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Evaluating the Impacts of Soil Erosion on Selected Hillslopes in UNN Using WEPP Model

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Abstract
Soil erosion is a major form of degradation experienced by Nsukka agricultural lands. Literatures have proven the problem to be one of the major reasons for reduced agricultural yield and other forms of land use. However, the use of hydrological models has aided the problem-solving approach towards its remediation. The Water Erosion Prediction Project (WEPP), a physically based hydrological model, was used in this study to estimate runoff and soil loss through predictive mechanisms across different scales of space and time. A number of hillslopes were considered, and different rainfall events were also monitored within the University of Nigeria, Nsukka (UNN) environment Data on soil, topography, land use, and rainfall events were entered into the model and the predicted runoff and soil loss values were compared to the measured values. However, observations from the WEPP model predicted a maximum soil loss of 0.038 kg/m^2 at 1111.460 m and 1145.140m along the hillslope profile and a minimum soil loss of -0.199 kg/m^2 at 3368.060 m along the hillslope profile. Therefore, it can be concluded that the amount of soil loss varies with the steepness or land configuration. These findings are particularly useful for farmers and engineers in improving farm management techniques, informing better soil and water conservation methods and site preparation, planning and design respectively.

Keywords: WEPP, Erodibility, UNN, Soil yield, Cligen, Hydrological model

1. Introduction

Soil remains essential input to agricultural production in Nigeria, where agricultural output is critical to development and the majority of the population's livelihoods rely on this abundant natural resource (Idah et al., 2008). However, Agricultural land use in Nigeria has frequently demonstrated a negative impact on natural soil fertility and productivity (Onweremadu et al., 2007). Due to the current rate of soil loss caused by numerous causes of erosion, the top soil resource is observed to be quickly moving into the sea, ocean, rivers, and streams, which commonly referred to as soil erosion. Soil erosion can also be simply described as the net long-term balance of all processes that separate and transfer soil away from its original location (Lupia-Palmieri, 2004). The term can alternatively be characterised as the geological phenomenon involving the displacement of soil and rock fragments from their initial positions, subsequent transportation, and eventual deposition in a different geographical setting. While soil erosion can be a naturally occurring geomorphic process, human activities also remain core to the significant rates of soil detachment and transport occurrences. The three primary factors contributing to erosion are water, wind, and tillage. Each requires distinct soil separation and transportation methods. As a result, each requires distinct strategies to reduce the corresponding erosion rates. The identification of the processes occurring at a location is a critical component of erosion control. However, soil erosion is caused by land levelling, soil quarrying, crop harvesting, explosive cratering, and trench digging, as well as by the forces created by the surface flow of water (runoff) (Poesen, 2018).

Soil erosion as a result of water is arguably the most severe and has received the most attention. It is noticed that soil separates from the soil mass in water erosion in two ways: by the forces imposed by moving water across the surface, and by the impacts of raindrop splashes on the soil surface (runoff). The thin sheets of runoff moving across the surface are the first to transport the separated dirt through flowing water (sheet erosion) and then the surface runoff which now collects in shallow incisions or narrow channels (rill erosion) or gullies (gully erosion). In both of these types of channels, the erosive force of the flow is significantly increased, producing water-caused rills and gullies as visible evidence of erosion in the landscape.

In this study the Water Erosion Prediction Project (WEPP), founded in 1985 with the intention of developing a new generation of water erosion prediction technology for use in soil and water conservation, as well as environmental planning and assessment (Abaci and Papanicolaou, 2009) was employed to evaluate the impact of soil erosion on some hillslopes within the university environment. The WEPP is a physically-based, continuous simulation computer programme that calculates daily runoff and erosion on hillslopes or watersheds for agriculture, forestry, and rangeland management (Flanagan and Nearing, 1995). Climate generator (Cligen), winter processes, irrigation, surface hydrology and water balance, subsurface hydrology, soils, plant growth, residue decomposition, overland flow hydraulics, and erosion are the nine components of the hillslope WEPP (Pieri et al., 2007). The WEPP model uses the steady-state sediment continuity equation to estimate soil erosion and deposition. The WEPP model divides soil erosion on hillslopes into two components: soil particles detached by raindrops and transported by thin sheet flow, known as the interrill erosion component, and soil particles detached by shear stress and transported by concentrated flow, known as the rill erosion component (Pudasaini et al., 2004).

The aim of this study remains to evaluate runoff and soil loss through predictive mechanisms across different scales of space and time using the WEPP model. A number of hillslopes were considered, and different rainfall events were also monitored within the University of Nigeria, Nsukka environment.

2.0 Material and methods

2.1 Materials

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The following materials were used in the study:
The Water Erosion Prediction Project Software (WEPP), Oven, Soil flume, 50-cl can, Filter paper, Digital weighing scale, Rain coat, Handheld GPS, Rain gauge, Metre rule, Masking tape, and desiccator

2.2 Methodology

*2.2.1 **MODELLING APPROACH***

The research was carried out at The University of Nigeria, Nsukka local government area, which is roughly positioned by Lat. 60 52| N and Long. 70 23| E and occupies the northern section of Enugu State. The annual total rainfall in the area is 1,708mm, with typical temperatures ranging from 270 to 280 degrees Celsius. The area used by the University is mostly arable, tree crops, and irrigation. These statistics are mostly obtained from (Asadu et al., 2002 & Ofomata, 1997) in terms of the basic agricultural land management practices used.

Climate parameters required by the WEPP model, such as daily precipitation, maximum and minimum air temperatures, and solar radiation, were measured at the National Centre for Energy Research and Development (NCERD), which is located near the research sites. Every rainfall event was documented, and other climatic parameters were measured every day. The discharge flowing through the stream at the outlet was measured continuously by recording staff gauge readings from a pre-calibrated Hydraulic flume. At the flow channel's outlet, manual sediment sampling was also carried out.

The sediment concentration in each collected sample was determined by filtering, drying, and weighing. The sediment production from a rainfall event was calculated by multiplying the volume of runoff (m^3) by the sediment concentration (mg L^{-1}). The sediment production values from all rainfall events in a year were added together to calculate the annual value in tons. The annual sediment yield was calculated by dividing the annual sediment production by the watershed area.

Finally, runoff was estimated along hillslopes at the University of Nigeria, with the hillslopes considered being in the Faculty of Engineering. The three hillslopes were named for proper identification as a result of the research work. One was near the NLNG laboratory, Electrical Engineering axis, and the other was the Chitis axis. A hydraulic flume was installed along the three hillslope flow channels to measure the flow depth and rate. On Google Earth, the slope steepness in percentage and distance in meters were calculated using the highest hillslope know as hilltop-slope gate as the reference point for all three runoff sample points collected.

2.2.2 **Model application**

A WEPP simulation requires climate, plant management, soil, and topographic data (Flanagan and Nearing, 1995). For this study, the WEPP model (hillslope version 2010.100) was applied to experimental hill slopes in Nsukka, Southeastern Nigeria. There are two ways to generate slope data for the WEPP model: non-dimensional distance to point and slope and slope length and steepness pairs. The latter approach was used in this study.

Table 1. Obtaining Slope Length and Percentage of Three Points with Single Reference Point

Sample Point	Latitude	Longitude	Altitude (m)	Ground Distance to Reference Point (m) {As the crow flies} (RUN)	Elevation Difference Against Reference Point (m) (RISE)
NLNG	6˚ 52’ 5.485” N	7˚24’35.817” E	408	1,173.47	38
Elec. Engine	6˚ 52’ 5.405” N	7˚24’32.256” E	407	1,187.27	39
Chitis	6˚51’59.826” N	7˚24’38.261” E	414	1,000.55	32

Reference Point	Latitude	Longitude	Altitude (m)
Hilltop Gate, UNN	6°51'27.60"N	7°24'40.52"E	446

Table 2: slope distance and steepness from Reference Point (RP)

RP to Sample Point	Slope Length (meters)	Steepness (%)
NLNG	1174.09	3.238
Electrical Engineering	1187.91	3.285
Chitis	1001.06	3.198

The textural composition of the soil was sourced from past findings, results from (Mbajiorgu and Ogbu, 2011), and particle size analysis obtained from the University of Nigeria, Nsukka's Soil Science Laboratory. The soil input parameters determine the soil albedo, which is calculated mathematically using the relationship proposed by Nicks et al. (1989). The WEPP model internally computed interrill erodibility, rill erodibility, critical shear stress, and effective hydraulic conductivity.

Table 3: Nsukka Soil Textural Analysis

Depth (mm)	Sand (%)	Clay (%)	CEC (meq/100g)	Organic matter (%)	Rock (%)	Texture
0-200	62	8.9	4.8	7.4	5	Sand Loam

Reports generated from surrounding farmers show all management information, which was supplemented by field observations. The farmers were observed to work with simple hand tools and likewise grow a variety of crops (Yam, pumpkin vegetables, and corn). However, the absence of Yam and pumpkin vegetables in the WEPP model crop database limited this study to corn. All management parameters were left at their default values, which did not correspond to the actual operation scenario in the field.

3.0 Results and Discussions

The weight of filter paper was determined to be 0.7725g, which was then subtracted from the weight of the oven-dried sample (filter paper plus soil sediment) after weighing to yield the actual weight of soil sediment after drying.

A. Soil yield from runoff collected

Table 4, Actual weight of soil sediment yield from runoff following each rainfall event:

Locations/points	First rainfall event(G)	Second rainfall event (G)	Third rainfall event (G)	Sediment average (G)
NLNG	0.0414	0.0236	0.0440	0.0363
CHITIS	0.0434	0.0945	0.0243	0.0544
ELECTRICAL ENG.	0.0019	0.0967	0.0253	0.0413

B. Soil loss graph

Figure 1. depicts the current state of soil erosion occurring along the hillslopes. The graphical representation exhibited a consistent and uniform slope. It is appropriate to assert that the gradient of the three designated areas surveyed during the experiment conducted at the University of Nigeria exhibited a fortuitous consistency, as evidenced by the graphical representation of the model outcomes. Nevertheless, the model demonstrates that the deposition along the slope results in a cumulative value of 0.02 kg/m2, indicating a discernible escalation in soil erosion. Additionally, it was noted that the soil detachment measured approximately 0.038 kg/m^2, leading to a subsequent deposition of 0.199 kg/m^2.

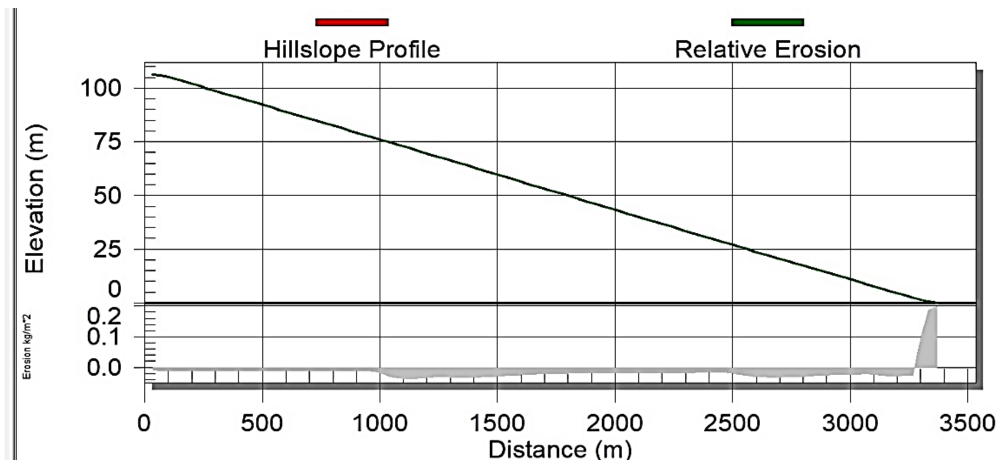

Fig. 1: WEPP representation of soil loss along hillslope

B. Soil loss along slope distance

Table 5: The result of soil loss from the top of the hillslope profile to the bottom (*WEPP Soil Loss Along Slope Distance)*

Distance (m)	Soil loss (kg/m^2)	Distance (m)	Soil loss (kg/m^2)	Distance (m)	Soil loss (kg/m^2)	Distance (m)	Soil loss (kg/m^2)
33.681	0.008	875.696	0.010	1717.711	0.021	2559.726	0.026
67.361	0.010	909.376	0.010	1751.391	0.020	2593.406	0.029
101.042	0.010	943.057	0.010	1785.072	0.020	2627.087	0.031
134.722	0.010	976.737	0.012	1818.752	0.019	2660.767	0.032
168.403	0.010	1010.418	0.021	1852.433	0.019	2694.448	0.032
202.084	0.010	1044.099	0.029	1886.114	0.019	2728.129	0.031
235.764	0.010	1077.779	0.035	1919.794	0.019	2761.809	0.030
269.445	0.010	1111.460	0.038	1953.475	0.019	2795.490	0.029
303.125	0.010	1145.140	0.038	1987.155	0.019	2829.170	0.028
336.806	0.010	1178.821	0.036	2020.836	0.019	2862.851	0.026
370.487	0.010	1212.502	0.034	2054.517	0.019	2896.532	0.025
404.167	0.010	1246.182	0.030	2088.197	0.019	2930.212	0.024
437.848	0.010	1279.863	0.030	2121.878	0.019	2963.893	0.023
471.528	0.010	1313.543	0.032	2155.558	0.019	2997.573	0.022
505.209	0.010	1347.224	0.033	2189.239	0.019	3031.254	0.022
33.681	0.008	1380.905	0.033	2222.920	0.019	3064.935	0.021

67.361	0.010	1414.585	0.033	2256.600	0.019	3098.615	0.023
606.251	0.010	1448.266	0.031	2290.281	0.018	3132.296	0.026
639.931	0.010	1481.946	0.030	2323.961	0.017	3165.976	0.027
673.612	0.010	1515.627	0.028	2357.642	0.016	3199.657	0.027
707.293	0.010	1549.308	0.026	2391.323	0.016	3233.338	0.026
740.973	0.010	1582.988	0.025	2425.003	0.016	3267.018	0.025
774.654	0.010	1616.669	0.023	2458.684	0.016	3300.699	-0.103
808.334	0.010	1650.349	0.022	2492.364	0.017	3334.379	-0.189
842.015	0.010	1684.030	0.021	2526.045	0.023	3368.060	-0.199

Based on the WEPP model, the hillslope profile exhibits a maximum soil loss of 0.038 kg/m2 at elevations of 1111.460m and 1145.140m. Conversely, a minimum soil loss of -0.199 kg/m2 is observed at an elevation of 3368.060m along the same hillslope profile. The decrease in soil loss at the terminus of the hillslope can be attributed to the minimal inclination towards the vertical observed at this location. A simulation spanning a duration of 10 years was conducted to allow for precise observation of significant fluctuations, yielding average annual estimations for precipitation, runoff, soil loss, and sediment yield. The results indicated values of 394.93mm, 1.88mm, 0.020 kg/m2, and 0.148 t/ha, respectively.

4.0. Conclusion

The significance of a precise soil erosion prediction model cannot be overstated, as calculations of soil loss offer vital information for the purposes of planning, design, and management. The WEPP model is valuable due to its ability to quantify the interrelationships and interactions among soil, climate, topography, and management variables that impact the occurrence of runoff and soil erosion or deposition at specific locations. Comparable findings were achieved through the application of the WEPP model to hillslopes, taking into account both rainfall and runoff factors. The hillslopes under investigation were situated exclusively within the premises of the University of Nigeria, Nsukka. The experiment was conducted on all three hillslopes that were previously mapped. Following laboratory analysis of sediment yields along each of the hillslopes resulting from the three recorded rainfall events, the sediment yields were obtained and arranged in ascending order based on the intensity of rainfall. The average sediment yields from the hillslopes at NLNG, Chitis, and Electrical Engineering were 0.0363g, 0.0544g, and 0.0413g, respectively. These values were influenced by the varying intensity of rainfall during the three considered rainfall events. The WEPP model, after conducting a 10-year simulation, projected a runoff of 1.8mm, based on an average precipitation of 394.93 mm. Additionally, the model estimated an annual accumulation of soil loss at 0.020 kg/m2.

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