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Assessment of Sediment Yield Using the Erosion Potential Method (Epm) in Yola South North-Eastern Nigeria

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ABSTRACT
Sediment yield assessment using Erosion Potential Method (EPM) is considered as one of the most suitable and accepted empirical model applied in soil erosion prediction study in the world. In Yola South LGA, North-eastern part of Nigeria volume of sediment loss on some three farmlands namely Mbamba, Bole and Yode pate areas were assessed using EPM method. Results revealed that erosion coefficient was generally high in all the areas with Bole has the maximum followed by Yolde pate and Mbamba. The annual volume of detached was higher in 2024 than in 2023 with Bole area recorded the highest increased value of 58, 451.79 m^3/year, Mbamba 14, 902.61 m^3/year and Yolde pate having 7,420.15 m^3/year respectively. Similarly, real sediment production (m^3/year) was increased from 2023 to 2024 as Bole recorded maximum increase of 4,846.89 m^3/year then Mbamba 1,860.65 m^3/year and Yolde pate 163.00 m^3/year. These rapid sediments loss on the farmlands have affected crop production and yield which requires ardent effective control measures. In conclusion, EPM model gave satisfactory results in estimating the average soil erosion and annual average sediment productivity in the subsystem with an increase in sediment volume of soil from past to present defining the functionality and activeness of gully processes. It can be applied in Yola region and in the North-eastern part of the country.

Keywords:
Erosion,
Potential,
Sediment, Yola

INTRODUCTION

Soil erosion is one of the most important phenomena affecting land composition and settlement. Among all natural causes of soil erosion such as rainfall intensity, temperature and wind, the human activity; massive deforestation and intensive agriculture, including the latest climate changes are considered as very important factors, especially nowadays (Marko, *et al.*, 2022). Erosion is considered to be a natural phenomenon that leads to the displacement of parts of soil and rock due to water, wind, ice and gravity (Tadić and Šljuka, 2018). The degree of erosion is mainly determined by physical factors, for example, soil characteristics, the formation of rocks, topography and the amount of soil material that is available for transfer, which usually is proportional to the erosion ability of soil and land use (Amiri, 2010). Intensity of soil erosion phenomena is mainly dependent on natural factors and human influence. Progress of such phenomena can be defined as slow, high or even very high in the cases where the factors causing it are very consistent.

Landscape properties which support erosion, such as rainfall, wind and temperature changes, can be listed as natural factors (Marko, *et al.*, 2022). There are some empirical models to estimate the erosion and sediment production in watershed such as RUSLE (Revised Universal Soil Loss Equation), MUSLE (Modified Universal Soil Loss Equation) (Williams 1975) and EPM (Erosion Potential Method) [Gavrilovic 1988].

One of the most widely accepted and applied empirical model is the Erosion Potential Model (EPM), also known as the Gavrilovic method. The method takes into consideration surface geology and soil properties, topographic features, land use type and distribution and the catchment's degree of erosion. It has been widely implemented throughout the Balkans as well as in other countries, providing reliable results on qualifying soil erosion severity, as well as implementing torrent regulation and other erosion control measures (Gavrilovic, 1970b)

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The EPM method was initially proposed by Gavrilovic for former Yugoslavia conditions and then applied in many similar situations [Gavrilovic 1988]. The method aims to estimate the amount of sediment production and transportation by indicating the areas potentially threatened by the erosion phenomena. The methodology proposed by Gavrilovic represents a semi quantitative analysis that can be applied in arid and semi-arid areas to estimate erosion. In Yola South LGA, many research have been conducted on soil erosion and degradation by researchers such as Sadiq, *et al*., (2019a), Sadiq, *et al.*, (2019b) Sadiq and Faruk (2022), Sadiq (2020) using both quantitate methods of filed measurement, predictive model and normograhic method. However, no any research conducted in the area towards application of EPM method to quantify the volume of sediment loss and the rate of erosion menace in the area. It is on this basis that this paper saddled to assess sediment yield using the Erosion Potential Method (EPM) in Yola South North-eastern Nigeria. The study aimed to estimate sediment yield using EPM and to compare erosion intensity between 2023 and 2024 and assess spatial variation across three farmlands.

MATERIALS AND METHODS

Study Area

The study was conducted in Yola-South Local Government Area of Adamawa State, Nigeria, where three arable lands were selected namely Yolde pate, Mbamba and Bole. Yolde Pate area lies between Latitude 9º 11' - 9º 13' North of the Equator and Longitude 12º 26' -12º 28' East of the Greenwich Meridian with an elevation of 157-162 m while Mbamba area lies between Latitude 9º 10' - 9º 11' North of the Equator and Longitude 12º 31' -12º 33' East of the Greenwich Meridian having an elevation ranges from 166-196 m and Bole Latitude 9º 8' - 9º 10' North of the Equator and Longitude 12º 28' -12º 31' East of the Greenwich Meridian with an elevation ranges from 175-219 m respectively (Sadiq and Vahyala, 2023).

Gully site selection

At each of the selected arable lands gullies were randomly selected based on the gully distributions. At Yolde pate four (4) gullies were selected while at Mbamba three (3) gullies and Five (5) were selected at Bole accordingly.

Application of Erosion Potential Method (E.P.M)

The Erosion Potential Method (E.P.M) was employed in this study because it can be implemented in all regions due to its flexibility as far as it takes into consideration of six (slope, rainfall, temperature, land use and soil) factors (Elbadaoui *et al.,* 2023). The EPM was designed by Gavrilovic (Gavrilovic 1988) and used for the estimation of sediment production and transportation, as well as the erosion coefficient and its classification. The annual volume of detached soil W (Equation 1), the temperature coefficient *T* (Equation 2), the erosion coefficient *Z* (Equation 3), the actual sediment yield G**y** (Equation 4), and the sediment delivery ratio D**r** (Equation 5). Equations and detailed description of the parameters used for the Erosion Potential Method are given below:
The annual volume of detached soil W (m^3/year) has been determined using the following equation:

$$W = \mu \times S \times T \times h \times \sqrt{Z^3} \tag{1}$$

where: S – is the watershed area (km2);
T – is the temperature coefficient (-);
h – is the mean monthly precipitation (mm);
Z – is the erosion coefficient (-).

The temperature coefficient T (-) depends on the mean annual temperature t (°C), and has been calculated using the following equation:

$$T = \sqrt{\frac{t}{10}} + 0.1 \tag{2}$$

Where T- is the temperature coefficient
t- Mean annual temperature

The erosion coefficient Z (-) has been estimated using the following equation and the detailed information of Appendix 8.

$$Z = x \times y \times (\varphi + \sqrt{i_m}) \tag{3}$$

where: x (-) indicates the protective nature of the land cover and is a function of land use; y (-) describes soil erodibility and is a function of geological characteristics; φ (-) shows the observed active erosion processes; i_m (%) is the mean slope of the studied areas.

The total volume of sediments produced does not fully reach the outlet. A portion of it is redeposited in streams or other areas of the basin; therefore, it is important to calculate the real sediment production G (m^3/year) by the following equation:

$$G = W \times D_r \tag{4}$$

where: W**a** (m3/year) is the annual volume of detached soil, and Dr (-) is the sediment delivery ratio, which represent the quantity of sediments that reach the downstream.
The equation for Dr, is as follows:

$$Dr = \frac{H \times P}{0.25 \times (L + 10)} \tag{5}$$

where: H – is the mean height distance of the basin (or sub unit), (km);
P – is the perimeter of the basin (or sub unit), (km);
L – is the length of the basin (km).

The spatial distributions of precipitation and temperature, expressed as monthly rainfall (h, mm) and monthly temperature (t, °C), were measured on the field and calibrated with the one obtained from the meteorological stations of Upper Benue River Basin Development

Authority (UBRBDA), Yola Other variables used are obtained from Table 1 below adopted based on Zemljic (1971) and adopted after De Vente, and Poesen, (2005), Kogo *et al.,* (2020) and Marko *et al.,* (2022) classification.

Table 1. Descriptive variables used in the Erosion Potential Model (EPM)

Coefficient of land cover	***x***
Mixed and dense forest	0.05–0.20
Thin forest with grove	0.05–0.20
Coniferous forest with little grove, scarce bushes, bushy prairie	0.20–0.40
Damaged forest and bushes, pasture	0.40–0.60
Damaged pasture and cultivated land	0.60–0.80
Areas without vegetal cover	0.80–1.00
Coefficient of soil erodibility	***y***
Hard rock, erosion resistant	0.2–0.6
Rock with moderate erosion resistance	0.6–1.0
Weak rock, schistose, stabilized	1.0–1.3
Sediments, moraines, clay and other rock with little resistance	1.3–1.8
Fine sediments and soils without erosion resistance	1.8–2.0
Coefficient of type and extent of erosion	***ϕ***
Little erosion on catchment	0.1–0.2
Erosion in water ways on 20 to 50% of the catchment area	0.3–0.5
Erosion in rivers, gullies and alluvial deposits, karstic erosion	0.6–0.7
50 to 80% of catchment affected by surface erosion and land slides	0.8–0.9
Whole catchment affected by erosion	0.9–1.0

RESULTS AND DISCUSSION

Values of different parameters needed for the application of EPM in the study area for the 2023 and 2024.

Values of different parameters needed for the application of EPM in the study area for the 2023

Elbadaoui *et al.,* (2023) explained passionately that the EPM method takes into consideration of six factors based on surface geology and soil properties (coefficient/erodibility factor (Y)), topographic features (slope (J)), climatic factors (annual rainfall (H), and annual temperature (T)), land use type and distribution (coefficient/soil protection factor (x)), and the catchment's degree of erosion (erosion and stream network development coefficient (*φ*

Values of different parameters needed for the application of EPM in the study area for the year 2023 are presented in Table 2. The results revealed that surface area of Yolde pate gully units ranged from 94.05-2.17 m^2, with perimeter (P) of 0.02-0.42 km and 1.80 of soil erodibility coefficient (y). The erodibity factor signified the high susceptibility of the soil to erosion processes. In addition, land cover coefficient (*x*) was found to be 0.80 having mean slope varied from 8.42-2.95 %, mean elevation (H) ranged from 167.42-172.75 m and 0.65 coefficient type and extent of erosion (*φ*). The coefficient of land cover obtained may significantly controls the formation and expansion of gullies in the area. Similar results was found with Zeghmar *et al.,* (2022) vegetation cover of Kebir Rhumel Watershed, Northeast Algeria varied from 0.8–1.0 occupying 23.35% of the surface area. Furthermore, Bole area was characterized with surface area ranged from 7.24-34.56 m^2, with 0.05-0.66 km perimeter, 1.90 value of soil erodibility coefficient (*y*) and 0.70 coefficient of land cover (*x*). The mean slope of the gully units varied from 3.57-12.50 % having mean elevation (H) of 178.87-186.92 m and 0.80 coefficient type and extent of erosion (*φ)* respectively. The (φ) values of (0.80) described that 50–80% of catchment area may be susceptible to be affected by surface erosion and landslides as characterized by Zeghmar *et al.,* (2022). At Mbamba subsystem, the surface area ranged from 10.88-23.44 m^2, with perimeter of 0.34-0.86 km and 1.90 coefficient of soil erodibility (*y*). The land cover efficient (x), mean slope, elevation (H) and erosion coefficient were observed 0.65, 5.00-6.85 %, 187.34-191.20 m and 0.50 respectively. Generally, these parameters shows greater values that may facilitate more production of sediment yiled and rapid expansion of gullies. Similar report of Marko *et al.*, (2022) explained that he parameter which mostly affects the value of the eroded sediment W, is the coefficient of soil erodibility y, where the Panariti watershed with the largest amount of eroded material has the highest value, equal to 1.5. Thus, for this study is 1.90 respectively.

Values of different parameters needed for the application of EPM in the study area for the 2024

Values of different parameters needed for the application of EPM in the study area for the year 2024 are presented in Table 3. Yolde pate subsystem has surface area varied from 10.69-85.25 m^2, 0.03-0.44 km perimeter, 1.80 of soil erodibility coefficient (y) and 0.80 land cover coefficient (*x*) accordingly. This high value of (0.80) land cover coefficient might contribute significantly to the gully formation and development in the area. According to the sensitive analyses performed by Dragicevic *et al.*, (2017), another parameter that affects the amount of eroded sediment W, is the land cover coefficient *x*. This findings is in conformity with results of Marko *et al.*, (2022) Panariti watershed has the highest value 0.8 of land cover coefficient as reflected in the results of the eroded material. The mean slope ranged from 3.33-8.42 %, having mean elevation of 167.42-172.75 m and 0.65 erosion coefficient (*φ*). At Bole area, the surface area varied from 158.02-29.05 m^2 with 0.06-0.68 (km) of perimeter and 1.90 soil erodibility coefficient (y). The coefficient of land cover was found to be 0.70 characterized with mean slope and elevation values ranged from 3.75-6.09 %, 181.80-186.92 m while 0.8 as erosion extent coefficient(*φ*). Mbamba gully units has observed surface area varied from 46.99-56.44 m^2, 0.38-0.92 km perimeter, 1.90 soil erodibility coefficient (y) and 0.65 land cover coefficient accordingly. The mean slope and elevation were ranged from 5.00-6.85 % and 187.34-191.20 m, while coefficient of type and extent of erosion (*φ*) was observed to be 0.5 accordingly. The gradual increased in slope and elevation across the area may also contributes to the presence of gully processes in the area.

Table 2. Values of different parameters needed for the application of EPM in the study area for the 2023

Name of watershed	**Gully Unit**	**SURFACE (S)**		**Perimeter (P) (km)**	**Coefficient of soil erodibility (*y*)**	**Land cover coefficient (*x*)**	**Mean slope im (%)**	**Mean elevation (*H*) (m a.s.l) ha km2**	**Coefficient of type and extent of erosion (ϕ)**
		ha	m^2						
	YP 001	0.09	94.05	0.36	1.80	0.80	8.42	167.42	0.65
Yolde pate	**YP 002**	0.03	37.36	0.42	1.80	0.80	2.95	170.63	0.65
	YP 003	0.00	7.74	0.07	1.80	0.80	6.25	172.75	0.65
	YP 004	0.00	2.17	0.02	1.80	0.80	3.33	172.33	0.65
	BL 001	0.03	34.56	0.07	1.9	0.70	12.50	178.87	0.80
BOLE	**BL 002**	0.03	39.42	0.66	1.9	0.70	6.09	184.62	0.80
	BL 003	0.04	49.12	0.42	1.9	0.70	3.57	182.52	0.80
	BL 004	0.00	7.24	0.05	1.9	0.70	4.00	181.80	0.80
	BL 005	0.00	7.24	0.28	1.9	0.70	5.00	186.92	0.80
	MB 001	0.02	23.44	0.86	1.9	0.65	5.00	187.34	0.50
MBAMBA	**MB 002**	0.02	20.56	0.34	1.9	0.65	5.26	189.47	0.50
	MB 003	0.01	10.88	0.64	1.9	0.65	6.85	191.20	0.50

Table **3**. Values of different parameters needed for the application of EPM in the study area for the 2024

Name of watershed	**Gully Unit**	**SURFACE (S)**		**Perimeter (P) (km)**	**Coefficient of soil erodibility (*y*)**	**Land cover coefficient (*x*)**	**Mean slope in (%)**	**Mean elevation (*H)* (m a.s.l) ha (km^2)**	**Coefficient of type and extent of erosion** (ϕ)
		(ha)	(m^2)						
	YP 001	0.08	85.25	0.38	1.80	0.80	8.42	167.42	0.65
Yolde pate	**YP 002**	0.14	141.6	0.44	1.80	0.80	2.95	170.63	0.65
	YP 003	0.03	31.3	0.08	1.80	0.80	6.25	172.75	0.65
	YP 004	0.01	10.69	0.03	1.80	0.80	3.33	172.33	0.65
	BL 001	0.11	117.47	0.08	1.90	0.70	12.50	178.87	0.80
Bole	**BL 002**	0.15	158.02	0.68	1.90	0.70	6.09	184.62	0.80
	BL 003	0.20	204.77	0.44	1.90	0.70	3.57	182.52	0.80
	BL 004	0.02	29.05	0.06	1.90	0.70	4.00	181.80	0.80
	BL 005	0.05	56.53	0.30	1.90	0.70	5.00	186.92	0.80
	MB 001	0.05	56.44	0.92	1.90	0.65	5.00	187.34	0.50
Mbamba	**MB 002**	0.09	91.04	0.38	1.90	0.65	5.26	189.47	0.50
	MB 003	0.04	46.99	0.72	1.90	0.65	6.85	191.20	0.50

Results on the Erosion Potential Model (EPM) of study areas for the year 2023 were shown in Table 4. At Yolde pate area having four (4) identified gully units, results revealed that mean temperature coefficient (T^o) of all the gully units was 0.63^{o}C considering the homogeneity of weather condition of the area operating in small climatic scale. In addition, the erosion coefficient (Z) of the gully units were 5.11, 3.40, 4.53 and 3.56 accordingly. These values of erosion coefficient (Z) of the gully units was rated as excessive erosion (Erosion Category I) based on Gavrilovic classifications (1988). It indicates the probability and intensity of erosion, and it has the ability to track the severity of erosion in the watershed. It depends on four factors that control erosion development (soil erodibility, soil protection, topography, and existing erosion indicator) as earlier reported by Ahmed *et al.* (2019); Efthimiou *et al*, (2016) and Kostadinov *et al*, (2008) accordingly. Furthermore, annual volume of detached soil (W) was highest at gully unit 1 while the lowest value was observed at gully unit 4 with the values ranged from 20, 727.23 -395.61 m^3/yr. This could be attributed to large size of gully unit 1 and small size of unit 4. Thus, volume of sediment loss is a product of increase in width, length and depth of the gully as also reported by Oparaku and Ogbeh (2018) in the north central part of Nigeria. In addition, erosion rate (E), and real sediment production (G) were also found to be highest at gully unit 1 and lowest at unit 4. The sediment delivery ratio (D_r) was greater at gully unit 2 (0.10), followed by unit 1 (0.09) and least value of 0.02 was obtained at unit 4 of the gully. These variations can be seen through sediment load deposited as unit 1 and 2 has high values. Hence, Dragicevic *et al.*, (2017) conducted a sensitivity analysis of the EPM method and classified the sediment deliv-ery ratio *Dr* as a very high sensitive parameter that affects only the sediment yield *G*. As it can be seen from the data used for the EPM evaluation, the first two unit 1 and 2 that have transported almost the entire amount of eroded material, are precisely the ones with the highest sediment production (G) and with the most pronounced increased in slopes, in contrast, the gully that has transported the smallest amount of eroded material is unit 4 which has the smallest *Dr*, (0.02)

Table 4. Results of the EPM method for all watersheds of Vithkuqi area for the 2023

Location	GULLY UNIT	*T* (°C)	*Z* (--)	*W* (m3/yr)	*E* (m3/ha/yr)	D_r (--)	*G* (m3/yr)
	YP 001	0.63	5.11	20727.23	12.29	0.09	1865.45
Yolde pate	YP 002	0.63	3.40	6715.51	3.98	0.10	671.55
	YP 003	0.63	4.53	1606.05	0.95	0.04	64.24
	YP 004	0.63	3.56	395.61	0.23	0.02	7.912
	BL 001	0.63	5.76	6718.89	0.50	0.03	201.56
Bole	BL 002	0.63	3.27	5744.24	0.43	0.12	689.30
	BL 003	0.63	3.57	7480.49	0.56	0.10	748.04
	BL 004	0.63	3.72	1126.03	0.08	0.03	33.78
	BL 005	0.63	4.03	1172.95	0.08	0.08	93.83
	MB 001	0.63	3.36	4218.71	0.38	0.14	590.61
Mbamba	MB 002	0.63	3.43	3740.81	0.34	0.09	336.67
	MB 003	0.63	3.83	2086.57	0.18	0.12	250.38

Keys: T: Mean Annual Temperature coefficient (°C) , **Z**: Erosion coefficient (-), **W**: Annual Volume of Detached Soil (m^3/year), **E**: Specific eroded sediments (m^3/ha/year), $\mathbf{D_r}$: Sediment Delivery Ratio (--), **G**: Real Sediment Production (m^3/year)

Furthermore, at Bole area five gully units were identified. The area has Tº 0.63 ºC with variations in Z values where unit 1 of the gully has higher value of 5.76 followed by unit 5 with 4.0.30. This value of Z (> 1.00) is characterized as very high intensity (category I) based on Gavrilovic, (1988) which implies high activity of the expansion and development of the gully units than the other units. The W, E and G values were higher at gully unit 3. This could be attributed to accelerated increase in morphometric features (L, W, D and CSA) coupled with gradual increase of hydro-morphometric processes (SADG and RSc) of the gully units. DragičevićMCE,*et al.,* (2016) have reported that Ristić *et al.,* (2012) analyzed the effect of the change of hydrological conditions by restoring the catchment upon erosion and flood processes to define effective erosion mitigation and protection measures and found a decreased in predicted volume of detached soil, and in erosion sediment transport via the river network. Similar results was reported by (Marko *et al.,* 2023).

Meanwhile, gully unit 4 was found to have lowest values of W, E, D_r and G with corresponding values of 1,126.03 m^3/yr, 0.08 m^3/ha/yr, 0.03 and 33.78 m^3/yr respectively. This might be connected to small to medium size of the gully unit due to lithologic effects which reduces the rate of formation and development of the gully. Lithology and the physical characteristics of rock, plays a significant role in the erosion of water (Simonneaux *et al.,* 2015). The type of rock can also influence the rate at which erosion occurs. Elbadaoui *et al.,* (2023) explained that sandstone is more porous and, therefore, more susceptible to erosion by water than a denser rock like basalt. Understanding the lithology of an area can help predict the erosion patterns and the potential impacts on the surrounding landscape.

Similar Tº of 0.63 ºC was recorded at Mbamba area where Z value of 3.36, 3.43 and 3.83 were identified at gully unit 1, 2 and 3 accordingly. It was revealed that gully unit 1 of Mbamba area has the highest values of W, E, D_r and G followed by gully unit 2 and gully unit 3 recorded the least values of 2,086.57 m^3/yr, 0.18 m^3/ha/yr, 0.12 and 250.38 m^3/yr respectively. The low values obtained at gully unit 3 could be connected to presence of more vegetation cover with about 80.00 % frequency than the other two units which will intercepts and slows down the flow of water, reducing the energy of the flow and decreasing the likelihood of erosion. Thus, land use/cover, or the type and density of vegetation and other surfaces on the land, can have a significant impact on water erosion (Molina, *et al.,* 2007 and Aslam, *et al.,* 2021). Vegetation can help stabilize the soil by rooting into the ground and holding it in place. On the other hand, areas with bare soil or impervious surfaces, such as asphalt or concrete, are more prone to erosion because the water flows more quickly and with greater energy over these surfaces as was reported also by Elbadaoui *et al*., (2023) accordingly.

Empirical analysis of erosion potential model (EPM) of study area for the year 2024

Results on the Erosion Potential Model (EPM) of study areas for the year 2024 were shown in Table 5. Results revealed that at Yolde Pate area T^o of 0.62 ºC was recorded while Z value was higher (5.11) at gully unit 1 then followed by unit 3 (4.53) and the lowest Z value was observed at unit 4 gully in the area. Thus, all the Z values are > 1.5 classified as high erosion intensity based on Gavrilovic classifications (1988). In addition, gully unit 2 was found to have high W, E and G W with corresponding values of 17,801.40 m^3/yr, 10.55 m^3/ha/yr and 1,424.11 m^3/yr respectively. In contrast, unit 1 gully shows highest value of D_r (0.09) followed by unit 2 (0.08) and unit 3 (0.03).It could be noted that gully unit 4 has the lowest values due to its small size (10.69 m^2) and the slope level (3.33 %).Thus, gully unit 4 is at formation stage having smaller morphometric features of depth, width and low sediment delivery. This is because size and slope of gully site can have a significant impact on water erosion, as steeper slopes are more prone to erosion than moderate slopes because the water flows more quickly and with greater energy over steep slopes. Therefore, understanding the relationship between slope and erosion is important for predicting erosion patterns and the potential impacts on the surrounding landscape (Wei *et al.,* 2009).

Table 5. Results of the EPM method of all the selected areas for the 2024

Location	GULLY UNIT	*T* (°C)	*Z* (--)	*W* (m3/yr)	*E* (m3/ha/yr)	D_r (--)	*G* (m3/yr)
	YP 001	0.62	5.11	13163.64	7.80	0.09	1184.72
Yolde pate	YP 002	0.62	3.40	17801.40	10.55	0.08	1424.11
	YP 003	0.62	4.53	4533.70	2.68	0.03	136.01
	YP 004	0.62	3.56	1365.81	0.81	0.02	27.31
	BL 001	0.62	5.76	20309.47	1.52	0.03	609.28
BOLE	BL 002	0.62	3.27	20490.14	1.54	0.12	2458.81
	BL 003	0.62	3.57	27732.21	2.08	0.10	2773.22
	BL 004	0.62	3.72	4017.98	0.30	0.03	120.53
	BL 005	0.62	4.03	8144.59	0.61	0.08	651.56
	MB 001	0.62	3.36	7092.07	0.64	0.15	1063.81
MBAMBA	MB 002	0.62	3.43	11564.83	1.05	0.10	1156.48
	MB 003	0.62	3.83	6291.80	0.57	0.13	817.93

Keys: T: Mean Annual Temperature coefficient (°C) , **Z**: Erosion coefficient (-), **W**: Annual Volume of Detached Soil (m^3/year), **E**: Specific eroded sediments (m^3/ha/year), $\mathbf{D_r}$: Sediment Delivery Ratio (**--**), **G**: Real Sediment Production (m^3/year)

Moreover, Bole area shows that the area has similar T^o of 0.62 ºC as that of Yolde pate with unit 1 of the gully having high Z (5.76) followed by 3.72 at unit 3 and lowest value of 3.27 was observed at unit 2. Gully unit 3 was revealed to have higher values of W (27,732.21 m^3/yr), E (2.08 m^3/ha/yr) and G (2,773.22 m^3/yr).This might be accelerated due to intensive farming activities (ecessive deep tillage, deforestation), and also topographic factors and soil erodibility indices of the area. Sediment transportation and deposition processes are primarily influenced by four main factors: topography, land use, climate, and soil erodibility and these processes can be aggravated by human activities such as agricultural practices and deforestation as was reported earlir by Sadiq *et al.,* (2020) and Sadiq and Faruk, (2020) accordingly. In addition, gully unit 2 has the second highest values while gully unit 4 has the lowest values of W (4,017.98 m^3/yr), E (0.30 m^3/ha/yr), D_r (0.03) and G (120.53 m^3/yr).

Moreover, similar T^o of 0.62 ^{o}C was recorded at Mbamba area where gully unit 2 was identified with Z value of 3.43 and high values of W, E and G (11, 564.83 m^3/yr, 1.05 m^3/ha/yr and 1,156.48 m^3/yr) then followed by unit 1 gully with corresponding values of 7,092.07 m^3/yr, 0.64 m^3/ha/yr and 1, 063.81 m^3/yr) while the lowest values (6, 291.80 m^3/yr, 0.57 m^3/ha/yr and 817.93 m^3/yr) was recognized at gully unit 3. However, D_r was high at unit 1 (0.15), then followed unit 2 (0.13) and unit 3 (0.10) accordingly. This might be attributed to geomorphic processes of the area with presence of more regolithic materials (bedrocks, pans pebbles) at unit 3 despite its high elevation and slope level. The elevation is a factor that is frequently used in research on flood and erosion susceptibility because it is a predisposing parameter that is influenced by various geologic and geomorphological processes (Xian, *et al.,* 2019). It could be noted that also the unit 3 gully has more vegetation (80 %) which may also reduce the rate of development and volume of sediment loss as was also reported by Aslam, *et al.,* (2021).

Empirical variation of erosion potential model (EPM) of the study areas for the year 2023 and 2024

Results on the empirical variation of Erosion Potential Model (EPM) of the Study Areas for the year 2023 and 2024 are presented on Table 6. It was revealed that Yolde pate has high T^o (°C) in 2023 than in 2024 with about 0.04 °C with the same Z value of 16.60. In contrast, W was higher in 2024 than in 2023 with a difference of values 7,420.15 m^3/yr. Similarly, the E and G were found higher in 2024 with total values of 21.84 m^3/ha/yr and 2,772.15 m^3/yr having difference of 4.39 m^3/ha/yr and 163.00 m^3/yr. This is mostly due to expansion of areas affected by medium to excessive erosion processes that are mostly oriented in the area. However, despite the high values of E and G in 2024, the sediment delivery ratio was low (0.22) than that of 2023 (0.25) having difference of 0.03 accordingly. This findings disagreed with the conclusion drawn by Gavrilovic, *et al.,* (2008) who stated that EPM estimation reveals that the annual sediment discharge in the Velika Morava catchments was reduced to a half as compared with the previous period. These increasing rate of gully development and rate of soil loss could be attributed to combines contributing driven factors physical state of the soil of high erodibility, topography, Vegetation cover, land use type and geomorphology of the area. Thus, the geomorphic process of the area is described as fluvial with fluvial slope processes having uniform fluvial erosion. Xian, *et al.,* (2019) make it clearly that critical predisposing parameter that is influenced erosion susceptibility and development are geologic and geomorphological processes. This approach allows for a good estimate of susceptibility to erosion in a specific area (Elbadaoui *et al.,* 2023).

Moreover, at Bole area the value of T^o was found to be higher (3.15 °C) in 2023 than in 2024 (3.10 °C). Meanwhile, Z was similar in both years with value of 20.35. The W, E and G were higher in the year 2024 than in 2023 with differences of 58,451.79 m^3/yr, 4.40 m^3/ha/yr and 4,846.89 m^3/yr respectively. It could be noted that the Dr was same (0.36) in both the years of study in the area. Zeghmar *et al.,* (2022) also used EPM method at the Kebir Rhumel Watershed, Northeast Algeria and found out that the average annual soil erosion was 17.92 Mg/ha/yr, maximum and minimum losses are 190.50 Mg/ha/yr and 0.21 Mg/ha/yr They concluded by saying that EPM model shows satisfactory results compared to some studies done in the basin, where the obtained results can be used for more appropriate management of land and water resources, sustainable planning, and environmental protection.

Furthermore, at Mbamba area except T^o having high value (1.89 °C) in 2023 than 2024 (1.86 °C) and Z having same value of 10.62, all other variables were higher in 2024 than in the year 2023 with a difference of 14,902.61 m^3/yr of W, 1.36 m^3/ha/yr of E, 0.03 of Dr and 1,860.56 m^3/yr of G respectively. This result of increasing of the annual volume of the detached soil (W) was not conformed to the findings of Dragičević, (2018) who reported that the average change in values throughout the catchment is found to decrease by 3% from the past to the present in the Dubracina River catchment area in Croatia using EPM. In the past, the average value of the detached soil in the catchment was 1564 m3/km2/year, and in the present, the value is 1512 m^3/km^2/year According to the study by Marouf and Remini (2011), the annual transport of sediment yield at the El Ancer hydrometric station is 850 Mg/km^2/yr, while Grarem station recorded an annual sediment yield of 741.12 Mg/km^2/yr. The study conducted by Tamrabet *et al.,* (2019) over a period of 30 years in the Dehamecha Watershed recorded an annual sediment yield of 1030.05 Mg·km^{2}·/yr.

Table 6. Empirical Variation of Erosion Potential Model (EPM) of the Study Areas for the year 2023 and 2024

Location	Years	T° (°C)	Z (--)	W (m^3/yr)	E (m^3/ha/yr)	Dr (--)	G (m^3/yr)
	2023	2.52	16.60	29,444.40	17.45	0.25	2,609.15
Yolde pate	2024	2.48	16.60	36,864.55	21.84	0.22	2,772.15
	Difference	**0.04**	**0.00**	**7,420.15**	**4.39**	**0.03**	**163.00**
	2023	3.15	20.35	22,242.60	1.65	0.36	1,766.51
Bole	2024	3.10	20.35	80,694.39	6.05	0.36	6,613.40
	Difference	**0.05**	**0.00**	**58,451.79**	**4.40**	**0.00**	**4,846.89**
	2023	1.89	10.62	10,046.09	0.90	0.35	1,177.66
Mbamba	2024	1.86	10.62	24,948.70	2.26	0.38	3,038.22
	Difference	**0.03**	**0.00**	**14,902.61**	**1.36**	**0.03**	**1,860.56**

Keys: T: Mean Annual Temperature coefficient (°C) , **Z**: Erosion coefficient (-), **W**: Annual Volume of Detached Soil (m^3/year), **E**: Specific eroded sediments (m^3/ha/year), $\mathbf{D_r}$: Sediment Delivery Ratio (--), **G**: Real Sediment Production (m^3/year)

CONCLUSION

The EPM model gave satisfactory results in estimating the average soil erosion and annual average sediment productivity in the areas with an increase in sediment volume of soil from 2023 to 2024 defining the functionality and activeness of gully processes. The increase in sediment loss leads to decline in soil nutrients which inconsequence affecting sustainable food production. It is therefore recommended to effective land management and conservation techniques should be adopted to prevent future reoccurrences of the menace. In addition, future research geared towards the use of GIS-based techniques should be employ in the area. EPM is suitable in Yola region and other area of the North-eastern part of the country.

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