Chapter

Evaluation of Soil Erosion and Its Prediction Protocols around the Hilly Areas of Mubi Region, Northeast Nigeria

Ijasini John Tekwa and Abubakar Musa Kundiri

Abstract

Soil erosion is a severe degradation phenomena that has since received huge attention among earth scientists in the developed worlds, and same efforts are now extending to Africa and other parts of underdeveloped worlds. This chapter focuses on collation, analyzing and appraising of soil erosion studies around Mubi region, Northeast Nigeria, where the Mandara mountain ranges is notably responsible for spurring soil erosion. This chapter reviewed reports on the: (a) Mubi regional soil properties, erosion processes and principles of their occurrence, (b) soil erosion predictions using empirical and physically-based models by researchers, and, (c) economicimplications and managements of soil erosion in the region. This chapter reveals that classical and rill/ephemeral gully (EG) erosion features received more research attention than surface erosion such as splash and sheet. No information was reported on effects of landslides/slumping noticeable along rivers/stream banks around the region. The few economic analysis reported for soil nutrient and sediments entrained by concentrated flow channels were very high and intolerable to the predominantly peasant farmers in the region. It is hoped that the considerable volumes of erosion researches and recommendations assembled in this chapter shall be carefully implemented by prospective farmers, organizations, and residents in the Mubi region.

Keywords: Hilly areas, soil erosion, erosion predictions, economics/managements of soil erosion, Mubi region

1. Introduction

Soil erosion is perhaps one of the leading threats to land use in many regions of the world regardless of the piling volume of research on soil erosion agenda [1]. Precisely, about 7348 articles were published on soil erosion between 2016 and 2018 alone, compared to the whole of the twentieth Century publications with just about 5698 articles [2]. Despite this long history and huge volume of research, soil erosion studies in most parts of sub-Saharan Africa, particularly Nigeria, are still grossly insufficient. Soil erosion event implies the net long-term balance of all activities that displaces soil from its initial location to another destination by any entrainment agent(s) [3]. Water and wind agents are largely responsible for soil erosion phenomena witnessed across the globe. However, [4] reported other agents of soil erosion to include mass wasting by soil slumping, explosion cratering, trench digging, land leveling, soil quarrying, and crop harvesting activities. Of all these agents, water erosion affects larger land area and has received more research attention than wind, plus all other erosion agents [5]. Gully erosion is likely to be the largest source of soil sediment yield among the other water-induced erosion types. It is formed where sufficient concentrated water flow occurs to incise soils progressively downwards until it contacts an underlying hard material(s). Classical gullies are incised channels that cannot be filled in by normal tillage operations, compared to the ephemeral (transient) gully (EG) erosion features [6, 7].

In recent years, few studies on the development, field processes and distributions of ephemeral or classical gully erosion features over the Mubi regional landscape were reported as either measured or predicted with empirical or physically-based models by a few erosion research scholars. These research efforts are largely tied to the pressing need to generate a local databank for consultations, as erosion datasets from other foreign places might not truly represent the local field conditions of the Mubi region. Essentially, [8] reported that local adaptation of scarce process-based models and erosion results from one region may not apply to another, due to differences in study methods, making data accuracy, reliability, and credibility debatable. This chapter, therefore, intends to, (i) review the few reports on soil erosion studies around the Mubi area, and (ii) harmonize the research views and highlight the salient ideas where agreement is less firmly established towards holistic management implementation options by potentially interested land users in the region, and perhaps, also to serve as reference material to the neighboring regions.

Mubi area which is situated in the Northeastern part of Nigeria on the western hillside of the Mandara Mountains gives its high and undulating topography that spurs runoff, surface incisions, and gullying with a consequently high soil loss rates along the region [9–12]. Previous studies on soil erosion features in the Mubi region were reported largely on both the classical and ephemeral gully (EG) erosion, and only a few or no works were carried out on splash, sheet, and rill erosion features. Thus, there is still a dearth of information concerning the splash, sheet, rill, and stream bank sloughing erosion activities in the region. The EG erosion is a recently recognized erosion class in the context of global erosion that still lacks both sufficient models and datasets to test and/or predict its processes [13, 14], while the classical gully is the advanced form of EG erosion feature with deeper (>0.3 m depth) and wider (>2.0 cm width) channels [6, 7, 13]. The menace of soil erosion has generated huge management concerns in recent times. Both government and private donors have devoted some attention to addressing the effects felt by residents along the riverine and/or floodplain sections of the Mubi region. More efforts are still expected to study and report erosion activities and consequent implications to both farmers and residents in the Mubi region. It is hoped that published reports on soil erosion studies are consulted and conned in this text and their views understood and refocused for better understanding and field use in the region.

2. The Mubi region

2.1 Description and location

Mubi region is the present headquarter of Northern Senatorial District of Adamawa state, Northeast Nigeria. The region consists of 5 Local Government Areas (LGAs) namely: Madagali, Maiha, Michika, Mubi-North, and Mubi-South. The Mubi region used to be a part of Northern Cameroon under the German Colony until 1922 when the area was given by the United Nations under Britain as

Trusteeship Territory and later merged under Independent Nigeria in 1961 [15, 16]. The regional land area is 4728.77 km^2 and has a population size of 759,045 people in 2003 (1991, census projected figure). The Mubi region lies between latitudes 9°30″ and 11°00″ North and between longitudes 13°00″ and 13°45″ East of the Greenwich Meridian (**Figure 1**). The predominant physical feature notable in the Mubi region is the Mandara Mountain ranges lying along its eastern border by the Republic of Cameroon. The region falls within the Sudan Savannah belt of Nigeria and is characterized by sparse trees and grass vegetation, aquatic weeds in river valleys, and dry land weeds interposed by weedy and shrub plants.

2.2 Climate and agriculture

The climate of the Mubi region is comprised of typical wet and dry seasons. The dry season spans for about 5–6 months (November to April), while the wet season usually starts from April or May to October each year. The average annual rainfall is usually within the ranges of 900 mm and 1050 mm depths with mean rain intensities of 18–24 mm as the highest in the region as reported by [17, 18]. The driest months are March and April when the relative humidity is about 13%. The average minimum temperature is 15.2°C in the months of December and January, while the

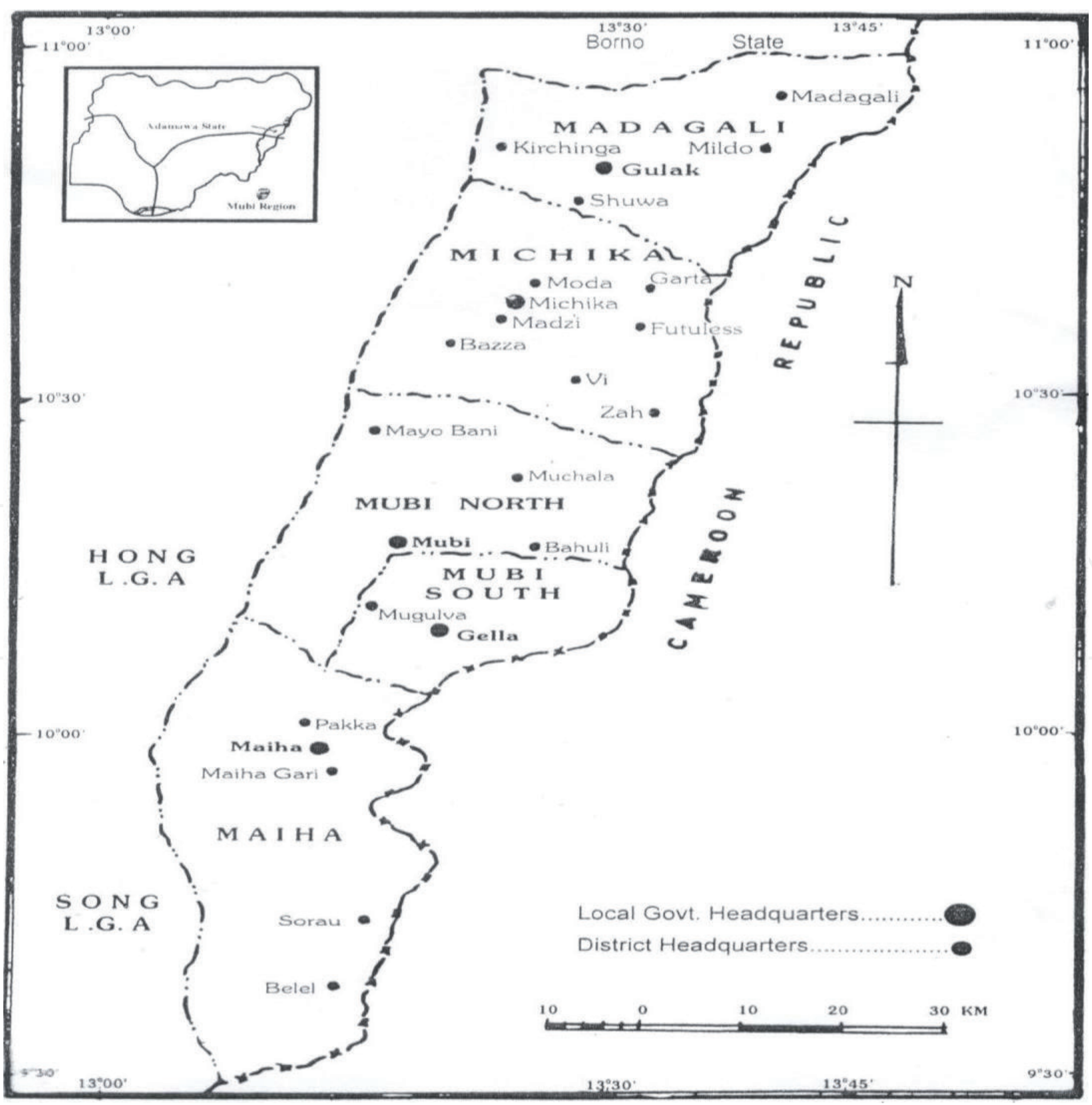


Figure 1.
Map of Mubi region showing LGAs and district headquarters. Source: Adapted from [17].

maximum temperature of up to 42°C is attainable in April [19]. Agricultural land use is mostly mixed farming systems involving cattle rearing and rain-fed arable farming, with few irrigation farming practices. Soil fertility is maintained using animal dung and inorganic fertilizer sources to support continuous crop production. The dominant crops cultivated in the area include maize, sorghum, rice, groundnut, and sugar cane. Sugar cane and vegetable crops are mainly grown on a few *fadama* lands under irrigation. The arable crops are usually grown as intercrops of maize/cowpea, sorghum/cowpea, or as sole crops of sorghum, cowpea, groundnut, and rice, which are sometimes grown in rotation based on economic reasons [17]. Basic conservation practices include tied ridges, contour bunds and shallow tillage using indigenous farm tools such as hoes, built terraces and stone lines, sandbag lines, and established vegetative barriers [20].

2.3 Soils and erosion activities

The soils of the Mubi region falls under the ferruginous tropical soil category based on genetic classifications, and as either lithosols, luvisols, or gleyic cambisols [17, 21]. The soils are derived from the underlying basement complex rocks, gneiss, and granites that characterize the Mandara Mountain ranges. The region's land topography is widely undulating with consequent erosion activities at varying levels of devastations [22–24]. There also exist a spatial pattern of land distributions often moderated by the annual rainfalls. The soils range from yellow through red to brown in colors. The soils have generally coarse, stony, and very shallow depths with nearly undefined profiles [25]. The soils are deeper at the foothills and thins out up the slopes with a predominantly sandy-loam and moderate to coarse soil textures. Soil reaction (pH) varies in the soils across the region but is generally slightly acidic to slightly alkaline with few incidences of low or high pH rates in some soils in the region. The soil organic matter (SOM) contents are widely moderate to low [10, 26]. Though the region has shallow soils (lithosols) with adequate drainage, it still has considerable soil fertility. However, the region's rockiness, isolated hills, slopes, and valleys have equally been responsible for the yearly colossal loss of soils and soil nutrients around the Mubi region. The relationship existing between soil erosion activities and their moderating variables is reported in **Table 1**.

The results reported in **Table 1** shows that soil bulk density, shear strength, clay content, and SOM contents reduced soil erosion progress, while soil erodability index, gully erosion channel length, depth, land slope, soil plastic limits, and surface runoff increased soil erosion activities around the Mubi region [27, 29].

Erosion activities are visibly spread across the region, particularly along the foothills of the Mandara Mountains such as the Mubi area (Mubi-North and South LGAs), where considerable studies were carried out to assess the magnitude of soil erosion. Field observation shows that sheet and gully erosion are the most commonly spread features on the gentle to moderately undulating terrains around Michika LGA, such as at Bazza, Garta, and Jeddel areas. The presence of such surface erosion features are found around Duhu-Yelwa, Gwaba, Sukur-Daurowa, and Kaya areas in Madagali LGA, and at Mayo-Bani District in the northern parts of Mubi-North LGA [9, 10, 17, 26]. Likewise, rill and gully erosion features are widely spread around the hilly areas of the Mubi area, especially at Digil, Vimtim, Muvur, and Betso in Mubi-North LGA, and as well as at Hurida, Madanya, Yewa, and Lamorde areas in Mubi-South LGA. Several other surface and channelized erosion features exist in most of the villages and/or farm locations scattered all around the Mubi regional landscape.

The notable agent responsible for spurring geologic soil erosion features is largely the regional terrain and/or topography that is periodically sharpened by rainfalls, agriculture, and other human activities in the Mubi region [19]. These

S/no.	Erosion predictor variable	The coefficient of determination of soil erosion activity	Relationship or role on erosion activity	Reference
1.	Soil bulk density (Mg/m^3)	−1254.68	Reduces erosion	[27]
2.	Soil erodability index	216.47	Increases erosion	[27]
3.	Soil shear stress (M/m^2)	−3310.08	Reduces erosion	[27]
4.	Ephemeral gully length (m)	0.38	Increases erosion	[27]
5.	Ephemeral gully depth (m)	10.70	Increases erosion	[27]
6.	Soil clay content (%)	−6.93	Reduces erosion	[28]
7.	SOM content (%)	−136.54	Reduces erosion	[28]
8.	Land slope rates (%)	6.60	Increases erosion	[28]
9.	Soil plasticity limit	17.20	Increases erosion	[28]
10.	Surface runoff (mm)	284.78	Increases erosion	[28]

Adapted from [27, 28].

Table 1.
Relationships between soil erosion and their predictor variables around the Mubi region.

factors make the landscape even more vulnerable to soil erosion severity and the probability of local floods around the region.

According to [11], raindrop or splash erosion was observed as one of the predominant forms of erosion by water on the scantly vegetated or nearly bare soil surfaces, particularly at the onsets of rainy seasons in the region. Hence, soil erosion risks were found to be higher on cultivated than on fallowed lands. However, such sheet and splash erosion features are often obliterated by regular tillage activities that suppress their activities from being noticed compared to channel erosion in the region. Even though, the continuous cultivation of farmlands in an up and downhill pattern on the commonly moderate to steep slopes are notably responsible for the moderate to severe soil erosion incidences noticed around the Mubi region.

Table 2 presents the prevailing soil degradation types and their causative factors. The results accounted for soil erosion as the main cause of soil degradation in the region [26]. Soil erosion such as splash, sheet, and rill features aggravate the destruction of organically enriched topsoils, while gullying activities worsen such problems by total removal of the top and sub-soils, plus their soil nutrients irreversibly. Findings in **Table 3** show that the channel lengths averaged between 107 m and 136 m long and between 114 m and 149 m in the months of April and in November, respectively.

The channel widths averaged between 7.12 m and 18.12 m wide in April, and was between 7.85 m and 15.19 m wide in the month of November in both years, while the channel depths respectively averaged between 2.03 m and 2.88 m in April, and was between 2.65 m and 3.77 m deep in November 2003/2004. Similar works by [9, 10, 26, 30] earlier reported comparable channel indices in the region. Previously, [9, 26] lamented the implication of such actions as they translate into poor soil fertility, lowered SOM, stoniness, and reduced agricultural production benefits, especially around areas along the Mandara mountain ranges in the region.

S/no.	Soil degradation type	Causative factor(s)	Reference
1.	Soil surface destruction	Sheet, rill, and gully erosion, incompatible tillage applications	[26, 30]
2.	Poor soil fertility, and low SOM contents	Sheet, rill, and gully erosion, crop nutrient removals, continuous cropping, incompatible tillage applications, overgrazing, deforestation, indiscriminate bush burning	[31]
3.	Stoniness, shallow soil depths	rill, sheet, and gully erosion, shallow underlying rock-basement	[9, 10]
4.	Soil salinity and acidification problems	Poor drainage/waterways, over-application of alkaline and acidic fertilizer sources, low soil topography, aridity/acid rains	[31]

Source: compiled by the author.

Table 2.
Observed factors of soil degradation around the Mubi region.

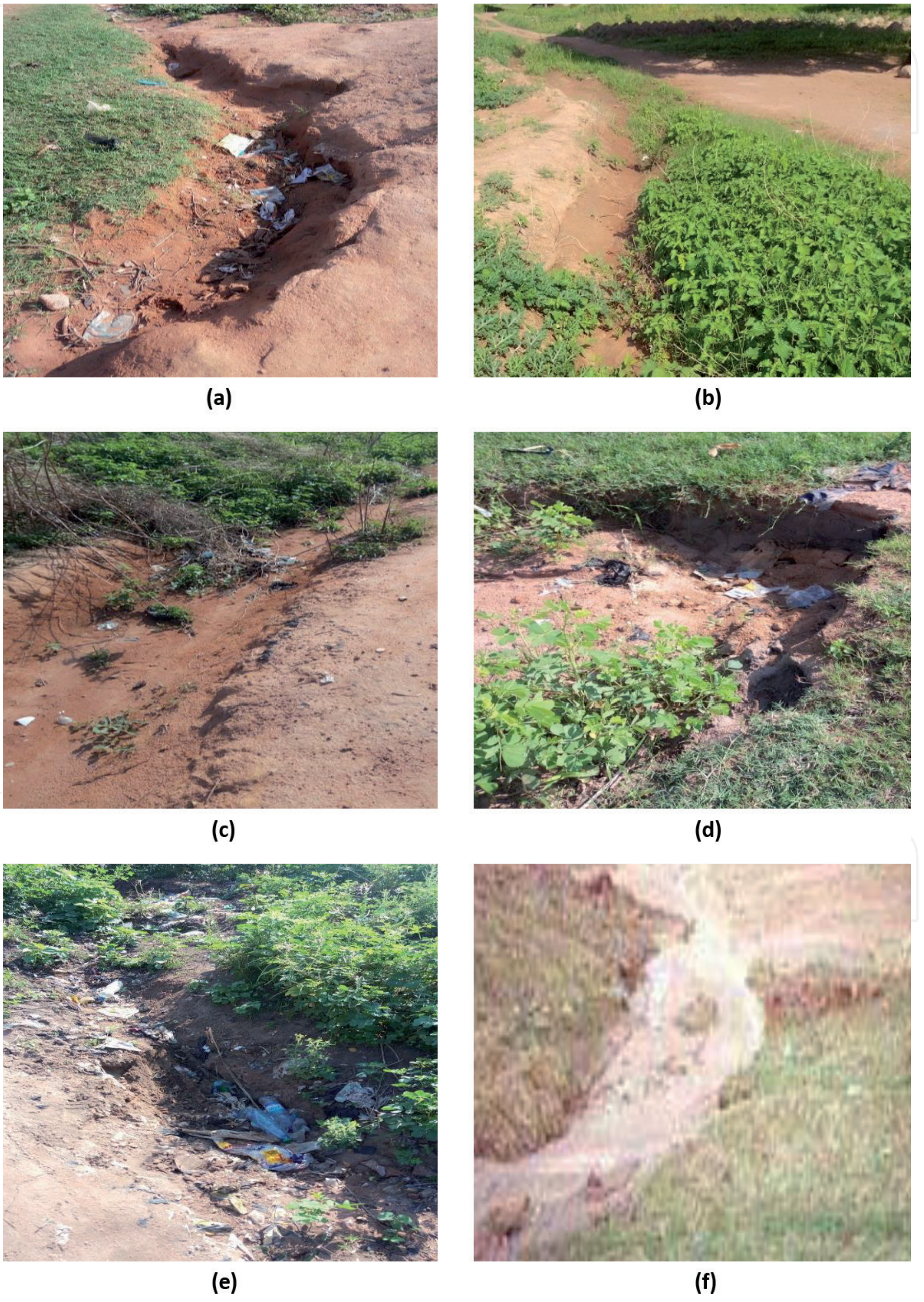
Site description	EG channel shape	Drainage area size (acre)	Topography (slope) (%)	Ephemeral gully channel parameters					
				Average length (m)		Average width (m)		Average depth (m)	
				Apr	Nov	Apr	Nov	Apr	Nov
Digil	V	2.61	0–4 (very flat-to-gentle)	113	119	10.4	11.67	2.03	2.65
Vimtim	U	3.63	4–6 (moderate to flat-to-gentle)	110	119	18.12	15.19	2.13	2.85
Muvur	U	4.80	6–8 (moderate or rolling)	107	114	9.52	10.47	2.04	2.77
Gella	V	2.40	20–22 (mountainous, hilly or steep)	116	123	7.12	7.85	2.23	3.04
Lamorde	U	2.78	18–20 (mountainous, hilly or steep)	136	149	10.64	12.60	2.88	3.77
Madanya	U	3.51	4–8 (moderate to flat-to-gentle)	118	126	10.45	11.57	2.83	3.63

Adapted from [10, 32].

Table 3.
Erosion channel and field characteristics at some sites in the Mubi area during 2003–2004.

3. Principle of soil erosion processes and development around the Mubi region

The underlying principle of such as gully erosion is governed by flow conditions on watersheds. Gullying occurs whenever the water flow rate (runoff) on a slopping landscape exceeds the threshold limit or resistance of soil, then erosion is initiated, followed by downward incision [33] and upstream head-cut migration [34]. Likewise, whenever the flow rate drops below the erosion potential, then the erosion process ceases [35]. Gully erosion processes are active on a sloppy or rolling topography that increases soil particle detachments on usually two intersecting planes and/or watershed areas due to applied runoff force that voids the soil surfaces such as around the Mubi region. The soil detachment continues in time steps, except otherwise, limited by the effect of slope and/or vegetation roughness. Since the flow rate is unsteady and spatially varied, the head-cut migration rate, rate of sediment entrainment, transport, channel width, and deposition will all vary accordingly in time and space [34, 36].



(a) (b) (c) (d) (e) (f)

Figure 2.
(a–f) Showing some channelized erosion features in the Mubi region.

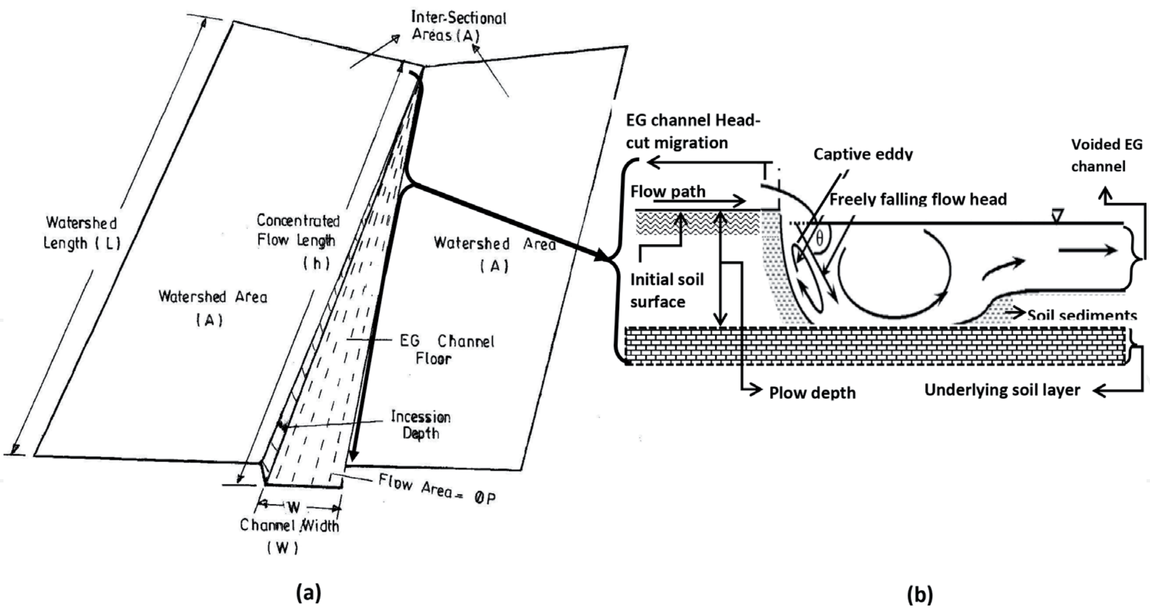


Figure 3.
Schematic diagrams of EG erosion showing, (a) EG erosion channel formed on a sloping intersectional watershed areas, and, (b) erosion processes describing a developing EG channel with an actively migrating head-cut in the upstream direction. Source: adapted from [32, 34, 40].

The periodic erosion processes, therefore, yields both head-ward migration in an upstream direction and soil sediments transportation at the gully outlets as deposited materials. The flow rate is proportional to the upstream drainage area that supplies runoff for transporting detached particles downslopes. The distance between the head-cut and the gully outlet defines the actual concentrated flow length. Depending on additional runoff, the head-cut first incises down to the tillage layer (lower boundary), before it starts migrating backward at a rate proportional to the flow rate [37]. As the erosion progresses, the head-cut continues to migrate upstream (**Figure 2**), and the contributing drainage area decreases, so that discharge at the head of the EG also decreases until it attains a maximum EG length for a given watershed area.

3.1 Conceptual framework of soil erosion processes

The concept of soil erosion formation begins with the understanding of the actual erosion process that is often caused by rainfall impacts, soil factors, and topographic variables that initiate soil erosion, then followed by subsequent channel morphological stages of development, if left unobliterated [13], as illustrated in **Figure 2**. Soil erosion is a natural phenomenon that is as old as the earth itself, and whose effects are targeted at a man and his ecosystem [38].

The soil erosion process starts with the gradual wash of soil surfaces by either water, wind, or human activities [39]. Generally, the soil erosion management principle is centered on prevention, rather than ignoring it to degenerate before controls, which often comes at very prohibitive costs. As has been the case around the neighboring parts of Adamawa State, Nigeria, and in most other parts of the world, the impacts of soil erosion such as sheet, rill, and gully erosion activities are widely spread across the regional landscape of the Mubi and her environs (**Figure 3**).

4. Soil erosion predictions around the Mubi region

In the past, erosion assessment tools were used to determine surface and channel erosion development, soil losses, and their morphological processes around the

Mubi region using field measurements (estimations) of such as sheet, rill, and gully erosion features [10, 11]. In addition, the use of empirical models for predicting area, volume, and weights of soil loss was developed and tested by [23]. Other linear models such as the universal soil loss equation were tested by [11]. Trials of sophisticated prediction models such as the ephemeral gully erosion model (EGEM), and its adapted versions, and the water erosion prediction project-WEPP model were respectively tested by [24, 32], while the RUSLE-2 and ArcGIS software 10.3 were also tested by [11, 12]. Even though, few erosion prediction technologies were tried around the Mubi region, yet, several other researchers are still only concerned about the channel morphological properties. Future studies are expected to be more involved in predictive, rather than limiting efforts to document channel properties without including soil losses and their accompanying economic implications in the region (**Table 4**).

4.1 Field studies of channelized erosion features around the Mubi region

4.1.1 Empirically predicted soil losses

Earlier, [9] reported that gullying activities are widely spread in areas along the foothills of the Mandara mountain ranges in the Mubi region. Researches have been documented on the scale and intensity of such channelized erosion processes in the region by a handful of earth scientists in recent times. **Table 5** presents the yearly soil loss reported at some gully erosion sites in the Mubi area during 2003/2004 and 2008/2009 respectively.

The erosion indices reported in **Table 5** shows an erosion trend from 2003 to 2004, and from 2008 to 2009. The reports clearly suggest a relative decrease in soil loss rates at the same erosion sites over the observation time intervals. These reductions were largely influenced by the conservation measures adapted at the erosion sites in order to curtail erosion progress at the same sites during the 6 years period.

4.1.2 Prediction of erosion indicators and soil losses using physically-based erosion models

Until recently, some highly sophisticated erosion models were adapted and tested in predicting EG and classical gully erosion processes around the Mubi region. Several works by [24, 32] evaluated the efficiencies of some foreign physically-based erosion models such as EGEM, RUSLE-2, and WEPP models, and were compared with some earlier tested empirical and mathematical equations in the same Mubi region.

In addition, [11] computed soil erosion on a watershed using a Kriging interpolation technique in ArcGIS software 10.3 model. On the other hand, the works of [9, 20, 26, 30, 44], reported some suitable conservation measures for erosion controls around the Mubi area, but without quantitative information.

Table 6 presents the reports of earlier predicted soil losses using the Revised Universal Soil Loss Equation (RUSLE-2) in ArcGIS software [11, 12], as well as the empirical, EGEM and WEPP models in the Mubi region [24, 32, 45]. Results from the different prediction tools used in the Mubi area reported an average soil loss of 3.52 tons/ha/year from a watershed area covering 148.43 km^2 using the RUSLE-2 software at Mubi-South LGA. Earlier works by [24] that tested an EGEM software technology recorded an average soil loss of between 0.37 and 1.37 tons/ha/year. at Mubi-South, and still found a relatively lower range of 0.50 - 1.15 tons/ha/year. of soil loss at Mubi-North LGA. The wide difference between the RUSLE-2 and EGEM predictions within the neighboring erosion sites accounted for the RUSLE-2

S/no.	Hydrological property		Method of determination	Reference
	Parameter	**Ranges**		
1.	Average annual rainfall (mm)	700–1050	Rain-gauge	[19]
2.	Total energy of effective rainfall (KE)	9917.16–10,136.30	Computed using Kriging interpolation technique in ArcGIS software 10.3	[11]
3.	Annual KE of rainfall (E)	9923.03–10,142.20	Computed using Kriging interpolation technique in ArcGIS software 10.3	[11]
4.	Runoff estimates (mm)	497.39–508.37	Computed using ArcGIS software 10.3	[11]
5.	Soil particle detachment (F)			
	a. Sandy loam	24.2–27.2	Computed using Kriging interpolation technique in ArcGIS software 10.3	[11]
	b. Sandy clay loam	37.2–49.7		
	c. Loamy sand	49.7–69.6		
6.	Soil clay content (%)	19.33–26.25	Bouyocus hydrometer method	[24]
7.	Soil resistance (cohesion)	3.43–6.74	Computed using ArcGIS software 10.3	[11]
8.	Total soil particle detachment (D)	25.26–69.66	Bouyocus hydrometer method	[24]
9.	Soil erodibility index (SEI)	−0.77 to 1.32	Computed using Mitchell & Bubnezer method	[24]
10.	Surface runoff/overland flow	−1.29 to 217.43	Computed using Kriging interpolation technique in ArcGIS software 10.3	[11]
11.	Soil bulk density (Mg/m^3)	1.33–1.41	Determined using Clod method by [41]	[29]
12.	Water holding capacity (%)	19.09–28.75	Determined using gravimetric method by [42]	[29]
13.	Soil reaction (pH)	4.65–6.15	Determined using electric pH meter	[10]
14.	Soil organic carbon—OC (%)	0.76–1.31	Wet oxidation method by [43]	[24]
15.	Total exchangeable bases (cmol(+)/kg)	14.67–31.70	By summation of exchangeable bases	[29]
16.	Soil erosion risk	Low-very high risk	Computed using Kriging interpolation technique in ArcGIS software 10.3	[11]

Adapted from [11, 19, 24, 29].

Table 4.
Some reported hydrological and physicochemical properties of soils of the Mubi Region.

as having over predictions compared to the EGEM outputs. This was perhaps due to the larger area coverage by the RUSLE-2 during the research, compared to the EGEM applied to EG erosion channels with smaller sizes. However, future trials and revalidation of RUSLE-2, and other technologies are strongly recommended towards developing suitable conservation alternatives in the Mubi region. Further trials by [32, 45] involving EGEM, WEPP, and empirical models show that the

S/no.	Gully location	Soil loss (tons/year)		Reference
		2003	2004	
1.	Mubi-North LGA			
	Digil	404.32	293.19	[10]
	Muvur	725.35	984.40	
	Vimtim	159.57	296.69	
2.	Mubi-South LGA			
	Gella	161.26	101.56	[10]
	Lamorde	589.62	620.09	
	Madanya	211.62	491.01	
		2008	2009	
3.	Mubi-North LGA			
	Digil	227.50	258.51	[23]
	Muvur	446.33	344.49	
	Vimtim	400.19	397.89	
4.	Mubi-South LGA			
	Gella	154.23	200.63	[23]
	Lamorde	196.20	228.67	
	Madanya	98.78	114.46	

Adapted from [10, 23].

Table 5.
Annual soil loss observed at some gully erosion sites in the Mubi area.

observed erosion strongly correlated with the empirical (r^2 = 0.67) than with both EGEM (r^2 = 0.57) and the WEPP (r^2 = 0.53) models. The results suggest opportunities for adaptability of even the more sophisticated foreign models around the Mubi region, and therefore, the need for further trials of other efficient erosion models towards the selection of more realistic and/or suitable tool for erosion management around the Mubi region.

4.2 Economic implications of soil erosion in the Mubi region

Although volumes of research works on economic implications of soil erosion exist elsewhere, the Mubi region is still facing a dearth of information on such an agenda in monetary terms, apart from the few research results reported by [46]. There are still no other published records of economic analysis on soil erosion devastations in the Mubi region.

Table 7 presents the results of some analyzed economic implications of soil and soil nutrient losses observed at 4 farm locations in the Mubi area in 2003 and 2004. The estimated weights of soils and their inherent nitrogen (N), phosphorus (P), and potassium (K) losses were quantified at costs within the range of $305 and $5698 for the study sites in both years. The gross cost of the nutrient loss over the 2 years was as high as $19,377, considering the small-sized erosion channels. Although, these values seem to fall within considerable limits, nutrient losses in larger erosion channels might be very disturbing and prohibitive.

S/no.	EG erosion location	Prediction Technology	Average soil loss (tons/ha/year)	Observation year	Reference
1.	Mubi-South LGA watershed	RUSLE-2 Software	3.52	2018	[11]
2.		Mubi-South LGA		2015	[32]
	Gella	EGEM software	0.37		
	Lamorde	EGEM software	1.37		
	Madanya	EGEM software	0.65		
3.		Mubi-North LGA		2015	[32]
	Digil	EGEM software	0.59		
	Vimtim	EGEM software	0.84		
	Muvur	EGEM software	1.15		
4.		Mubi-South LGA		2016	[32]
	Gella	Empirical model	0.59		
	Lamorde	Empirical model	1.43		
	Madanya	Empirical model	0.63		
5.		Mubi-North LGA		2016	[32]
	Digil	Empirical model	0.90		
	Vimtim	Empirical model	1.13		
	Muvur	Empirical model	1.05		
6.		Mubi-South LGA		2021	[32]
	Gella	WEPP model	0.80		
	Lamorde	WEPP model	1.77		
	Madanya	WEPP model	0.83		
7.		Mubi-North LGA		2021	[32]
	Digil	WEPP model	0.80		
	Vimtim	WEPP model	1.90		
	Muvur	WEPP model	1.50		

Keywords: RUSLE = revised universal soil loss equation, EGEM = ephemeral gully erosion, WEPP = water erosion prediction project, LGA = local government area.
Adapted from [11, 32].

Table 6.
Predicted soil loss estimates from ephemeral gully (EG) features using some adapted physically-based erosion models in the Mubi region.

The results in **Table 8** presents a similar economic analysis of the quantity of soil loss by gully erosion as reported by [46] in the same Mubi region. However, such economic analysis on erosion-related researches has not yet been reported, apart from those reported by [46]. The results show that locations such as the Muvur site with wider and/or deeper gullies recorded larger soil removals with proportionate

Location	Weight of soil loss (kg)	Soil analytical data			Weight of nutrient loss (kg)			Equivalent number of fertilizer bags (50 kg)			Estimated cost of nutrient loss ($)			Total costs of nutrient loss ($)
		N (%)	P (ppm)	K cmol(+)/kg)	N	P_2O_5	K_2O	N (urea)	P (SSP)	K (MOP)	N	P	K	
2003														
Muvur	725,345	0.27	20.88	3.47	1958.43	34.58	1177.93	85	4	39	3905	103	949	4957
Vimtim	159,574	0.14	14.33	4.23	223.40	5.24	315.90	10	1	10.5	460	26	255	741
Gella	161,257	0.15	22.65	1.36	241.89	8.36	102.64	10.5	1	3.5	482	26	85	593
Lamorde	589,620	0.17	25.88	2.03	1002.35	34.95	560.16	43.5	4	19	1999	103	462	2564
	Gross annual cost										6846	258	1551	8855
2004														
Muvur	984,401	0.21	21.00	3.85	2067.24	47.33	1773.69	90	5	59	4135	128	1435	5698
Vimtim	266,689	0.15	35.03	4.45	445.03	23.79	617.88	19	3	20.5	873	77	499	1449
Gella	101,556	0.11	23.17	1.51	111.71	5.38	71.77	5	1	2	230	26	49	305
Lamorde	620,090	0.20	26.34	2.06	1240.18	37.40	606.53	54	4	20	2481	103	486	3070
	Gross annual cost										7719	334	2469	10,522
	Gross total cost													**19,377**

Keywords: (1) conversion factor of P (kg) into P_2O_5 = 2.29 and K (kg) into K_2O = 1.20, (2) conversion rate of 1$ = N370 in Nigerian currency, (3) a bag of (a) urea fertilizer cost $46, (b) a bag of single superphosphate (SSP) costs $26, and (c) a bag of murate of potash (MOP) in 2021.
Adapted from [46].

Table 7.
Soil and nutrient loss and their cost estimates per hectare per annum (2003–2004).

Erosion site location	Weight of soil loss (kg/ha/year)		Equivalent number of tipper load (156 T) (6160 kg)		Cost of soil loss ($)	
	2003	2004	2003	2004	2003	2004
Digil	404,321.63	239,185.65	66	36	2640	1560
Muvur	725,345.01	984,400.56	178	160	7120	6400
Vimtim	159,574.14	296,680.60	26	48	1040	1920
Gella	161,257.14	101,566.00	26	17	1040	680
Lamorde	589,619.57	620,089.74	96	101	3840	4040
Madanya	211,619.27	491,007.60	34	80	1360	3200
Total	**2,251,736.72**	**2,732,930.15**	**426**	**445**	**17,040**	**17,800**
Gross total cost						**34,840**

Keywords: (1) equivalent weight of tipper load (156 T) = 6160 kg, (2) unit cost of a tipper load = $40.
Adapted from [46].

Table 8.
Soil loss and cost estimates.

economic losses, while other locations with the narrowest and/or shallowest channels such as the Gella site, had lesser soil and associated economic losses. The gross cost of soil loss ($19,377) was over twice the cost of nutrient loss ($34,840) during the 2 study seasons. These soil and nutrient loss cost estimates ($54,217) appear very high and prohibitive, if converted into the Nigerian local currency (N20,060,290). This is an amount that could pay off 1 month salary bills of about 50 professors in the Nigerian Universities.

4.3 Erosion management practices adopted around the Mubi region

The erosion features in the Mubi region have also received considerable management efforts from farmers, residents, government officials, and environmental scientists over the years. **Table 9** presents some of the management measures adopted at some villages across the Mubi region [10, 32]. The report details the major soil degradation sources adopted conservation practices, and their corresponding impacts on arable agriculture around the Mubi region. The major soil degradation sources include soil erosion such as sheet, rill, and gully, Sloughing along gullies, impeded drainages, and soil exhaustion. The majority of the gullies and stream bank erosion features have been controlled over time with such as stone lines/bunds, sandbag lines, vegetative barriers, earthen-contour bunds, and hillside-terraces. In addition, soil exhaustion caused by continuous cropping and selective plant nutrient uptakes, have been remedied with the application of organic manure, and some other soil-enriching mulching practices to restore soil quality after erosion damages. These measures have shown some proven protection of soil surfaces against the menacing effects of such as gullying, siltation problems, and channelized erosion spread in the Mubi region.

A handful of researchers such as [10, 11, 17, 18, 20, 26–28, 30, 31] suggested several, but varying soil erosion control options for implementation around the Mubi region. According to [30, 31], overgrazing, deforestation, and indiscriminate bush burning that leaves the soils bare during dry seasons up to the onsets of rainfalls makes the soils more vulnerable to surface destructions at the slightest impacts of rain splash, rills, or gullying activities in the region.

Farm location	C.F.experience (years)	Present land use	Vegetation	Major crop grown	Soil texture	Major soil degradation sources	Major conservation practices	Conservation practice impacts
Digil	5–28	Arable farming/ Animal grazing	Few trees, grasses, and shrubs	Maize	SCL	Sheet Erosion gully-landslides	Rice-bran mulch, trash lines, sand-bag lines, vegetative barriers, and organic manuring.	Protects soil surface, retains earth, and conserves moisture with longer conservation effectiveness.
Duda	10–22	Arable farming/ Animal grazing	Few trees and grasses	Guinea-corn	SCL	Rill and gully Erosion	Stone bunds /lines Hillside Terraces and stone-lines.	Protect rill and gully erosion, Conserves soil moisture with longer conservation effectiveness.
Hurida	5–30	Orchard	Trees and Shrubs	Vegeta-bles	SL	Gully-landslides	Stone-lines/bunds vegetative barriers, sand-bag lines, and trash lines.	Retains earth, checks gully erosion, and conserves soil moisture. Enhances good drainage conditions. Reclaims degraded lands.
Humbu.	11–25	Arable farming	Tall grasses and few trees	Sweet potato	CL	Impeded drainage	Earth-contour bunds, vegetative barriers, rice-bran mulch, and organic manuring.	Redirect run-off water and enhance good drainage conditions.
Yewa	7–38	Arable farming/ animal grazing	Few trees, grasses, and shrubs	Sugar-cane	SCL	Sheet and gully Erosion	Vegetative barriers, trash lines, sand-bag lines, and stone bunds/lines, and Rice-bran mulch.	Protects gully and sheet erosion spreads, reduces slope lengths and flattens land slopes for arable use.

Keywords: C.F. = conservation farming, SCL = sandy clay loam, Sicl = silty clay loam, SL = sandy loam, CL = clay loam, SC = sandy clay, Conserv. = conservation, Humbu = Humbutode, Vegeta = vegetables.
Source: adapted from [10].

Table 9.
Field and conservation practices for controlling erosion processes around the Mubi region.

5. Conclusions

This study found out that only a few quantitative data exist on the soil erosion agenda in the Mubi region at present. The available literature reported only a little or no information on the sheet, splash, and rill erosion processes, compared to EG and classical gully erosion features that are widely spread across the Mubi region. Other works such as [18, 20, 26, 30, 31] also dwelled on soil erosion management and conservation measures practiced around the Mubi region. The study noted field measurements, observations, and trials of empirical and few other physically-based foreign erosion models such as ArcGIS 10.3 software, EGEM software, and WEPP software technologies, have been implemented successfully, especially around the foothills of the Mubi area.

It suffices to conclude that, more of the researches were more concentrated in the Mubi area (Mubi-North and South LGAs) [10] than at any other part of the Mubi region. Only a little information related to the economic analysis of soil erosion implications around the Mubi region was reported, and there exists the need to improve. However, soil loss researches by a handful of authors were considerably reported in the region [9, 10, 18, 22–24, 26, 29, 32, 44–46]. Reports related to soil degradation and recommendable conservation measures in the Mubi region were as well documented [26, 29–32]. Recently, erosion risk analysis on a watershed using ArcGIS software at the Mubi South LGA was reported by [11, 12], with about 3.52 tons/ha/year of soil loss as being of high risk in the Mubi area.

Future research efforts need to be focused on finding soil losses and their economic implications of such as the commonly visible land sloughing along with gully features and river/stream banks, and also from sheet erosion features being the inadequately studied agenda, in order to complement existing research works.

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Conflict of interest

The author declares no conflict of interest.

Notes/thanks/other declarations

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Author details

Ijasini John Tekwa* and Abubakar Musa Kundiri
Faculty of Agriculture and Life Sciences, Department of Soil Science and Land Resources Management, Federal University Wukari, Wukari, Taraba State, Nigeria

*Address all correspondence to: jasini.john2@gmail.com

References

[1] Food and Agriculture Organization of the United Nations (FAO/UN) and Intergovernmental Technical Panel on Soils (ITPS). Status of the World's Soil Resources—Main Report. Rome; 2015. p. 649. Available from: http://www.fao.org/3/a-i5199e.pdf

[2] Web of Science. Available from: www.webofknowledge.com [Accessed: 20 March 2019]

[3] Lupia-Palmieri E. Erosion. In: Goudie AS, editor. Encyclopedia of Geomorphology. London, UK: Routledge; 2004. pp. 331-336

[4] Poesen J. Soil erosion in the Anthropocene: Research needs. Earth Surface Processes and Landforms. 2018;**43**(1):64-84

[5] Pennock DJ, Appleby PG. Site selection and sampling design. In: Zapata F, editor. Handbook for the Assessment of Soil Erosion and Sedimentation using Environmental Radionuclides. Amsterdam: Kluwer; 1st Edition. 2003. pp. 59-65

[6] Laflen JM, Watson DA, Franti TG. Ephemeral gully erosion. In: Proceeding of 4th Federal Agency Sedimentation Conference. Vol. 1. Interagency Advisory Committee on Water Data. Michigan, USA: Subcommittee on Sedimentation; 1986. pp. 3-29-3-37

[7] Castillo C, Gómez JA. A century of gully erosion research: Urgency, complexity and study approaches. Earth-Science Reviews. 2016; **160**:300-319

[8] Lal R. Soil degradation by erosion. In: Land Degradation and Development. Vol. 12. USA: John Wiley & Sons Ltd; 2001. pp. 519-539

[9] Ekwue EI, Tashiwa YI. Survey of gully erosion features in Mubi local government area of Adamawa state. Annals of Borno. 1992;**8/9**:181-191

[10] Tekwa IJ, Usman BH. Estimation of Soil loss by gully erosion in Mubi, Adamawa state, Nigeria. Journal of the Environment. 2006;**1**(1):35-43

[11] Thlakma SR, Iguisi EO, Odunze AC, Jeb DN. Prediction of soil erosion risk in Mubi South catchment area, Adamawa state, Nigeria. IOSR Journal of Environmental Science, Toxicology and Food Technology. 2018;**1**:40-47

[12] Thlakma SR, Iguisi EO, Odunze AC, Jeb DN. Estimation of soil erosion risk in Mubi South watershed, Adamawa state, Nigeria. Journal of Remote Sensing and GIS. 2018;**7**:1-10. DOI: 10.4172/2469.1000226

[13] Capra A, Mazzara LM, Scicolone B. Application of the ephemeral gully erosion model to predict ephemeral gully erosion in Sicily, Italy. Catena. 2004;**59**(2):1-13

[14] Foster GR. Understanding ephemeral gully erosion in National Research Council, Board on Agriculture. In: Soil conservation: Assessing the National Research Inventory. Vol. 2. Washington, DC: National Academy Press; 1986. pp. 90-118

[15] Kirk G. Adamawa: Past and present. London, Oxford: Oxford University Press; 1969

[16] Nwafor JC. Historical development 2: Nigeria since independence. In: Barbour KM et al., editors. Nigeria in Maps. London: Hodder & Stoughton; 1982. pp. 38-39

[17] Adebayo AA. Mubi Region: A Geographical Synthesis. 1st ed. Yola-Nigeria: Paraclete Publishers; 2004. pp. 32-38

[18] Reij C, Scoones I, Toulmin C. Sustaining the Soil: Indigenous Soil and Water Conservation in Africa. UK: Earthscan Publications Ltd; 1996. pp. 191-201

[19] Adebayo AA, Tukur AL. Adamawa State in Maps. 1st ed. Yola: Department of Geography F.U.T.; 1999. p. 92

[20] Tekwa IJ, Belel MD. Impacts of traditional Soil conservation practices in sustainable food production. Journal of Agriculture and Social Sciences. 2009; **5**:128-130. Available from: http://www.Fspublishers.org

[21] Food and Agricultural Organization/United Nation Economic, Scientific and Cultural Organization (FAO/UNESCO). FAO: Soil Map of the World. Paris; 1988

[22] Tekwa IJ, Usman BH, Ibrahim A. Estimation of soil nutrient loss by gully erosion and its economic implications in Mubi LGA, Nigeria. Journal of Environmental Sciences. 2006;**10**(2):1-12

[23] Tekwa IJ, Alhassan AB, Chiroma AM. Effect of selected erosion predictors on seasonal soil loss from ephemeral gully erosion features in Mubi area, Northeastern Nigeria. Scholarly Journal of Agricultural Sciences. 2013;**3**(10):401-409. Available from: http://www.scho larly-journals.com/SJAS

[24] Tekwa IJ, Laflen JM, Kundiri AM. Efficiency test of adapted EGEM model in predicting ephemeral gully erosion around Mubi, Northeast, Nigeria. International Soil and Water Conservation Journal. 2015;**3**(1):15-27. Available from: www.sciencedirect.com www.elsevier.com/locate/iswcr

[25] Yohanna E. Soils and vegetation. In: Adebayo AA, editor. Mubi Region: A Geographical Synthesis. Yola, Nigeria: Paraclete Publishers; 2004. pp. 38-48

[26] Ray HH. Cultural soil conservation techniques practiced in Mubi and environs. Journal of Sustainable Development in Agriculture and Environment. 2006;**2**:163-167

[27] Tekwa IJ, Sadiq AS. Sensitivity analysis of some environmental variables as EGEM inputs to predict ephemeral gully erosion in Mubi, semi-arid Northeast Nigeria. Asian American Environment and Agriculture Research Journal. 2014;**1**:1-12

[28] Tekwa IJ. Prediction of soil loss from ephemeral gully erosion on some soils of Mubi, Northeast Nigeria [thesis]. Nigeria: University of Maiduguri; 2014

[29] Tekwa IJ, Laflen JM, Yusuf Z. Estimation of monthly soil loss from ephemeral gully erosion features in Mubi, Semi-arid Northeastern Nigeria. International Research Journal—Agricultural Science Research Journal. 2014;**4**(3):51-58. Available from: http://www.resjournals.com/ARJ

[30] Sadiq AA, Tekwa IJ. Soil fertility and Management practices in Mubi region. 1st ed. Yola, Nigeria: Life-Line International Printing Press; 2018. pp. 3-5, 23-33, 65-70

[31] Sadiq AA, Abdullahi M, Ardo AU. An overview of soil fertility degradation in Mubi area, Northeastern part of Nigeria. International Journal of Scientific and Research Publications. 2019;**9**(2):692-697

[32] Tekwa IJ, Laflen JM, Kundiri AM, Alhassan AB. Evaluation of WEPP versus EGEM and empirical model efficiencies in predicting ephemeral gully erosion around Mubi area, Northeast Nigeria. International Soil and Water Conservation Research. 2021;**9**:11-29

[33] Foster GR. Modeling the soil erosion process. In: Haan CT, editor. Hydrologic

Modeling of Small Watershed. St. Joseph, MI: American Society of Agricultural Engineers; 1982. Monograph No. 5. pp. 297-379

[34] Gordon LM, Bennett SJ, Bingner RL, Theurer FD, Alonso CV. Simulating ephemeral gully erosion in AnnAGNPS. American Society of Agricultural and Biological Engineers. 2007;**50**(3): 857-866

[35] Casali JJ, Lopez J, Giraldez JV. Ephemeral gully erosion in Southern Navarra (Spain). Catena. 1999;**36**:56-84

[36] Thomas AW, Welch R. Measurement of ephemeral gully erosion. Transactions of the American Society of Agricultural Engineers. 1988;**31**:1723-1728

[37] Alonso CV, Bennett SJ, Stein OR. Predicting headcut erosion and migration in concentrated flows typical of upland areas. Water Resources Research. 2002;**38**(12):39-1-39-15

[38] Rose E. Traditional and modern strategies for soil and water conservation in the Sudano-Sahelian area of West Africa. In: Rimwanich S, editor. Land Conservation for Future Generations. Bangkok: Department of land development; 1992. pp. 913-924

[39] Pennock D. Soil Erosion: The Greatest Challenge for Sustainable Soil Management. Rome: Food and Agriculture Organization of the United Nations; 2019. pp. 1-23

[40] Watson DJ, Laflen JM, Franti TG. Ephemeral gully erosion estimator. In: Woodward DE, editor. Method to Predict Cropland Ephemeral Gully Erosion. Vol. 37. Michigan, USA: Catena; 1986. pp. 393-399

[41] Wolf B. Diagnostic Techniques for Improving Crop Production. USA: Haworth Press; 2003

[42] Trout TT, Garcia-castillas IG, Hart WE. Soil Water Engineering Field and Laboratory Manual. New Delhi, India: M/S Eurasia; 1987

[43] Walkley A, Black C. Chronic acid titration method for determining soil organic matter. Soil Science Society of America Journal. 1934;**37**:29

[44] Tekwa IJ, Bele MD, Alhassan AB. The effectives of indigenous soil conservation techniques on sustainable crop production. Australian Journal of Agricultural Engineering. 2010;**1**(3): 74-79

[45] Tekwa IJ, Kundiri AM, Chiroma AM. Efficiency test of modeled empirical equations in predicting soil loss from ephemeral gully erosion around Mubi, Northeast Nigeria. International Soil and Water Conservation Research. 2016;**4**:12-19

[46] Tekwa IJ, Ambali OY, Abubakar B. Economic analysis of soil and associated nutrient loss by gully erosion in Mubi area, Adamawa state, Nigeria. In: Proceedings of the 6th National Conference on Organic Agriculture; 21-24 November; 2010, Maiduguri, Nigeria: University Press; pp. 145-151