Event-based sediment yield modeling for small watersheds using MUSLE in north-central Nigeria

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Abstract: The misapplication of empirical hydrologic models with regard to the spatial context of their development and application is rife. The Modified Universal Soil Loss Equation (MUSLE) model was calibrated and validated for Ofuloko Watershed (612 ha) in North-Central Nigeria. Hydro-meteorological data for 20 rainfall events (occurring from 2nd June to 14th July 2017) were obtained from a station installed adjacent the watershed. The control points of the Ofuloko Watershed were obtained at 10 m intervals from a survey conducted with a hand-held GPS receiver to delineate the watershed and generate the Digital Elevation Model (DEM) in Surfers 10 environment. Sediment yield was measured at the watershed outlet and soil samples obtained from the watershed was analysed in a laboratory. The Curve Number method was used to estimate the runoff volume, peak runoff for the watershed was estimated using the Rational Method and the time of concentration was computed using the method developed by Kirpich. The slope length and steepness factors were obtained using the McCool equations. Correction factors were applied to the soil erodibility factor to obtain the actual values for tropical soils. Data from the first 10 storm events were used to calibrate the MUSLE while data from the remaining 10 storm events were used to test and validate the model. A comparison of the measured (observed) sediment yield and the predicted sediment yield using the Chi-square goodness-of-fit test showed that they are not significantly different at 5% significance level. The Nash-Sutcliffe Efficiency Coefficient value of 0.8805, which is acceptable for most hydrologic applications was also obtained after the comparison. Strict adherence to the application requirements of MUSLE as documented in this research has demonstrated its utility as a watershed management tool in the derived ecological zone of Nigeria.

Keywords: sediment yield, MUSLE, calibration, validation, watershed

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1 Introduction

Soil and water losses are among the top ten intractable environmental problems in the world (Liangyi and Baoli, 2002). According to estimates by the WorldWatch Institute (Lo, 1990), an estimated 23 billion tons of soil is lost each year from croplands alone in excess of new soil formation worldwide. The land and water systems, underpinning many key food-producing systems worldwide, are being stressed by unprecedented levels of demand as a result of increasing human population (FAO, 2011). The situation is further aggravated as cultivation is being extended into ever more marginal areas of land (Lo, 1990). Apart from reduction in the nutrient status of the soil, Vanoni (2006), Morgan et al (1998), Mihara et al (2005), and Sadeghi and Mizuyama (2007) have identified siltation of water channels, loss of reservoir storage volumes, nutrient pollution and flooding as major consequences of sediment yield from watersheds which results from soil loss within the catchment (Pongsai et al, 2010). About US$13 billion is expended annually in replacing lost reservoir storage in the world as a result of sedimentation

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(Palmieri et al., 2003). Sediment yield from a watershed is therefore the output form of an erosion process (Bhunya et al., 2010) and it can be defined as the amount of sediment reaching or passing a point of interest in a given period of time in tonnes per year or kg/year (White, 1996). This also refers to the amount of sediment generated from a basin over a period of time, which is also the amount that will enter a reservoir located at the downstream limit of the watershed after accounting for deposition in channels between the watershed outlet and the reservoir (Morris and Fan, 1998). In his study on sediment transport and river basin management in Nigeria, Oyebande (1981) had reported a maximum annual suspended sediment yield of 483 t km^{-2} $year^{-1}$ which underscores the severity of the problem in the country. Reduced agricultural productivity occasioned by nutrient loss associated with sediment transport is a major threat to national effort to diversify Nigeria's economy from petroleum resources to agriculture. Secondly, absorbed pesticides and herbicides are washed down with eroded sediments, thereby adversely affecting surface water quality in reservoirs. Water (2018) had reported that the growing demand for water, which is currently estimated to be increasing at about 1% per annum, is expected to rise particularly in developing economies (like Nigeria) thereby placing extra demand on reservoirs. Sedimentation does not only reduce the useful life of downstream water-receiving bodies (dams and reservoirs), it also raises other water qualities issues and ecological concerns.

The Modified Universal Soil Loss Equation (MUSLE) was developed by Williams (1975) from the traditional Universal Soil Loss Equation (USLE) by Wischmeier and Smith (1965) as a watershed-based model to estimate the sediment yield produced by each individual storm event. Modeling sediment yield at watershed scale is critical because it not only serves as a unit for anthropogenic processes to occur and interact, it is also a socio-economic and political unit for planning and management (Sarangi et al., 2004). The MUSLE was originally developed under micro-watershed conditions for modelling sediment yield in small watersheds (Smith et al., 1984). The empirical relationship computes sediment yield from a rainfall event X_t (in tonnes) as:

$$X_t = 11.8(Q_v q_p)^{0.56}\,\mathrm{KLSCP} \qquad (1)$$

The rainfall (R) factor is replaced with a term that combines storm runoff volume Q_v (m^3) and peak runoff rate q_p (m^3 s^{-1}), and interprets the other USLE factors; soil erodibility factor K (Mg MJ^{-1} MM^{-1}), slope steepness and length factor LS (dimensionless), crop management factor C (dimensionless) and conservation practice factor P (dimensionless) on an event and catchment-scale basis. The runoff factor which is a better indicator and driver of the erosion process (than rainfall erosivity factor in the USLE) represents the energy used in transporting as well as in detaching sediment on a single storm event basis (Foster, 1982). The MUSLE has been applied in many parts of the world with various degrees of success. A few of these countries where the MUSLE has been applied are; Thailand (Pongsai et al, 2010), Iran (Sadeghi et al., 2007), the United States of America (Golson et al, 2000; Jackson et al, 1987), Turkey (Cambazoglu and Gogos, 2004), Puerto Rico (Santos and Canino, 1997), Canada (McConkey et al, 1997), India (Kumar et al, 2015), Brazil (Junior et al, 2008).

In tropical Africa the USLE and RUSLE (Revised Universal Soil Loss Equation) are difficult to apply because of the unrealistic values obtained for tropical soils from the equation's erodibility nomograph (Mulengera and Payton, 1999; Ndomba, 2007). It has also been observed that the table developed for estimating crop and soil management factors in the USA are inconsistent with farming practices in tropical Africa (Mulengera and Payton, 1999). Conversely, the Modified Universal Soil Loss Equation has been observed to give good results in various applications in some parts of tropical Africa (Ndomba, 2007). There has been no reported application of MUSLE in Nigeria.

Apart from its demonstrated success in sub-Saharan Africa, the application of the MUSLE as a lumped model is also suitable for small watersheds given its inherent inability to model the complexities and variability associated with large catchments. For ungauged basins, data acquisition for an event-based model like the MUSLE can be relatively cheaper as weather stations and other hydrologic data collection equipments can be deployed, installed and monitored for a short period of time. In data-sparse watersheds in poor sub-Saharan African countries, this can make the application of the

MUSLE particularly appealing. The objective of this research, therefore, was to explore the applicability of the MUSLE as a tool for the prediction of sediment yield in small watersheds in Nigeria using the Ofuloko Watershed as a case study.

2 Study area

Administratively, Ofuloko watershed is located in Igalamela/Odolu Local Government Area of Kogi State in the Federal Republic of Nigeria. Ofuloko watershed as shown in Figure 1, lies between latitudes $7^0 11'34.64''$N and $7^0 14'55.80''$N and between longitudes $6^0 46'59.36''$E and $6^0 50'33.48''$E with an average altitude of 186.3 meters above sea level. The wet season within this ecological zone, described by Clayton (1961) as derived savannah occurs between March and November while the dry season runs through the remaining months (Okonkwo and Mbajiorgu, 2010).

Figure 1 The Ofuloko Watershed in Kogi State of Nigeria

The average monthly precipitation as computed by Audu (2012) from 30 years rainfall data at the nearest weather station (Lokoja) is as depicted in Figure 2. The mean annual precipitation is 1216.83 mm based on data collected from 1981 to 2010. The watershed has an area of 6.12 km^2 (612 ha) and a perimeter of 12.99 km. Runoff and sediments from the highly undulating Ofuloko watershed drains into the River Niger. The watershed is mainly used for growing cashew and intercropped with maize (*zea mays*) and sorghum. The soil is described as red ferralsols on loose sandy sediments (FAO, 1964) and with sedimentary intergranular/fracture acquiferous properties (Tijani et al, 2016).

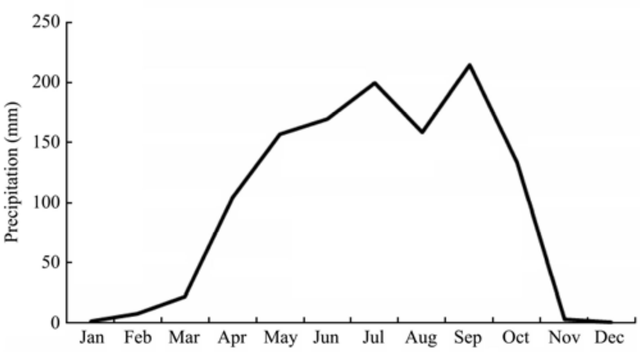

Figure 2 Average Monthly Precipitation Pattern of Ofuloko Watershed (Audu, 2012)

The temperature variation across the months for the Ofuloko watershed is as shown in Figure 3. From the geometry of the watershed as obtained from the digital elevation model, a Circularity Ratio (compactness coefficient) of 5.92, Form Factor of 0.23, and an Elongation Ratio of 0.496 was established for Ofuloko watershed.

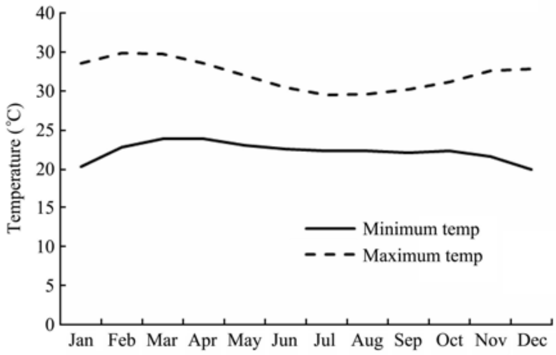

Figure 3 Minimum and Maximum Temperature Variation of the Ofuloko watershed (Amadi et al., 2014)

3 Research Methodology

The control points of the Ofuloko Watershed were obtained at 10 m intervals using a hand-held Holux GPS receiver to delineate the watershed and generate the Digital Elevation Model (DEM) in Surfers 10 environment from where the area, average slope and perimeter of the watershed were determined. A hydrometeorological weather station was installed in an open field at latitude 7°13′14.76″N, longitude 6°46′54.48″E from where rainfall amount, rainfall duration, rainfall intensity and other hydrometeorological data were recorded for 20 events from 2nd June to 14th July 2017. Rainfall hyetographs for the 20 storm events as recorded at the weather station are as shown in Figure 4.

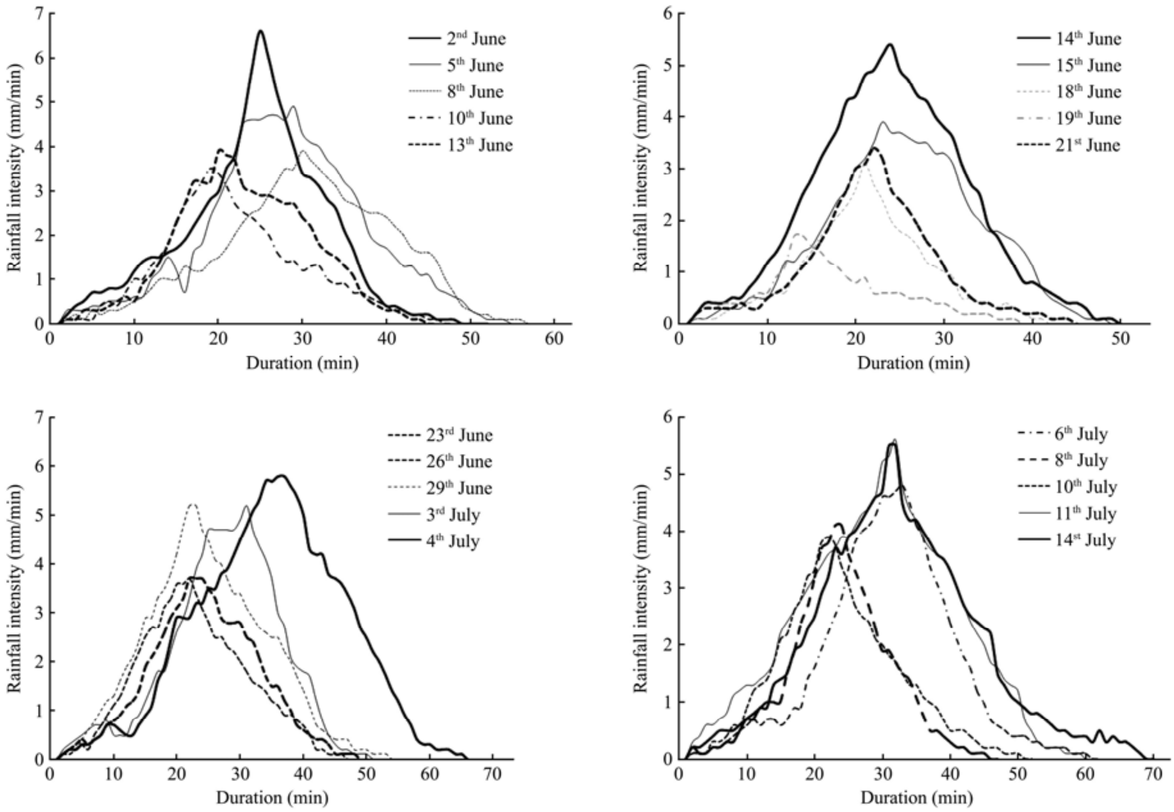

Figure 4 Hyetograph for 20 the Storm Events

In order to estimate the sediment yield from the watershed, the ‘Grab Samples’ method of estimating suspended sediment load as recommended by FAO (1993) and described by Hudson (1993) was used in collecting 6 samples (equally spaced at a distance of one-sixth the cross-section) at half the depth of the flowing water for the 20 rainfall events at the watershed outlet. The samples were analysed at the Soil and Water Engineering Laboratory of the University of Nigeria, Nsukka; 100 mL of each sample were taken and the sediments filtered out and weighted with the results as shown in Table 1. The mean of the 6 samples is computed to be the suspended sediment load. The grassed undulating water channel in the watershed will definitely reduce the bedload component of the sediment load as most of it will be trapped before getting to the outlet of the watershed, so it was not measured and considered in this research. Desmond (2005) and Knighton (1998) have demonstrated that suspended sediments are the dominant component of sediment yield from a watershed and hence provide a reasonable estimate of the total particulate flux.

Table 1 Laboratory analysis of sediment load obtained from the Ofuloko Watershed

Storm Event	Volume Analysed (mL)	Sediment Yield Sample 1 (g)	Sediment Yield Sample 2 (g)	Sediment Yield Sample 3 (g)	Sediment Yield Sample 4 (g)	Sediment Yield Sample 5 (g)	Sediment Yield Sample 6 (g)	Mean
1	100	0.6	0.7	0.7	0.7	0.7	0.6	0.66667
2	100	0.5	0.7	0.5	0.6	0.6	0.5	0.56667
3	100	0.5	0.5	0.4	0.5	0.5	0.4	0.46667
4	100	0.4	0.4	0.5	0.5	0.4	0.4	0.43333
5	100	0.4	0.4	0.4	0.4	0.3	0.4	0.38333
6	100	0.8	0.7	0.7	0.8	0.7	0.7	0.73333
7	100	0.6	0.5	0.6	0.5	0.5	0.5	0.53333
8	100	0.4	0.5	0.3	0.4	0.4	0.5	0.41667
9	100	0.5	0.3	0.4	0.5	0.4	0.3	0.40000
10	100	0.2	0.1	0.1	0.2	0.2	0.2	0.16667
11	100	0.5	0.4	0.5	0.3	0.4	0.3	0.40000
12	100	0.7	0.5	0.6	0.6	0.5	0.5	0.56667
13	100	0.4	0.4	0.5	0.4	0.5	0.5	0.45000
14	100	0.2	0.3	0.3	0.2	0.3	0.3	0.26667
15	100	0.5	0.6	0.5	0.7	0.6	0.6	0.58333
16	100	0.9	0.9	0.8	0.8	0.8	0.9	0.85000
17	100	0.7	0.6	0.6	0.7	0.6	0.6	0.63333
18	100	0.3	0.4	0.4	0.4	0.3	0.4	0.36667
19	100	0.5	0.5	0.4	0.5	0.6	0.4	0.48333
20	100	0.7	0.5	0.6	0.7	0.6	0.6	0.61667

The following methodologies were employed in computing the parameters of the MUSLE as given in Equation (1):

Runoff Volume (Q_v): Curve Number method (also called the Soil Conservation Service method) as reported by Huffman et al. (2011) was used to estimate the runoff volume (Q_v in Equation (2)). It is expressed as:

$$Q_v = (I - 0.2S)^2/(I + 0.8S) \quad (2)$$

where, Q_v = Runoff volume in mm; I = Rainfall depth in mm; S = Maximum potential difference between rainfall and runoff (mm) which is defined as given in Equation (3)

$$S = (25400/CN) - 254 \quad (3)$$

Given its moderately low runoff potential as a result of soil that is predominantly sandy, the soil in Ofuloko watershed is assigned hydrological soil group B while a Curve Number (CN) of 58 which best describes the vegetation as presented by Huffman et al (2011) was chosen. The result of the computation in given in Table 2 for the 20 storm events which was further used to calculate the sediment yield from the watershed for the storm events by simple proportion.

The peak runoff (q_p): The peak runoff, q_p (m^3 s^{-1}) for the watershed was estimated using the Rational Method (Equation (4)).

$$q_p = 0.278CIA \quad (4)$$

where, C is the coefficient of runoff, I (mm hr^{-1}) the rainfall intensity in the time of concentration (T_c) when the whole watershed is assumed to be contributing to flow at the outlet and A (km^2) the area of the watershed.

Table 2 Runoff volume (Q_v) and sediment yield for the 20 Storm Events

Storm Events	Mean Sediment Yield per 100 mL of sample analysed (g)	Runoff Volume (Q_v in m^3)	Total Sediment Yield (tonnes)
1	0.66667	18272.9	121.82
2	0.56667	18275.2	103.56
3	0.46667	20187.7	94.21
4	0.43333	19580.9	84.85
5	0.38333	21634.1	82,93
6	0.73333	17029.2	124.88
7	0.53333	18148.2	96.79
8	0.41667	18580.7	77.42
9	0.40000	18210.0	72.84
10	0.16667	40445.2	67.41
11	0.40000	19565.0	78.26
12	0.56667	17279.9	97.92
13	0.45000	18651.1	83.93
14	0.26667	25664.7	68.44
15	0.58333	16915.0	98.67
16	0.85000	16289.4	138.46
17	0.63333	17704.8	112.13
18	0.36667	19671.6	72.13
19	0.48333	17636.0	85.24
20	0.61667	16926.4	104.38

The choice of the Rational Method is informed by the reliability of the peak runoff estimates it provides for watershed area of <8 km^2 (Huffman et al., 2011). The runoff coefficient of the Rational Method was read from a Table of Runoff Coefficients for Agricultural Watersheds as given in Schwab et al (1993). Rainfall intensity data was obtained from the weather station. The area of the watershed (6.12 km^2) was obtained from the Digital Terrain Model (Figure 5) of the catchment generated in Surfers 10 environment. The method developed by Simas and Hawkins (2002) for estimating lag time (T_{LC} in hours) for small watersheds ranging from 0.001214 to 14.123741 km^2 was adopted in this study to compute the time of concentration. The method is captured by Equation (5), (6) and (7).

$$T_{LC} = 0.0051 W^{0.594} S^{-0.15} S_{nat}^{0.313} \quad (5)$$

where; W is the watershed width (obtained by dividing the watershed area by the watershed length); S is the slope as the ratio between the maximum difference in elevation to the watershed longest flow-path; S_{nat} is the storage coefficient and defined in Equation (6).

$$S_{nat} = 1000/CN - 10 \quad (6)$$

With CN earlier assumed to be 58, Equation 6 is reduced to:

$$S_{nat} = 1000/CN - 10 = 1000/58 - 10 = 7.24$$

Given the other parameters of Equation 5 established from the DEM of the watershed, the estimated lag time (T_{LC}) in Equation (5) becomes;

$$T_{LC} = 0.0051(1.311)^{0.594}(0.03947)^{-0.15}(7.24)^{0.313} = 0.0181$$

The Natural Resources Conservation Service converted the lag time (T_{LC}) to time of concentration (T_c) using the relationship in Equation (7) (Fang et al., 2006).

$$T_c = 1.417 T_{LC} \quad (7)$$

Using Equation 7, the time of concentration T_c for Ofuloko watershed becomes:

$$T_c = 1.417(0.0181) = 0.02565 = 92$$

With the different rainfall intensities for the 20 storm events, different values of the peak runoff (q_p) were obtained.

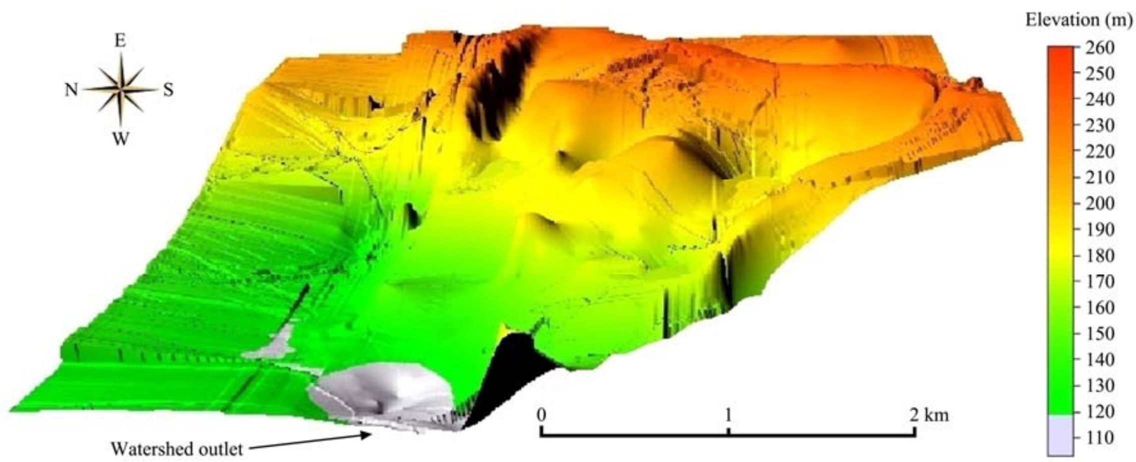

Figure 5 Digital Terrain Model of Ofuloko Watershed

The LS factor: The slope length factor of the watershed (L) and the slope steepness factor (S) were obtained using McCool et al (1987) equations. The equation is given as:

$$LS = (l/22.13)^m (16.8\sin\theta - 0.5) \quad (8)$$

where, l is the slope length; θ is the field slope angle while m is a dimensionless exponent defined as given in equation (9):

$$m = \sin\theta / [\sin\theta + 0.269(\sin\theta)^{0.8} + 0.05] \quad (9)$$

The slope length and angle were determined from the DEM of the watershed to be 3150m and 2.866^0 respectively. Substituting these values into equations 8 and 9 will yield the following:

$$m = 0.006224 \text{ and } LS = 0.351$$

Since the geomorphology of the watershed remained constant during the 20 storm events, the LS factor of 0.351 remained constant throughout the storm events.

Soil Erodibility Factor (K): The K factor was determined using Wischmeier and Smith (1978) equation from simple soil properties which were measured from soil samples obtained from the watershed and analysed in the Soil and Water Laboratory of the University of Nigeria. The equation is expressed as:

$$K = 2.8\times10^{-7} M^{1.14}(12-a) + 4.3\times10^{-3}(b-2) + 3.3\times10^{-3}(c-3) \quad (10)$$

where, M = particle size parameter = (% silt + % very fine sand)(100 − % clay); a = % of organic matter; b = soil structure code: (very fine granular = 1; fine granular = 2; medium or coarse granular = 3; blocky, platy, or massive = 4); c = profile-permeability class: (rapid = 1; moderate to rapid = 2; moderate = 3; slow to moderate = 4; slow = 5; very slow = 6).

Given the uniformity in vegetation and soil type as observed by the researcher, the random composite sampling method which is appropriate for watersheds of area less than 30 ha was adopted in obtaining 18 different samples. The first six samples were obtained from the lower end of the watershed, another 6 was obtained around the middle of the middle of the watershed while the remaining 6 was gotten from the upper end of the watershed. The samples were obtained with the aid of a shovel at a depth of 8 inches below the ground surface. The soil samples for each of these sections of the watershed were thoroughly mixed together before 2 kg of soil sample representing that section was obtained. The results of the laboratory analysis of the three representative soil samples (Sample A, Sample B and Sample C) obtained from the field are shown in Table 3.

Table 3 Results of Laboratory Soil Analysis

Tests	Soil sample A (%)	Soil sample B (%)	Soil sample C (%)
Sand	9.85	11.56	12.2
Very fine sand	14.95	16.42	18.15
Silt	61.65	57.16	51.13
Clay	8.68	11.34	12.87
Organic content	4.87	3.52	5.65

Correction factors from a study on 28 tropical soils from Cameroon and Nigeria as reported by Nill et al (1996) were applied to the soil erodibility factor obtained from Equation (10) to obtain the actual values for tropical soils.

The crop management factor ‘C’ measures the total effect of canopy cover (C_1), the influence of mulch cover (C_2) and the residual effect of previous vegetation (C_3). The product of these subfactors is computed as shown in Equation (11), in the absence of data specific to tropical crops.

$$C = C_1 C_2 C_3 \quad (11)$$

Crop and Practice Management Factors

Using the procedure enunciated by Nill et al (1996), a value of 0.73 for the crop management factor was determined for the watershed. Since there is no soil loss control practice in the watershed, the practice factor P was equated to unity.

4 Model calibration

A major drawback of empirical models is their inability to provide reliable results outside the conditions under which they were developed. It is, therefore, necessary to ‘recondition’ the model to the desired place of application which will be different from the specific conditions of their development. Interestingly, however, Sadeghi and Mizuyama (2007) based on their research in Khanmirza Watershed, Iran, have shown that the use of continuous sediment sampling may not necessitate the calibration of MUSLE before useful predictions can be made by the model. This useful result which is yet to be corroborated by studies in other catchments is, however, tangential to the methodology adopted by the developers of MUSLE. It is understandable that future trends as enunciated at the 4th biennium of the Prediction in Ungauged Basins Decade (an initiative of the International Association of Hydrological Sciences) which culminated in a workshop in 2011 recommend the use of methods that help constrain, rather than calibrate, model parameters. Non-stationarity of watersheds as a result of changes in land-use, climate and water use were advanced as reasons for this recommendation (Spence et al., 2013).

Data collected for the first 10 rainfall events were used for calibrating the MUSLE while the remaining 10 were used for prediction. The 10 rainfall events used for the calibration of the model occurred on 2nd June 2017, 5th June 2017, 8th June 2017, 10th June 2017, 13th June 2017, 14th June 2017, 15th June 2017, 18th June 2017, 19th June 2017, and 21st June 2017. Calibration is done by adjusting the values of the calibrated parameters for reasonable agreement between the predicted sediment yield and the observed (measured) sediment yield. By reasonable agreement is meant an order of magnitude correspondence between the simulated and recorded series, which is consistent within the duration of an event (Mbajiorgu, 1995).

The MUSLE parameters '*a*' and '*b*' of the general form of the equation, as given in Equation (12), were used to calibrate the model.

$$X_t = a(Q_v q_p)^b \text{KLSCP} \tag{12}$$

'*a*' and '*b*' are parameters associated with the location where the MUSLE was developed in the United States and values of 11.8 and 0.56 were obtained for them, respectively (Sadeghi et al., 2013). Inputs of X_t, Q_v, q_p, K, L, S, C and P (as measured on the field) were made for the 10 storm events to obtain 10 different simultaneous equations. K, L, S, C and P are constant during the period of the research. A total of 45 pairs of these equations were then solved to obtain the values of 'a' and 'b' which are given in Table 4.

Table 4 Results of the MUSLE Location Parameters from 10 Storm Events

Events	a,b	Events	a,b	Events	a,b
Storm 1, Storm 2	13.4, 0.46	Storm 2, Storm 9	11.7, 0.55	Storm 5, Storm 6	12.1, 0.39
Storm 1, Storm 3	12.6, 0.44	Storm 2, Storm 10	13.4, 0.63	Storm 5, Storm 7	13.9, 0.42
Storm 1, Storm 4	12.4, 0.53	Storm 3, Storm 4	12.1, 0.46	Storm 5, Storm 8	11.6, 0.60
Storm 1, Storm 5	11.7, 0.62	Storm 3, Storm 5	12.4, 0.48	Storm 5, Storm 9	12.4, 0.43
Storm 1, Storm 6	12.2, 0.49	Storm 3, Storm 6	12.8, 0.43	Storm 5, Storm 10	13.3, 0.56
Storm 1, Storm 7	11.7, 0.61	Storm 3, Storm 7	13.2, 0.45	Storm 6, Storm 7	12.7, 0.59
Storm 1, Storm 8	13.2, 0.63	Storm 3, Storm 8	11.1, 0.54	Storm 6, Storm 8	13.3, 0.44
Storm 1, Storm 9	12.7, 0.68	Storm 3, Storm 9	12.1, 0.39	Storm 6, Storm 9	11.1, 0.40
Storm 1, Storm 10	13.0, 0.41	Storm 3, Storm 10	11.4, 0.62	Storm 6, Storm 10	13.5, 0.44
Storm 2, Storm 3	11.1, 0.49	Storm 4, Storm 5	14.1, 0.34	Storm 7, Storm 8	12.2, 0.45
Storm 2, Storm 4	11.4, 0.63	Storm 4, Storm 6	11.3, 0.40	Storm 7, Storm 9	10.5, 0.66
Storm 2, Storm 5	10.9, 0.48	Storm 4, Storm 7	14.2, 0.64	Storm 7, Storm 10	13.6, 0.46
Storm 2, Storm 6	11.0, 0.54	Storm 4, Storm 8	13.1, 0.53	Storm 8, Storm 9	12.4, 0.52
Storm 2, Storm 7	12.3, 0.44	Storm 4, Storm 9	12.9, 0.48	Storm 8, Storm 10	12.3, 0.43
Storm 2, Storm 8	13.6, 0.72	Storm 4, Storm 10	11.9, 0.61	Storm 9, Storm 10	11.2, 0.55

Given the standard deviation of the distribution as $\sigma_a = 0.942648322$ and $\sigma_b = 0.092862449$, the mean of the parameters, $a = 12.4$, $b = 0.51$, were adopted as a good representation of the MUSLE location parameters.

The calibrated form of the MUSLE for Ofuloko watershed then becomes Equation (13):

$$X_t = 12.4(Q_v q_p)^{0.51} \text{KLSCP} \tag{13}$$

5 Results and discussion

The calibrated form of the MUSLE equation for Ofuloko Watershed (as given in Equation (13)) was used to simulate sediment yield from the watershed. Table 5 are the values obtained from the simulation as compared to the measured values from the Ofuloko watershed.

Table 5 Measured and Predicted Sediment Yield for 10 Storm Events

Date of storm event	$X_t$simulated (tonnes)	$X_t$measured (tonnes)
23rd June 2017 (Storm 11)	72.43	78.26
26th June 2017 (Storm 12)	103.35	97.92
29th June 2017 (Storm 13)	75.94	83.93
3th July 2017 (Storm 14)	74.23	68.44
4th July 2017 (Storm 15)	102.68	98.67
6th July 2017 (Storm 16)	151.05	138.46
8th July 2017 (Storm 17)	117.32	112.13
10th July 2017 (Storm 18)	77.64	72.13
11th July 2017 (Storm 19)	91.22	85.24
14th July 2017 (Storm 20)	111.47	104.38

The graph in Figure 6 compares the sediment yield simulated from the calibrated MUSLE and the sediment yield measured at the outlet of Ofuloko watershed.

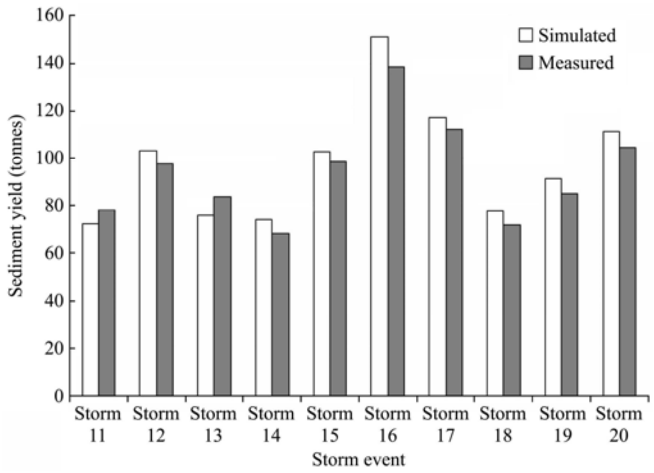

Figure 6 Comparison of the predicted and measured sediment yield for 10 storm events

From the graph, it is observed that the calibrated model under-predicted twice for the first 3 storm events but consistently over-predicted for the remaining 7 storm events.

Chi-square (χ^2) goodness-of-fit test between the measured series (m_i) and the predicted series (s_i) was conducted.

$$\chi^2 = \sum(m_i - s_i)^2/s_i = 4.71643791 \quad (14)$$

$\chi^2_{calculated}$ (4.71643791) < $\chi^2_{tabulated}$ (16.919) at 5% significance level.

The simulated and the measured sediment yield from Ofuloko Watershed are not significantly different at 5% significance level.

The efficiency of the calibrated MUSLE is determined using the Nash-Sutcliffe Efficiency Coefficient (E):

$$E = 1 - [\sum(s_i - m_i)^2] / [\sum(m_i - \acute{m}_i)^2] \quad (15)$$

where, $\acute{m}_i$ is the mean of the measured sediment yield for the 10 storm events.

$$E = 1 - 0.1195 = 0.8805e$$

The Nash-Sutcliffe Efficiency Coefficient value of 0.8805 is acceptable for most hydrologic applications.

The result of the chi-square goodness-of-fit test, the Nash-Sutcliffe Efficiency test and the fairly constant degree of over-prediction and under-prediction as shown in Figure 6 by the Modified Universal Soil Loss Equation over the simulation run show that the model can be used to obtain useful and reliable sediment yield predictions for the watershed and others within the Derived Savanna ecological zone of Nigeria. From Figure 6, the largest difference between the measured and the predicted sediment yield occurred during the 16th storm event (6th July 2017). This was also the storm event that produced the sediment yield despite the fact that the rainfall event for that day was not the highest in intensity and amount as observed from the hyetographs in Figure 4. This can be attributed to the ridging carried out by a few farmers within the watershed on 5th July 2017. The loosening of the soil (manually with hoes) during this operation has predisposed the soil to detachment and transport hence the highest sediment yield during the study period was recorded on 6th July 2017. The results obtained also demonstrate the importance of strict adherence to the spatial context from which MUSLE was developed and expected to be applied. The choice of the MUSLE for the modeling of sediment yield for this small watershed and the use of the Rational Formula which provides reliable estimates of peak runoff for watersheds <8 km^2 is informed by this important consideration. Many of the published works on the application of the MUSLE (and other sediment yield and erosion prediction empirical models) have shown disregard for the spatial scale required for its application, hence the poor and unreliable results obtained from them.

6 Conclusion

This research work was conducted in Ofuloko Watershed, within the derived savannah ecological zone of Nigeria to determine the applicability of the MUSLE in the prediction of sediment yield in the zone. The results obtained show that the MUSLE is not only reliable for the estimation of sediment yield from small watersheds within the ecological zone, but is also a useful tool for the management of sediments discharged into water bodies. Though the simulation of sediment yield for more storm events would have been desirable, the application of MUSLE to the very small Ofuloko Watershed (612 ha) is congruent with the spatial context of its development.

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