Gashua Journal of Irrigation and Desertification Studies
Available online at www.gjidsfugashua.org.ng

Volume 3, No. 1

EMPIRICAL MODELS ASSOCIATED WITH GULLY DEVELOPMENT AND PREDICTOR VARIABLES INFLUENCING LITHOSOL SOIL IN GIREI LOCAL GOVERNMENT AREA, ADAMAWA STATE, NIGERIA

[*1] Gundiri J.W., [2] Buji I. B., [3] Kwari S. J., [4] Akwoga J. A. and [5] Joshua B.N.

[1, 2 & 3] Department of Soil Science, University of Maiduguri [4] Department of Soil Science and Land Resource Management, Taraba State University [5] Department of Crop Protection, University of Maiduguri, Nigeria

E-mail: gundirijohn@gmail.com (*Corresponding Author)* 07031200986

ABSTRACT:

A 2-year field study was carried out in Girei to evaluate the relationship between dependent variables (volume, Area and Mass of soil loss) and independent variables (watershed characteristics and related soil hydro-physical properties) by developing a regression model. This prediction model revealed how predictors impacted gully erosion development in 41 different gully locations. The results of the first model revealed that the coefficient of determination for VSL, ASL and MSL were 0.8143, 0.6286 and 0.7865, respectively, which implies that the aggregate impact of the predictor variables for VSL, ASL and MSL was 81 %, 62% and 78%, respectively. While the result of the final model revealed that volume of runoff and altitude impacted gully development (VSL and MSL) by 82.6% and 83.8%, respectively., On the other hand, porosity and gully head-cut height influenced ASL by 67.2%, which also implied that volume of runoff, altitude, porosity and gully head-cut were highly significant in predicting and influencing gully erosion in those areas. Hence, modeling empirical equation that could compute soil loss on monthly basis remains a challenge to potential research works, This study recommend further development of research model that could answer more research questions, and, measures that could reduce the rate of runoff down slope should be encouraged and practiced as its evident in the prediction by the model so thatcontour farming, ridging across the slope, sand bagging and bond making to reduce water velocity. Most importantly, encroaching into the hills for cultivation should be avoided.

Key words: Volume, Area and Mass, Soil, Lithosol, Models, Gully, and Girei

INTRODUCTION:

Nigeria, a West African country located in the tropical zone of the world (between latitude 4o and 14 ° N, and longitude 2 ° E), has a land area of about 923,769 km2, with the northern region covering about 79% of the entire land mass (Salako, 2003; Aregheore, 2005). The region is inhabited by over 50% of the country's estimated population of 220 million people and is home to over two-thirds of the country’s 250 ethnic groups (Pate and Dauda, 2013). Although Northern Nigeria contributes to a greater percentage of the country’s 42% GDP, the region is suffering from both economic and infrastructural deficiencies as indicated by the country’s Human Development Index (Macaulay, 2014). In this region, as in many other parts of sub-Saharan Africa (SSA), food grain production per capita has declined significantly over the past decades. Although part of this decline can be attributed to high rates of population growth, periodic drought, and unfavorable agricultural production and marketing policies of the national governments, much of it results from the steady and continuing degradation of agricultural lands from soil erosion and nutrient depletion and the subsequent loss of soil productivity (FAO, 2006). Gully erosion is one of the types of water erosion. Its development can cause severe soil degradation. Gully is considered to be one of the most important soil erosion processes (Seeger et al., 1997). At one time, it was thought that gullies developed as enlarged rills, but studies of the gullies revealed that their initiation is a more complex process (Morgam, 2009). Gully is a channel with a minimum width and depth equal to 0.3 m and 0.6 m, respectively to Brice (1996). Imeson & Kwaad (1980) used a minimum depth of gully equal to 0.5 m. Gully erosion is one form of accelerated soil erosion, and the occurrence of gullies often indicates an extreme form of land degradation warranting special attention (Yitbarek, 2007). Gully erosion usually represents a permanent loss of soil where agricultural production proceeds without appropriate protective measures and re-cultivation (Zachar, 1982). Soil properties, rainfall and runoff intensity, wind action, geological, hydro-geochemical and geotechnical characteristics, and anthropogenic activities are factors generating soil and gully erosion processes (Egboka and Orajaka, 1987). Studies have shown that soil physical properties can be effective in gully erosion development. In this case, the studies of dry regions of northern Nigeria indicate that sediment production due to gully development is related to three variables, including drainage area, silt and sand percent of the watershed above the gully heads (Soleymanpour et al.,2010). Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils (Wall et al., 2003). According study by Vahyala et al (018) demonstrated that gully depth has a direct relationship with clay content. The geographical location, climatic conditions and dry winds blowing in the northeast have caused over 80 percent of the country's total area (164 million hectares) of land to have dry and semi-dry conditions to an extent that the rate of rainfall in these regions was between 50 to 350 mm per year. It was evident that this condition favoured soil gully erosion. In this study area, Girei, the contribution of the relevant erosion predictor variables exhibited both increasing and decreasing behavior on the soil loss pattern. The soil shear strength, hydraulic conductivity, slope rate, porosity and organic matter content reduced soil loss. On the other hand, soil erodibility, infiltration rate, runoff, clay content, gully head cut and altitude increased soil erosion (Gundiri, 2023). This study is aimed at predicting the best independent variable that influenced soil loss, and also their relationships with the responding variables (VSL, ASL and MSL) in the Girei watershed.

MATERIALS AND METHODS

The Study Area

Girei Local Government Area is located between latitude 9º00´ and 9º 32´ N and Longitude 12º10´ and 12º48´E and situated at an altitude of 158.5m above sea level, Adamawa state (Adebayo et al., 2020). It is bounded to the north by Song Local Government Area, to the South and West by Yola North and South Local Government Area, and to the east by Fufore Local Government Area (Figure 1). The climate of the area comprises typical wet and dry seasons, with average annual rainfall ranging from 700-1000mm. The temperature ranges from 15 to 39ºC. The amount of sunshine hours ranges from 2500 in the south to 3000 hours in the extreme north (Adebayo et al., 2020). The vegetation in the area comprised a few grasses and shrubs, which is typical of a savannah region with scattered trees, mainly shea butter, acacia, eucalyptus and locust bean tree. While the dominant grass species include panicum maximum, aristida longiflora and andropogon gayanus (Adebayo, 2004; Tekwa and Usman, 2006 and Adebayo et al., 2020). All the gully sites occurred on both cultivated and non-cultivated lands, while some occurred on cattle route paths; there were fewer grasses, shrubs and trees observed at all the locations. The Geology of Girei, according to the Nigerian Geological Survey Agency (NGSA) (2006), is described as upper cretaceous rocks, Precambrian basement complex, a mixture of rock types and minerals. Most of the area is underlain by Magmatite and some Porphyritic granite, especially in the Eastern part of the Local Government area. Some medium to coarse-grained biotite is also found. The relief of Girei LGA comprises flat, relatively flat and rugged terrain with hills and mountains spread across all the districts. Hydrology of the area is dependent on the rainfall pattern and the underground reservoir, mostly in areas underlain by sedimentary rock formations. According to Adebayo (1999), the water resources available in the State (Adamawa), including Girei LGA, are adequate if utilized properly. The rivers in the area are seasonal in nature. The parent materials are heterogeneous and comprise predominantly of loamy sand, clay and sandy clay of a range of colors, which are also predominantly alfisols, luvisols, regosols, leptosols, cambisols, vertisols, and lithosols having lithic and paralithic (Vahyala, et al., 2018).

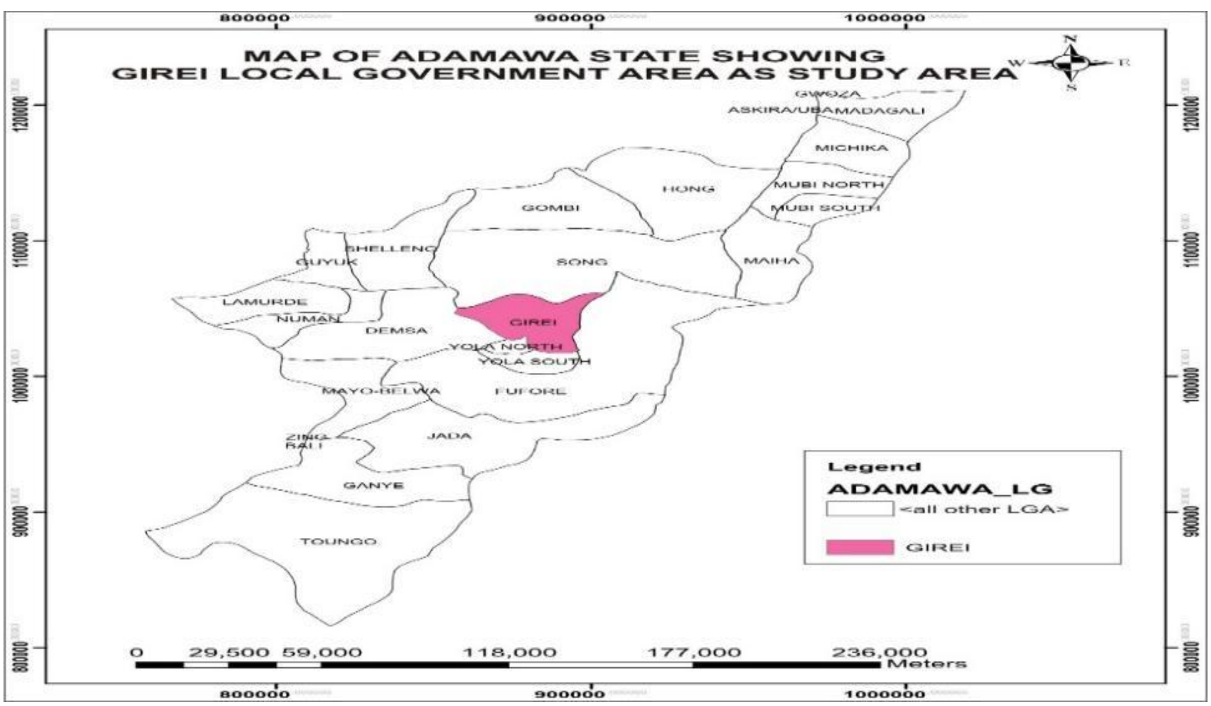

Figure 1: Map of Nigeria Showing Adamawa State and Adamawa Showing Girei LGA (Gundiri, 2023)

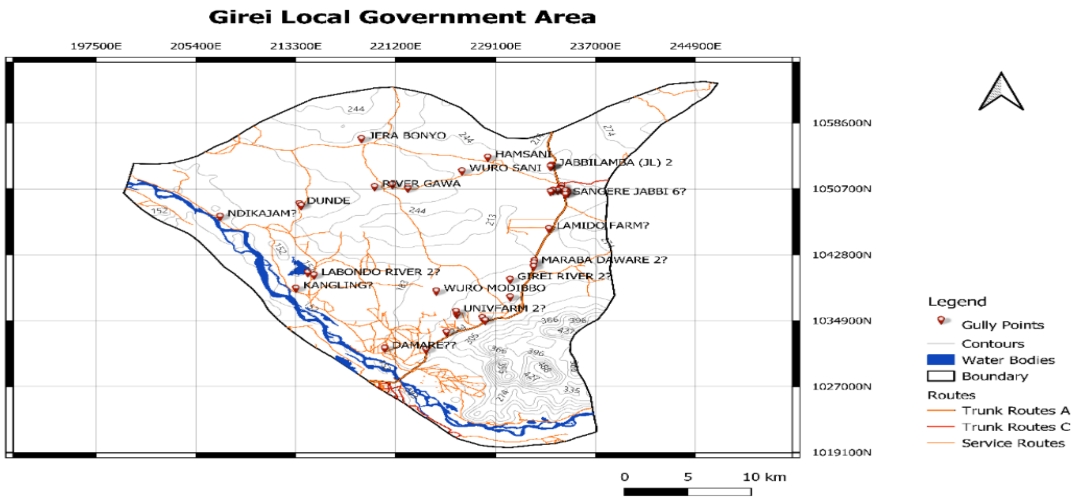

Figure 2: Map of Girei LGA showing Gully locations, Roads, Topography and Water Bodies

(Gundiri, 2023)

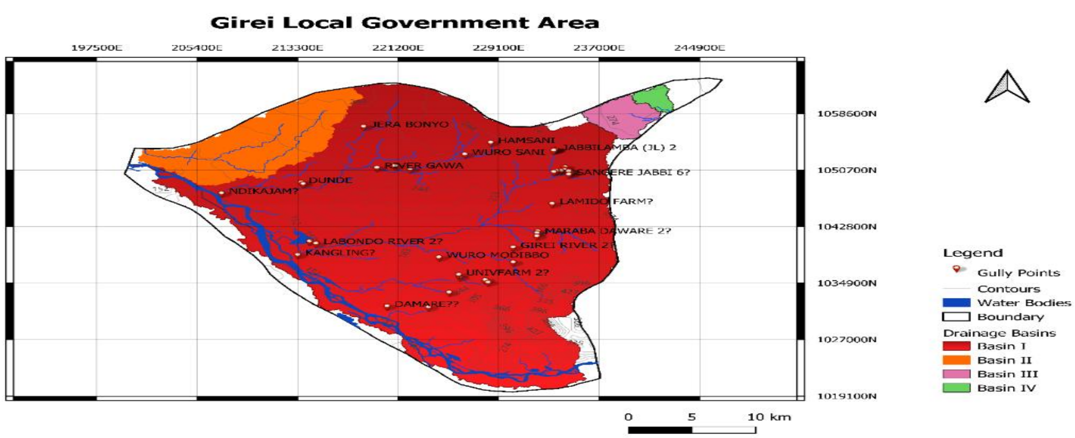

Figure 3: The Map of Girei Showing the Drainage Basins (Watershed) and Gully Points

(Gundiri, 2023)

Method of Data Collection and Analysis

Determination of gully erosion Channel parameters (length, depth, and width)

During the 2019 and 2020 wet seasons, the following measurements were carried out in the selected gullies: (1) the head-cut retreat (longitudinal growth) and gully widening (or lateral retreat) down-slope from the head-cut, and (2) the gully expansion rates and associated amount of soil loss along the total gully length.

To estimate gully expansion and the amount of soil loss from the total gully reach, three gully topographic surveys (before and after the rain phases of 2019 and 2020) were conducted. The soil loss in the various sites was then computed using the measured length (l), width (w), and depth (d) of each gully feature. Thus, actual soil loss estimates were determined using mathematical expressions relating gully length, width, and depth as follows:

Width = (W)

Average width $\frac{(WT+WM+WB)}{3}$ -- -- -- -- --- (1)

Where: TW= Top width, MW = Middle width and BW = Bottom width

Depth = (D)

Average depth $=\sum\left(\frac{(d1+d2+d3+d4+d5+--\mp d)}{n}\right)$ -- -- - (2)

Length = (Li)

Where L is the length of considered gully segment (m)

Cross-sectional area (A) $=$ Average depth $*$ Average width=, Gully $V = A * L$ (3)

The gully volume was estimated using the formula: **V=Σ**$\boldsymbol{L_i A_i}$ -- -- -(4)

Where Li is the length of considered gully segment (m) and Ai is the representative cross-sectional area of the gully segment (m^2)

2.2.2 Area of soil loss (ASL)

Cross-sectional area (A) = Average width * Average depth

Area of gully = wd -- -- -- -- -- (5)

Net area of gully $=(wd2 - wd1)$-- -- -- -- (6)

Where: w = width of gully channel

d = depth of gully channel

w_1 = width of gully channel before seasonal rainfall event

d_1 = depth of gully channel before seasonal rainfall event

w_2 = width of gully channel after seasonal rainfall event

d_2 = depth of gully channel after seasonal rainfall event

The total ASL =Net

2.2.3 Volume of soil loss (VSL)

Gully Volume = Cross-sectional area (A) * Length (L)

The gully volume was estimated using the formula: V= $\sum L_i A_i$ -- -- (7)

Where Li is the length of considered gully segment (m) and Ai is the representative cross-sectional area of the gully segment (m^2)

Net volume of soil loss $(VSL_1 - VSL_1) = \sum L_i A_i 2 - \sum L_i A_i 1$ -- -- (8)

Where: Li_1 = is the length of considered gully segment before seasonal rainfall event

Ai_1 = is the representative cross-sectional area of the gully segment before seasonal rainfall event

Li_1 = is the length of considered gully segment after seasonal rainfall event

Ai_1 = is the representative cross-sectional area of the gully segment after seasonal rainfall event

The total soil loss volume over the monitoring period will then be obtained by taking the difference in VT after and before the 2019 and 2020 rain phase:

Total VSL = $NetVSL(2019) + NetVSL(2020)$ -- -- -- (9)

Mass of soil loss (MSL)

The mass of the soil loss was calculated by multiplying the soil loss volume for each subsection by the measured average bulk density of the soils which was an expression described by Wolf & Snyder (2003):

Mass of soil loss =

Total volume of soil loss (VSL) $\times$ Soilδb -- -- (10)

Where: δ_b = Soil bulk density

Development of Empirical Equation for Prediction of Soil Loss

The relationships between the change in gully head-cut dimensions (lateral, head-ward and volumetric erosion) and the controlling factors: drainage area, head-cut height, site slope rate, volume of runoff water and soil physical properties such as bulk density, soil texture, Aggregates stability erodibility index, organic matter content was analyzed, using multiple linear regression equation, using measured soil loss (area, volume, and mass of soil loss) (Hudson, 1989). Coefficient of determinants (r^2) for the various predictor variables were used to formulate the multiple linear regression equation of the form:

$Y_i = ß_{oi} + ß_{1i}X_{1i} + ß_{2i}X_{2i} + \ldots ßp_{-1i}X_{p-1i} + \varepsilon_i$ -- -- -- -- (11)

Where Yi is the respondent (dependent variable), $ß_{oi}$, $ß_{1i,}$ $ß_{1i}$ and$ß_{p-1i}$ are parameters,

X_{1i}, X_{2i}, X_{p-1i} are variables (independent predictors), and ε_i is error term.

$Y = \alpha + \beta_1 X_1 + ß_2X_2 + ß_3X_3 + ß_4X_4 + ß_5X_5 +$------------- $+ ß_9X_9$ -- -- (12)

Where: Y = estimate of soil loss, α and β = regression parameters, X_1 = shear strength, X_2 = head-cut height, X_3 = site slope rate, X_4 = volume of runoff, X_5 = bulk density, X_6 = clay content, X_7 = aggregate stability, X_8 = erodibility index, X_9 = organic matter content, X_{10} = Infiltration rate, X_{11} = Hydraulic Conductivity and X_{12} = Altitude.

Additionally, empirical relationships between the volumetric retreat (V) and the lateral (W) and longitudinal (L) retreat was developed.

Model Validation:

A cross-validation approach was conducted to evaluate the efficiency and error of the prediction models for soil properties. The root-mean-square-error (RMSE) and the mean error (ME) of the model were also calculated. A value of RMSE close to zero illustrates the accuracy of prediction of the model. The following formulas were followed to calculate the RMSE and ME values:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}[Z(x_i) - Z*(x_i)]^2} \quad \text{-- -- --} \quad (13)$$

$$ME = \frac{1}{n}\sum_{i=1}^{n}[Z(x_i) - Z*(x_i)] \quad \text{-- -- -- -- --} \quad (14)$$

RESULTS AND DISCUSSION

Empirical Relationship

Empirical relationship between (ASL, VSL and MSL) and 12 relevant erosion predictor variables. Modelling Area of soil loss, Volume of soil loss and Mass of soil loss based on some soil, hydraulic and watershed properties. An empirical soil loss prediction equation was developed based on multiple linear regression between measured soil loss (ASL, VSL and MSL) and 12 relevant erosion prediction variables (Bulk density, clay content, erodibility index, organic matter content, soil shear strength, site slope rate, volume of run-off water, hydraulic conductivity, infiltration rate, aggregates stability, porosity, gully head cut height and altitude) studied in the area and expressed as: Model 1: In the first model, 12 erosion predictors were imputed into the model, but the model only selected 7 significant variables that were left in the model: The full model yielded the following results obtained from Table 1-3

YASL = 19.7412 – 1.7041(X1) + 0.52311 (X2) + 63.1405 (X3) – 0.2454 (X4) – 2009.2 (X5) + 0.00839 (X6) – 529.78 (X7) + 0.42571 (X8) – 0.4187 (X9) – 0.1765 (X10) + 6.35432 (X11) +

0.03245 (X12) r2 = 0.7618 -- -- -- -- -- -- -- -- -- (15)

YVSL = 5616.57 + 9733.22 (X3) – 315652 (X5) – 225.96 (X13) + 3.56929 (X6) – 291090 (X7) + 47.4296 (X8) – 50.382 (X10) r2 = 0.72 -- -- -- -- -- (16)

YMSL = 11193 + 14346 (X3) + 51.2271 (X4) – 671432 (X5)) – 515.56 (X13) + 5.6188 (X6) + 91.9095 (X8) – 106.89 (X10) r2 = 0.7647 -- -- -- -- -- -- (17)

Where, YASL = predicted area of soil loss, YVSL = predicted volume of soil loss, YMSL = predicted mass of soil loss. The relative impact of these predictor variables on erosion (ASL, VSL and MSL) in the first model revealed that the various variables impacted the soil erosion either positively or negatively. The level of impacts of the variables on each of soil loss were different, the r2 value for area of soil loss was 0.6286 implying the aggregate impact of 62% on the area of the soil loss (ASL), Secondly, the r2 value for volume of soil loss was 0.8143 implying that the aggregate impact of the selected variables left in the model was 81%, this shows that the variables have actually impacted gully erosion (VSL) in the area. The same goes for the mass of soil loss, with the r2 value of 0.7865, meaning the aggregate impact of the variables on the mass of soil loss was 78%. According to the various percentage impacts, we can say that those predictor variables in the model have actually affected gully erosion in the area, either by increasing or decreasing the soil loss. This observation was in line with the study of (Tekwa 2014), who reported that the 7 relevant erosion predictor variables expressed both reducing and increasing effects on soil loss. This led us to the;

Model 2: Another model was formed to further investigate and select the best and most significant predictor. Thus, 7 predictor variables were included.

The full model yielded the following results, presented in Table 4-6

$$Y_{ASL}=5.89418 + 110.004\,(X_3) - 0.5505\,(X_4) + 0.00772\,(X_6) - 0.5274\,(X_9) + 6.44154\,(X_{11})$$

- -- -- -- -- -- -- -- -- (18)

$$Y_{VSL} = -7405.6 + 12241\,(X_3) - 147844\,(X_5) - 294.2\,(X_{13}) + 3.77319\,(X_6) + 60.7373\,(X_8) + 36.9299\,(X_{12}) -$$

-- -- -- -- -- -- -- (19)

$$Y_{NSL} = -9295 + 22797\,(X_3) - 3682290\,(X_5) - 545.51\,(X_{13}) + 7.07538\,(X_6) + 109.226\,(X_8) + 54.6449\,(X_{12})$$

-- -- -- -- -- -- -- (20)

In model 2, 5 variables were picked to impact erosion both negatively (those inhibiting erosion) and positively (erosion promoters), Table 4 to 6. For the ASL, erodibility, organic matter content, volume of runoff, aggregate stability and gullyhead-cut were selected by the model as significant predictors. This suggests that shear strength and aggregate stability activity (Table 5) in soils were strong compared to other erosion-limiting variables, especially soil organic matter and clay content, in reducing water erosion. Morgam (1996) and Adekalu et al. (2007) reported similar relevance of soil shear strength, aggregate stability and organic matter. Ekwue and Stone (1994) also observed that soil clay content and shear strength help in increasing cohesion activities and erosion resistance against eventual soil particle detachment. Lal (2001) similarly reported that soil resilience against erosion menace was increased by shear strength, high organic matter content and soil structural stability. In other words, soil loss progress was increased by some of the predictor variables, including soil erodibility index, site slope and run-off, implying an increase in erosion as their value increased (Table 4-6). Soil erodibility index exhibited the highest elicitation on the VSL, ASL and MSL estimates. This strong effect of soil erodibility on erosion was not unconnected with its relation to other climatic, soil properties and watershed characteristics that also affected erosion, compared to the other water erosion increasing variables. Similar contribution of the soil properties was reported by Brady and Weil (2002), Capra and Scicolone (2002) and Poosen et al. (2003). Model 3: Collinearity observed between porosity and bulk density suggests that one of the two parameters should be dropped from the model; as such, bulk density was not included in the model of volume of soil loss (VSL) and mass of soil loss (MSL), but it was included in the equation of area of soil loss (ASL). Six independent variables; soil erodibility index (SEI), soil shear strength, slope rate, volume of runoff, infiltration rate (IR) and Altitude were included in the equation of VSL and MSL respectively (Tables 8 and 9), while gully head cut, organic matter content and dry stable aggregates were selected by the model in the equation for ASL (Table 7)

The full models were given as:

$$Y_{ASL} = 5.89418 + 110.004\,(X_3) - 0.5505\,(X_4) + 0.00772\,(X_6) - 0.5274\,(X_9) + 6.44154\,(X_{11})$$ -- -- -- -- -- -- -- -- (21)

$$Y_{VSL} = -7405.6 + 12241\,(X_3) - 147844\,(X_5) - 294.2\,(X_{13}) + 3.77319\,(X_6) + 60.7373\,(X_8) + 36.9299\,(X_{12})$$ -- -- -- -- -- -- (22)

$$Y_{MSL} = -9295 + 22797\,(X_3) - 368290\,(X_5) - 545.51\,(X_{13}) + 7.07538\,(X_6) + 109.226\,(X_8) + 54.6449\,(X_{12})$$ -- -- - -- -- -- (23)

It was observed that the outcome of model 3 revealed the most 3 significant predictor variables left in the model, while; IR, SHEAR and SLOPE were dropped as not highly significant in the prediction for impacting VSL and MSL, while, RUNOFF and DSA were also dropped out of the model as not highly significant in determination of ASL whereas, ERODIBI, OM and Headcut were left in the model as highly significant in the prediction.

Model 4: SEI, Vol of runoff and altitude were selected by the model in determining VSL and MSL, while SEI, Organic matter content and gully head cut were equally selected by the model for determining ASL. A step-wise selection procedure was employed and equally selected those variables; the models were therefore run based on the three parameters to obtain a final model (Table 10-12).

$$Y_{VSL} = -11255 + 11586\,(X_3) + 3.44181\,(X_6) + 43.5891\,(X_{12})$$ -- (24)

$$Y_{ASL} = -3.1176 + 87.7743\,(X_3) - 0.5374\,(X_4) + 8.63461\,(X_{11})$$ -- (25)

$$Y_{MSL} = -11255 + 11586\,(X_3) + 3.44181\,(X_6) + 43.5891\,(X_{12})$$ -- (26)

Another model was formed to further select the most highly significant variable predicting soil erosion, as such, 3 of the variables for VSL and MSL; ERODI, RUNOFF and Alt were fitted, 2 variables were equally selected for determining erosion (VSL and MSL), while ERODI, OM and Hcut were fitted into the model for ASL, 2 variables were equally selected as the most highly significant predictors (Table 10-12). These two parameters (runoff and altitude) were the most highly significant factors to determine VSL and MSL. The two variables are also correlated, implying that, rise in altitude produces high runoff; the lower the altitude, the less will be the runoff, especially when the slope is steep or gentle. Organic matter and headcut were selected by the model to influence ASL this shows that when the soil surface is well aggregated, breakage will be minimal, because of the presence of organic matter. But when the level of organic matter is low, the surface hardly resists heavy runoff, and as such, the gully headcut is affected. This was similar to the observation of Zegeye et al. (2016), who reported that as water flows down the slope, the ability of the gully head to resist pressure determines the ability of the soil to withstand the agent of erosion. Model 5: Two of these parameters, volume of runoff and altitude, were selected by the model to be the most highly significant in predicting VSL and MSL, while porosity and gully headcut were also selected to be the most highly significant in predicting ASL. These variables were further subjected to a step-wise selection procedure to select among the 2 variables the best, most highly significant predictor; both variables were equally selected in predicting VSL, ASL and MSL (Table 12). The model was therefore run based on the four parameters (volume of runoff, altitude, porosity and head cut) to obtain a final model as:

$$Y_{VSL} = -8317 + 3.53919\,(X_6) + 36.2111\,(X_{12}) \quad (27)$$

$$Y_{ASL} = 36.8875 - 0.7524\,(X_{10}) + 5.93336\,(X_{11}) \quad (28)$$

$$Y_{MSL} = -4786.6 + 2.85858\,(X_6) + 22.552\,(X_{12}) \quad (29)$$

The results of the empirical analysis revealed that the volume of run-off and altitude (elevation) were the most significant in determining and impacting soil erosion (VSL and MSL). This finding may be attributed to the fact that source of the water channels originated from the high mountains, with the highest elevation being 488 m. This observation showed that the distance from the highest elevation, which is the mountainous area, to the locations like Jabbilamba, Sangere, Safini and other locations situated below was long enough to generate run-off volume that can cause erosion. Maybe that was why altitude and runoff were the most significant predictors. These results were in line with other reports of other findings by Tekwa (2014), that topography influences runoff generation and peak discharge of concentrated flow channels. Although, Idowu et al. (2013), reported that Overland flow is the upper reaches of the hydraulic length, shallow flow begins where overland flow converges to form gullies while channel flow is available man-made drains, this observation was in accordance to the results obtained where it revealed that most of the gully erosion were situated at the shallow flow levels which can also be attributed to human activities aggravation. Gully headcut retreat is the major process of gully expansion, as evident by the nature of the gullies. Poesen et al. (2003) define gully head cut height to be a natural, nearly vertical drop in gully channel-bed elevation. Gullies are often characterized by actively retreating headcuts. For the gully headcut to be significant in determining the area of soil loss in this study, it was never a surprise due to the activities of men happening around the hilly area. Because Rengers et al. (2014) reported that headcut retreat rates correlate with the square root of drainage area approximately, and investigated how a drainage area controls headcut retreat, it translates into the longitudinal profile morphology over time.

Model Validation

Model validation of empirical ASL VSL and MSL aggregates estimate

Table 13 presents the results for the efficacy of the model developed for the prediction of ASL, VSL and MSL. In the whole of the study area, the model recorded low values of RMSE 0.0536 and 0.1022 in 2019 and 2020, respectively, for ASL, while for VSL, the RMSE recorded 0.0904 and 0.1403 for 2019 and 2020, respectively. The RMSE values for MSL were 0.0982 and 0.1421 for the respective years. The values of RMSE recorded indicated that the model should be accepted since the values were close to zero, and any value of RMSE close to zero signified the genuineness of the model as an accurate prediction. This was in line with the findings of Radim et al. (2013), who observed and reported that the smaller the RMSE and ME values, the more accurate the model developed for prediction.

CONCLUSION AND RECOMMENDATIONS

The study provides the extent of gully erosion in the study area, which was quantified using local field measurements and an empirical equation under the local conditions of the Girei environment. It is evident to conclude that in the first model, gully erosion was influenced by the actions of erosion prediction variables that both increased (soil erodibility, infiltration rate, organic matter, altitude, head cut height and vol of runoff.) and decreased erosion (soil shear strength, hydraulic conductivity, bulk density, aggregate stability, porosity and slope rate), while the final model of determining VSL, MSL and ASL revealed volume of runoff and altitude to be the best most highly significant for VSL and MSL while, porosity and gully head-cut to be the best most highly significant for ASL as evident in the final model. Measures that reduce the rate of runoff down slope should be encouraged and practiced, such as contour farming, ridging across the slope, sand bagging and bond making to reduce water velocity, and also avoid encroaching into the hills for cultivation. Secondly, prediction models that could compute research variables on a monthly basis should be developed further by both researchers and policy makers.

REFERENCES

Adebayo, A.A. (1999). Climate I: Sunshine, Temperature, Evaporation and Relative Humidity. In: *Adamawa State in Maps*. Adebayo, A.A. and A.H. Tukur (Eds.) Paracletes Publishers and Department of Geography Federal University of Technology Yola, Nigeria. Pp: 3-5.

Adebayo, A.A. (2004). *Mubi Region:A Geographical synthesis* (Ist Ed.) Paraclete Publisher, Yola-Nigeria. P 32-38

Adebayo, A.A., A.H. Tukur and Zemba, A.A. (2020). Climate I: Sunshine, Temperature, Evaporation and Relative Humidity. In: *Adamawa State in Maps*. Adebayo, A.A., A.H. Tukur and Zemba, A.A. (Eds.) Paracletes Publishers and Department of Geography FederalUniversity of Technology Yola, Nigeria. Pp : 3-5.

Adekalu, K.O., Okunade, D.A. and Osunbitan, J.A (2007). Estimating trafficability of three Nigerian agricultural soils from shear strength-density moisture relations.*International Agrophysics.* Vol. 21: 1-5. Also found at www.ipan.lublin. Pl/intagraphysics.

Aregheore, E. M. (2005). Feeds and forages in Pacific Islands farming systems. *Animal Science Department Alafua Campus, the University of the South Pasific.Retrieved from http://www.fao.org/ag/AGP/AGPC/doc/Newpub/feeds_forages/feeds_forgaes.htm*.

Brady, N. C., and Weil, R.R. (2002). *The Nature and Properties of Soils* (13^{th} Eds). Person Education (Singapore), Delhi, India.

Brice, J.B. (1996). "Erosion and deposition in the loess-mantled Great plains, Medecine creek drainage Medecine creek drainage basin, Nebraska. U.S." Geological SurveyProfessional, 235-339.

Capra, A. and B. Scicolone (2002). Ephemeral gully erosion in a wheat cultivated area in Sicily (Italy) *Biosystems Engineering.* Vol. 83. Scopus, Sicily, Italy.

Department of Soil Science, Faculty of Agriculture, (2005) University ... by Faculty of Agriculture, University of Maiduguri, Nigeria. Year of Publication..

Egboka, B.C.E. and I.P. Orajaka, (1987). "Soil and gully erosion models for effective control programmes." Geoforum., 18(3): 333-341.

Ekwue, E.I and Stone, R.J (1994). Organic matter effects on the strength properties of compacted agricultural soils. *Transaction of the A merican Society of Agricultural Engineers* 38 (2) 357-365.

FAO/WHO Expert Committee on Food Additives. Meeting, Joint FAO/WHO ExpertCommittee on Food Additives, & Meeting Staff. (2006). *Compendium of foodadditive specifications: joint FAO/WHO expert committee on food additives: 67th meeting 2006* (Vol. 3). Food & Agriculture Org..

Gundiri J. W. (2023). Impacts of Soil Hydro-physical Properties and Watershed Characteristics on development of Gully Erosion sites in Girei Local Government Area of Adamawa State,Nigeria (Ph.D Thesis 2022)

Hudson, N.W. (1989). Soil Conservation. Batsford, 2nd. Edu.

Idowu, T. O., Edan, J. D., & Damuya, S. T. (2013). Estimation of the quantity of surface runoff to determine appropriate location and size of drainage structures in Jimeta Metropolis, Adamawa State, Nigeria. *Journal of Geography and Earth Science*, *1*(1), 19-29.

Imeson, A. and F.J.P.M. Kwaad, (1980). "Gully types and gully prediction," 5: 430-441.

Lal, R. (2001). Soil degredation by erosion. *Land Degredation and Development* 12: 519-539.John Wiley & Sons Ltd, USA.

Macaulay, B. M. (2014). Land degradation in Northern Nigeria: The impacts andimplicationso pf human-related and climatic factors. *African Journal of Environmental Science andTechnology*, *8*(5), 267-273.

Morgam, R. P. C. (2009). *Soil erosion and conservation*. John Wiley & Sons.

Nigeria Geological Survey Agency (NGSA). (2006). Published by the Authority of the FederalRepublic of Nigeria.

Otim, D., Smithers, J., Senzanje, A., & van Antwerpen, R. (2019). Design norms for soil and water conservation structures in the sugar industry of South Africa. *Water SA*, *45*(1), 29-40.

Pate, U. A., & Dauda, S. (2013). Media and socio economic development in Northern Nigeria. *Jurnal Komunikasi: Malaysian Journal of Communication*, *29*(1).

Poesen, J., Nachtergaele, J., Verstraeten, G., & Valentin, C. (2003). Gully erosion and environmental change: importance and research needs. *Catena*, *50*(2-4), 91-133.

Radim VA Š ÁT, Lenka P AV L Ů, Luboš BORŮVKA, Ondřej DRÁBEKandAntonín NIKODEM (2013). Mapping the Topsoil pH and Humus Quality of ForestSoils in theNorth Bohemian Jizerské hory Mts. Regionwith Ordinary, Universal, and Regression Kriging: Cross-Validation Comparison *Soil & Water Res*.,8, (3): 97–104

Rengers, F. K., & Tucker, G. E. (2014). Analysis and modeling of gully headcut dynamics, North American high plains. *Journal of Geophysical Research: Earth Surface*, *119*(5), 983-1003.

Salako, F. K. (2004). *Soil physical conditions in Nigerian savannas and biomass production* (No. INIS XA--989).

Seeger, K.M.M., I.J.B. Ries, (1997). "Identification of gully-development processes in semi-arid NE-Spain." Zeitschrift für Geomorphologie 53 (2009)4. - ISSN 0372-8854 – pp: 417 431(N 0372-8854): 417-431.

Soil Science Society of Nigeria (SSSN) (2011). Soil fertility map of Nigeria.

Soleymanpour, S.M., Soufi, Majid, Ahmadi, Hasan, (2010). "A study on the topographic threshold and effective factors on sediment production and gully development in Neyriz,Fars Province " Range and watershed management (Iranian Journal of natural resources), 63(1): 41-53.

Tekwa, J. I., & Usman, B. H. (2006). Estimation of soil loss by gully erosion in Mubi, Adamawa State, Nigeria. *FUTY Journal of the Environment*, *1*(1), 35-43.

Tekwa, I. J., Alhassan, A. B., Chiroma, A. M., & Laflen, J. M. (2014). Prediction ofEphemeral Gully Erosion in Mubi. *Northeast Nigeria, Agric. Sci. Res. J*, *4*(7), 115-125

Vahyala, I.E., John, W.G. and Solomon, R.I. (2018). Infiltration Characteristics of Soils Affected by Gully Erosions in Girei Local Government Area of Adamawa State-Nigeria.*International Journal of Science, Environment and Technology*, Vol. 7, No 3, 1093-1107

Wall, J., C.S. Baldwin, I.J. Shelton, (2003). "Soil Erosion - Causes and Effects " Factsheet.

Wolf, B., & Snyder, G. (2003). *Sustainable soils: the place of organic matter in sustaining soils and their productivity*. CRC Press.

Yitbarek, T., (2007). Economic valuation of gully rehabilitation; a case study at Farta Woreda, in South Gondar, Ethiopia. Environmental Science. Addis Ababa, Addis Ababa University. Master, 96.

Zachar, D., (1982). Soil erosion / Dusan Zachar; [translation editor, M. Cowan]. Amsterdam; New York:, Elsevier Scientific Pub. Co.: distribution for the U.S.A. and Canada, Elsevier North-Holland, Inc.

Zegeye, A. D., Langendoen, E. J., Stoof, C. R., Tilahun, S. A., Dagnew, D. C., Zimale, F. A., ... & Steenhuis, T. S. (2016). Morphological dynamics of gully systems in the subhumid EthiopianHighlands: the Debre Mawi watershed. *Soil*, *2*(3), 443-458.

APPENDIX 1

Table 1: Parameter Estimate for Volume of Soil Loss Model 1

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	5616.57	2281.75	1E+07	6.06	0.0194
ERODI	9733.22	3628.25	1.2E+07	7.2	0.0115
SHEAR	-315652	138001	9045040	5.23	0.0289
_SLOPER	-225.96	119.754	6155293	3.56	0.0683
_RUNOFF	3.56929	0.52309	8E+07	46.56	<.0001
Ksat	-291090	263495	2109900	1.22	0.2775
IR	47.4296	30.0932	4294538	2.48	0.1248
PORO	-50.382	42.6084	2417260	1.4	0.2457

Key: Erodibility= ERODI, Shear Strength = SHEAR, Slope Rate= SLOPER, Volume of Run-off= RUNOFF, Hydraulic Conductivity = Ksat, Infiltration Rate = IR and Porosity = PORO

Table 2: Parameter Estimate for Area of Soil Loss Model 1

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	19.7412	21.4069	0.92	0.3649	0
BD	-1.7041	10.1914	-0.17	0.8685	-0.0264
_CLAY	0.52311	0.29781	1.76	0.0908	0.24014
ERODI	63.1405	26.6627	2.37	0.0256	0.28281
OM	-0.2454	0.23073	-1.06	0.2973	-0.1541
SHEAR	-2009.2	984.256	-2.04	0.0515	-0.2462
_SLOPER	-1.2515	0.86766	-1.44	0.1611	-0.1822
_RUNOFF	0.00839	0.00439	1.91	0.0669	0.31635
Ksat	-529.78	1845.1	-0.29	0.7763	-0.0386
IR	0.42571	0.24815	1.72	0.0981	0.23449
DSA	-0.4187	0.27887	-1.5	0.1453	-0.1633
PORO	-0.1763	0.29175	-0.6	0.5508	-0.0714
hcut	6.35432	1.39798	4.55	0.0001	0.61817
Alt	0.03245	0.05069	0.64	0.5276	0.08596

Key: Erodibility= ERODI, Shear Strength = SHEAR, Slope Rate= SLOPER, Volume of Run-off= RUNOFF, Hydraulic Conductivity = Ksat, Infiltration Rate = IR, Porosity = PORO, Bulk density = BD, Clay Content= CLAY, Organic Matter = OM, Aggregate Stability= DSA, Headcut height = Hcut and Altitude = Alt

Table 3: Parameter Estimate for Mass Soil Loss Model 1

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	11193	4597.54	4.2E+07	5.93	0.0207
ERODI	14346	8083.12	2.2E+07	3.15	0.0854
OM	51.2271	61.1516	4999748	0.7	0.4084
SHEAR	-671432	290996	3.8E+07	5.32	0.0277
_SLOPER	-515.56	237.11	3.4E+07	4.73	0.0372
_RUNOFF	5.6188	0.93504	2.6E+08	36.11	<.0001
IR	91.9095	64.932	1.4E+07	2	0.1666
PORO	-106.89	84.453	1.1E+07	1.6	0.2148

Key: Erodibility= ERODI, Shear Strength = SHEAR, Slope Rate= SLOPER, Volume of Run-off= RUNOFF, Hydraulic Conductivity = Ksat, Infiltration Rate = IR and Porosity = PORO

Table 4:Parameter Estimate for Area of Soil Loss Model 2

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	5.89418	6.9435	68.5209	0.72	0.4017
ERODIBI	110.004	27.3883	1533.98	16.13	0.0003
OM	-0.5505	0.1937	768.106	8.08	0.0074
_RUNOFF	0.00772	0.00379	395.605	4.16	0.049
DSA	-0.5274	0.2981	297.661	3.13	0.0856
hcut	6.44154	1.42524	1942.39	20.43	<.0001

Key: Erodibility= ERODI, Aggregate Stability = DSA, Volume of Run-off= RUNOFF, Organic Matter =OM and Headcut height = Hcut

Table 5: Parameter Estimate for Vol of Soil Loss Model 2

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-7405.6	2423.76	1.8E+07	9.34	0.0044
ERODIBI	12241	3888.41	1.9E+07	9.91	0.0034
SHEAR	-147844	72765	8031279	4.13	0.05
_SLOPE	-294.2	117.358	1.2E+07	6.28	0.0171
_RUNOFF	3.77319	0.48395	1.2E+08	60.79	<.0001
IR	60.7373	32.3594	6853865	3.52	0.0691
Alt	36.9299	8.39874	3.8E+07	19.33	0.0001

Key: Erodibility= ERODI, Shear Strength = SHEAR, Slope Rate= SLOPER, Volume of Run-off= RUNOFF, Hydraulic Conductivity = Ksat, Infiltration Rate = IR and Altitude = Alt

Table 6: Parameter Estimate for Mass of Soil Loss Model 2

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-9295	4675.89	2.9E+07	3.95	0.0549
ERODIBI	22797	7501.49	6.7E+07	9.24	0.0045
SHEAR	-368290	140378	5E+07	6.88	0.0129
_SLOPE	-545.51	226.406	4.2E+07	5.81	0.0215
_RUNOFF	7.07538	0.93363	4.2E+08	57.43	<.0001
IR	109.226	62.4274	2.2E+07	3.06	0.0892
Alt	54.6449	16.2028	8.2E+07	11.37	0.0019

Key: Erodibility= ERODI, Shear Strength = SHEAR, Slope Rate= SLOPER, Volume of Run-off= RUNOFF, Infiltration Rate = IR and Altitude = Alt

Table 7:Parameter Estimate for Area of Soil Loss Model 3

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-3.1176	5.19061	28.1279	0.36	0.5528
ERODIBI	87.7743	28.9779	715.387	9.17	0.0051
OM	-0.5374	0.1878	638.483	8.19	0.0077
hcut	8.63461	1.13581	4506.2	57.79	<.0001

Key: Erodibility= ERODI, Organic matter= OM and Headcut height = Hcut

Table 8: Parameter Estimate for Volume of Soil Loss Model 3

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-11255	2166.82	6.1E+07	26.98	<.0001
ERODIBI	11586	4054.72	1.9E+07	8.16	0.007
_RUNOFF	3.44181	0.49739	1.1E+08	47.88	<.0001
Alt	43.5891	8.67449	5.7E+07	25.25	<.0001

Key: Erodibility= ERODI, Volume of Run-off= RUNOFF and Altitude = Alt

Table 9: Parameter Estimate for Mass of Soil Loss Model 3

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-11255	2166.82	6.1E+07	26.98	<.0001
ERODIBI	11586	4054.72	1.9E+07	8.16	0.007
_RUNOFF	3.44181	0.49739	1.1E+08	47.88	<.0001
Alt	43.5891	8.67449	5.7E+07	25.25	<.0001

Key: Erodibility= ERODI, Volume of Run-off= RUNOFF and Altitude = Alt

Table 10: Parameter Estimate for Volume of Soil Loss Model 4

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-10460	3257.85	3.5E+07	10.31	0.0029
_RUNOFF	6.37303	0.60427	3.8E+08	111.23	<.0001
Alt	47.8546	12.8236	4.7E+07	13.93	0.0007

Key: Volume of Run-off= RUNOFF and Altitude = Alt

Table 11: Parameter Estimate for Area of Soil Loss Model 4

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	36.8875	11.655	587.413	10.02	0.0037
PORO	-0.7524	0.24812	539.178	9.19	0.0052
hcut	5.93336	0.97914	2153.35	36.72	<.0001

Key: Porosity = PORO and Headcut = Hcut

Table 12: Parameter Estimate for Mass of Soil Loss Model 4

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-4786.6	2537.67	3694624	3.56	0.0684
_RUNOFF	2.85858	0.75053	1.5E+07	14.51	0.0006
Alt	22.552	9.90675	5381445	5.18	0.0297

Key: Volume of Run-off= RUNOFF and Altitude = Alt

APPENDIX II

PLATE 1: A typical example of a gully erosion showing an actively migrating headcut in upstream direction at Sangere 6

Plate 2: A diagram of a gully erosion showing an active expansion of headcut and width in upstream direction at Sangere 6 in April, 2019

Plate 3: A diagram of a gully erosion showing an active expansion of headcut, width and length in upstream direction at Sangere 6 in November, 2019

Plate 4: A typical diagram of a gully erosion showing an active expansion of headcut, width and length in upstream direction at Sangere 6 in November, 2020 with some sand deposition

APPENDIX 2

Table 13: Model Validation for ASL, VSL and MSL 2019 and 2020

	ASL		VSL		MSL	
	2019	2020	2019	2020	2019	2020
Mean	20.4004878	31.10536585	2004.278171	3425.860488	3757.697484	6334.396495
SUMERRSQ	2021.19	17003.86683277000000	55162656.370999900	388418320.52557800	228986558.34	1361974213.2303500
RMSE	0.053750021	0.102247966	0.090381747	0.140312487	0.098219863	0.142100413

Table 14:VSL, ASL, MSL and the 13 Relevant Predictor Variables

	VOLUME (M^3)	AREA (M^2)	M S L (Kg/ac)	BD		ERODIBILITY	OM	SHEAR STRENGTH	SITE SLOPER	VOL OF RUNOFF	KSat	IR	%WSA	POROSITY	h. cut Height	Altitude
				(g/cm3)			(g/kg)	τ_c (Nm)	%	(m3/sec)	10^{-1} cm/s	(cm/h)		~~%~~	(m)	(M)
Jabbilamba 1	2497.5	7.95	5119.88	2.05	28.80	0.21	20.46	0.008848	4	101.42	1.66×10^{-3}	1.8	19.30	43.60	2	244
Jabbilamba 2	624	3	1154.4	1.85	20.80	0.2	15.99	0.00581	4	101.36	9.35×10^{-4}	1.2	16.00	35.88	1.6	244
Jabbilamba 3	1823.9	25.57	3775.47	2.07	22.80	0.2	15.13	0.007857	4	296.25	7.67×10^{-4}	1.5	17.10	41.50	2.5	244
Jabbilamba 4	279	-10.24	605.43	2.17	16.80	0.2	15.99	0.00482	4	45.32	8.46×10^{-4}	3	22.30	36.25	3.3	244
Safini 1	6380	37.2	14291.2	2.24	10.80	0.1	23.73	0.008518	4	777.22	2.97×10^{-3}	6	8.10	47.50	3.8	244
Safini 2	14868.8	39.52	29440.2	1.98	12.80	0.03	19.09	0.00964	4	2415.11	5.79×10^{-3}	6	13.80	44.90	4	244
Safini 3	228	8	435.48	1.91	18.80	0.16	21.5	0.007923	4	37.03	2.35×10^{-3}	0.9	23.80	44.50	2.7	244

Sangere 1	228.5	6.7	450.145	1.97	8.80	0.22	27.69	0.008914	4	37.11	2.41×10^{-3}	2.4	13.80	47.13	3.5	244
Sangere 2	280.5	5.7	608.685	2.17	4.80	0.19	20.29	0.007197	4	45.56	1.65×10^{-3}	2.7	18.20	49.25	1.7	244
Sangere 3	2530	10.4	4984.1	1.97	22.80	0.21	23.22	0.007923	4	410.94	2.83×10^{-3}	6	8.20	32.13	2	244
Madalu 1	915	22.5	1701.9	1.86	16.80	0.06	23.9	0.009904	4	148.62	5.76×10^{-4}	0.9	8.80	38.40	4	244
Madalu 2	0	0	0	2.17	26.80	0.19	17.37	0.007197	4	0.00	5.01×10^{-4}	0.6	31.10	39.25	0.6	244
Sangere 4	626	2.2	1208.18	1.93	8.80	0.10	27.17	0.00832	4	25.42	1.46×10^{-3}	8.8	14.50	44.50	2	244
Sangere 5	2168.6	23.34	4489	2.07	14.80	0.11	21.67	0.006933	4	88.06	1.56×10^{-3}	6	17.70	49.38	2.6	244
Sangere 6	1680	11.8	3141.6	1.87	14.80	0.12	21.84	0.007725	4	68.22	1.61×10^{-3}	1.5	14.30	52.75	1.6	244
Lamido Farm	1161.5	14.05	2369.46	2.04	20.80	0.02	9.8	0.00416	4	47.17	7.25×10^{-4}	0.6	8.10	42.80	1.8	244
Daware J 1	119.4	2.9	259.098	2.17	8.80	0.16	17.54	0.005018	9	3.15	3.68×10^{-3}	3.3	19.80	43.75	1	275
Daware J 2	287.5	19.75	623.875	2.17	20.80	0.17	6.71	0.004754	9	7.59	1.89×10^{-3}	4.2	15.00	44.98	2.5	275
Daware J 3	2526.7	13.45	5710.34	2.26	8.80	0.14	12.38	0.004688	9	66.69	2.32×10^{-3}	9.3	16.00	35.88	2.5	275
Girei River 1	-46.08	3.6	-103.68	2.25	16.80	0.07	16.85	0.00581	9	-5.61	2.37×10^{-3}	11.6	20.90	41.20	1.6	244
Girei River 2	8746.5	35.7	16268.5	1.86	8.80	0.10	20.46	0.006141	9	1065.51	2.49×10^{-3}	12	8.80	40.75	7	244
Hona 1	162.72	13.08	320.558	1.97	8.80	0.08	10.32	0.008848	9	19.82	1.33×10^{-3}	13.2	22.00	51.06	2.5	244
Hona 2	455.79	24.68	711.032	1.56	6.80	0.04	10.83	0.006999	4	55.52	2.12×10^{-3}	14.1	17.60	44.88	3.1	244
Prof Q	809.16	28.68	1674.96	2.07	6.80	0.07	20.29	0.009244	4	98.57	9.88×10^{-4}	12	14.50	46.38	4.3	275
Fed Housing	1162	4.92	2289.14	1.97	10.80	0.01	8.77	0.005612	4	141.56	1.18×10^{-3}	1.5	14.60	47.85	1.4	244
Damare	6147.5	22.4	11618.8	1.89	2.80	0.16	13.24	0.003367	4	249.63	3.95×10^{-4}	2.4	11.40	46.75	2.3	305

Lambondo 1	6715	7.14	11818.4	1.76	4.80	0.22	19.78	0.006141	4	272.68	6.76×10^{-4}	36	11.80	50.70	1.7	336
Lambondo 2	12422.4	26.88	22360.3	1.80	20.80	0.19	22.7	0.007593	4	504.44	1.99×10^{-3}	0.3	3.10	38.40	2	336
Ndikajam	14154	40.71	21797.2	1.54	10.80	0.16	14.62	0.005744	4	1724.25	1.30×10^{-3}	2.4	16.70	27.60	4.5	336
Kangling	36069	199.3	67449	1.87	14.80	0.04	17.02	0.009838	4	1464.65	1.52×10^{-3}	1.2	15.90	41.60	6	336
Univ Farm 1	4820	46	8772.4	1.82	6.80	0.05	22.87	0.007989	9	587.18	1.27×10^{-3}	16.2	9.80	38.13	2	244
Univ Farm 2	884	12.92	1794.52	2.03	10.80	0.07	22.7	0.008782	9	107.69	1.86×10^{-3}	18.6	12.50	48.53	2	244
Jatau	2600.4	26.5	4186.64	1.61	8.80	0.06	0.06	0.006075	4	7.36	1.55×10^{-3}	12.4	14.80	47.88	4	275
Amsami	1090.7	17.9	1712.4	1.57	10.80	0.11	0.11	0.008716	4	3.90	6.80×10^{-4}	18.6	15.20	38.13	2	275
Dunde	5505	66.5	8422.65	1.53	12.80	0.15	0.15	0.007197	4	22.42	1.75×10^{-3}	18	17.40	50.50	3	244
Jera	221	7	397.8	1.80	6.80	0.10	0.10	0.00832	4	16.19	1.28×10^{-3}	16.2	9.30	51.25	1	244
Sani	1792	9.6	2795.52	1.56	10.80	0.08	0.08	0.006273	4	22.60	6.71×10^{-4}	8.8	13.50	42.00	1.5	244
Kaftarare	884	9	1502.8	1.70	12.80	0.09	0.09	0.009178	4	1.97	4.71×10^{-4}	12	11.00	46.00	1	244
Mashi	1934	6	3307.14	1.71	4.80	0.01	0.01	0.008584	4	0.97	2.22×10^{-3}	20.6	25.90	38.40	2	275
Modibbo	1310	3	2109.1	1.61	8.80	0.09	0.09	0.009178	4	0.71	1.55×10^{-3}	12	17.30	47.13	1	244
Ngawa	7820	65.5	13685	1.75	20.80	0.14	0.14	0.007857	4	0.41	6.56×10^{-4}	1.3	13.80	48.63	3.5	305