# Evaluation of Empirical and Nomograph Method of Predicting Erodibility Index for Selected Savannah Soils.

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## ABSTRACT

Soil erodibility index for Typic haplustult and Petroferric haplustult soils were determined by direct field measurement under natural rainfall in IAR research farm located in Samaru, Zaria, latitude $11^\circ 11' N$, longitude $7^\circ 38' E$ . Two runoff plots, each measuring 5m x 2m, with 0.765m$^3$ underground collection tanks were established on each of the two soil types. Rainfall intensity was monitored using a daily recording rain gauge. Also monitored were the variations in soil properties as against the initial values over the period of the experiment. Estimate of soil erodibility index were made using empirical equation of Bouyoucos, (1935) and nomograph developed by Wischmeier et al., (1971) as Kb and Kn respectively. Results from the study indicate that Typic haplustult soil recorded the highest erodibility index (0.48) while Petroferric haplustult soil recorded the least (0.343) as determined by direct field measurement.

The results of the study indicate that both soil falls within a low-moderate erodibility index range. Results of estimated erodibility indices by Bouyoucos and K-nomograph indicated that values obtained by Bouyoucos ratio under estimated those obtained by direct measurement while from K-nomograph over estimated measured values. However, results of statistical t-test reveals that at 95% confidence interval, there is no any significant difference between measured value and estimated value by K-nomograph. The study therefore suggest that accurate direct measurement and K-nomograph methods for determining erodibility index can represent each other and are regarded as more reliable and suitable methods for the soil type in the study area. The current climate change and the sharp changes being experienced on some climate parameters require a more reliable method for the prediction of erodibility index in the savannah regions of Nigeria.

(Keywords: evaluation, erodibility, index, empirical, nomograph, Savannah, soil)

## INTRODUCTION

The intensive human interference of the biotic phenomena has been disturbing ecological balance that in turn causes erosion at an alarming rate. Soil erosion is a natural process and has occurred throughout geological history. Human activities, particularly agriculture and deforestation, however, have increased erosion rates, as they tend to remove the protective vegetation and reduce the stability of the soil.

This human influenced process is termed “accelerated erosion”. Since 1950s, accelerated erosion has resulted in the loss of 1/5 of the topsoil from the world’s agricultural land and 1/5 of the topsoil from tropical forest (Rawland, 1999).

Quantitative data on soil erosion at Sefa in Senegal where climatic and soil are similar to that of Samaru in Nigeria have been given by Roose as reported in Kowal and Kossam, (1976). On average, 26% of rain water carried off about 7.3 tonnes/hectares/year equivalent to loss in 25mm thick of soil in 42 years. Global average soil erosion rates from croplands are estimated at 5tonnes/ha/year (Walling, 1996) and that Asia, Africa and South America have the highest soil erosion rates of 3 – 4tonnes/ha/year (Primental et al., 1995). Further fertility of land also gets deteriorated due to erosion. It means that any effort towards food production will not be effective for long range until means are device to check these menaces to our natural gift, Earth.

The most significant achievements of the last 60years in soil erosion research have been the universal soil loss equation (USLE) and its gradual but systematic improvements (Wischmeier et al, 1971). The equation is composed of factor components that represent the influence of climate, soil, topography and land management. The soil factor usually referred to as soil erodibility index, K, is the vulnerability or susceptibility of soil to erosion that is the reciprocal of its resistance to erosion. A soil with high erodibility index will suffer more erosion than a soil with low erodibility index if both are exposed to the same rainfall (Hudson, 1963).

Many approaches are used to determine or estimate erodibility index (K) among which are empirical indices method, Wischmeier nomograph and direct field plot technique. Direct field plot technique is the best and most accurate method of determining K index but is generally expensive, time consuming and it is also difficult to established field plot in remote areas (Arab, 2000).

The suitability and accuracy of empirical indices method and Wischmeier nomograph varies with soil types. Difficulties arise, with attempt to estimate values from nomograph and in extrapolating empirical indices from one soil to another. Therefore, all methods of estimating erodibility index of soil should be regarded as second best substitute for direct determination by direct field measurement under natural rainfall. Thus the need to determine this parameter by direct field measurement under natural rainfall is very important.

The main thrust of the study was the determination of the erodibility index for Typic haplustult and Petroferric haplustult soil by direct field measurement and by empirical method (Bouyoucos ratio and K - nomograph) and the comparison of these methods so as to identify the most suitable and accurate method of determining erodibility index for the selected soil types in the study area.

## MATERIALS AND METHOD

The experiment was carried out within the Northern Guinea Savannah Ecological (NGSE) zone of Nigeria precisely at the Institute of Agricultural Research farm, Ahmadu Bello University, Samaru, Zaria, Nigeria, latitude $11^{\circ}11^{l}N$, longitude $7^{\circ}38^{l}E$ and altitude 686m.

Field runoff plots were established at the two major soil types in the farm: Typic haplustult and Petroferric haplustult soil (soil taxonomy classification). The experimental plot layout is shown in Figure 1 and a brief description of the soils physical characteristics is given in Table 1.

The plots A and B (5m x 2m) were sited on the two major soil types and are replicated twice as A1 and A2 on Typic haplustult soil and B1 and B2 on Petroferric haplustult soil. The plots edges were protected by wood planks which extend 150mm both below and above the soil surface. At the downstream end, a collecting trough that lead to a collecting drum ($0.765m^3$) buried at the downstream end of each plot was position. The slope of the two plots A and B were determine to be 21% and 9%, respectively, after ploughing along the slope direction (this makes the conservation practice factor, P, equal to 1).

Both plots were fallow for 2 years prior to the setting of the experimental plots and that makes crop management factor equal to 1. Topography factor (LS) was computed to be 0.39 and 0.10 for plot A and B respectively using the Equation 1:

$$LS = \frac{\{n\}^m}{22.13}\left(0.065 + 0.45s + 0.0065s^2\right) \quad \textbf{(1)}$$

Where:

$$n = slope\ length; \quad s = slope\ gradient;$$
$$m = an\ \exp onent\ depending\ on\ the\ slope$$

### Erodibility Index Computation

The erodibilty index was computed after every four rainfall events using Equation 2 and the average for the rainy season (from June to September) was computed.

This gives the erodibility index (Kd) for the representative soil type obtained under natural rainfall by direct field measurement.

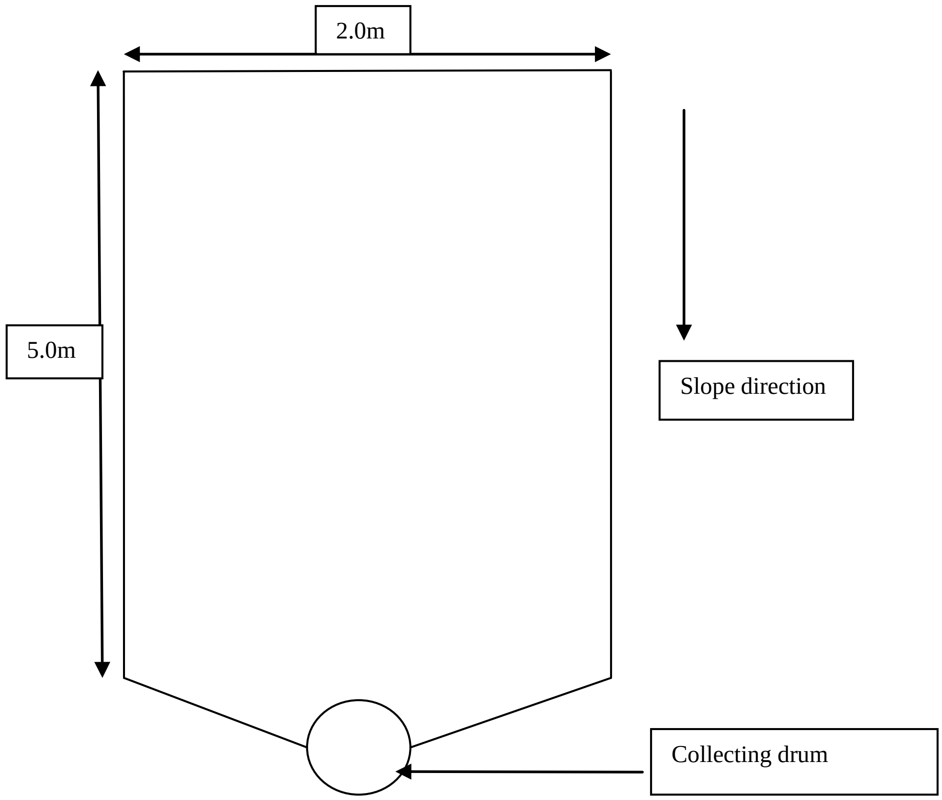


**Figure 1:** Experimental Plot Layout.

**Table 1:** Physical Characteristics of Soils in the Site.

| Soil Type | Particle Size Distribution | | | | Organic matter (%) | Soil Structure | Soil Texture | Soil Permeability (mm/hr) |
|---|---|---|---|---|---|---|---|---|
| | Sand (%) | Silt (%) | Clay (%) | Very Fine Sand (%) | | | | |
| Typic Haplustult | 44 | 42 | 14 | 25 | 1.13 | Fine granular | Loam | 13 |
| Petroferric Haplustult | 50 | 37 | 13 | 15 | 1.22 | Coarse granular | Sandy loam | 25 |

$$Kd = \frac{A}{0.25 \times R \times LS} \qquad \textbf{(2)}$$

Where:

$A = soil\ loss\ (kg/m^2)$; $R = erosivity\ index$

$0.25$ *is the coefficient to convert ton/acre used in the equation to* $kg/m^2$

Erodibility index for Typic haplustult and Petroferric haplustult soils were estimated using empirical equation of Bouyoucos, 1935 (Equation 3) and Wischmeier nomograph as Kb and Kn respectively:

$$Kb = \frac{\%Sand + \%Silt}{\%Clay} \qquad \textbf{(3)}$$

## RESULT AND DISCUSSION

### Measured Soil Erodibility

The data on the soil erodibility for Typic haplustult and Petroferric haplustult soils is presented in Tables 2 and 3. Results indicate that Typic haplustult soil has the highest mean erodibility index (0.48) while Petroferric haplustult soil recorded the least (0.34). This indicates that both soils falls within a low – moderate erodibility range. The results also fall within the range reported by El-swaify and Dangler, (1977) for the soil series in Northern Guinea Savannah Ecological (NGSE) zone (0.14 to 0.62) and the range reported by Roose, (1977) for ferruginous and ferrallitic soils in West Africa (0.12 to 0.69).

The data also indicate the variability in the measured values of K for different rains recorded during a period of 1year. This high variability is also indicative of the need for more replications. The cumulative erodibility index, K, ranged from 0.28 to 0.43 for Typic haplustult soil and 0.23 to 0.31 for Petroferric haplustult soil.

**Table 2:** Measured Erodibility Values (Kd) for Typic Haplustult Soil (Plot A).

| Duration | Plot | Soil Loss (A) kg/m2 | Erosivity, R | Slope Length Factor (LS) | Erodibility (Kd) | | Cumulative Parameters | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Actual | Mean | Ac | Rc | Kc |
| Week 1 | 1 | 1.46 | 73.043 | 0.39 | 0.205 | 0.206 | - | - | - |
| | 2 | 1.47 | 73.043 | 0.39 | 0.206 | | - | - | - |
| Week 2 | 1 | 2.49 | 69.395 | 0.39 | 0.368 | 0.361 | 3.95 | 142.44 | 0.284 |
| | 2 | 2.39 | 69.395 | 0.39 | 0.353 | | 3.86 | | 0.278 |
| Week 3 | 1 | 3.51 | 88.449 | 0.39 | 0.407 | 0.412 | 7.46 | 230.89 | 0.331 |
| | 2 | 3.6 | 88.449 | 0.39 | 0.417 | | 7.46 | | 0.331 |
| Week 5 | 1 | 2.1 | 91.649 | 0.39 | 0.235 | 0.234 | 9.56 | 322.54 | 0.304 |
| | 2 | 2.08 | 91.649 | 0.39 | 0.233 | | 9.54 | | 0.303 |
| Week 7 | 1 | 4.4 | 98.315 | 0.39 | 0.459 | 0.451 | 13.96 | 420.85 | 0.34 |
| | 2 | 4.25 | 98.315 | 0.39 | 0.443 | | 13.79 | | 0.336 |
| Week 10 | 1 | 0.96 | 13.946 | 0.39 | 0.706 | 0.776 | 14.92 | 434.79 | 0.352 |
| | 2 | 1.15 | 13.946 | 0.39 | 0.846 | | 14.94 | | 0.352 |
| Week 11 | 1 | 5.72 | 81.592 | 0.39 | 0.719 | 0.718 | 20.64 | 516.39 | 0.41 |
| | 2 | 5.7 | 81.592 | 0.39 | 0.717 | | 20.64 | | 0.41 |
| Week 13 | 1 | 1.26 | 21.574 | 0.39 | 0.599 | 0.594 | 21.9 | 537.96 | 0.418 |
| | 2 | 1.24 | 21.574 | 0.39 | 0.59 | | 21.88 | | 0.417 |
| Week 14 | 1 | 1.74 | 28.553 | 0.39 | 0.625 | 0.627 | 23.64 | 566.52 | 0.428 |
| | 2 | 1.75 | 28.553 | 0.39 | 0.629 | | 23.63 | | 0.428 |
| Week 16 | 1 | 4.96 | 119.976 | 0.39 | 0.424 | 0.426 | 28.6 | 686.49 | 0.427 |
| | 2 | 5 | 119.976 | 0.39 | 0.427 | | 28.63 | | 0.428 |
| **Mean measured erodibility index for Typic haplustult soil** | | | | | | **0.480** | | | |

**Table 3:** Measured Erodibility Values (Kd) for Petroferric Haplustult Soil (Plot B).

| Duration | Plot | Soil Loss (A) kg/m2 | Erosivity, R | Slope Length Factor (LS) | Erodibility (Kd) | | Cumulative parameters | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Actual | Mean | Ac | Rc | Kc |
| Week 1 | 1 | 0.7 | 73.043 | 0.1 | 0.38334 | 0.386 | - | - | - |
| | 2 | 0.71 | 73.043 | 0.1 | 0.38881 | | - | - | - |
| Week 2 | 1 | 0.4 | 69.395 | 0.1 | 0.23056 | 0.225 | 1.1 | 142.44 | 0.309 |
| | 2 | 0.38 | 69.395 | 0.1 | 0.21904 | | 1.09 | | 0.306 |
| Week 3 | 1 | 0.5 | 88.449 | 0.1 | 0.22612 | 0.219 | 1.6 | 230.89 | 0.277 |
| | 2 | 0.47 | 88.449 | 0.1 | 0.21255 | | 1.56 | | 0.27 |
| Week 5 | 1 | 0.36 | 91.649 | 0.1 | 0.15712 | 0.166 | 1.96 | 322.54 | 0.243 |
| | 2 | 0.4 | 91.649 | 0.1 | 0.17458 | | 1.96 | | 0.243 |
| Week 7 | 1 | 0.4 | 98.315 | 0.1 | 0.16274 | 0.165 | 2.36 | 420.85 | 0.224 |
| | 2 | 0.41 | 98.315 | 0.1 | 0.16681 | | 2.37 | | 0.225 |
| Week 10 | 1 | 0.16 | 13.946 | 0.1 | 0.45891 | 0.488 | 2.52 | 434.79 | 0.232 |
| | 2 | 0.18 | 13.946 | 0.1 | 0.51628 | | 2.55 | | 0.235 |
| Week 11 | 1 | 0.95 | 81.592 | 0.1 | 0.46573 | 0.478 | 3.47 | 516.39 | 0.269 |
| | 2 | 1 | 81.592 | 0.1 | 0.49024 | | 3.55 | | 0.275 |
| Week 13 | 1 | 0.25 | 21.574 | 0.1 | 0.46352 | 0.454 | 3.72 | 537.96 | 0.277 |
| | 2 | 0.24 | 21.574 | 0.1 | 0.44498 | | 3.79 | | 0.282 |
| Week 14 | 1 | 0.46 | 28.553 | 0.1 | 0.64442 | 0.637 | 4.18 | 566.52 | 0.295 |
| | 2 | 0.45 | 28.553 | 0.1 | 0.63041 | | 4.24 | | 0.299 |
| Week 16 | 1 | 0.62 | 119.976 | 0.1 | 0.20671 | 0.212 | 4.8 | 686.49 | 0.28 |
| | 2 | 0.65 | 119.976 | 0.1 | 0.21671 | | 4.89 | | 0.285 |
| **Mean measured erodibility index for Petroferric haplustult soil** | | | | | | **0.343** | | | |

## Comparison Between Measured and Predicted Erodibility Indices

Table 4 shows the erodibility indices as determined by direct field measurement, by Bouyoucos Ratio and by Wischmeier nomograph. The result indicates that predicted values by Bouyoucos Ratio under-estimated those obtained by direct measurement with about 42% and 28% difference for Typic haplustult (S1) and Petroferric haplustult (S2) soils, respectively. This is due to the fact that Bouyoucos Ratio does not take into account some of the most important factors affecting soil erodibility especially organic matter, soil permeability, soil structure etc.

The table further reveals that values obtained by K-nomograph over-estimated the measured values with about 15% and 13% difference for Typic haplustult (S1) and Petroferric haplustult (S2) soils respectively. Although the percent difference is relatively lower in both soils, but nevertheless, it indicate that either susceptibilities of S1 and S2 soils to erosion by water depends on yet undetermined properties or on inter-relation of properties in addition to those included in the K-nomograph. Another strong option is the possibility that both soils (S1 and S2) are not similar in characteristics to those found in the USA upon which the K-nomograph was based.

**Table 4:** Three (3) Method-Base Erodibility Indices.

| Three method base Erodibility indices | | | | | | |
|---|---|---|---|---|---|---|
| | By direct field measurement (Kd) | | By Bouyoucos Ratio (Kb) | | By K-nomograph (Kn) | |
| S/No | S1 Soil | S2 Soil | S1 Soil | S2 Soil | S1 Soil | S2 Soil |
| 1 | 0.206 | 0.386 | 0.057 | 0.073 | 0.67 | 0.43 |
| 2 | 0.361 | 0.225 | 0.061 | 0.073 | 0.67 | 0.43 |
| 3 | 0.412 | 0.219 | 0.053 | 0.061 | 0.65 | 0.4 |
| 4 | 0.234 | 0.166 | 0.057 | 0.061 | 0.67 | 0.4 |
| 5 | 0.451 | 0.165 | 0.067 | 0.073 | 0.64 | 0.43 |
| 6 | 0.776 | 0.488 | 0.067 | 0.073 | 0.62 | 0.43 |
| 7 | 0.718 | 0.478 | 0.061 | 0.061 | 0.61 | 0.55 |
| 8 | 0.594 | 0.454 | 0.061 | 0.061 | 0.57 | 0.55 |
| 9 | 0.627 | 0.637 | 0.061 | 0.061 | 0.57 | 0.55 |
| 10 | 0.426 | 0.212 | 0.061 | 0.061 | 0.57 | 0.55 |
| **MEAN** | **0.480** | **0.343** | **0.061** | **0.066** | **0.624** | **0.472** |

S1= Typic haplustult soil; S2 = Petroferric haplustult soil

However, the results of statistical t-test between measured value (Kd) and predicted values by Bouyoucos Ratio (Kb) and K-nomograph indicated that at 95% confidence interval, there is a significant difference between measured value and predicted values by Bouyoucos Ratio for the two soil types while between measured value and predicted by K-nomograph it indicated that there is no significant difference at 95% confidence interval for the two soil types. This suggest that both accurate direct measurement and K-nomograph method of determining erodibility index can represent each other and are regarded as a more reliable and suitable methods in the study area.

## CONCLUSION

The direct field measured erodibility index of two Northern Guinea Savannah Ecological (NGSE) zone soils indicates relatively low-moderate values. These erodibility values falls within the range reported by some other researchers (El-swaify and Dangler, 1977; Roose, 1977) for the soil series of this zone. The Bouyoucos estimated values of soil erodibility differ significantly from those measured directly and therefore there is a need for appropriate modifications to Bouyoucos Ratio method if it is to be used for NGSE zone soils.

Although, values predicted by K-nomograph do not differ significantly at 5% significance level from those measured directly but nevertheless, it indicate that either erodibility of soil in the zone depend on yet undetermined properties or on inter-relation of some properties in addition to those included in the K-nomograph. Another alternative is the possibility that both soils (S1 and S2) are not similar in characteristics to those found in U.S.A upon which the K-nomograph was based.

## RECOMMENDATIONS

Based on the results of the study, it is recommended that for the purpose of design and evaluation of conservation works at farm level, K-nomograph can safely be used as the best substitute for direct field measurement method of determining erodibility index in the study area. This more so where accuracy is of much concern such as in dam construction, design of irrigation channel and other hydraulic structures.

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## SUGGESTED CITATION


Arab, A.I., S.Z. Abubakar, and U.D. Idris. 2013. "Evaluation of Empirical and Nomograph Method of Predicting Erodibility Index for Selected Savannah Soils". *Pacific Journal of Science and Technology*. 14(1):517-523.

Pacific Journal of Science and Technology