EXTENT AND VOLUME OF SOIL LOSS USING RUSLE MODEL IN AGULU – NANKA – OKO AND EKWULOBIA GULLY EROSION COMPLEXES OF ANAMBRA STATE, SOUTH EASTERN NIGERIA

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ABSTRACT

Over 65% of the soil on earth is said to have displayed degradation phenomenon as a result of soil erosion, salinity and desertification (Abegunde, *et al*., 2006). Anambra State is known to be under severe erosion problems with the Agulu-Nanka-Oko and Ekwulobia gully as the epicenter of gully development in the state. The study attempts to utilize the revised version of the Universal Soil Loss Equation (RUSLE), combined with remote sensing and GIS technology to estimate the extent of soil loss so that planning of management techniques can be suggested. GIS data layers including, rainfall erosivity (R), soil erodability (K), slope length and steepness (LS), cover management (C) and conservation practice (P) factors were computed to determine their effects on average annual soil loss in the study area. The classified soil loss map shows that 4.92% of the total area has soil loss between 0.432 – 12.473 (ton/ha/yr) followed by 49.93% of the total area with rate of soil erosion between 12.474 – 30.534 (ton/ha/yr). Next is 16.88% of the total area with average annual soil loss between 30.535 – 53.412 (ton/ha/yr). Other soil loss categories cover 27.33% and 0.94% of total area with average annual soil loss between 53.413 – 88.330 (ton/ha/yr) and between 88.881 – 153. 953 respectively. The total area of soil loss is 599.17 (Km^2). It is therefore recommended that Sustainable solutions which increase vegetation cover and curtail soil erosion should be integrated in the recovery plan for the study area. To reduce soil loss, intervention should be focused on slope length and steepness factor (*LS)*, Crop Management Factor *(C)* and Support Practice (*P)* factors as the Soil Erodibility (*K)* and Rainfall Erosivity (*R)* factors cannot be changed. It is necessary to educate and empower the communities of the need for vegetation, soil and water conservation.

Keywords: Soil erosion, soil loss, RUSLE, Remote sensing and GIS

Introduction

The highest concentration of severe gully erosion in Nigeria is found in five Eastern states of Anambra, Enugu, Abia, Imo, and Akwa Ibom. Anambra is famous with its Agulu-Nanka-Oko and Ekwulobia gullies. Gullies of about 120m depth and 2km width have been recorded in this area (Obi *et al.,* 2017). The Agulu – Nanka – Oko and Ekwulobia gully erosion complex is selected for this study due to its devastating nature that has attracted wide attention over the years. The gully complex has a large concentration of gully systems within the same drainage basin and geologic formation and accounts for large loss of agricultural land in southeastern Nigeria. (Osadebe, *et al.,* 2014)

The Agulu-Nanka-Oko and Ekwulobia gullies are so terrifying that it has been declared a national disaster. This has prompted the researcher to develop interest in this particular site with the aim of making an input as part of contributing to restoration and management strategies. It will also serve as a reference point for interest groups for further works on the subject.

A considerable number of researches on erosion have been conducted in the study area. Ajaero *et al.,* (2011) examined the impact of Agulu-Nanka gully erosion menace on the population of the area with the use of questionnaire, findings showed that the menace has destroyed houses and land of the people. Okengwo, *et al.,* (2015) evaluated the geologic conditions and geotechnical parameters that influence the formation of gullies at Ekwulobia, Oko and Nanka towns of southeastern Nigeria. Field geological study of the area revealed that the erosion hazard/problem has remained active over the years, defying control measures put in place by government, communities and individuals. Osadebe, *et al.,* (2014) evaluated the stability of gully wall profiles in parts of Anambra State. The result shows that the observed profiles are consistently steeper (especially at the bottom) than the predicted profiles. Ndubuisi *et al.,* (2016) assessed the socio-economic problems caused by soil erosion in Awka, Anambra state with the use of secondary data. Results showed that Socio-economic problems caused by soil erosion include removal of nutrients

from soil leading to low farm produce, destruction of farms resulting in collapse of buildings and homeless inhabitants.

Even though there seem to be much research regarding the erosion hazard in the study area, little information is available in the area of levels of erosion hazard and the extent and estimate of soil loss in the study area. Every year new erosion sites develop while the existing ones increase. Hence, there is need to assess the current situation of the gully hazard in the study area.

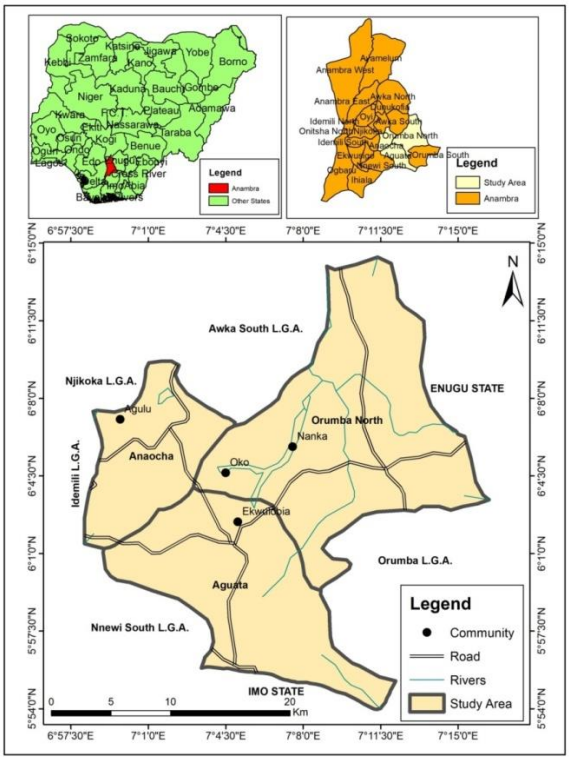
The study attempts to utilize the revised version of the Universal Soil Loss Equation (RUSLE), combined with remote sensing and GIS technology to:

Estimate the extent of soil loss so that planning of management techniques can be suggested.

Background of the Study Area

The study area, (Agulu – Nanka – Oko and Ekwulobia gully complex) is located in the Southeastern part of Anambra state. It is situated between latitudes 6° 10′ and 6° 05′ north of the Equator and longitudes 7° 05′ and 7°10′ east of the Greenwich meridian, covering an area of about 1709 km^2 within the Anambra Basin.

Agulu town is situated within Anaocha Local Government Area; Nanka and Oko towns are located in Orumba North Local Government Area while Ekwulobia is within Aguata Local Government Area.



Source: Google Map (2021)

Figure 1: Study area (Anambra State showing Agulu, Nanka, Oko and Ekwulobia Communities)

The study area is situated within the sub-equatorial south climatic region characterized by uniformly high temperatures and a seasonal distribution of precipitation and high relative humidity. The climate is of humid tropical climatic condition. (Okoro e*t al.,* 2010).

The geologic formation of the study area is the Eocene Nanka unconsolidated or poorly consolidated sands. The sand is poorly sorted, cross bedded and medium to coarse grained as well as porous making it easily erodible. The highland region is a low asymmetrical ridge or cuesta in the northern portion of the Awka Orlu Uplands, which trend roughly southeast to North West, in line with the geological formations that underlie it (Okoro *et al.,* 2010). The Agulu Nanka, Oko and Ekwulobia soils are typified by the coastal plain sands characteristics and are highly susceptible to erosion. The types of vegetation found include fresh water swamp forest, dominated grass species and lowland rain forest.

Materials and methods

Landsat TM imageries of 1985 and 1995 with 30m spatial resolution; Landsat (ETM +) and Landsat 8 imagery for 2005 and 2020 respectively with spatial resolution of 30m were used for the study. Annual rainfall distribution data was obtained from stations bordering the study area. Existing vegetation/ Land use, geology, rainfall, relief, drainage, road and soil maps printed and published by ministry of lands, Survey and Urban planning, Awka, Anambra State from 1985 to 2020 were obtained. The elevation data (DEM) and contour map of Anambra state was derived from Advanced Space borne thermal Emission and Reflection (ASTER). Relevant data was also obtained from archival sources. The study area was downloaded and images exported to (Arc GIS 10.1). Images were geo referenced and subsequently the affected areas were digitized and calculated from the attribute table using the field geometry in metres. Features were processed from DEM image and subsequent analysis.

Data were analyzed through the use of Digital image-processing software: (Erdas Imagine 9.2) and GIS software: (Arc GIS 10.1) were used in processing and analyzing images as well as other geographic data acquired for this research. The revised universal soil loss equation (RUSLE) model is described by (Bonilla *et al.*, 2010; Kouli *et al*., 2008; Renard *et al*., 1991) as

$A = R \times K \times LS \times C \times P$ ……. (1)

Where: *A* is the soil loss (t/ha/yr); *R* the rainfall run-off erosivity factor (MJ mm ha/h/yr); *K* the soil erodibility factor (t h $MJ^{-1}mm^{-1}$); *LS* the slope length and steepness factor; *C* the vegetative cover factor (dimensionless); and *P* the conservation practice factor are dimensionless.

Rainfall Runoff Erosivity Factor (R)

The rainfall erosivity index *R* measured the potential ability of rain to cause soil erosion. High *R* values mean high rainfall intensity with a higher potency of dislodging soils; hence the expected soil erosion from the land surface will be high. Low *R* value implies low rainfall intensity and run-off, consequently erosion and sediment yield will be low. Not all rainfall events caused erosion. An erosive event is a rainfall event with more than 12.50 mm of total rainfall accumulation or with at least 6 mm of rainfall accumulation in 15 minutes (Petkovšek and Mikoš, 2004; USDA-ARS, 2008). Erosive rainfall events are called effective events and were denoted by *Re* in the study. In this study the rainfall erosivity index was calculated using effective events *(Re)* to derive *R* of equation (1). The *Re* factor map was derived from monthly $EI30^{1}$values using Shamshad *et al.*,(2008) regression equation (2) based on the modified Fournier index ($MFIe^{2}$):

$R = 227 MFIe^{0.548}$..... (2).

The modified Fournier index (*MFIe*) was estimated using total effective monthly erosive rainfall amounts (Smithen and Schulze, 1982):

$MFIe = pei^2/p_t$…… (3)

Where: *Pei*, represents effective monthly precipitation of month i, *Pt*, annual rainfall amount (mm). Erosive event was fixed at ≥ 12.5 mm of total rainfall accumulation within 24 hours (Petkovšek and Mikoš, 2004; USDA-ARS, 2008). The rationale for the choice of these equations is that they were developed in humid tropics such as West Africa and Malaysia which are characterized by similar rainfall conditions (intensity and amounts) as the study area. The mean annual erosivity map was then produced in ArcGIS for the erosivity index using effective rainfall data (i.e, *Re*).

Soil Erodibility Factor (K)

K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and run-off (Stone and Hilborn, 2000). When the *K* value is high, it implies deterioration in the physical properties of the soil such as low organic matter, coarse soil texture, coarse granular structure etc.; thus the soil is more prone to erosion. Therefore, the higher the *K* value, the more the soil is prone to erosion. When *K* values are low, it implies an enhancement in the physical properties of the soil such as increase in organic matter, fine soil texture, fine granular structure etc., which increases the cohesiveness of soil particles to resist erosion. This will result in low soil erosion. The FAO *K* factor values of soils in the study area were used to produce a raster layer of *K* factor map.

Table 1: Soil erodibility K-Factor values of the soil type in the study area

Soil type	K-Factor
Fluvisols	0.0646
Acrisols	0.0009
Nitisols	0.004
Lixisols	0.000

Source: FAO (1987)

Slope length and steepness factor (LS)

Slope length and steepness factor (*LS*) measure the effects of topography on soil erosion and the steeper and longer the slope, the higher the risk for erosion, and vice versa. The *LS* factor map for

a cell area was computed with equation (4) below in ArcGIS using upslope contributing area and slope gradient computed from the digital elevation model (DEM) of the study area. The DEM was generated from a 1:50,000 scale contour map. The contours were interpolated at 30 m pixel resolution using the 'topo to raster' command in ArcGIS to create a hydrologically correct DEM (e.g., Jain *et al*. 2010; Jain and Das, 2010). The generated DEM was further reconditioned to a depressionless DEM using the 'fill sink' command to determine the maximum downhill slope and the flow direction (e.g., Jain *et al.*, 2010; Jain and Das, 2010). The slope (*S*) factor and flow accumulation were then derived from the depressionless DEM and then an *LS* map was generated based on equation (4) in ArcGIS using the raster calculator module (Jain *et al*., 2010; Jain and Das, 2010; Engel, 2003):

$$LS = \left(\frac{As}{22.13}\right)^{0.4} . \left(\frac{\sin \emptyset}{0.0896}\right)^{1.3} \ldots\ldots\ldots \quad (4)$$

Where As is the upslope contributing area for overland grid per unit width normal to flow direction and $\emptyset$ is the slope angle in degrees. On the basis of total length of erosion channel of a 1:50,000 topographic map of the study area and the study area, a channel initiation threshold value of 0.65km^2 was extracted and used to define channel cells (Jain and Das, 2010).

Cover Management Factor (C)

The cover management factor *C* is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. High *C* factor implies low vegetation cover in the area, and when *C* values are low, it implies good vegetative cover and erosion will be low. The cover management factor map for *C* was determined using a classified land cover and land use map of Landsat 8 OLI 2020 (e.g., Jain *et al.*, 2010; Jain and Das, 2010; Jain and Kothyari, 2000). The image was classified with reference to topographical maps, Google Earth and training areas of sites taken in the field using a global positioning system (GPS). Five land cover types were classified using the maximum likelihood classifier module in Idrisi (Table 2). *C* factor values suggested by Wischmeier and Smith (1978) were assigned to cells of the respective classes as shown in Table 2.

Table 2: Land Cover Types and Cover Management (C) factor values

Land cover	C-Factor
Built-up Land	0.3500
Water body	0.000
Bare land	0.3500
Vegetation	0.0001
Agricultural Land	0.5429

Source: Jain and Kothyari, 2000

Support Practice (P) Factor

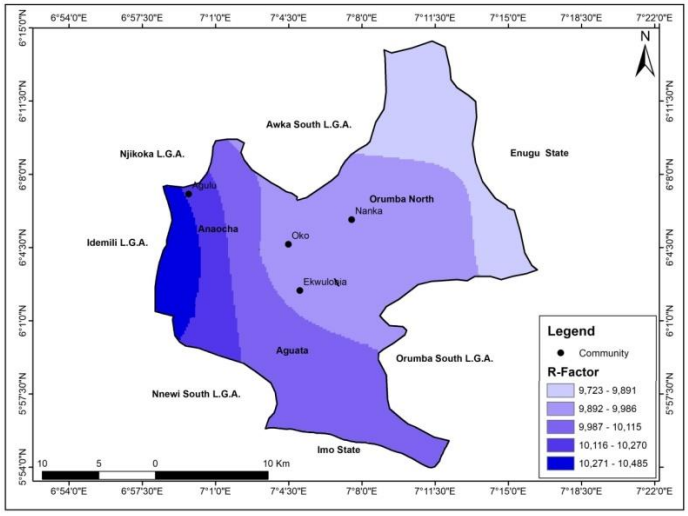
The support Practice (*P)* factor reflects the effects of soil erosion support practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The *P* factor varies from 1 for bare soil with no erosion control to 0.01 where there is much cover on gentle slopes (Arekhi, 2008). No specific soil erosion control management is practiced by farmers. A *P* factor of 1 was assigned to the built-up land, 0 to water bodies and 0.5 was the factor for strip cropping of 2 year rotation to other classes of the classified image which had some form of land cover.

Results and Discussion

Figure 2 shows the variation of R factor from 9,723 to 10,485 MJ.mm/ha.h.yr. With a mean value of 10,104 MJmm/ha/h/yr. The western part of the study area is observed to have the highest R factor value. Areas in the south western side also showed high R factor value. Both areas are very rugged areas.

Figure 2 shows that higher intensities of R prevail around Agulu, Nanka, Oko and Ekwulobia, the zones of high erosivity will be more erosive due to the higher intensity of rainfall events. Similar pattern in rainfall erosivity of the study were observed in an erosivity map of Ghana and west Africa produced by Oduro-Afriyie (1996) and Roose (1997) With reference to *R* classification of $R \leq 2{,}452$ = low erosivity; $2{,}452 < R \leq 4{,}905$ = medium erosivity; $4{,}905 < R \leq 7{,}357$ = medium-strong erosivity; $7{,}357 < R \leq 9{,}810$ = strong erosivity; $R > 9{,}810$ = very strong erosivity (Silva, 2004), the rainfall erosivity index of the study area is very strong indeed.

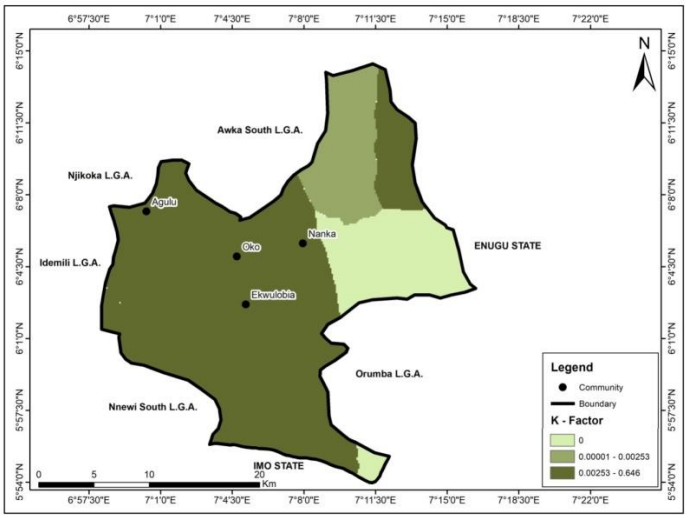
This result encourages high erosion potential. The result was correlated with similar studies carried out in Ghana and India (Ashiagbor *et al.,* 2013 and Rahaman *et al.,* 2015)



Source: GIS Analysis, 2021

Figure 2: Spatially distributed map of R factor of the study area (MJ. mm/ha.h.yr)

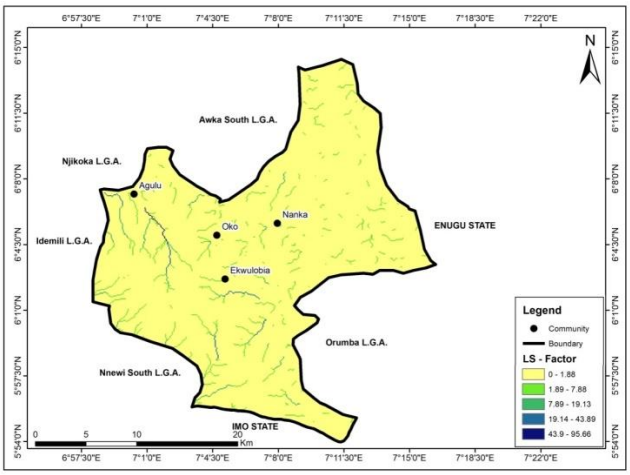
Figure 3 shows the variation of K factor from 0 to 0.646 t.ha.h.ha^{-1} MJ. study area is underlain by four (4) major soil types (Fluvisols, Acrisols, Nitisols, Lixisols), with Lixisols and Nitisols having erodibility values of 0 and 0.004 respectively, Acrisols with erodibility value of 0.0009 and Fluvisols being the most erodible (0.0646thMJ^{-1}mm^{-1}) (Table 1) the most erodible soils (fluvisols) are concentrated in almost all the study area. Result show that soil erodibility is highly dominated by Fluvisols.



Source: GIS Analysis, 2021

Figure 3: Spatially distributed map of K Factor of the study area (t.ha.h./ha.MJ.mm)

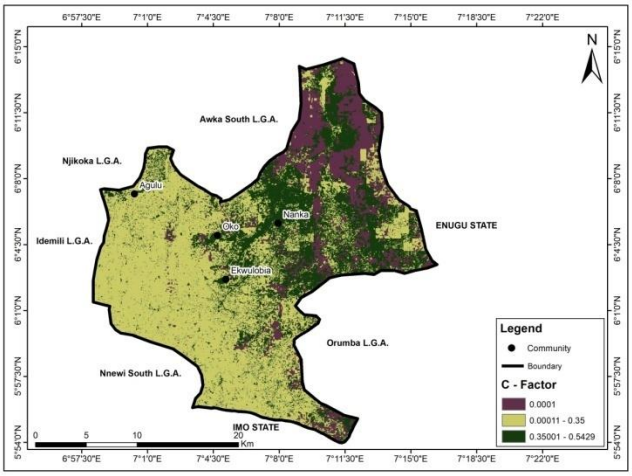
Figure 4 shows the variation of *LS* factor from 0 to 95.66. It can be observed that LS factor is high for areas with high elevation or hilly area and low for areas with low elevation. It is observed that the slope length is long which encourages cumulative runoff. (Figure 4)



Source: GIS Analysis, 2021

Figure 4: Spatially distributed LS factor map of the study area

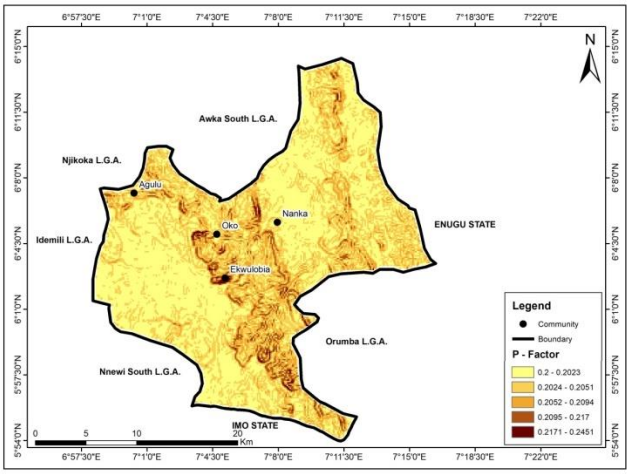
The C factor value of the study area varies from 0.0001 to 0.5429 as shown in figure 5. Areas with the highest C factor value occur around the Northern tip of the study area while areas with the lowest C factor value dominate the western part of the study area. It can be observed that the heavily forested hilly areas are having very low C value. However, with less vegetation in the other parts of the study area. Forest vegetation making up the closed canopy had the best vegetative cover while built-up area had sparse vegetative cover.



Source: GIS Analysis, 2021

Figure 5: Spatially distributed map of C Factor of the study area

Figure 6 shows the variation of P factor from 0.2 to 0.24512. The P factor reflects the land use and land cover of the study area.



Source: GIS Analysis, 2021

Figure 6: Spatially distributed map of P Factor of the study area

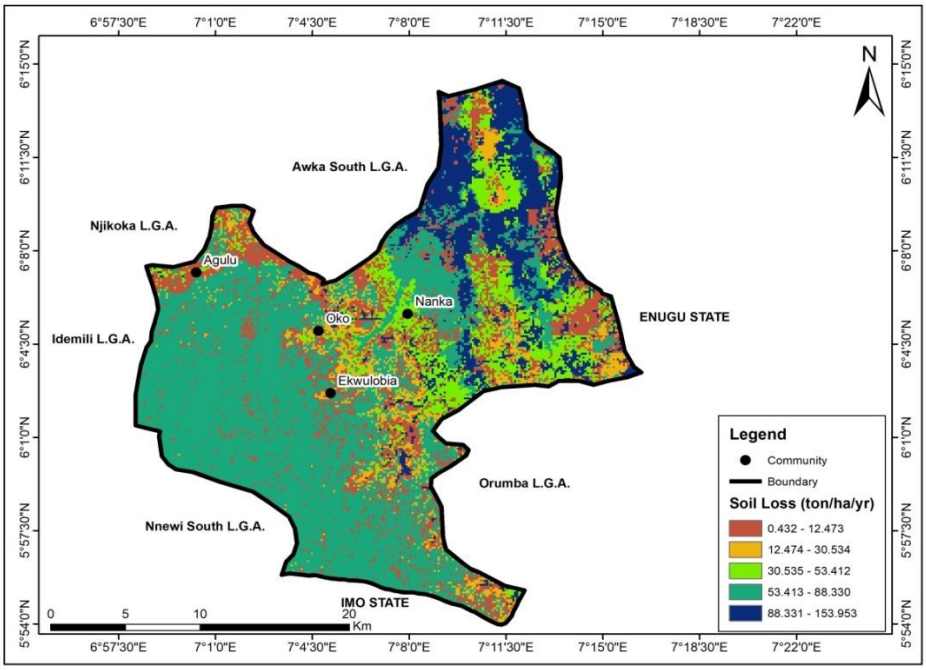
Soil loss map of the study area

After multiplication of the six factors as per RUSLE formula (Eq. 1) average annual soil loss of the study area figure 7 was generated. Figure 7 illustrate soil loss map. Estimated soil loss from a cell ranged from 0-153.953 t/ha/yr with a mean of 70.5887 t/ha/yr and standard deviation of 49.7426 t/ha/yr. comparing the mean value of soil loss to the classification scheme of FAO (1987, cited by Silva *et al.*,2010) in t/ha/yr (a) < 10 = very low, (b) 10–50 = moderate, (c) 50–120 = high, and (d) >120 = very high, the study area is characterized by high soil loss risk.

The high soil loss risk is attributed to steep slopes underlain by fluvisols which is very susceptible to erosion figure 7. The highest soil loss occurs in Nanka community followed by Agulu, Ekwulobia and Oko. High runoffs generated during rainfalls cause serious erosion, creating rills and gullies.

The classified soil loss map shows that 4.92% of the total area has soil loss between 0.432 – 12.473 (ton/ha/yr) followed by 49.93% of the total area with rate of soil erosion between 12.474 – 30.534 (ton/ha/yr). Next is16.88% of the total area with average annual soil loss between 30.535 – 53.412 (ton/ha/yr). Other soil loss categories cover 27.33% and 0.94% of total area with average annual soil loss between 53.413 – 88.330 (ton/ha/yr) and between 88.881 – 153. 953 respectively table 1. The total area of soil loss is 599.17 (Km^2**)** (table 3)

The results were correlated with similar studies carried out in Ghana and India (Ashiagbor *et al.*, 2013 and Rahaman *et al.*, 2015).



Source: GIS Analysis, 2021
Figure 7: Spatially distributed soil loss map of the study area

Table 3: Soil loss in relation to different range in the Area

Soil Loss (ton/ha/yr)	**Area (Km^2)**	**%**
0.432 - 12.473	29.48	4.92
12.474 - 30.534	299.17	49.93
30.535 - 53.412	101.14	16.88
53.413 - 88.330	163.75	27.33
88.881 - 153.953	5.63	0.94
Total	**599.17**	**100**

From the forgoing which is a quantitative assessment of average annual soil loss in the erosion area which was performed with RUSLE method in GIS platform considering rainfall, soil, topographic and satellite imagery datasets. GIS and remote sensing technique was successfully used to calculate all the factors and prepare a 30 m resolution spatially distributed raster map for each factors (i.e. *R, K, LS* and *C*). The spatially distributed map of annual average soil loss rate was prepared by multiplying the raster maps of each factor using raster calculator in GIS platform.

Conclusion

The study area is characterized by high soil loss risk which is attributed to steep slope and Fluvisols. The highest soil loss occurred in Nanka community followed by Agulu, Ekwulobia and Oko. High runoffs generated during rainfalls cause serious erosion, creating rills and gullies. Total area soil loss is estimated to range from 4.92% - 0.94%. The loss of soil in the area will lead to loss of agricultural productivity and disruption of socio-economic activity in the area of study.

Based on the findings of this study, the following recommendations were suggested. To reduce soil loss, intervention should be focused on *LS, C* and *P* factors as the *K* and *R* factors cannot be changed. For the LS factor, the management of terraces will reduce the length of the slope and consequently the soil loss. For the C factor, the choice of the types of cultivation and tillage methods will lead to reduction of erosion. For the P factor, conservation practices, such as culture against the slope, should be used to ensure that sediments are deposited close to their source. Extensive afforestation program can be very effective in the control of gully erosion especially when well applied. This helps to protect the soil from the direct impact of raindrops and runoff as well as maintain the moisture content of the soil at responsible level during the dry season.

References

Ajaero K. C, and Mozie T. A. (2011). The Agulu-Nanka gully erosion menace in Nigeria: What does the future hold for population at risk? In: M. Leighton, X. Shen and K. Warner (eds.) *Climate Change and Mitigation: Rethinking Policies for Adaption and Disaster Risk Reduction.* Enugu, Nigeria, UNU-EHS 72-80

Arekhi, S., (2008). Evaluating Long-Term Annual Sediment Yield Estimating Potential of GIS Interfaced MUSLE Model on Two Micro-Watersheds. *Pakistan Journal of Biological Sciences 11* (2), 270-274.

Ashiagbor, G., Forkuo, E. K., Laari, P. and Aabeyir, R (2013) Modeling Soil Erosion using RUSLE and GIS tools. *International journal of Remote sensing and Geoscience*, 2, 7 -16

Engel, B. (2003). Estimating Soil Erosion Using RUSLE (Revised Universal Soil Loss Equation) Using ArcView. (Accessed 20 October, 2011).

FAO-UNESCO. (Food and Agriculture Organization and United Nations Educational, Scientific and Cultural Organization) (1987) Soil Map of the World, 1:5,000,000, Volume VI, UNESCO, Paris.

Jain, M. K., Das, D., (2010). Estimation of Sediment Yield and Areas of Soil Erosion and Deposition for Watershed Prioritization using GIS and Remote Sensing. *Water Resources Management* 24, 2091-2112.

Jain, M. J. K. and Kothyari, U. C., (2000). Estimation of Soil Erosion and Sediment Yield using GIS. *Hydrological Sciences Journal* 45 (5), 771-786.

Jain, M. K., Mishra, S. K. and Shah, R. B., (2010). Estimation of Sediment Yield and Areas Vulnerable to Soil Erosion and Deposition in a Himalayan Watershed Using GIS. *Current Science* 98 (2), 213-221.

Ndubuisi, U. S., Chike, O., Kanu, E., Okosun, A., Amerobo, C., Obi., N.I., Emeasoba, U.R.B., Agwuna, K. K. and Iroegbu, A (2016). Soil erosion in Awka, Anambra state (Nig) Assessing the social and environmental effects. www. *research gate.net*

Obi, N. I. and Okekeogbu, C. J. (2017). Erosion problems and their impacts in Anambra State of Nigeria. (A case of Nanka community) *International journal of environment and pollution research,* 5 (1), 24-37

Oduro-Afriyie, K., (1996). Rainfall erosivity map for Ghana. Geoderma 74, 161-166.

Okengwo, O. N., Okeke, O. C., Okereke, C. N. and Paschal, A. C. (2015) Geological and Geotechnical Studies Of Gully Erosion at Ekwulobia, Oko and Nanka Towns, Southeastern Nigeria. *EJGE*, 20, Bund. 1

Okoro, E. I, Egboka, B. C. E, and Onwuemesi, A. G, (2010). Evaluation of the Aquifer Characteristics of Nanka Sands Using Hydrological Method in combination with Vertical Electrical Sounding (VES). *Journal of Applied Science and Environmental Management*. June, 2010 14 (2), 5 – 7

Osadebe, C. C., Abam, T. K. S., Obiora, F. I., and Sani, R. O. (2014). Evaluating the Stability of Gully Walls in Agulu-Nanka-Oko gully erosion complex area of Anambra State, Nigeria, using empirical approach. *Science web Publishing*

Petkovšek, G., Mikoš, M., (2004). Estimating the R factor from daily rainfall datain the sub-Mediterranean climate of southwest Slovenia. *Hydrological Sciences Journal* 49 (5), 869-877

Rahaman, S. A., Aruchamy, S., Jegankumar, R., and AbdulAjeez, S., (2015) Estimation of Annual Average soil loss based on RUSLE model in Kallar watershed, Bhavani Basin, Tamil Nadu, India. ISPRS Annals of the Photogrammetry, Remote sensing and spatial

information science. Vol. 11-2/w2, joint international Geoinformation conference 2015. Kuala Lumpur

Roose, C. W., Coughlan, K. J., Ciesiolka, C. A. A., Fentie, B. (1997) Program GUEST (Griffith University Erosion System Template). In A New Soil Conservation Methodology and Application to Cropping Systems in Tropical Steep lands; ACIAR Technical Report; Coughlan, K.J., Rose, C.W., Eds.; ACIAR: Canberra, Australia; 34–38.

Shamshad, A., Azhari, M. N., Isa, M. H., Wan Hussin, W. M. A. and Parida, B. P., (2008). Development of an Appropriate Procedure for Estimation of RUSLE EI_{30} Index and Preparation of Erosivity Maps for Pulau Penang in Peninsular Malaysia. Catena 72, 423-432.

Silva, R. M., Santos, C. A. G., Montenegro, S. M. G. L., Silva, L. P. E., (2010). Spatial Analysis of Vegetal Cover and Sediment Yield in Tapacurá River Catchment Based on Remote Sensing and GIS. Annals of Warsaw University of Life Sciences – Land Reclamation 42 (1), 5-16.

Silva, A. M., (2004). Rainfall Erosivity Map for Brazil. Catena 57, 251-259.

Smithen, A. A., and Schulze, R. E. (1982). The Spatial Distribution in Southern Africa of Rainfall Erosivity for use in the Universal Soil Loss Equation. Water SA 8 (2), 74-78.

Stone, R. P., Hilborn, D., (2000). Universal Soil Loss Equation (USLE), Ministry of Agriculture Food and Rural Affairs, Ontario, Factsheet Order No. 00-001.

USDA-ARS (2008). DRAFT USER'S REFERENCE GUIDE - Revised Universal Soil Loss Equation Version 2 (RUSLE2), Prepared for USDA-Agricultural Research Service, Washington D.C. http://www.ars.usda.gov/sp2UserFiles/Place/64080510/RUSLE/RUSLE2_User_Ref_Guide.pdf. (Accessed 8 March, 2011).

Wischmeier. W. H., and Smith, D. D., (1978) Predicting Rainfall Erosion Losses: A Guide to Conservation Planning, U.S. Dept Agric. Handbook537, Washington DC.