Analysis of Soil Erosion Causative Factors and Susceptibility in Anambra State, Southeastern, Nigeria

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ABSTRACT

Soil erodibility depends on the texture, aggregate stability, shear strength, infiltration capacity, organic and chemical contents of the soil. This study considers other factors of soil erosion both static and dynamic which include slope, land use/land cover, soil erodibility and dynamic factors such as land surface temperature (LST), Soil Moisture Index (SMI) and rainfall erosivity are the variables for this research. The study area is Anambra State Southeastern Nigeria. This research used both primary and secondary data. Secondary data include Satellite images, aerial photo, topographic maps, meteorological and population data collected from different governmental and non-governmental organizations. The primary data involved field survey and observations using Global Positioning System (GPS) for ground truth verification and collection of soil samples for extraction of soil properties. Eight (8) prominent Causative Factors (CFs), factors were identified, which include drainage density, Lineament Density, Slope Length and Soil Erodibility as static factors, and Land Surface Temperature, Soil Moisture Index, Normalized Difference Vegetation Index and Rainfall Erosivity as dynamic factors. These Causative Factors (CFs), were analyzed and tested with Hierarchical Regression Model using SPSS version 20 software. Conclusively, the research showed that the dynamic causative factors influences soil susceptibility and triggers erosion hazards in Anambra State, Southeastern Nigeria. The approach employed is very important to sustainable land-use management and erosion prevention. Therefore, appropriate selections of the vital causative factors are required in order to achieve accurate estimate and sustainable mediation.

KEY WORDS: SOIL ERODIBILITY, CAUSATIVE FACTORS, ANAMBRA STATE, EROSION, SUSCEPTIBILITY.

INTRODUCTION

Background of the Study: Soil susceptibility is proneness of soil to be eroded by running water. Erodibility on the other hand is a measure of a soil's susceptibility to particle detachment and transport by agents of erosion. Therefore, soil erosion is termed erodibility. Erodibility is strictly attributed to soils while erosivity is a rainfall attribute. The two terms are used interchangeably and one cannot discuss susceptibility of soils without talking about erodibility. Soil erodibility is usually regarded as the susceptibility of a soil to erode. In a fundamental sense, it should be defined as the amount of soil loss per unit exogenic force or erosivity such as rainfall, surface flow

and seepage. Knowledge of soil erodibility has been useful in soil loss predictions (Wischmeier, 1960; Ayadiuno, Ndulue, Mozie & Ndiechie, 2021).

Soil erosion process involves interaction of different complex biophysical and anthropogenic factors including soil properties, topography, climatic condition, land use, population and management practices. These factors vary both spatially and temporally from one location to the other (Shi et al., 2013), (Shakirudeen et al., 2018) had it that soil erosion creates serious implication on water quality and downstream siltation with great consequences on biodiversity and ecosystem services including domestic and industrial usage. The study of soil susceptibility to erosion will consider the factors of soil erosion both static and dynamic factors including slope, land use/land cover, soil erodibility and dynamic factors such as land surface temperature (LST), Stream Moisture Index (SMI) and rainfall erosivity all of which are the variables for this research.

Soil erodibility is a function of soil texture, infiltration capacity, shear strength, aggregate stability, organic matter, vegetation and chemical contents of the soil

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(Nwunonwo, 2013); (Ndukwe et al., 2013) (Jafar-Zadeh, et al., 2014); (Ayadiuno & Ndulue 2021). Unsustainable land use practices leads to an addition of environmental challenges of soil erosion which is caused by anthropogenic activities especially in developing countries (Shakirudeen, et. al, 2018) (Igwe & Egbueri, 2018) (Emeh & Igwe, 2018). Land use and land management practices have serious impacts on natural resources including water, soil nutrients; other effects on land include urban sprawl, land degradation, salinization and desertification (Igbokw & Ejikeme, 2013). Research findings by (Igwe & Egbueri 2018) revealed that poor geotechnical properties and anthropogenic activities predispose these soils to be susceptible to erosion.

The rate of operation of erosion hazards in Anambra is high and variations in their intensity could be due to differences in Causative factors and type of geologic formation (Egbueri & Igwe, 2020). Anambra State has more of the youngest and friable sedimentary deposit hence the highest number of erosion sites (over 700) (Ifejiofor, 2019), (Orji & Nwankwoala, 2019), while Ebonyi State with the least or fewest number of erosion sites (over 250) (Orji & Nwankwoala, 2019) has more of the oldest and well consolidated sediments (Nwajide 2013), hence the need for a research such as this in Anambra state.

MATERIAL AND METHODS

Study Area: Anambra state lies between latitudes and longitudes 6°00' and 7°00" North, and 6°45' and 7°20' East with a land mass of about 4844km² (figure 1). It is located within the humid tropical rainforest zone of West Africa. There is increased human activity in the area of urbanization, development of infrastructure such as road construction, expansion of existing ones and other primary extractive activities like deforestation and quarrying that have exposed the bare and led to the loss of the original ecosystem and biodiversity (Igwe & Egbueri 2018) (Ayadiuno & Ndulue, 2021).

There are two distinct seasons in study area and they are the rainy season which starts from April and ends in October and the dry season which starts from November and ends in March respectively. The effect of Climate change has exacerbated more, the problems and menace of soil erosion in addition to already anthropogenic inflicted problems on land use in the study area (Farauta, et. al., 2012) (Igwe & Egbueri 2018) (Ayadiuno & Ndulue, 2021).

This research used both primary and secondary data. The primary data are measurements taken from frequent geo-physical field visit, surveys and observations. Global Positioning System (GPS) was used for ground truth verification. Secondary data consulted and used are Satellite images, aerial photo, topographic maps, meteorological and population data collected from different governmental and non-governmental organizations, and other published and non published literatures. The identified causative factors - Drainage

Density (DD), Erosion Density (ED), Lineament Density (LD), Slope Length (LS), Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Rainfall and Soil Moisture Index (SMI), were subjected to statistical analysis (Hierarchical Regression) using the statistical package for the social sciences (SPSS) soft ware version 20 to determine and predict the contribution of the various identified causative factors that can induce, initiate and or trigger soil erosion in the study area. The equation is stated thus:

Figure 1: Study Area

Source: USGS, Modified by the Authors, (2021) (GPS) was used for ground truth verification. Secondary data consulted and used are Satellite images, aerial photo, topographic maps, meteorological and population data collected from different governmental and non-governmental organizations, and other published and non published literatures. The identified causative factors - Drainage Density (DD), Erosion Density (ED), Lineament Density (LD), Slope Length (LS), Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Rainfall and Soil Moisture Index (SMI), were subjected to statistical analysis (Hierarchical Regression) using the statistical package for the social sciences (SPSS) soft ware version 20 to determine and predict the contribution of the various identified causative factors that can induce, initiate and or trigger soil erosion in the study area. The equation is stated thus:

$$Y_1 = \beta_0 + \beta_1 \alpha_1 + \epsilon_1 \quad (1)$$

where

Y_1 = Dependent variable

β_0 = Intercept

β_1 = Beta coefficient

α_1 = Independent variable

ϵ_1 = Random Error term

Analysis of variation (ANOVA) was also carried out and F-ratio was evaluated to assess the improvement of the

model by addition of the dynamic CFs. F-ratio represents the ratio of improvement in the model prediction to the residual errors present in the model. ANOVA is given by the formula.

$$SS = \sum \frac{(x - \bar{x})^2}{N - 1} \quad (2)$$

$$MS = \sum \frac{(x - \bar{x})^2}{df} \quad (3)$$

Where

x = Variables

$\bar{x}$ = Mean

N = Number of observation

df = Degree of freedom

RESULTS AND DISCUSSION

Determination of the Influence of the Studied Variables on the K-Factor: A hierarchical regression model was applied to evaluate the influence of the variables in the model. All the assumptions of multiple regression which guides Hierarchical regression were examined - Normality test (Shapiro-wilk test), Independence, multicollinearity test (residual analysis) and outliers check using Z-Score statistic. HR was carried out on all the variables and 'not significant model' was obtained. An exploratory data analysis was then done and the variables were divided into blocks and grouped based on the k-factor. Each of the blocks was then analyzed and the results are shown below.

Six (6) blocks were considered and grouped together starting from Block 1 with just one variable LST. This block explains only 39% of the variation in the k-factor as determined by the adjusted R^2 in Table 28. In Block 2, LD was combined with R, which led to an increase in the value of R^2 to 70.7%. In Block 3, DD, LD and NDVI were considered and they increased the value of adjusted R^2 to 82.6%. In Block 4, when four variables ED, LD, NDVI and R were considered, the block explained 89.5%. The variables in block 5 are DD, ED, LD, LST and R which explained 98.0%. When more variables DD, ED, LD, LS, LST and R were considered in blocks 6, there was an increase in adjusted R^2 to 97.6%.

The model summary in the table above shows the variability in soil loss occurrence that can be accounted for by the individual as well as all the CFs in the model blocks. This was evaluated by analyzing the changes in the coefficient of the determination (R^2) values for each Block in the model. The coefficient of the determination (R^2), explains the percentage prediction made by the independent variables to the dependent variable. The independent variables predicted 46.7% (NDVI) in Block 1; 78% (LD and R) in Block 2; 89.1% (DD, LD and NDVI) in Block 3; 94.8% (DD, ED, LD, LST and R) in Block 4; 99.3% (DD, ED, LD, LST and R) in Block 5 and 99.4% (DD, ED, LD, LS, LST and R) in Block 6 respectively as causative factors of soil erosion (k-factor). In other words - DD, ED, LD, LS, LST and R contributed 99.4% to soil erosion hazards in the study area. This implies that the combination contributed the highest out of all the causative factors examined in this study, leaving the rest with only 0.6%

Table 1. Model Summary of the Variables

Block	Variables	R^2	Adjusted R^2	$R^2(\text{pred})$	Durbin-Watson
1	NDVI	46.7	39	0.00	1.17908
2	LD, R	78.0	70.7	0.00	1.22525
3	DD, LD, NDVI	89.1	82.6	21.07	1.11047
4	ED, LD, NDVI, R	94.8	89.5	33.79	1.36101
5	DD, ED, LD, LST, R	99.3	98.0	69.15	2.93702
6	DD, ED, LD, LS, LST, R	99.4	97.6	46.39	3.13247

Source: SPSS Output, (2020)

The Model of Summary table also shows that the Durbin-Watson levels ranged from 1.11047 in block 3 to 3.13247 in block 6. The levels are within 0 – 4, even though the levels tended towards 1.1 – 3.1 which indicates that blocks 1, 2, 3 and 4 have very weak negative correlation, while blocks 5 and 6 have very weak positive correlation, but are all significant since there is no general rule to what is acceptable or not, outside the critical value. However, between 1.5 and 2.5 generally would have been better. The implication is that the model is significant.

Table 2 above shows the Analysis of Variance table for the group which contain the F-value and p-values for testing of the significance of each model in each block. Block 1 is significant with an F-value of 6.12 and P-value of 0.043, since the P-value is less than 0.05. In Blocks 2, F-value is 10.65 and P-value is 0.011, and is significant since the P-value is less than 0.05. In Block 3, F-value is 13.63 and P-value is 0.008, and is not significant since the P-value is greater than 0.05; likewise in block 4, F-value is 18.06 and P-value is 0.008, and is significant since the P-value is greater than 0.05. In Block 5, F-value

is 79.50 and P-value is 0.002, and is significant since the P-value is less than 0.05, and in Block 6, F-value is 55.32 and P-value is 0.018, and is also significant since

the P-value is less than 0.05. The results show that all the blocks are significant and therefore considered as the best group depending on the variables of interest.

Table 2. Analysis of Variance (ANOVA) of the Variables

Block 1	Source	Analysis of Variance (ANOVA)			F	P
		DF	SS	MS		
	Regression	1	0.0015397	0.0015397	6.12	0.043
	Residual Error	7	0.0017597	0.0002514		
	Total	8	0.0032995			
2	Source	DF	SS	MS	10.65	0.011
	Regression	2	0.0025746	0.0012873		
	Residual Error	6	0.0007249	0.0001208		
	Total	8	0.0032995			
3	Source	DF	SS	MS	13.63	0.008
	Regression	3	0.00294003	0.00098001		
	Residual Error	5	0.00035946	0.00007189		
	Total	8	0.00329949			
4	Source	DF	SS	MS	18.06	0.008
	Regression	4	0.00312637	0.00078159		
	Residual Error	4	0.00017312	0.00004328		
	Total	8	0.00329949			
5	Source	DF	SS	MS	79.50	0.002
	Regression	5	0.00327477	0.00065495		
	Residual Error	3	0.00002471	0.00000824		
	Total	8	0.00329949			
6	Source	DF	SS	MS	55.32	0.018
	Regression	6	0.00327973	0.00054662		
	Residual Error	2	0.00001976	0.00000988		
	Total	8	0.00329949			

Source: SPSS Output, (2020)

Table 3 above shows the coefficient(s) estimate as well as the p-values for testing of the significance level at 0.05 for each block. The coefficient(s) table above shows the individual contribution of the predictor(s) variables to the response or dependent variable and is used to explain the multiple linear regression equation which is thus:

$$Y_1 = \beta_0 + \beta_1 \alpha_1 + \epsilon_1$$

In Block 1, $Y_1 = 0.06541 + 0.4628(\text{NDVI})$. This means that the value 0.06541 is the base constant; that is, the value of K - factor before the effect of changes in the predictor variable is noticed. The equation means that every unit increase in NDVI, will increase K - factor by 0.4628.

In Block 2, $Y_1 = -1.0364 + 0.07789(\text{LD}) + 0.00013733(\text{R})$. This means that the value -1.0364 is the base constant; that is, the value of K - factor before the effect of change in the predictor variables is noticed. The equation means that every unit increase in LD will increase K - factor by 0.07789, while every unit increase in R will increase K - factor by 0.00013733.

In Block 3, $Y_1 = 0.00753 + 0.5974(\text{ED}) + 0.12172(\text{LD}) + 0.5032(\text{NDVI})$. This means that the value 0.00753 is the base constant; that is, the value of K - factor before the effect of change in the predictor variables is noticed. The equation means that every unit increase in ED will increase K - factor by 0.5974, while every unit increase in LD and NDVI will increase K - also by 0.12172 and 0.5032 respectively.

In Block 4, $Y_1 = -0.4672 + 0.4233(\text{ED}) + 0.11499(\text{LD}) + 0.3477(\text{NDVI}) + 0.00005993(\text{R})$. This means that the value -0.4672 is the base constant; that is, the value of K - factor before the effect of change in the predictor variables is noticed. The equation means that every unit increase in ED, LD, NDVI and R will increase K - factor by 0.4233, 0.11499, and 0.00005993, while every unit increase in ED and LD will increase K - factor by 0.3157 0.3477 and 0.00005993 respectively.

In Block 5, $Y_1 = -0.3397 + 0.11055(\text{DD}) + 0.6357(\text{ED}) + 0.102061(\text{LD}) - 0.0065177(\text{LST}) + 0.00007163(\text{R})$. This means that the value -0.3397 is the base constant; that

is, the value of K - factor before the effect of change in the predictor variables is noticed. The equation means that every unit increase in DD, ED, LD and R will increase K - factor by 0.11055, 0.6357, 0.102061 and 0.00007163 respectively, while every unit increase in LST will decrease K - factor by 0.0065177.

In Block 6, $Y_i = -0.2854 + 0.10827(DD) + 0.6249(ED) + 0.10002(LD) - 0.002909(LS) - 0.007465(LST) + 0.00006857(R)$. This means that the value -0.2854 is the base constant; that is, the value of K - factor before the

effect of change in the predictor variables is noticed. The equation means that every unit increase in DD, ED, LD and R will increase K - factor by 0.10827, 0.6249, 0.10002 and 0.00006857 respectively, while increase in LS and LST will decrease K - factor by 0.002909 and 0.007465 respectively.

The table above shows that the variables have moderate correlation among each other except for few, and is explained thus:

Table 3. Coefficient(s) of the Variables

Block 1	Predictor	Coefficient(s) for each Block			P	VIF
		Coef (β)	SE Coef	T		
2	Constant	0.06541	0.03985	1.64	0.145	1.000 VIF
	NDVI	0.4628	0.1870	2.47	0.043	
	Predictor	Coef	SE Coef	T	P	
	Constant	-1.0364	0.2759	-3.76	0.009	
	LD	0.07789	0.02291	3.40	0.015	
	R	0.00013733	0.00003184	4.31	0.005	
3	Predictor	Coef	SE Coef	T	P	VIF
	Constant	0.00753	0.02502	0.30	0.776	3.360 3.275 1.094
	ED	0.5974	0.2118	2.82	0.037	
	LD	0.12172	0.02862	4.25	0.008	
	NDVI	0.5032	0.1046	4.81	0.005	
4	Predictor	Coef	SE Coef	T	P	VIF
	Constant	-0.4672	0.2296	-2.03	0.112	4.237 3.345 2.027 2.870
	ED	0.4233	0.1845	2.29	0.083	
	LD	0.11499	0.02244	5.12	0.007	
	NDVI	0.3477	0.1105	3.15	0.035	
	R	0.00005993	0.00002888	2.07	0.107	
5	Predictor	Coef	SE Coef	T	P	VIF
	Constant	-0.3397	0.1052	-3.23	0.048	2.452 6.638 3.439 1.291 2.199
	DD	0.11055	0.02096	5.27	0.013	
	ED	0.6357	0.1008	6.31	0.008	
	LD	0.102061	0.009926	10.28	0.002	
	LST	-0.0065177	0.0009110	-7.15	0.006	
	R	0.00007163	0.00001103	6.49	0.007	
6	Predictor	Coef	SE Coef	T	P	VIF
	Constant	-0.2854	0.1384	-2.06	0.175	2.500 6.765 3.682 2.926 3.614 2.481
	DD	0.10827	0.02318	4.67	0.043	
	ED	0.6249	0.1114	5.61	0.030	
	LD	0.10002	0.01125	8.89	0.012	
	LS	-0.002909	0.004109	-0.71	0.552	
	LST	-0.007465	0.001669	-4.47	0.047	
	R	0.00006857	0.00001283	5.34	0.033	

Source: SPSS Output, (2020)

DD as a variable has a weak positive correlation with K - factor (0.245) and is not significant at 0.525. This means that DD as a variable alone cannot make any meaningful contribution that will cause any change in K - factor. ED as a variable has a weak positive correlation with K -

factor (0.034) and is not significant at 0.931. This means that ED as a variable alone even though positive cannot make any meaningful contribution that will cause any change in K - factor. However, with DD, there is a strong negative correlation (-0.720) and is significant also at

0.029 which is less than 0.05 level of significance. LD as a variable has a weak positive correlation with K - factor (0.315) and is not significant at 0.409.

This means that LD as a variable alone cannot make any meaningful contribution that will cause changes in K - factor. Correlating LD with DD shows a positive relationship (0.570) and is not significant at 0.109, which is greater than 0.05 level of significance. On the

other hand, LD has a strong negative relationship with ED (-0.833) and is significant at 0.005. LS as a variable has a weak positive relationship with K - factor (0.260) and is not significant at 0.485; compared with DD, it has a weak negative relationship (-0.105), which is not significant at 0.787; with ED, it has a very weak positive relationship (0.006) and is not significant at 0.988 and finally with LD, it has a very weak negative relationship (-0.008) and is not significant at 0.984.

Table 4. Correlation Matrix of the Variables

	Correlations: K_Factor, DD, ED, LD, LS, LST, NDVI, R, SMI							R
	K-Factor	DD	ED	LD	LS	LST	NDVI	
DD	0.245 0.525							
ED	0.034 0.931	-0.720 0.029						
LD	0.315 0.409	0.570 0.109	-0.833 0.005					
LS	0.26 0.485	-0.105 0.787	0.006 0.988	-0.008 0.984				
LST	-0.680 0.044	0.037 0.924	-0.072 0.854	-0.047 0.904	-0.747 0.021			
NDVI	0.683 0.043	0.271 0.480	0.293 0.444	-0.249 0.518	0.383 0.309	-0.600 0.087		
R	0.598 0.089	-0.229 0.554	0.590 0.095	-0.447 0.228	0.071 0.857	-0.388 0.303	0.693 0.038	
SMI	0.607 0.083	0.061 0.875	0.355 0.349	-0.308 0.419	0.465 0.208	-0.560 0.117	0.904 0.001	0.806 0.009

Source: SPSS Output, (2020)

LST as a variable has a strong negative relationship with K - factor (-0.680) and is significant at 0.044; compared with DD, it has a weak positive relationship (0.037) and is not significant at 0.924; with Ed, it has a very weak negative relationship (-0.072) and is not significant at 0.854; with LD, it has a very weak negative relationship (-0.047) and is not significant at 0.904; and finally with LS, it has a strong negative relationship (0.747) and is significant at 0.021.

NDVI as a variable alone has a strong positive relationship with K - factor (0.683) and is significant at 0.043; compared with DD, it has a weak positive relationship (0.271) and is not significant at 0.480; also compared with ED, it has a weak positive relationship (0.293) and is not significant at 0.444; with LD, it has a weak negative relationship (-0.249) and is not significant at 0.518; also with LS, it has a positive relationship (0.383) and is not significant at 0.309 and finally, when compared with LST, it has a strong negative relationship (-0.600) and is not significant at 0.087. R as a variable alone has a positive relationship with K - factor (0.598) and is not significant at 0.089; compared with DD, it has a negative

relationship (-0.229) and is not significant at 0.554; also compared with ED, has a positive relationship (0.590) and is not significant at 0.095; with LD, it has a negative relationship (-0.447) and is not significant at 0.228; also with LS, it has a very weak negative relationship (-0.071) and is not significant at 0.857 and when compared with LST, it has a negative relationship (-0.388) and is not significant at 0.303; and finally when compared with NDVI, it has a strong positive relationship (0.693) and is significant at 0.038.

SMI as a variable alone has a positive relationship with K - factor (0.607) and is not significant at 0.083; compared with DD, it has a very weak positive relationship (0.061) and is not significant at 0.875; also compared with ED, it has a weak positive relationship (0.355) and is not significant at 0.349; with LD, it has a weak negative relationship (-0.308) and is not significant at 0.419; also with LS, it has a weak positive relationship (0.465) and is not significant at 0.208 and when compared with LST, it has a negative relationship (-0.560) and is not significant at 0.117; when compared with NDVI, it has a very strong positive relationship (0.904) and is significant at 0.001

and finally when compare with R, it has a strong positive relationship (0.806) and is significant at 0.009.

CONCLUSION

The research showed that dynamic causative factors - Drainage Density, Erosion Density, Lineament Density, Slope Length, Land Surface Temperature, Normalized Difference Vegetation Index, Rainfall and Soil Moisture Index, influence soil susceptibility to, initiate and trigger erosion hazards in Anambra State, Southeastern Nigeria. The approach employed is very important for sustainable land-use management and erosion prevention. Therefore, understanding the appropriate selection or combination of the vital causative factors is required to achieve accurate susceptibility estimate. The major objective is to know the percentage contribution of dynamic causative factors to occurrence of soil erosion in Anambra State. The study was able to pin-point the dynamic CFs such as DD, ED, LD, LS, LST and R, which contributed 99.4% to Soil Erodibility (K - Factor) that encourages and helps in triggering soil erosion in the study area in addition to other already known and unknown factors of soil erosion called redundant factors in the context of this research.

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