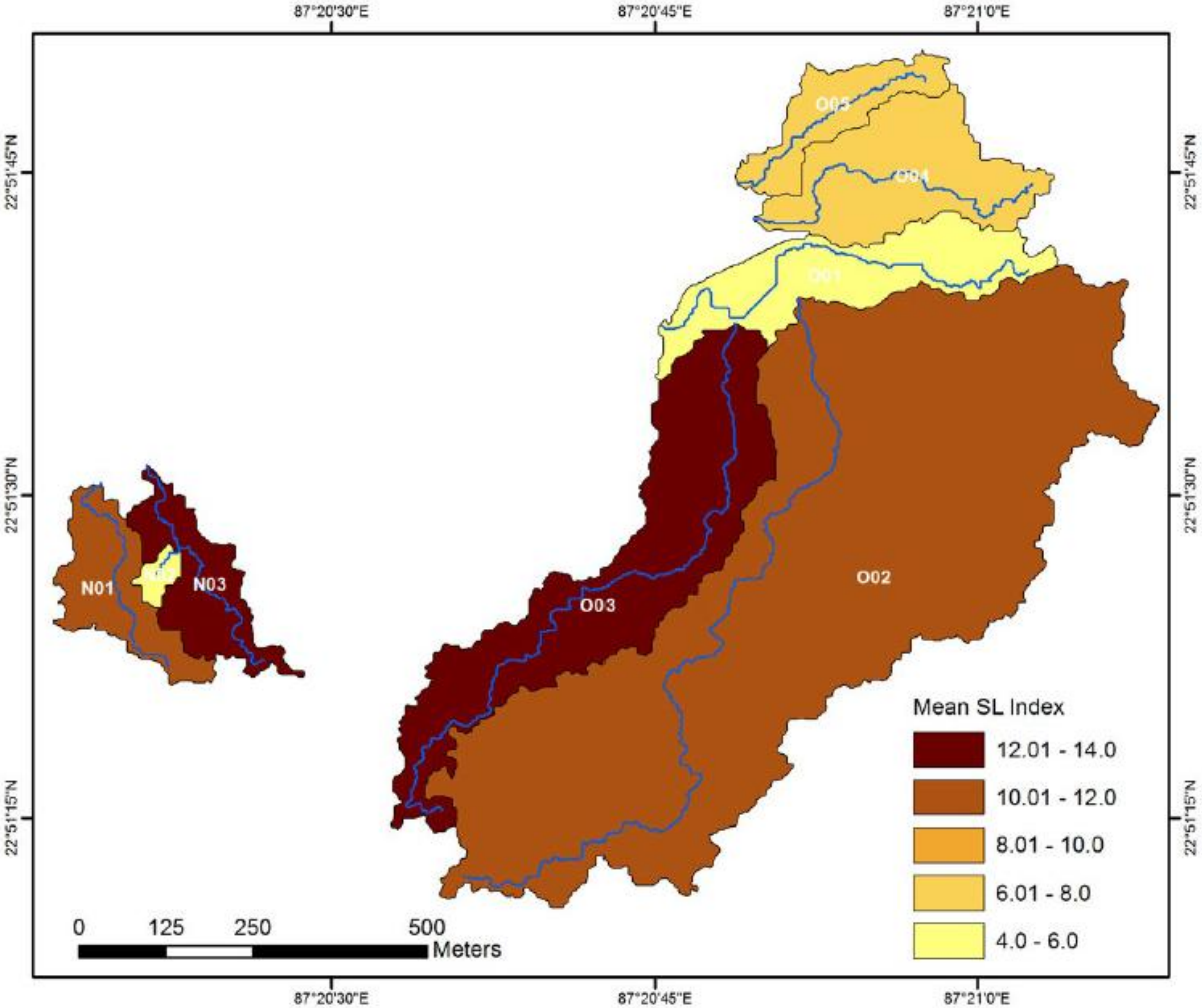
Basin relief is higher for the basins within the NBT than in the OBT.
Mean basin slope values for three NBT basins are all higher than five OBT basins.
Indication of relatively longer evolution of OBT basins as these are larger.
Highest drainage density is reported by Basin N03, showing a presently more vigorous rill/stream network therein.
HI values for NBT basins suggest late youth stage. OBT is in stages ranging from late youth through late maturity .


Hypsometric Curve of Gully O01
HI: 0.42
Hypsometric Curve of Gully O02
HI: 0.57
Hypsometric Curve of Gully O03
HI: 0.56
Hypsometric Curve of Gully O04
HI: 0.63
Hypsometric Curve of Gully O05
HI: 0.63
Hypsometric Curve of Gully N01
HI: 0.68
Hypsometric Curve of Gully N02
HI: 0.63
Hypsometric Curve of Gully N03
HI: 0.65
h / H
a / A


O01
y = -0.0222x + 52.028
R² = 0.879
O02
y = -0.0168x + 62.402
R² = 0.971
O03
y = -0.0217x + 64.918
R² = 0.951
O04
y = -0.0297x + 53.378
R² = 0.973
O05
y = -0.0367x + 50.666
R² = 0.959
N01
y = -0.0719x + 60.256
R² = 0.917
N02
y = -0.1769x + 49.127
R² = 0.967
N03
y = -0.0708x + 63.799
R² = 0.909
Elevation (m)
Distance Downstream (m)


Semi-log Profile of Gully O01
Avg SL - 5.730
y = -1.90ln(x) + 54.20
R² = 0.410
Semi-log Profile of Gully O02
Avg SL - 10.694
y = -7.12ln(x) + 94.95
R² = 0.805
Semi-log Profile of Gully O03
Avg SL - 12.239
y = -2.86ln(x) + 68.89
R² = 0.329
Semi-log Profile of Gully O04
Avg SL - 7.550
y = -1.86ln(x) + 54.40
R² = 0.378
Semi-log Profile of Gully O05
Avg SL - 6.605
y = -1.44ln(x) + 50.68
R² = 0.344
Semi-log Profile of Gully N01
Avg SL - 10.755
y = -3.10ln(x) + 61.03
R² = 0.358
Semi-log Profile of Gully N02
Avg SL - 4.411
y = -1.04ln(x) + 47.04
R² = 0.340
Semi-log Profile of Gully N03
Avg SL - 12.311
y = -3.24ln(x) + 63.80
R² = 0.306
Elevation (m)
Cumulative Distance Downstream (m)


O01
O02
O03
O04
O05
N01
N02
N03
SL Index
Distance Downstream (m)



Gully channels exhibit a visually close relation to concave- up profiles (or straight- line plots) for parts of courses.

Marked variations seen in few parts/ entire gully (O01, O03, N01, N03).

Changes brought about by variations in the local substrate and the differential hardness and thereby resistance to erosion of the ambient rock layers over which these gullies have incised (i.e. local differences in the resistance of the individual laterite, sandstone and compacted clay layers).

Fluctuations of the profiles about the expected straight (graded) path are seen to occur more markedly for the NBT basins than for the OBT basins.

Superimposed normalised profiles

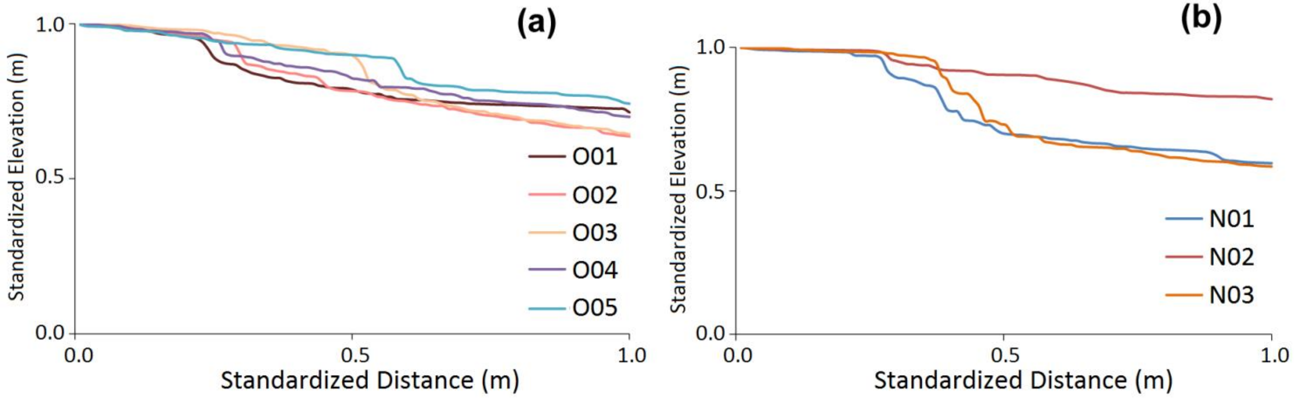
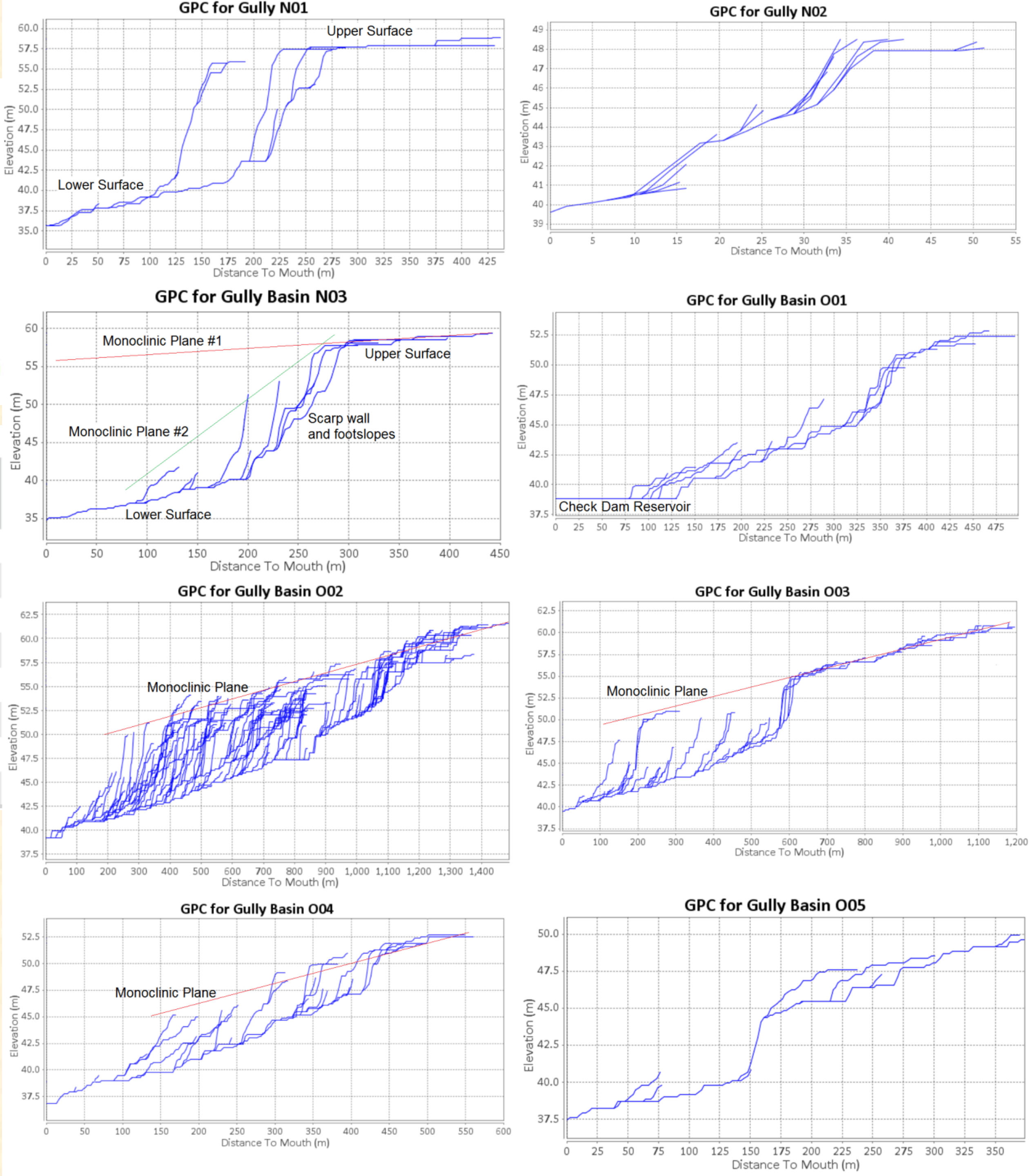


TABLE 2 Gully channel-wise channel segment gradient attributes

Gully channel	Mean SL index	Average rate of change of SL index	Ideal SL index	Average NSL
O01	5.730	−44.28	1.90	3.016
O02	10.694	−61.51	7.12	1.502
O03	12.239	−122.32	2.86	4.279
O04	7.550	−178.53	1.86	4.059
O05	6.605	−103.49	1.44	4.587
N01	10.755	−64.20	3.10	3.469
N02	4.411	−69.48	1.04	4.241
N03	12.311	−90.88	3.24	3.800

Stream segment gradient indices for gully long profiles

Alignment of Monoclinic Surface with superimposed main and tributary long profiles in each gully basin



Hack, J. T. (1973). Stream-profile analysis and stream gradient index. Journal of Research of the US Geological Survey, 1, 421–429.

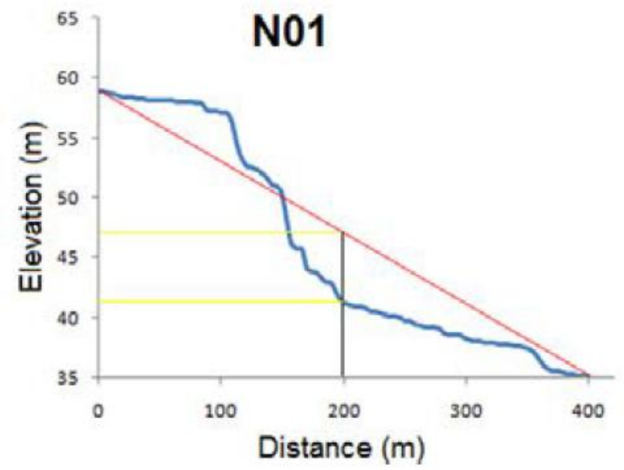
Li, J., Xiong, L., & Tang, G. (2019). Combined gully profiles for expressing surface morphology and evolution of gully landforms. Frontiers of Earth Science, 13, 551–562.

TABLE 3 Morphometric attributes of the studied gully channels

Gully channel	Elevation at gully source (m)	Elevation at gully mouth (m)	Fall (m)	Gully length (m)	Langbein (1964) concavity index (θ)	Gully evolution index (Li et al., 2019)
O01	53.21	38.00	15.21	744.55	0.460	0.612
O02	61.43	39.11	22.32	1,498.12	0.224	0.516
O03	61.55	39.48	22.07	1,215.87	0.453	0.444
O04	52.97	37.05	15.92	590.37	0.126	0.524
O05	49.99	37.10	12.89	379.72	0.155	0.490
N01	58.90	35.12	23.78	399.83	0.463	0.546
N02	48.40	39.66	8.74	58.32	0.023	0.505
N03	60.20	35.21	24.99	459.72	0.320	0.506

TABLE 4 Curve fitting on normalized gully profiles

	R^2 values for the different curve fits				
Gully channel	Linear	Exponential	Logarithmic	Power	Best-fit curve
O01	.879	.898	.410	.402	Exponential
O02	.970	.981	.805	.782	Exponential
O03	.950	.946	.329	.315	Linear
O04	.972	.981	.378	.365	Exponential
O05	.959	.954	.344	.331	Linear
N01	.916	.934	.358	.348	Exponential
N02	.966	.969	.340	.333	Exponential
N03	.908	.920	.306	.299	Exponential



Langbein, W. B. (1964). Profiles of rivers of uniform discharge (Professional Paper 501B). Washington, DC: U.S. Geological Survey.
Lee, C.-S., & Tsai, L.-L. (2010). Quantitative analysis for geomorphic indices of longitudinal river profile: A case study of the Choushui River, central Taiwan. Environmental Earth Sciences, 59, 1549–1558.

TABLE 5 Derived correlation coefficients between the various derived gully basin and channel morphometric parameters

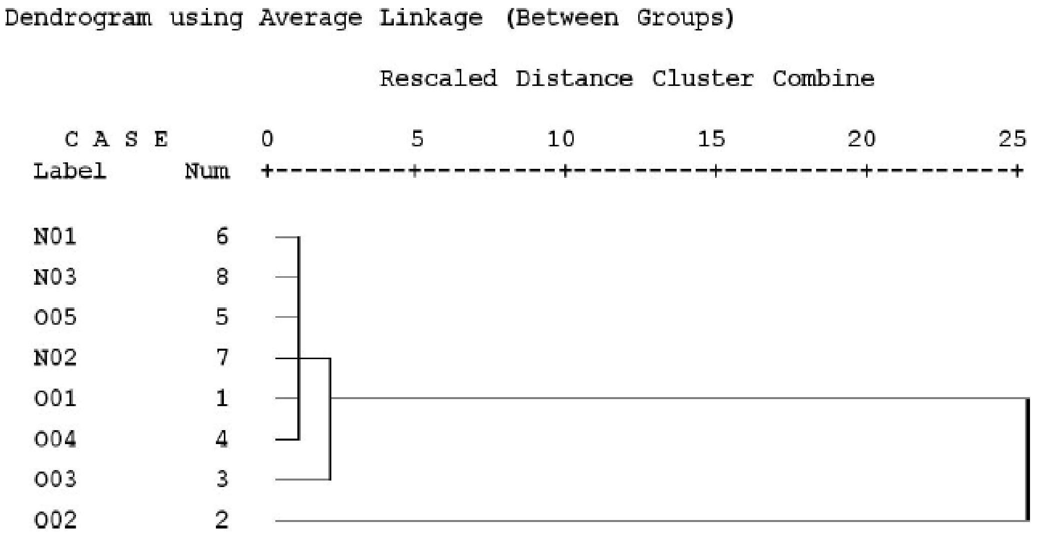
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}
x_1	1.00																					
x_2	.94	1.00																				
x_3	.35	.28	1.00																			
x_4	.34	.32	-.02	1.00																		
x_5	.27	.30	.50	-.50	1.00																	
x_6	-.50	-.67	.21	-.11	.16	1.00																
x_7	.76	.84	.46	.38	.02	-.70	1.00															
x_8	.97	.89	.47	.36	.18	-.49	.84	1.00														
x_9	.14	.37	.28	-.45	.40	-.58	.51	.17	1.00													
x_{10}	.17	.21	.48	-.62	.99	.19	-.05	.10	.44	1.00												
x_{11}	.23	.36	.47	-.59	.93	-.10	.18	.18	.71	.94	1.00											
x_{12}	-.23	-.37	-.30	-.65	.35	.42	-.72	-.35	-.30	.42	.18	1.00										
x_{13}	.54	.69	.38	-.31	.83	-.39	.46	.45	.70	.79	.91	-.01	1.00									
x_{14}	.41	.39	-.10	.94	-.30	-.04	.27	.36	-.51	-.44	-.46	-.46	-.16	1.00								
x_{15}	.36	.51	.38	-.57	.84	-.34	.34	.30	.79	.85	.96	.13	.95	-.45	1.00							
x_{16}	.85	.98	.19	.34	.25	-.73	.84	.80	.45	.16	.35	-.46	.70	.40	.51	1.00						
x_{17}	.01	.27	.39	-.25	.40	-.36	.43	.03	.80	.40	.62	-.41	.63	-.29	.66	.37	1.00					
x_{18}	.35	.51	.16	-.50	.84	-.34	.21	.23	.67	.83	.92	.23	.95	-.32	.96	.52	.55	1.00				
x_{19}	.18	.11	.77	.20	.19	.18	.31	.30	-.01	.14	.12	-.33	.07	.07	.04	.01	.30	-.11	1.00			
x_{20}	.92	.88	.51	.00	.57	-.42	.68	.89	.35	.51	.56	-.05	.75	.09	.65	.78	.19	.61	.27	1.00		
x_{21}	.82	.96	.07	.35	.25	-.72	.75	.74	.39	.15	.32	-.39	.69	.45	.48	.99	.32	.54	-.08	-.69	1.00	
x_{22}	-.09	-.14	.61	-.003	-.25	.06	.38	.14	.23	-.19	-.12	-.48	-.23	-.27	-.12	-.15	.26	-.41	.48	-.06	-.30	1.00

Note: x_1, gully basin area; x_2, gully basin perimeter; x_3, maximum basin elevation; x_4, minimum basin elevation; x_5, basin relief; x_6, mean basin slope; x_7, basin longest dimension; x_8, total stream length; x_9, drainage density; x_{10}, dissection index; x_{11}, ruggedness index; x_{12}, hypsometric integral; x_{13}, gully source elevation; x_{14}, gully mouth elevation; x_{15}, gully channel fall; x_{16}, gully channel length; x_{17}, Langbein's profile concavity index for the gully channel; x_{18}, mean SL index; x_{19}, average SL index change rate; x_{20}, ideal SL index; x_{21}, mean NSL; and x_{22}, gully evolution index.

The HI and GEI parameters are negatively correlated and this is quite obvious.

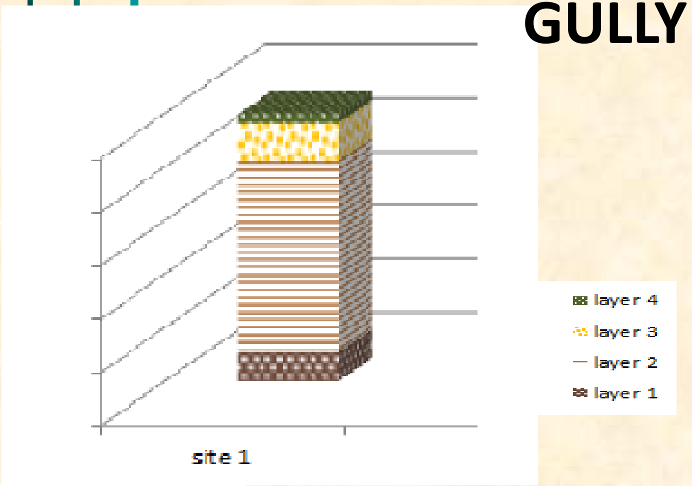
A more denuded basin (i.e., having lower HI) will have gullies incising down relatively quicker along their course from the upper reaches towards the larger spatial coverage/ extents of the basin floor, and this greater profile concavity shall elicit a higher GEI value.

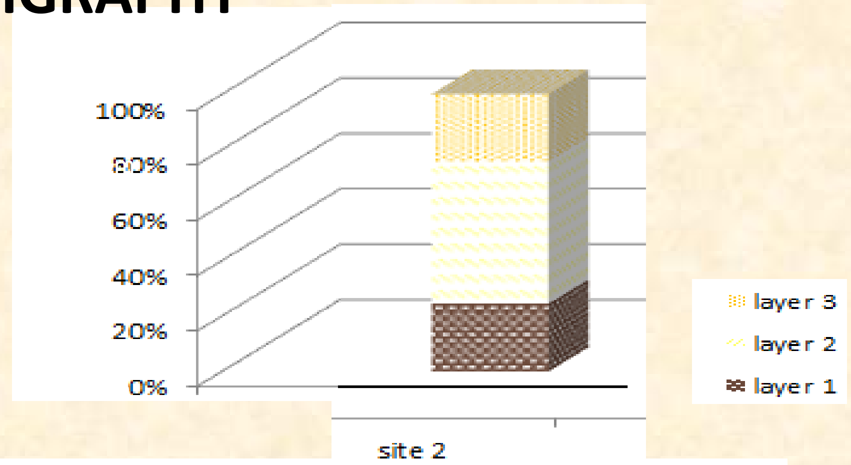
- **All gully basin and channel parameters were extracted and used them in a hierarchical cluster analysis.**
- **Dendrogram shows grouping of likely similar basins among those examined.**
- **Apparent that the Basin O02 is an anomaly and stands out from the rest.**
- **This occurs not only due to its excessively large size and much greater gully channel length, but also possibly because of its much older age and relatively more advanced geomorphic stage (evidenced by the profile concavities and basin hypsometry values).**

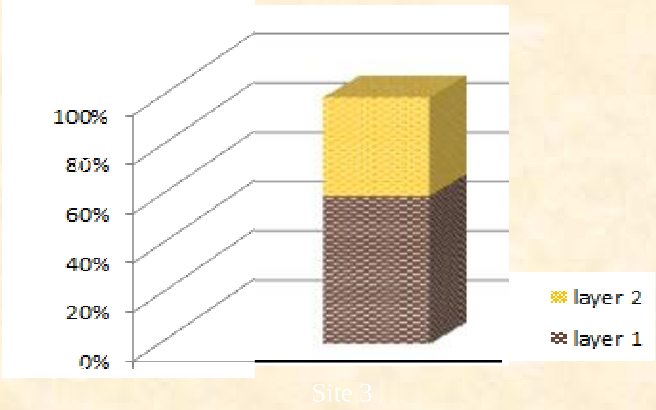


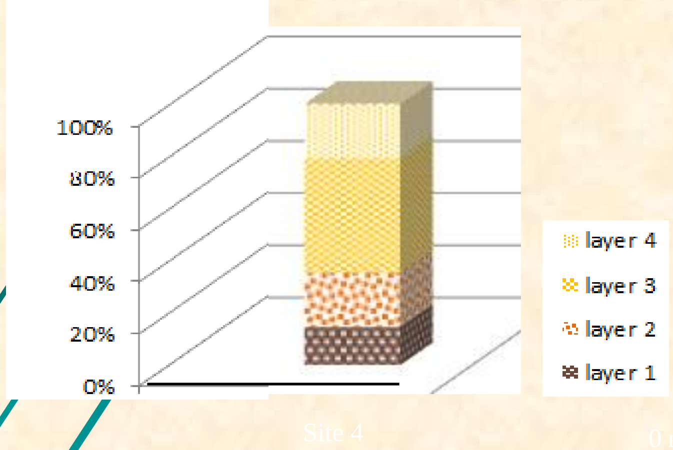
Dendrogram-based clustering of studied gully basins and channels

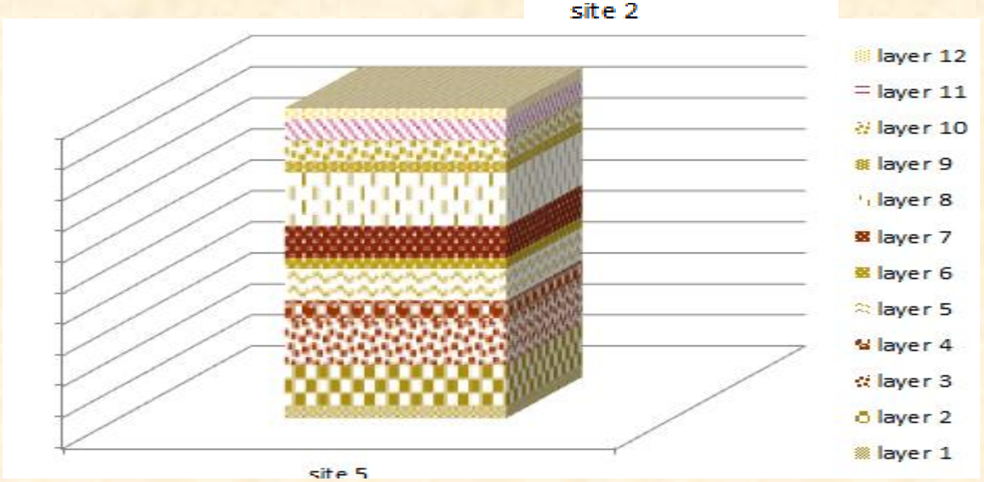
GULLY STRATIGRAPHY

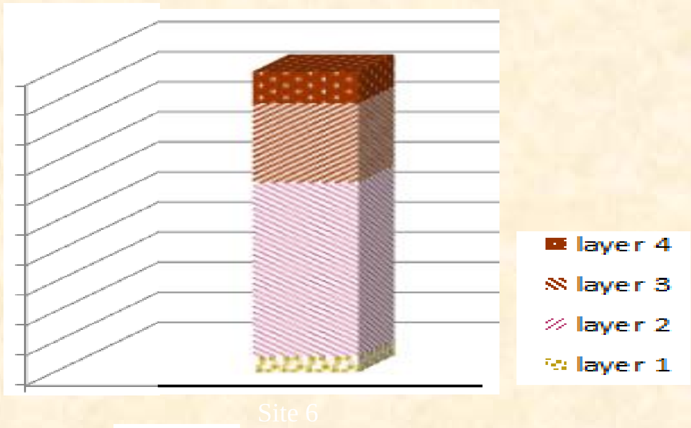




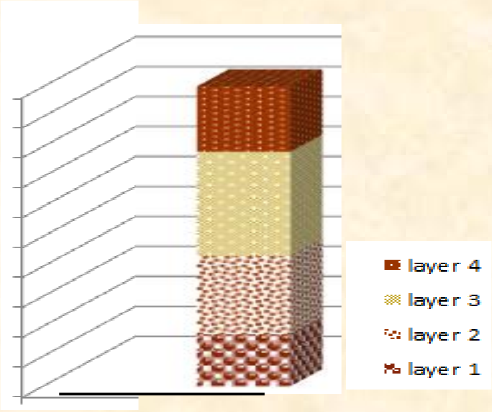


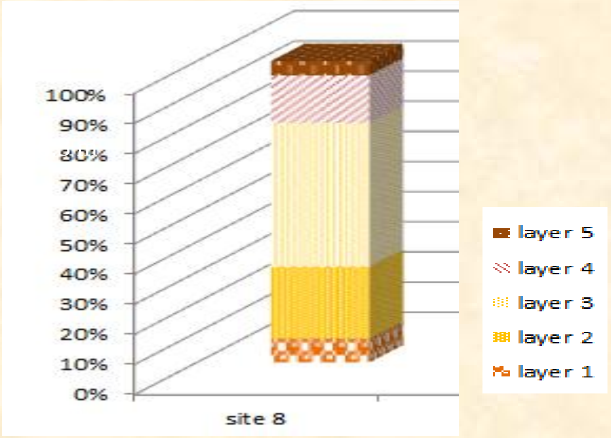


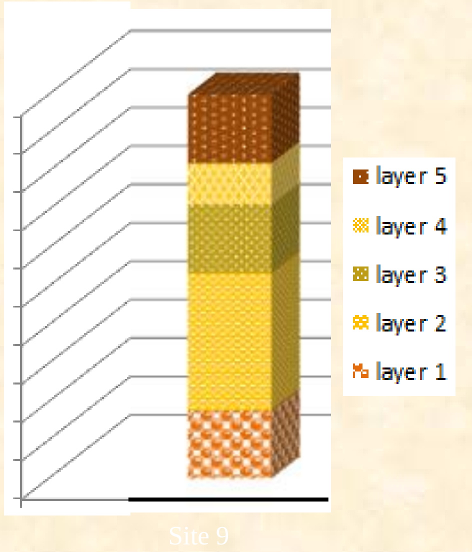




Primarily compacted clays and sandstones in multiple alternating layers below lateritic caprock







Sections normalised from 0-100 % length for comparison


max-15.5
Min-11
Mean-
12.2
Field


Max-21.5
Min-16
Mean-
18.11
Hard black old alluvium


Max-26.5
Min-19.5
Mean-
23.05
New gully extreme top
most duricrust


Max-40
Min-16
Mean-
24.55
Compacted duricrust bottom of
stair case


Max-14.5
Min-11
Mean-
12.55
Along path

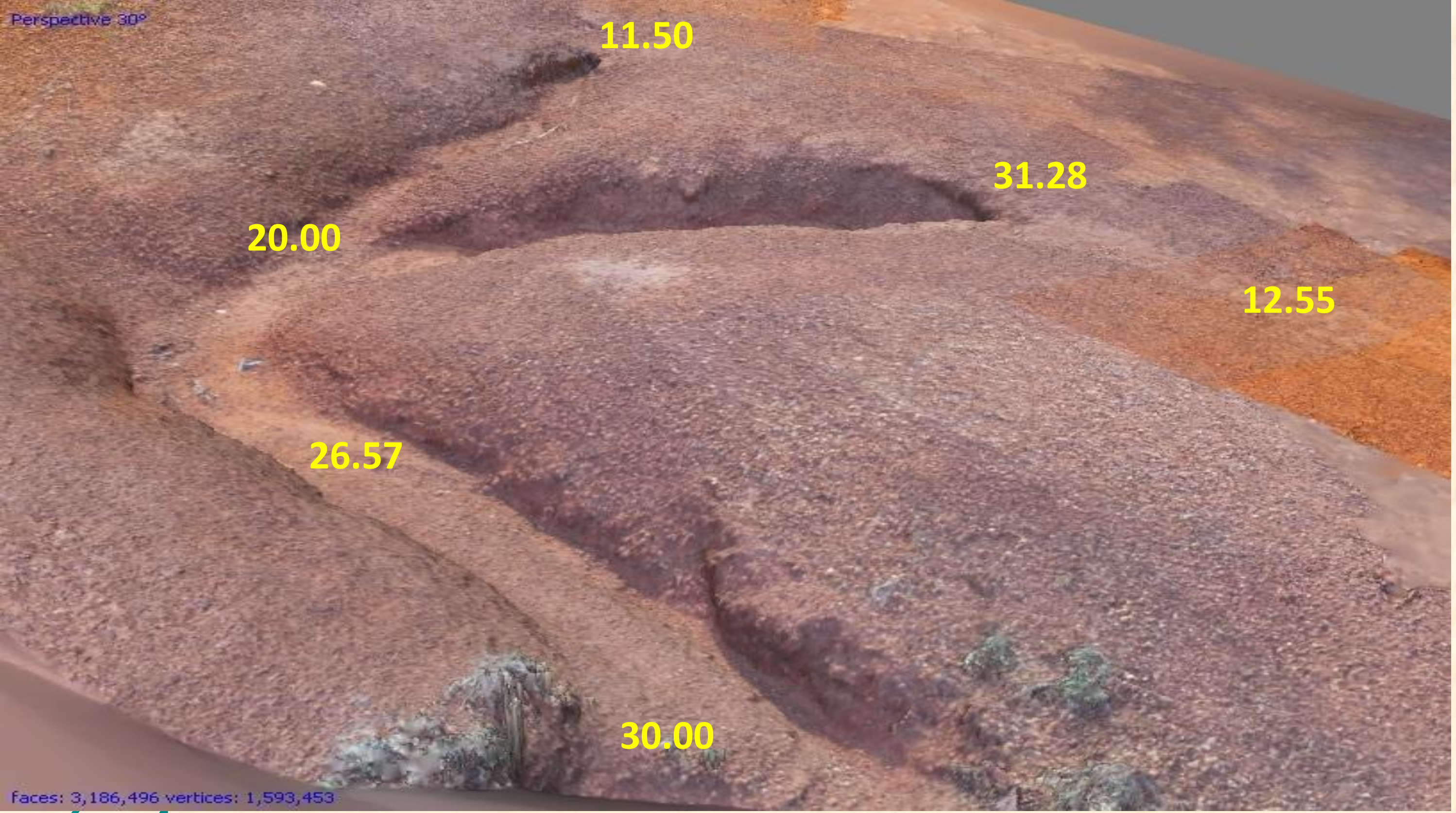

Max- 21.5
Min-11.5
Mean-14.38
Compacted Clay band


Max-14
Min-10
Mean-
12.27
Above undercut


Max-36.5
Min-19.5
Mean-
28.5
Topped down blocks on
gully bed


Max-45
Min-34
Mean-
39.72
Topped down blocks near change of
gully bed surface


Max—72.5
Min-20
Mean-44.94
Hard protrusion gully bed



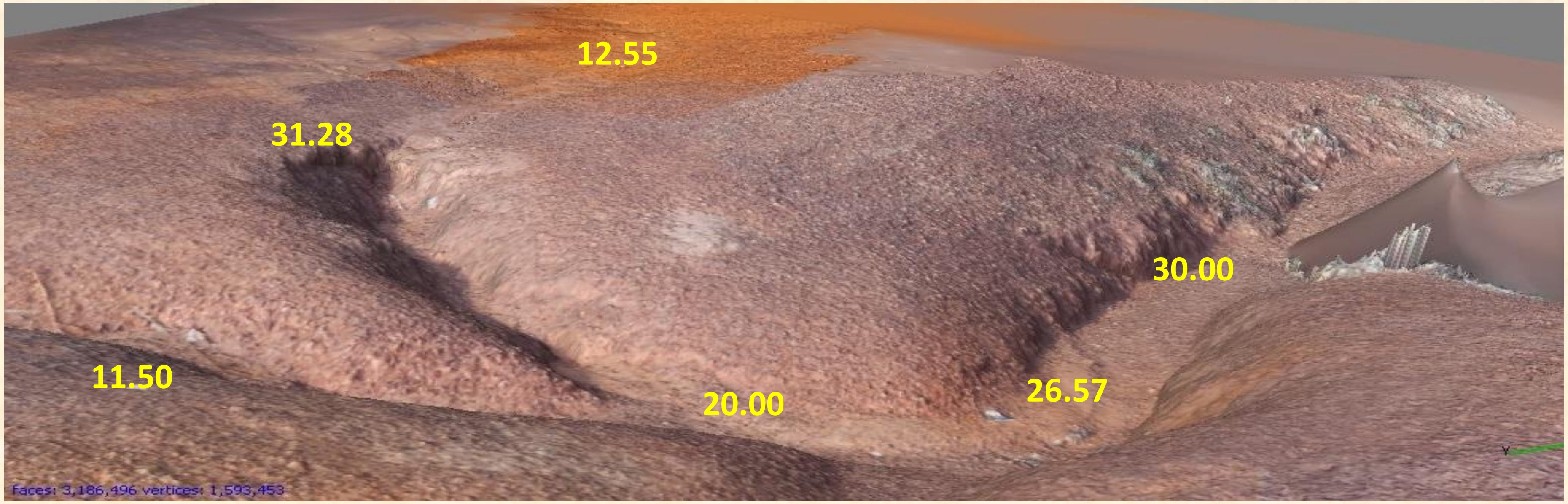
A Rill head on the upper surface

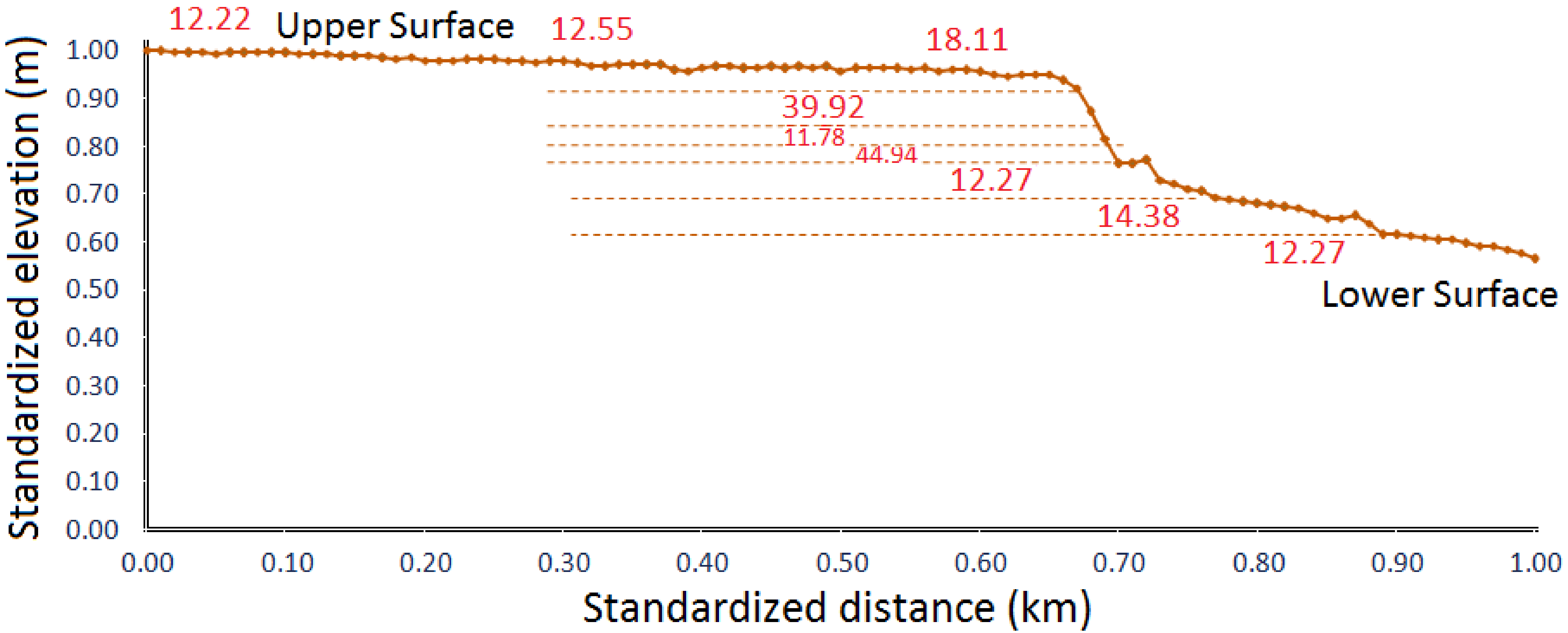
The "Q"-value [=rebound V divided by inbound V] represents the physical rebound coefficient.

Comparable Q values for other materials obtained during calibration are as follows:

Sandstone block	– 32.00
Haematite block	– 58.57
Marble block	– 72.32

Q values generally increase downstream along the rill from the friable upper surface towards the hardpan caprock over which the rill then plunges



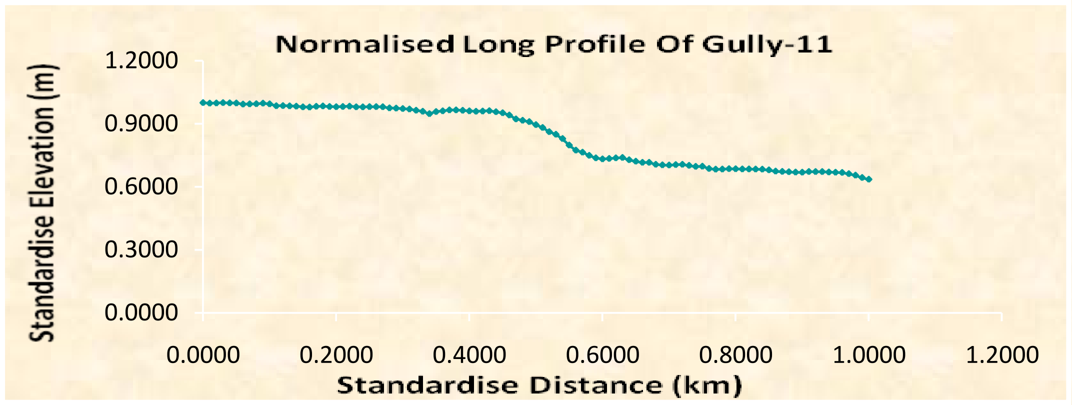


Variations in hardness of the ambient layers control the long profile form and development, with steeper scarp slopes in middle sections represent the plunge over the latertic hardpan caprock.

The upper course lies across low gradient but durable caprock or gravelly lateritic *moram* surface while the lowermost portion creates puny cascades through erodible compact clay layers.

Uneven hardness in compacted sediment/rock layers creates -

1)



Uneven long profiles

2)

Soil pipes

3)

Earth pillars

4)

Rock fall

5)

Basal sapping

Sfm-based models of gully features

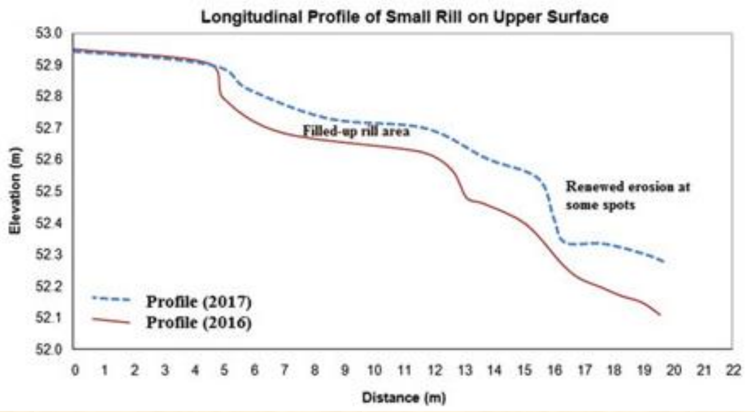
The 3-D model was prepared via the Structure-from-Motion technique using multiple photographs. A number of minor geomorphic features can be distinguished, which have formed along the channel wall of on of the main gullies in Gangani. Piping is evident, along with the development of a hollow to the left of the figure. Weathered and broken down blocks that have detached from the main gully wall are seen towards the right. The alternate fine depositional layers are distinguishable by their differential colours and nodules of weather ferricrete are visible on some of the minor slope segments.

Piping along gully wall

Earth pillars and caving on gully headwall

Rill in 2016

Rill in 2017



Change

Toe-slope erosion along gully channel

Rill cut into duricrust – changes in longittudinal profile before and after earth-filling

What may be finally inferred...

Significant gully erosion has occurred at Gangani (Garhbeta), with this being more significant in its western portion (NBT).

The longitudinal forms of the gullies reflect the lateritic hardpan/durictust nature of the landscape, and the high scarp that has formed locally. These are reflected in the higher SL values in their middle portion.

There is a notable variation in the substrate, with multiple layers present – lateritic duricrust is the upper surface, then alternating compacted clay layers and finally sandstone.

Rilling, piping and formation of earth pillars has occurred due to the lateritic scarp presence. Each of these have then own typical morphometry.

Overhangs and caving has occurred at the scarp base which cannot always be captured by satellite imaged DEMs. SfM provides a feasible way of documenting these and tracking there evolution from repeat surveys.

Some related publications

Using Ground-Based Photogrammetry for Fine-Scale Gully Morphology Studies: Some Examples

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Priyank Pravin Patel, Rajarshi Dasgupta, and Sayoni Mondal

P. K. Shit et al. (eds.), *Gully Erosion Studies from India and Surrounding Regions*, Advances in Science, Technology & Innovation,
https://doi.org/10.1007/978-3-030-23243-6_12

DOI: 10.1111/tgis.12828

RESEARCH ARTICLE

Transactions in GIS WILEY

An investigation into longitudinal forms of gullies within the "Grand Canyon" of Bengal, Eastern India

Priyank Pravin Patel[1] | Rajarshi Dasgupta[2] | Sreeparna Chanda[2] | Sayoni Mondal[1]

With gratitude...

This study has been funded by a University Grants Commission Start-Up Grant under its Faculty Research Promotion Scheme for early career researchers (Letter No. F.30-78/2014(BSR) dated 22nd January 2015) and the high resolution satellite images were obtained courtesy of the DigitalGlobe Foundation via an Imagery Grant (issued on 3rd August 2015), both to Priyank Pravin Patel.

Thank you for your kind patience.

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