ASSESSMENT OF POTENTIAL SOIL EROSION AND ANNUAL SOIL LOSS IN THE KONAM RESERVOIR, USING THE RUSLE MODEL WITH GIS TECHNIQUES

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Abstract:-

Soil erosion is a serious issue, causing loss of agricultural productivity, increase in sediment deposit in the riverbeds, and damage to the ecological balance of the affected areas. Proper assessment of the rate of soil erosion is essential for the management of natural resources. The present study employs GIS-based RUSLE (Revised Universal Soil Loss Equation) model for the estimation of annual soil loss in Konam reservoir of Andhra Pradesh, India. To identify the soil erosion susceptible areas, annual average rainfall, soil properties, topographic characteristics, and LULC were taken as inputs. The result revealed that annual soil loss of the study area ranges between 0.38 to 41.95 t ha^{-1} yr^{-1}, with a mean annual soil loss of 9.12 t ha^{-1} yr^{-1}. The entire region was classified into six soil loss severity classes, around 17.8% of the area was found to be very slightly affected (< 1 t ha^{-1} yr^{-1}) by soil erosion, around 19.2 % slightly affected (< 5 t ha^{-1} yr^{-1}), roughly 27.4% moderately affected (5-10 t ha^{-1} yr^{-1}), around 14.1% moderate high (10 – 20 t ha^{-1} yr^{-1}), nearly 12.6 % area affected severely (20 -40 t ha^{-1} yr^{-1}) and very severely affected areas (> 40 t ha^{-1} yr^{-1}) contributes 8.9 %. The outcome of the research can help in the effective implementation of conservation and management practices to check soil erosion in the study area.

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1. Introduction:-

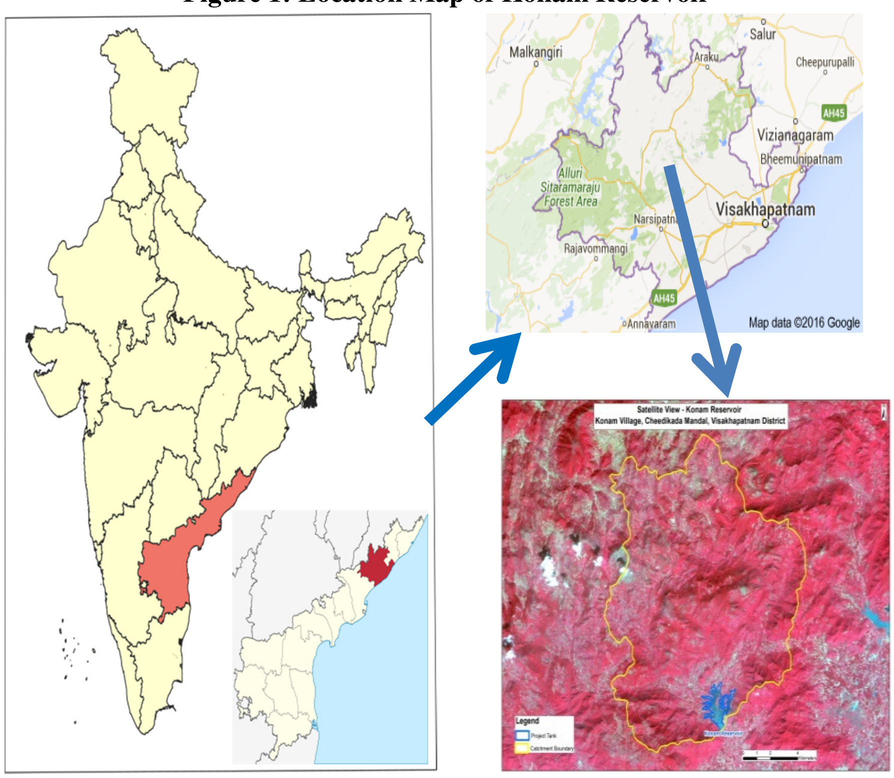
One of the most important natural resources in the world is soil. It is a diverse and complex ecosystem that supports a diverse range of biodiversity. It also supports the growth of vegetation for feed, fibre and fuel, and it has the potential to aid in the combat and mitigation of climate change. However, many people need to be made aware of the importance of soil conservation. One of the significant environmental risks that reduce agricultural productivity causes loss of fertility and disrupts ecosystems globally is soil erosion. Soil erosion estimation of a study area has limitations if done only by field-based studies because of the complexity of the earth's surface that governs the soil erosion process (Saha & Pande, 1993). Geoinformatics tools can assess the erosion process by considering complex earth surfaces in terms of spatial aspects. The soil erosion rate varies because of elevation changes, soil type, land use/land cover, rainfall, etc. (Mallick et al., 2014). Water erosion is the leading cause of soil degradation (Bekele & Gemi, 2021; Efe et al., 2008). About 80% of the world's agricultural land suffers from moderate to severe erosion (Ritchie et al., 2005). In recent years, the integration of the Revised Universal Soil Loss Equation (RUSLE), Geographic Information Systems (GIS), and remote sensing (RS) techniques have been reported as a powerful approach for soil erosion mapping and management. RUSLE Model in a GIS framework has been used in a variety of situations, including mountainous tropical watersheds, large-scale watersheds, agriculturally dominant watersheds, regions with distinct wet and dry seasons, and regions with dynamic changes in land cover patterns, agricultural farmlands, and developments. It was initially created to evaluate the risk of soil erosion for small regional watersheds (Jahun et al., 2015). It consists of 5 parameters. They are rainfall erosivity factor (R), soil erodibility factor (K), slope-length and slope steepness factor (LS), conservation practice factor (P), and land management factor (C).

This study aims to assess the soil erosion risk regions of a reservoir. Soil erosion assessment was carried out by utilizing a GIS base modelling strategy in combination with derived parameters from satellite remote sensing. The study was carried out in the Konam-reservoir in the Sarada river basin of Visakhapatnam district, Andhra Pradesh, India.

2. Study area-Konam Reservoir:-

The Eastern Ghats of Andhra Pradesh are the source of the Bodderu River, a tributary of the Sarada. In the Visakhapatnam district, close to Konam village, the Bodderu River was crossed to build the Konam reservoir project (Figure 1). Because of the hills and trees, there is no upper use. The earth dam and the concrete spillway make up the two halves of the dam. For the protection of the dam's upper slope, huge rubble stones line the barrier of the concrete Levine, which is constructed of impermeable soil. Rainwater is emptied down drainage chutes, and premium turf is installed on the downstream slope. This reservoir is of a moderate size. The dam is 930 meters long overall, of which 300 meters are a fabricated earthen dam, and the remaining portion is a naturally occurring earthen embankment. The dam can reach a maximum height of 26.65 meters from the most profound base. The earthen dam's highest level is 104.25 meters, and its peak width is 5.0 meters. At whole reservoir level (101.25 m), the reservoir has a gross storage capacity of 48.14 M Cum.

Figure 1: Location Map of Konam Reservoir



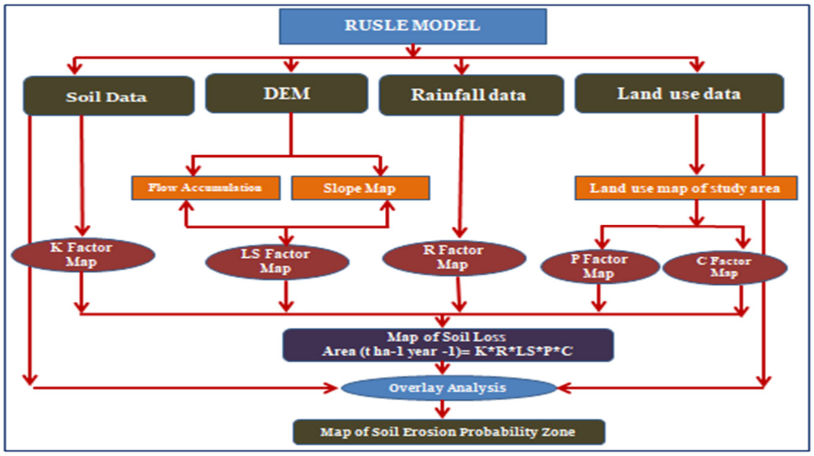
3. Materials and Methods:-

The soil erosion modelling by RUSLE (Revised Universal Soil Loss Equation) is a modified form of the USLE (1971). RUSLE is expressed as

$$A = R * K * LS * C * P \qquad \text{\_\_\_ (Eq.1)}$$

Where, A is the annual rate of soil loss (t ha^{-1} yr^{-1}), R is the rainfall erosivity (MJ mm ha^{-1} h^{-1} yr^{-1}), K is the soil erodibility (t ha h ha^{-1} MJ^{-1} mm^{-1}), LS is the topographic factor stated as slope length and steepness, C is the factor for crop management and P stands for conservation supporting practice.

Figure 2: Methodology Flow chart of RUSLE Model



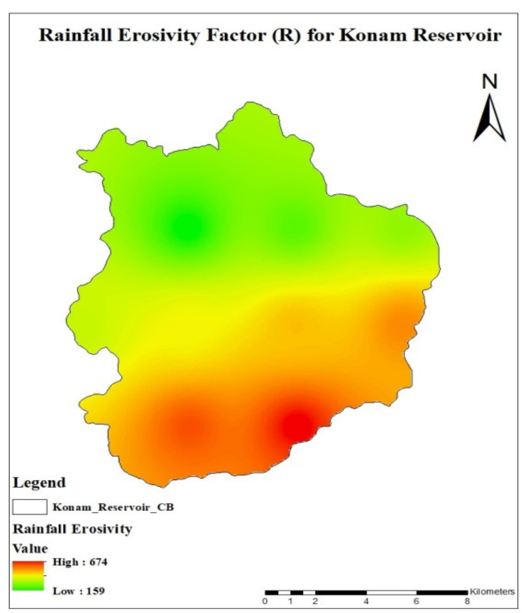
A. Rainfall Erosivity:

Rainfall erosivity is one of the critical elements in RUSLE because it directly affects the disintegration of aggregates, the detachment of soil particles, and the transport of eroded particles through runoff. Erosion is primarily caused by rainfall. The average yearly sum of the individual storm erosion index values (EI_{30}), where E is the total storm kinetic energy, and I_{30} is the most incredible rainfall intensity in 30 minutes, is the rainfall erosivity. Wischmeier and Smith (1978) advised the need for at least 20 years of continuous rainfall data in order to compute storm EI30. Babu et al., (2004) developed an empirical method for India that calculates the rainfall erosivity factor using readily available rainfall data. The formula is:

$$\mathbf{R = 81.5 + 0.38 * P} \qquad \text{\_\_\_\_ } (\textbf{\textit{Eq.2}})$$

Where, P is the annual precipitation for areas where annual precipitation ranges between 240 mm and 3500 mm. The mean annual precipitation over the most recent 30 years ranges from approximately 352.15 mm to 1025.8 mm around the study area. The rainfall erosivity factor was calculated by using Equation (2). A spatially distributed R-factor map of the study area (Figure 3) was derived by ordinary Kriging spatial interpolation that was performed in ArcGIS 10.1. The Rainfall erosivity factor (R) during the year 1992-2022 ranges from 159.25 MJ mm ha^{-1} h^{-1} yr^{-1} to 674.21 MJ mm ha^{-1} h^{-1} yr^{-1}. In the study area, the mean R-value is 258.32 MJ mm ha^{-1} h^{-1} yr^{-1}.

Figure 3: Rainfall Erosivity Map of Konam Reservoir



B. Soil Erodibility Factor (K):

The inherent susceptibility of the soil to erosion depending on the soil profile characteristics is represented by the soil erodibility factor (K). In this study, the soil type map was extracted from the digital soil map of the world (DSMW) published by the Food and Agriculture Organization (FAO) of the UNESCO and the K factor is estimated using the equation of Williams (1995). The K factor of soil can be ascertained using a nomograph to evaluate the texture (silt%, sand%, clay%, permeability%, soil structure%, organic matter %), permeability, and soil structure [15].

$$\mathbf{K=27.66 * m1.14*10-8* (12-a) + 0.0043 *(b-2) + 0.0033*(c-3)} \quad \text{\_\_ } \textit{Eq. 3}$$

Where, K= soil erodibility, m = silt (%) + very fine sand (%) × (100-clay (%)), a = organic matter (%), b = structure code: *where,* 1 is very structured or particulate, 2 is fairly structured, 3 are slightly structured and 4 is solid; c = profile permeability code: *where,* 1 is rapid, 2 is moderate to rapid, 3 is moderate, 4 is moderate to slow, 5 is slow and 6 very slow. However, using Equation 4 to get the K-value requires determining a number of parameters, some of which are not easily accessible for the given location. Therefore, using published research (Table 1) that was easily accessible, soil erodibility values for different soil texture classes in the study area were determined (Singh & Khera, 2009) (USDA, 1972).

Table 1: Soil types with their Texture (silt%, sand%, clay%, permeability%, soil structure%, organic matter %)

S.No	Soil type	% Sand	% Slit	% Clay	m	b	c	a (%)
1	Barren Land	60	13	27	5329	3	4	2
2	Built Up area	62	12	26	5338	3	4	2
3	Clayey soils	20	20	60	1600	1	6	0.6
4	Fine loamy soils	25	65	10	7235	4	5	1
5	Fine loamy to loamy skeletal soils	22	66	12	7249	4	5	1
6	Fine soils	20	65	15	7225	4	5	1
7	Loamy skeletal soils	41	41	18	6724	2	3	1.5
8	Waterbody	60	13	27	5329	3	4	2

The zones with moderate K values (0.25-0.35) were huge, including the total catchment area of 30,811.76 hectares. Up to 3,492 ha of high K factor areas (0.35-0.45) were found in southern regions. In contrast, areas with a low K-factor (0.10-0.25) accounted for 5,886.60 ha that spread from the northern to the southern regions. The lowest K (<0.10) and highest K (>0.45) factors correlate with the 951.84 ha and 150.81 ha of total catchment area (TCA), as depicted in Figure 4 and Table 2.

Figure 4: K-factor Map of Konam Reservoir

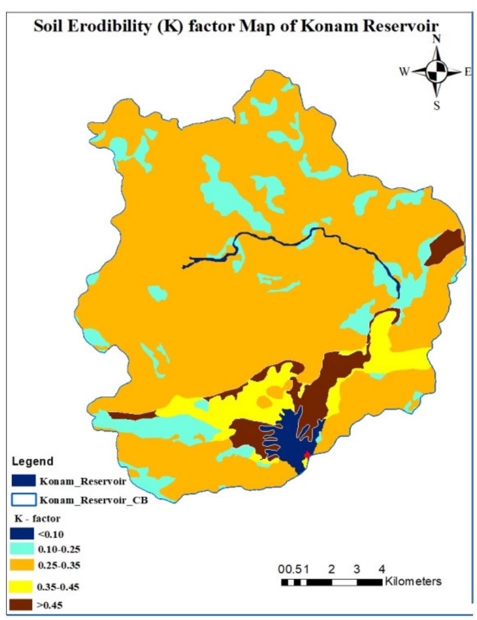


Table 2: K-factor values of Konam Reservoir

S.No	K factor	Area in ha
1	<0.10	951.84
2	0.10-0.25	5,886.60
3	0.25-0.35	30,811.76
4	0.35-0.45	3,492
5	>0.45	150.81

C. Slope length and Steepness Factor (LS):

The slope length and steepness factor accounts for the effect of topography on erosion. Many workers have used the L and S factors as a combined LS-factor. The LS factor has been computed by an empirical formula as suggested by Moore and Wilson (1972):

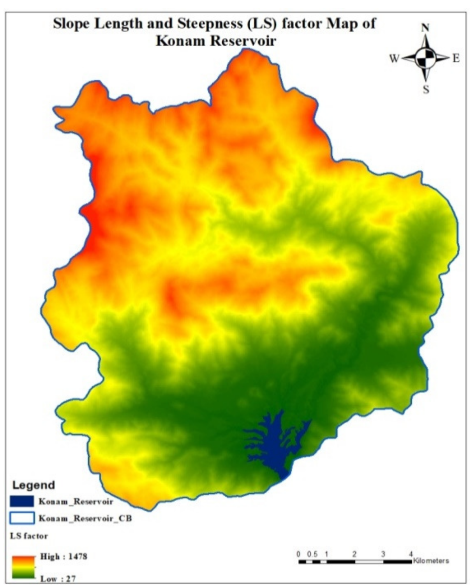
LS*=1.4 (*Flow accumulationCell size*/22.1322.13.) 0.4* (*Sin slope**0.0896)1.3 __*Eq.4***

Where, LS = combined slope length and slope steepness factor; Flow accumulation = accumulated upslope contributing area for a given cell; Cell size = size of grid cell (for this study cell size is 30 m) and Sin slope = slope degree value in sin. In the study, reservoir topography is primarily composed of low slope class, comprising 14,659.02 ha; near slope, which covers 7,804.38 ha; moderate slope, which consists of 8,878.00 ha; steep slope, which encompasses 6,276.54 ha; and very steep slope, which includes 3,675.08 ha, tabulated in Table 3 and Figure 5.

Table 3: LS-factor values of Konam Reservoir

S.No	Values of LS factor	LS class	Area in ha
1	<5	Low slope	14,659.02
2	05 to 10	Nearly slope	7,804.38
3	10 to 20	Moderate slope	8,878.00
4	20-40	Steep slope	6,276.54
5	>40	Very steep slope	3,675.08

Figure 5: LS-factor Map of Konam Reservoir



D. Cover Management Factor (C):

The cover management factor explains how vegetation cover affects soil erosion. Cover management factor (C) is the soil loss ratio from an area with specific cover and management methods to the same amount of soil loss from continuously fallow, clean-tilled land. The kind, growth stage, and plant cover percentage all affect the value of C. The Normalized

Difference Vegetation Index (NDVI) was used to calculate the C-factor, which was then created using Sulistyo's (2016), equation:

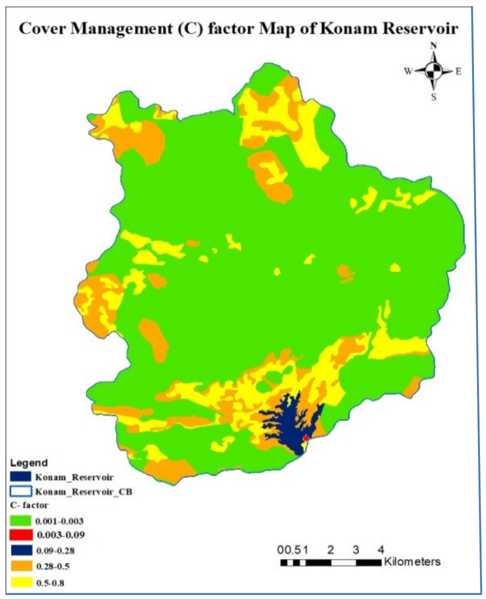
$$C = 0.6 - 0.77\ NDVI \qquad \text{(Eq. 5)}$$

The majority of the reservoir catchment area is covered by the 0.001-0.003 class, encompassing 30,061.31 ha. The remaining are 0.003-0.09 class (619.40 ha), 0.09-0.28 class (3,509.91 ha), 0.28-0.5 class (4,211.89 ha), and 0.5-0.8 class (2,890.51 ha) respectively, illuminated in Table 4 and Figure 6.

Table 4: C-factor values of Konam Reservoir

S.No	C factor	Area in ha
1	0.001-0.003	30,061.31
2	0.003-0.09	619.40
3	0.09-0.28	3,509.91
4	0.28-0.5	4,211.89
5	0.5-0.8	2,890.51

Figure 6: C-factor Map of Konam Reservoir



E. Conservation practice factor (P):-

To mitigate the adverse effects of precipitation, techniques such as contouring, terracing, and strip cutting provide the necessary support (Chakrabortty et al., 2022; Mallick et al., 2022). Land uses, including agriculture, were categorized into general groups based on factor P by Ghosh et al., (2023). Since different management techniques are more effective on different slopes, the farmland was divided into six slopes and assigned a probability value to each. Accordingly, this inquiry used a technique considering the average slope and parcel shape. P-values were assigned to various combinations of slope and LULC category (Table 5) after the slope thematic map and LULC categories were converted to vector format.

Table 5: Values of the support practices (P) factor for various LULC classes

S.No	LULC Category	P-Factor
1	Agriculture Crop Land	0.5
2	Agriculture Fallow	0.9
3	Degraded Forest	1
4	Dense forest	0.8
5	Built up area	1
6	Wastelands	1

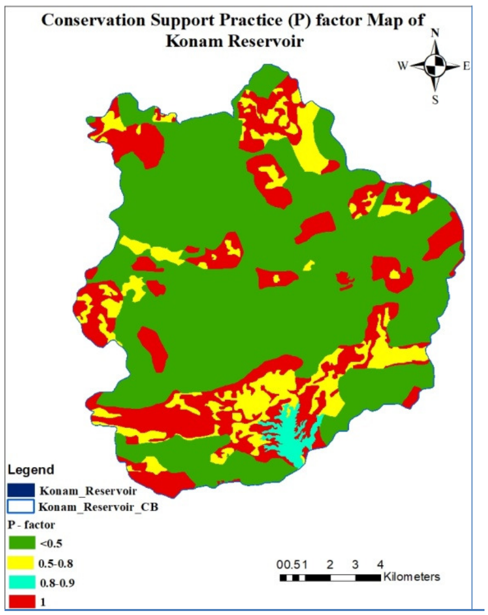
7	Waterbodies	1

The Tatipudi reservoir catchment area is mostly dominated by a P-factor of <0.5 class with 28,203.13 ha followed by 0.9-1 class accounts for 4,955.16 ha, 0.5-0.8 class with 4,624.82 ha and 0.8-0.9 class covers 3,509.91 ha tabulated in Table 6 and Figure 7.

Table 6: P-factor values of Konam Reservoir

S.No	P factor	Area in ha
1	<0.5	28,203.13
2	0.5-0.8	4,624.82
3	0.8-0.9	3,509.91
4	0.9-1	4,955.16

Figure 7: P-factor Map of Konam Reservoir



4. Results and Discussion:-

Following the preparation of all RUSLE parameters (R, K, LS, C, and P), the corresponding raster maps were maintained with a uniform projection and cell size of 30 meters. The RUSLE Equation was then used to superimpose these factor maps in a raster calculator, generating a soil erosion risk map or estimated soil erosion. Based on the rate of erosion, the study area's soil erosion is divided into six classes: very low-soil erosion (0–1 t ha^{-1} yr^{-1}), low soil erosion (1–5 t ha^{-1} yr^{-1}), moderate soil erosion (5–10 t ha^{-1} yr^{-1}), moderately severe soil erosion (10–20 t ha^{-1} yr^{-1}), severe soil erosion (20–40 t ha^{-1} yr^{-1}), and extreme soil erosion (>40 t ha^{-1} yr^{-1}), as indicated in the Table 7.

Table 7: Soil Erosion Zones Classification

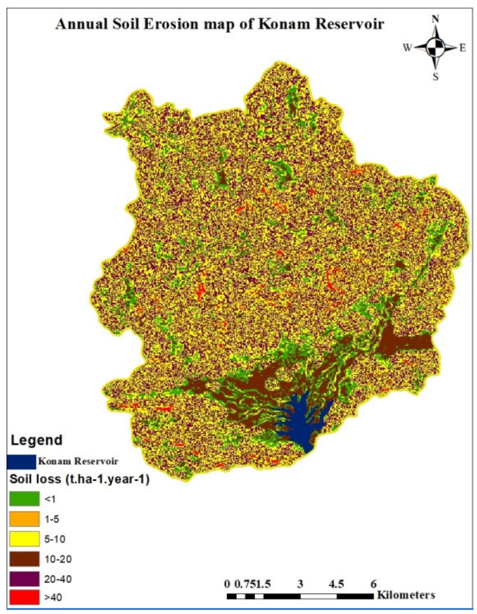
Class	Soil Loss Zones (t ha^{-1} yr^{-1})	Indicator
1	0 to 1	Very Low
2	1 to 5	Low
3	5 to 10	Moderate
4	10 to 20	Moderately severe
5	20-40	Severe
6	> 40	Extreme

Most of the catchment area of Konam reservoir (11,314.3 ha) has been dominated by moderate-class soil erosion. Followed by low-class soil erosion (7,928.3 ha), very low class soil erosion (7,350.2 ha), moderately severe class soil erosion (5,822.3 ha), severe class soil erosion (5,202.9 ha), and extreme class soil erosion (3,675.1 ha) as illustrated in the Figure 8 and Table 8.

Table 8: Annual Soil Erosion Zones of Konam Reservoir

Class	Rate of erosion (t ha^{-1} yr^{-1})	Area (ha)	Area (%)	Average soil loss (t.ha^{-1} yr^{-1})	Total soil loss (t yr^{-1})
1	0 to 1	7,350.2	17.8	0.38	2,793.1
2	1 to 5	7,928.3	19.2	1.26	9,989.6
3	5 to 10	11,314.3	27.4	5.54	62,681.1
4	10 to 20	5,822.3	14.1	12.25	71,323.4
5	20-40	5,202.9	12.6	20.82	1,08,324.8
6	> 40	3,675.1	8.9	41.95	1,54,169.5

Figure 8: Annual Soil Loss (A) Map of Konam Reservoir



5. Conclusion:-

Prioritization of various micro-watersheds on the basis of morphometric analysis and soil erosion risk maps is necessary to plan soil and water conservation measures at watershed scale in order to conserve the natural resources. Remote sensing and GIS techniques have been effectively used in recent times as tools to carry out the morphometric analysis. The incorporation of empirical hydrological models like RUSLE with remote sensing and GIS techniques has increased the applicability of these models to identify the erosion prone area in the watersheds and to evaluate the best management practices to reduce the soil erosion from the prioritized areas.

The average annual soil loss from the Konam reservoir's catchment area is 9.12 t ha^{-1} yr^{-1}. Very low-class soil erosion accounts for the largest portion, covering an annual loss of 17.8%. Low class, moderate class, moderately severe class, severe class, and extreme soil erosion accounted for 19.2%, 27.4%, 14.1%, 12.6%, and 8.9%, respectively.

Data availability Statement:-

The authors confirm the data supporting the findings of this study are available with the article and its Supplementary material. Raw data that support the findings of the study are available from the corresponding author, upon reasonable request.

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Declarations Conflict of interest: -

The authors claim that they have no known financial conflicts of interest or close personal relationships that would have affected the work presented in this study.

References:-

1. Babu, R., Dhyani, B.L. and Kumar, N., (2004). Assessment of erodibility status and refined iso-erodent map of India. Indian Journal of Soil Conservation, 32(3), 171-177.
2. Bekele B, Gemi Y. (2021). Soil erosion risk and sediment yield assessment with Universal Soil Loss Equation and GIS: in Dijo Watershed, Rift Valley Basin of Ethiopia. Model Earth Syst Environ. 7(1):273–291.
3. Chakrabortty, Rabin, Subodh Chandra Pal, Alireza Arabameri, Phuong Thao Thi Ngo, Indrajit Chowdhuri, Paramita Roy, Sadhan Malik, and Biswajit Das (2022). "Water-Induced Erosion Potentiality and Vulnerability Assessment in Kangsabati River Basin, Eastern India." Environment, Development and Sustainability 24 (3): 3518–3557.
4. Efe R, Ekinci D, C€urebal _I. (2008). Erosion analysis of sahin Creek Watershed (NW of Turkey) using GIS based on RUSLE (3D) method. J Appl Sci. 8(1):49–58.
5. Ghosh, Amlan, Sayandeep Rakshit, Suvarna Tikle, Sandipan Das, Uday Chatterjee, Chaitanya B. Pande, Abed Alataway, Ahmed A. Al-Othman, Ahmed Z. Dewidar, and Mohamed A. Mattar. (2023). "Integration of GIS and Remote Sensing with RUSLE Model for Estimation of Soil Erosion." Land 12 (1), https://doi.org/10.3390/land12010116
6. Jahun, B. G., Ibrahim, R., Dlamini, N. S., Musa, S. M., 2015. Review of soil erosion assessment using RUSLE model and GIS. J. Biol. Agric. Health c, 5(9):36-47.
7. Mallick, J., Alashker, Y., Mohammad, S. A. D., Ahmed, M., & Hasan, M. A. (2014). Risk assessment of soil erosion in semi-arid mountainous watershed in Saudi Arabia by RUSLE model coupled with remote sensing and GIS. *Geocarto International*, *29*(8), 915-940.
8. Moore, I. D. and Wilson, J. P., (1992).Length-slope factors for the Revised Universal Soil Loss Equation: simplified method of estimation. Journal of Soil and Water Conservation, 47(5), 423–428.
9. Pal SC and Shit M., (2017). Application of RUSLE model for soil loss estimation of Jaipanda watershed, West Bengal. Spat Inf Ress25 (3):399–409.
10. Ritchie JC, Nearing MA, Nichols MH, Ritchie CA. (2005). Patterns of soil erosion and redeposit ion on Lucky Hills Watershed, Walnut Gulch Experimental Watershed, Arizona. Catena. 61(2–3):122–130.
11. Saha, S. K., & Pande, L. M. (1993). Integrated approach towards soil erosion inventory for environmental conservation using satellite and agro meteorological data. *Asia-Pacific Rem. Sens. J*, *5*(2), 21-28.
12. Singh, M. J., & Khera, K. L. (2009). Nomographic estimation and evaluation of soil erodibility under simulated and natural rainfall conditions. *Land Degradation & Development*, *20*(5), 471-480.
13. Sulistyo, B. (2016, November). The effect of choosing three different C factor formulae derived from NDVI on a fully raster-based erosion modelling. In *IOP Conference Series: Earth and Environmental Science* (Vol. 47, No. 1, p. 012030). IOP Publishing.
14. Williams, J. R., (1995). The EPIC model. In: Computer Models of Watershed Hydrology, Singh, V. P. (Ed.). Highlands Ranch, Colorado: Water Resources Publications, pp: 909-1000.
15. Wischmeier, W.H.; Smith, D.D. (1978). Predicting Rainfall-Erosion Losses—A Guide to Conservation Planning; Agriculture Handbook No. 537; U.S. Department of Agriculture: Washington, DC, USA, p. 58.
16. USDA-SCS, (1972). National Engineering Handbook, Section 4, Hydrology Chapter 21. Design Hydrographs. US Department of Agriculture, Washington DC, USA. Available at: http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=18393.wba [access date: 05.08.2016].
17. Renard, K.G., Foster, G.R., Weesies, G.A., Porter, J.P., 1991. RUSLE. Revised Universal Soil Loss Equation. J. Soil Water Conserv. 46, 30–33.