Spatial Statistical Mapping of Geomorphometry and Drivers of Gully Erosion of the Sedimentary Basin of South-eastern Nigeria

Saheed Adekunle Raji[1], Akinlabi Akintuyi[2], Emmanuel Wunude[2], and Busayo Fashoto[2]

[1]Federal University of Petroleum Resources, Effurun
[2]University of Lagos

November 22, 2022

Abstract

Abstract The south-eastern Nigeria as other parts of the tropics have been experiencing diverse levels of soil erosion for decades. An enquiry of the physical and anthropogenic drivers of soil erosion can provide a better insight into the proximate and underlying processes of occurrence of soil erosion. In this study, we employed the basin approach to investigate the nexus between geomorphometry and the socio-physical drivers of gully erosion development in the sedimentary Anambra basin. Multi-sourced remotely sensed and geospatial data were fit to multinomial regression to simulate probability maps of gully development. The laws of basin geomorphometry were also tested on linearity, shape, topographic and dimensionless metrics using digital surface model (DSM) data. Proximity to existing gully, soil, stream order, vegetation index, rainfall, flow direction, curvature and slope were found to be statistically significant to gully development across all models. The result of the study also showed that Anambra is a 7th-order basin: bifurcating averagely at 1.55; with elongation index, circularity ratio, relative relief, sinuosity index, drainage density, and mean peak flow of 3.42, 0.05, 0.21, 0.96, 0.54 km/km^2 and 2,916 respectively. This suggests a synergised gully formation process such that the fluvio-dynamics and surficial factors of the basin contribute to gully development. This study thus provides decision-support mechanism for basin management such that the progressive occurrence of sheet erosion can be identified and managed prior to advancing to a fully blown gully. It also provides database for environmental engineering-oriented basin management such that disaster risk can be curtailed while ensuring safe and secured environment for the populace.

Spatial Statistical Modeling of Geomorphometry and Drivers of Gully Erosion of the Sedimentary Basin of South-eastern Nigeria

Raji, S.A.[1, 2], Akintuyi, A.O.[1], Wunude, E.O.[1], Fashoto, B.T.[1]

1) Department of Geography, University of Lagos, Nigeria. **2)** Department of Environmental Management & Toxicology, Federal University of Petroleum Resources, Nigeria.

1. Introduction

Globally, sedimentary basins are highly susceptible to varying degrees of gullying depending on natural anthropogenic drivers (Vanmaercke et al. 2020). An enquiry into the influence of these drivers coupled with nonlinear anthropogenic activities can provide a better insight towards understanding the progressive development of gully erosion (Ogbonnaya et al. 2020). While literature is awash with various attempts at investigating this phenomenon using various approaches especially at the basin-scale, the nexus between this geohazard and the inherent morphometric characteristics remains unresolved. Morphometric analysis, which numerically explains the diverse terrain characteristics of a basin, can also express the fashion of the fluvial cum edaphic processes that stimulate gully occurrence. When this is further subjected to predictive spatially-explicit modeling system, it can bring to light the gully development phases and the pattern of expansion across space and time. In this study, we employed multifactorial approach with multinomial logistic regression to model the major factors driving gully erosion occurrence in the Anambra basin of southeastern Nigeria. This approach will aid the better understanding of the integrated approach useful for gully management.

2. Study objectives

- Test the laws of basin geomorphometry based on linearity, shape, topographic and dimensionless metrics of the Anambra Basin.
- Analyse the level of importance of spatially-explicit environmental covariates of gully erosion occurrence in the study area.
- Predict the occurrence of gully erosion using multinomial logistic regression.

3. Methods

- The ALOS World 3D Digital Surface Model data with one arcsecond (~30 metres) acquired from the Japanese Aerospace Exploration Agency (JAXA) was used as digital topographic data of this study.
- Image error checks including removal of pixel noise which may trigger abrupt changes in river morphology were addressed using cut & fill tool.
- Seventeen (17) environmental cum anthropogenic covariates of gully erosion were tested.
- The overall study procedure is presented in Fig. 1.

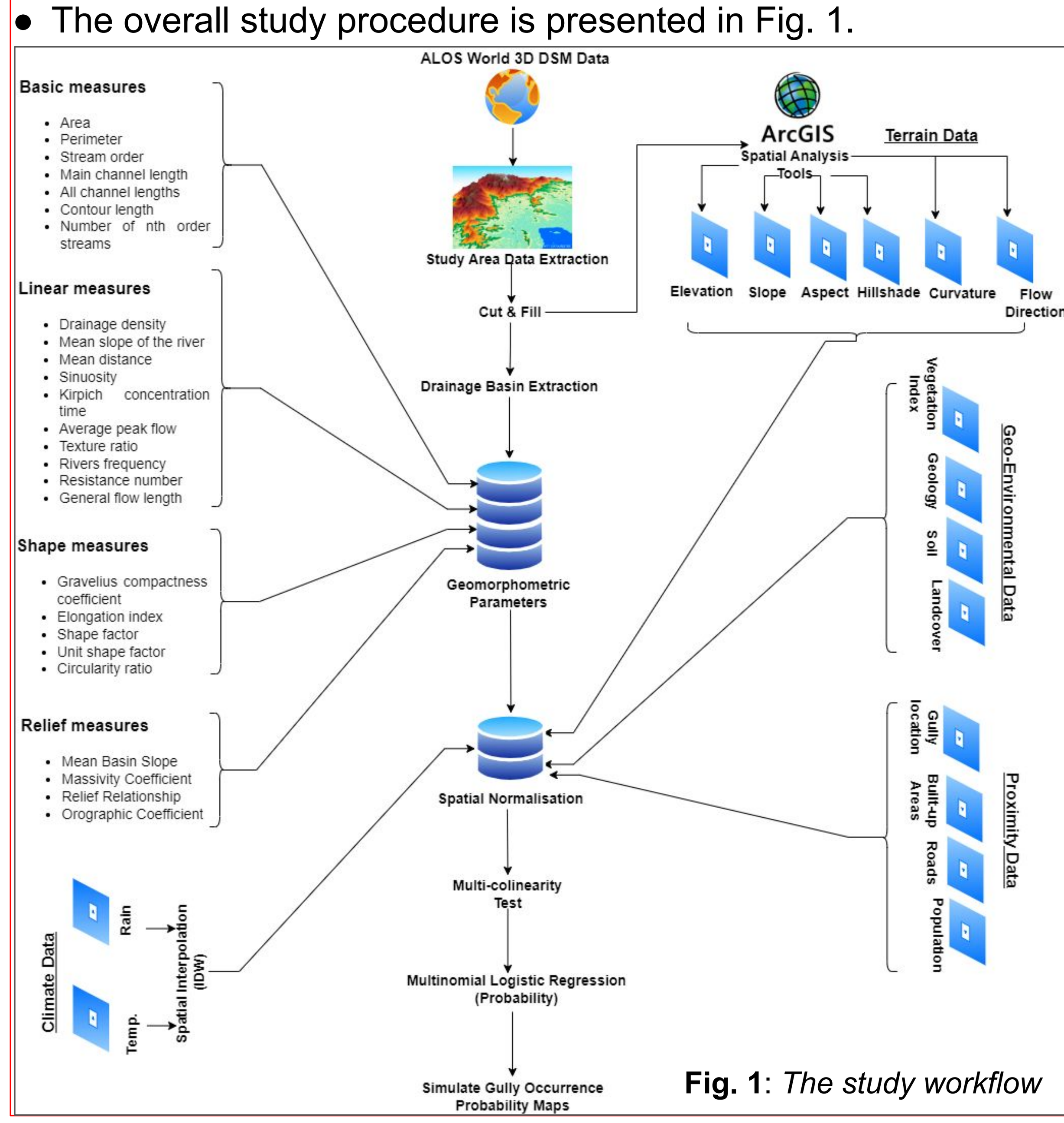
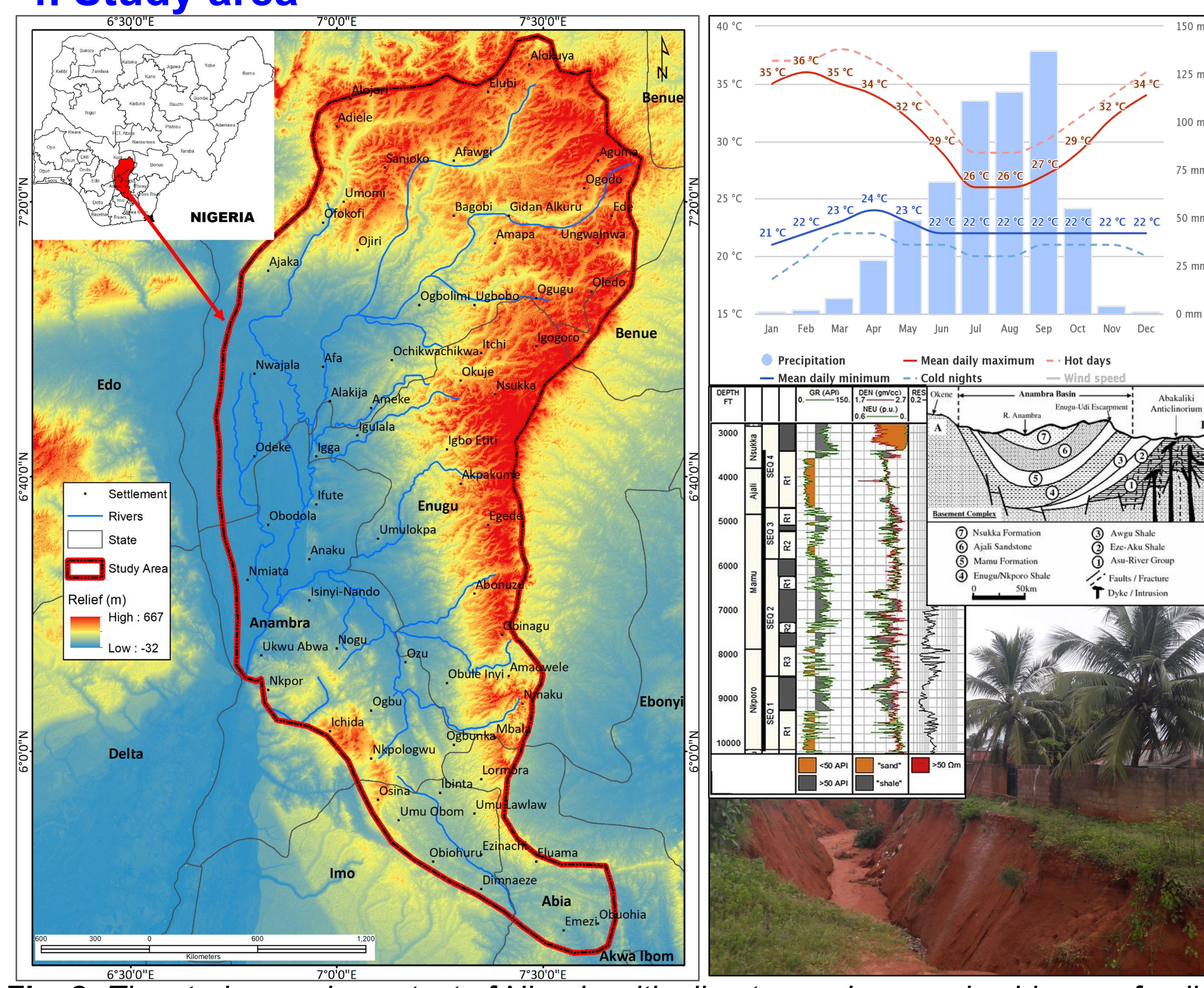


Fig. 1: *The study workflow*

Further data sources and methods

- The terrain datasets - elevation, slope, aspect, hillshade, curvature, flow directions were derived from Spatial Analysis Tools of ArcGIS 10.8 software.
- Other datasets such as NDVI, soil, geology, soil, climate and land cover were sourced from multi-sources such as NASA, ESA, and government agencies.
- Multicollinearity test was based on correlation and regression.
- Multinomial logistic regression (probabilistic): $\pi_j(x) = [\exp(\boldsymbol{\alpha}_j + \beta'_j(x) / (1 + \sum \exp(\boldsymbol{\alpha}_h + \beta'_h(x))]$ where: $\boldsymbol{\alpha}$ = 0 constant, x = predictive factors, j & h = model coefficients, = β predictor coefficients.
- The outcome was based on 3 models of gully erosion.

4. Study area



Context

- Traverses Anambra, Kogi, Enugu, Imo and Abia States (Fig.2).
- Forms hydrologic basin with Rivers Imo, Adada, Oji, Mamu, Obe, Ota-Alu.
- Morphologically parallel with the Niger River.
- Sedimentary underlain by quaternary and tertiary rocks.
- Climate is humid tropical with dual seasons.
- Annual rainfall is 1500-2000 mm with peaks during the wet season.
- Livelihood is traditionally agrarian.

Fig. 2: *The study area in context of Nigeria with climate, geology, and evidence of gullying*

5. Geomorphometry of Anambra Basin (Horton's Law validation)

Geomorphometric dimensions	Specific variables	Explicit equation	Computed value
Linearity	Drainage Density (D_d)	$D_d = \sum L_u / A$	0.54
	Mean Slope of Anambra River (j)	$j = (H_{max} - H_{min}) / L_c$ X 100	144
	Sinuosity of Anambra River (S)	$S = L_c / Lb^2$	0.96
	Kirpich Concentration Time (TcK)	$TcK = 0.066 (Lb^2/j)^{0.77}$	0.21
	Average Peak Flow (Q_p)	$Q_p = 43A^{0.522}$	2,916
	Texture Ratio (T)	$T = Nu / P$	10.97
	Rivers Frequency (F_u)	$F_u = N_u / A$	1.2749
	Resistance Number (R_n)	$R_n = H_{max}$ X D_d	755.56
	General Flow Length (L_o)	$L_o = ½$ X D_d	0.2713
Shape	Drainage Intensity (D_i)	$D_i = F_u / D_d$	2.3497
	Gravelius Compactness Coefficient (C_c)	$C_c = P/2\sqrt{\pi A}$	1.42
	Elongation Ratio (R_e)	$R_e = 1.1284 \sqrt{(A/L_c)}$	0.11
	Shape Factor (R_f)	$R_f = A/Lb^2$	60.62
	Elongation Index (I_a)	$(I_a) = Lb^2 /W$, W = basin breadth	3.42
	Unit Shape Factor (R_U)	$R_U = Lb^2 /A^{0.5}$	2.14
	Circularity Ratio (R_c)	$R_c = 4\pi A/P^2$	0.05
Relief	Mean basin slope (J)	$J = (\sum L_i E/A)$ X 100	88.24
	Massivity Coefficient (tga)	$tga = H_{med} / A$	0.01
	Relief Relationship (R_h)	$R_h = H_{max} / Lb$	1.47
	Relative Relief (R_r)	$R_r = H_{max} / P$	0.21
	Orographic Coefficient (C_o)	$(C_o) = H_{med}$ X (tga)	2.27
Basic	Area (A)	Surface area of the basin (km^2)	16,858
	Perimeter (P)	Perimeter of the basin (km)	1,959
	Length (Lb)	Length of the basin (km)	278.08
	Stream order (u)	Dimensionless stream order	7th order basin
	Main Channel Length (L_c)	Main flow river length (km)	268
	All Channel Lengths (L_u)	Length of all the streams in the basin (km)	9,147.27
	Contour Length (L_i)	Contour lines' length (km)	14,875.06
	Number of streams (N_u)	Dimensionless number of streams in the basin	21,493
	Maximum Height (H_{max})	Maximum elevation of the basin (m)	408
	Minimum Height (H_{min})	Minimum elevation of the basin (m)	21
	Medium Height (H_{med})	Medium elevation of the basin (m)	196

6. Drivers of gully occurrence in the Anambra Basin

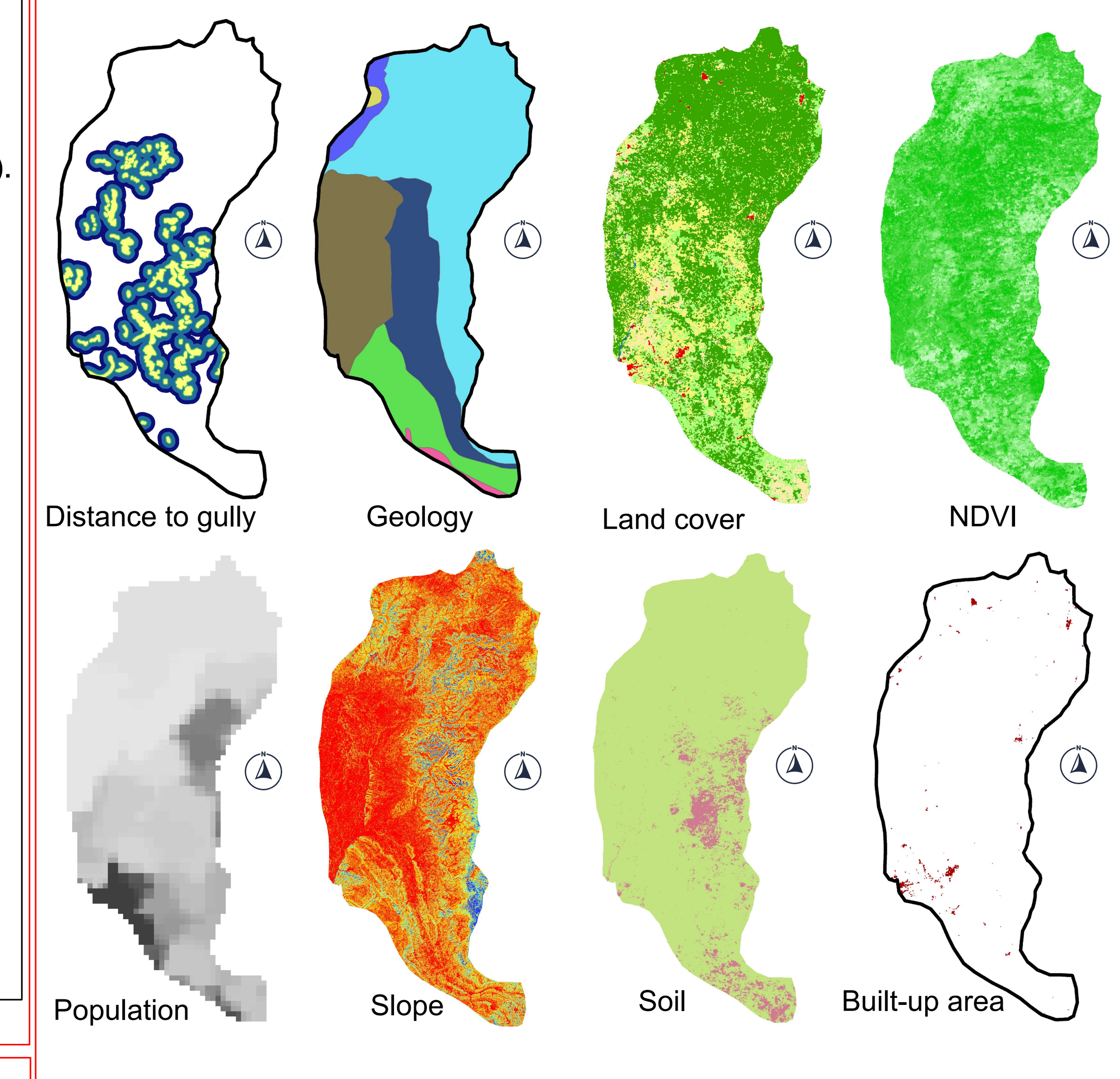


Fig. 3: *Driving factors of gully erosion occurrence within the Anambra Basin*

Table 1: *Performance assessment of gullying drivers*

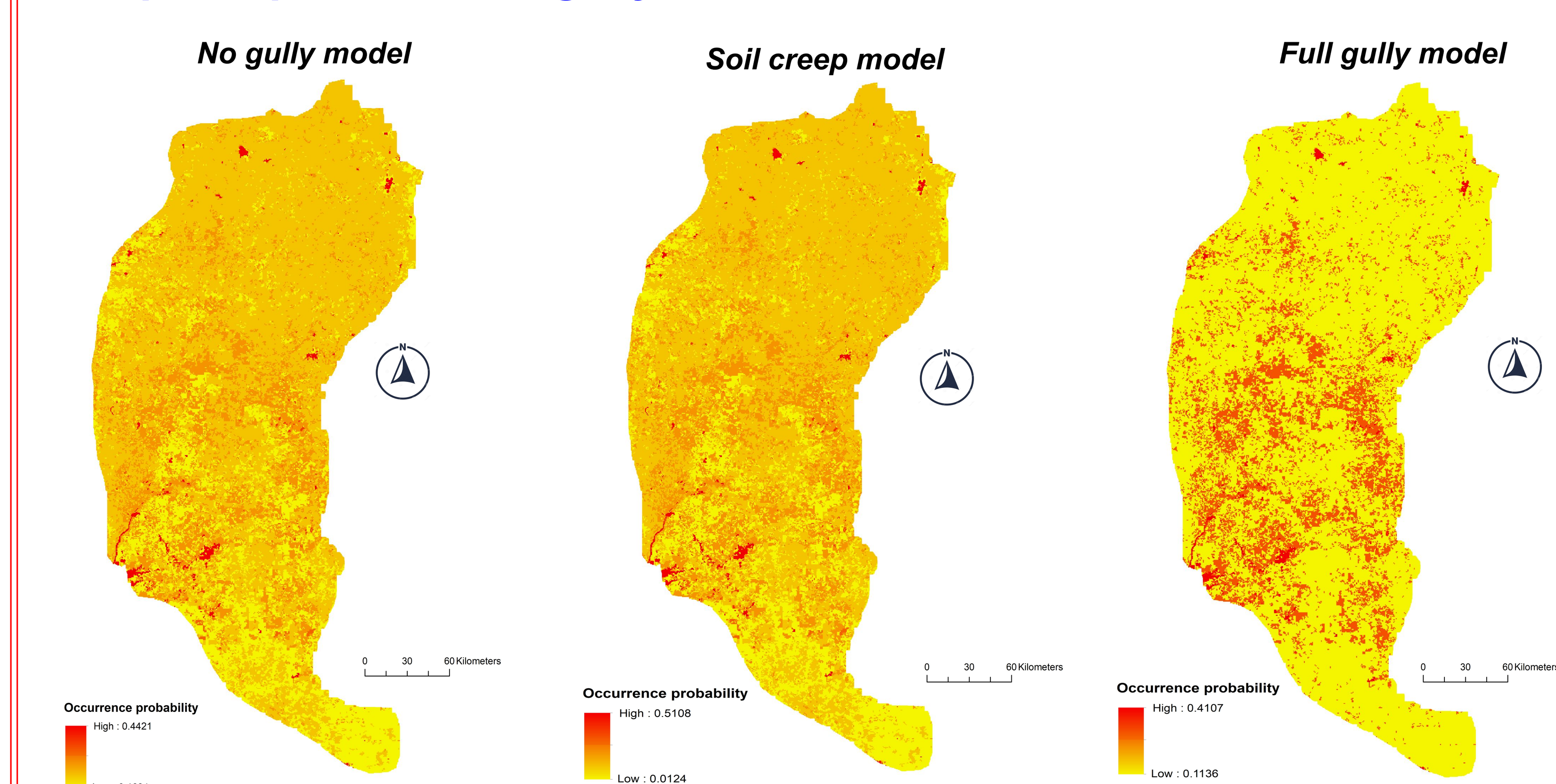
Gully erosion drivers	β	S.E.	Sig.	Exp (β)
Road distance to gully	-.009	.023	.709	.991
Distance to gully	.997	.070	.000	2.709
Aspect	-.026	.024	.278	.975
Curvature	-.055	.108	.607	.946
Elevation	-.082	.039	.037	.921
Flow	.032	.050	.523	1.033
Geology	-.093	.040	.020	.911
Hillshade	.113	.102	.268	1.120
Land cover	.143	.044	.001	1.154
NDVI	-.359	.070	.000	.698
Population	-.099	.034	.004	.906
Rainfall	-.149	.116	.200	.861
Slope	-.116	.045	.010	.891
Soil	-.486	.064	.000	.615
Stream order	-.077	.143	.593	.926
Built-up areas	-.079	-.092	.001	.912
Temperature	.238	.137	.083	1.269
Intercept	6.119	1.282	.000	

β = Beta, S.E = Standard error of β, Sig = significance, Exp(β) =exponent (antilog) Beta

Key observations

1. Multicollinearity checks depict that no redundant and causally-irrelevant covariates were detected hence all drivers are statistically fit for modeling.
2. Out of the 17 spatially-explicit environmental factors assessed, 8 were found to be statistically significant.

7. Spatial prediction of gully erosion across models



Key observation

- The model suggests that existing gully will remain and ~45% of the basin will not be susceptible to gully occurrence.

Key observation

- The model suggests that soil creep will occupy roughly 10% of the basin under the influence of identified drivers.

Key observation

- The model suggests that existing gully locations will expand spatially to other areas while new gully sites will emerge.

8. Conclusions

- This study has shown the geomorphometric nature of the Anambra Basin as well as the nature of its associated stream morphology, relief, and shape dimensions.
- The primate drivers of gullying were physical cum anthropogenic in functionality. The behaviour of these aided the probabilistic prediction of gully occurrence such that the full multinomial logistic regression suggests a future expansion of the existing gully sites.

References

Vanmaercke, M., Chen, Y., Haregeweyn, N., De Geeter, S., Campforts, B., Heyndrickx, W., Tsunekawa, A., & Poesen, J. (2020). Predicting gully densities at sub-continental scales: a case study for the Horn of Africa. Earth Surf. Process. Landforms 45, 3763–3779. https://doi.org/10.1002/esp.4999.

Ogbonnaya, I., Ugwuoke, I. J., Onwuka, S., Ozioko, O. (2020). GIS-based gully erosion susceptibility modeling, adapting bivariate statistical method and AHP approach in Gombe town and environs Northeast Nigeria. Geoenviron Disasters 7, 32. https://doi.org/10.1186/s40677-020-00166-8

Contact us

SCAN ME