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Identification and Mitigation of Soil Erosion in Tropical Regions using Nuclear Techniques

[1*]Jules Lwembe Kimpinde, [2]Yvan Muteba, [2]Sangith Kumar

[1]Department of radioprotection at Général atomic Énergie commission

[2]Department of geology at Général atomic Énergie commission

https://orcid.org/0009-0001-0016-0376

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Abstract

Purpose: The process of soil erosion involves the separation, movement and deposition of soil particles as a result of a variety of circumstances, including wind, rain, and human activity. It poses important threats to agricultural productivity, water quality and ecosystem stability, necessitating effective management strategies or sustainable land use and conservation efforts. The purpose of this research is to utilize nuclear techniques for soil erosion identification and mitigation in tropical regions. This study investigate the efficacy of nuclear method to diagnose erosion dynamics, quantify rates and inform sustainable land management strategies for mitigating soil erosion in tropical regions.

Methodology: Nuclear tracing methods, such as Cesium 137, X-ray fluorescence (XRF), lead-210, Chlorine-36, and Beryllium-7 are capable of providing an incredible amount of data on soil loss rates correlated to drill and sheet erosion, as well as the movements and redistribution of that sediment across the tropical regions. This research conducted a comparative assessment of nuclear tracing methods to evaluate their effectiveness in quantifying erosion rates and understanding soil redistribution processes.

Findings: Finding converged across methods, offering valuable insights into erosion quantification, spatial characterization and the impact of farming practices. Nuclear techniques have been created in response to the shortcomings of traditional strategies, offering erosion evaluation at a lower cost and with greater speed.

Unique Contribution to Theory, Practice and Policy: These results underline the efficacy of nuclear techniques as vital supplements and alternatives to traditional methods in addressing soil erosion hazards.

Keywords: *Soil Erosion, Tropical Regions, Identification and Mitigation, Nuclear Techniques.*

1. Introduction

The primary danger to the globe's soil reserves is thought to be soil erosion. It has also been demonstrated in the twenty-first century to drastically reduce crop yields and putting food security at risk in tropical regions where population growth is outpacing levels that are acceptable [1]. The White Nile–Congo rift (NiCo) region presents unique challenges for soil redistribution and subsequent sediment delivery due to its steep topography, high rainfall erosivity and extreme intra-annual seasonality [2]. Global soil deterioration and loss are largely caused by changes in land use, such as clearing and deforestation. In tropical and sub-tropical zones, one of the more common forms of shifts in land use is the conversion of indigenous forests into tea plantations [3]. Changes in land use, such as forest clear-cutting accelerate soil erosion in catchment tropical regions across the globe. One of the most unsustainable land-use changes is deforestation, which has several detrimental effects both on and off-site [4]. A major worldwide problem, soil erosion results in nutrient loss as well as impeding productivity in agriculture and profitable agricultural development. Geologist erosion, often referred to as natural erosion, is the process by which bedrock is eroded by frozen water, wind and gravity, resulting in the formation of organic debris that adds to the underlying appearance in the tropical regions [5]. The transformation of uncultivated regions into cultivated ones is unavoidable due to the requirement for intensive crop production spurred by a quickly expanding population and a desire for higher standards of living. In actuality, the country's land use has changed considerably more quickly during the last 50 years than the preceding century and this trend is expected to continue [6]. The largest global threat to land degradation, faster soil erosion, is causing alarm for an increasing number of individuals. Soil erosion might worsen, especially in developing nations, making it a major barrier to agricultural intensification. Soil erosion is mostly caused by improper land management practices and vegetation clearing. Changes in precipitation brought by climate change will exacerbate soil erosion to unsustainable levels [7]. The world's cultivated land has suffered from soil deterioration on an area of about 1.9 billion hectares because of severe and moderate erosion episodes caused by surface water action. This in turn causes ecological and social effects, such as decreased soil productivity, contaminated water and the sedimentation of rivers and reservoirs [8]. The increasing population has put pressure on the land and water resources in recent years. Since there is less land available for use per person, many nations will have significant difficulties in supplying enough fresh water and food, as well as adequate infrastructure, sustainably. Due to erosion of soil and relaxation, the ground has significantly deteriorated, increasing the risks related to it. The projected amount of degraded land worldwide is 1.9 billion hectares [9]. Soil security has a critical role in preserving the ecosystem, guaranteeing water, energy and food security, mitigating the effects of global warming and providing ecological services [10]. The aim is to utilize nuclear methods in conjunction with other scientific and technological instruments to gain a comprehensive understanding, control and mitigation of soil erosion in tropical regions. This will support sustainable land management practices and ensure the health of ecosystems.

2. Literature Review

A study that quantified the erosion of soil using a radiometric approach using 137Cs looked into geographic variations in soil drainage as well as the effects of reforestation activities on soil erosion. Although cesium has a maximum penetrating depth of 30 cm, soil specimens from various degrees of degradation were collected in 2 cm stratification employing an excavation plate [11]. Using the "Revised Universal Soil Loss Equation (RUSLE)" approach for the Wadi Isser basin, the study created scenarios for erosion management that minimize soil losses. Geographic data collection and methods of remote sensing were utilized to produce conceptual diagrams of the algorithm's many parts [12]. The study provided an important direction for coastal area functional layout design and urban planning. The findings also facilitate educated decision-making processes and help understand storm surge disaster risks, which enhances disaster preparedness and resilience in disaster-prone coastal locations [13]. Fallout environmental radioisotopes 7Be and 137Cs were used to evaluate the stability of the ground. Two isotope analyses were carried out on soil samples obtained from 25 different locations within the study region [14]. Challenges encompass fluctuating market dynamics, the consequences of urbanization and industrialization on the quantity of cultivable land accessible, along with the unpredictability and alteration of climate. To boost productivity, many nations particularly those with dense populations and/or distinctive ecosystems that need to be studied for conservation were unable to expand agriculture into new areas [15]. The objectives of the study were to determine how the level of soil and land use affected Soil Organic Carbon (SOC) content, whether land use and soil erosion caused variations in SOC, and the way land attrition and SOC levels varied depending on the kind of land use. They examined the Total Soil Nitrogen (TSN) and SOC quantities for each one of the three land use groups [16]. Glomalin enhances the physical qualities of soil, aids in the sequestration of carbon, boosts microbial activity, increases nutrient levels, stabilizes contaminants, and finally supports ecological reinstatement [17]. The study employed the Logarithmic-Mean Divisia Index (LMDI) model to compute the parameters of the wrap of the plant factor and the erosivity of rainfall components that change in the erosion of soil at the level of the pixel. This model allowed for an exponential breakdown of the contributing factors [18]. Fishing, hydroelectric power generation, flood control, and the collection and storage of water were all facilitated by reservoirs. The majority of the reservoir's capacity was being reduced by increased sedimentation rates due to population growth, climate change, and increased anthropogenic activity [19].

3. Materials and Methods

The application of nuclear approaches to identifying and reducing soil erosion in tropical regions is covered in this section.

3.1 Study Area

One of the main rivers in the state of Odisha that flows seasonally is the Brahmani River shown in **Fig. 1**. The Sankh rivers and South Koel, which are placed among “longitudes 83° 52′ and 87° 30′ E” and “latitudes 20° 28′ and 23° 35′ N”, met to form this river. The basin has a surface size of 39,633.12 km^2. The three states that make up the entire basin's spatial distribution are Odisha, Jharkhand, and Chhattisgarh, with areas of 22,516, 15,405, and 1347 km^2, respectively. The Sankh River, a major contributing river, rises quite near the boundary between Jharkhand and Chhattisgarh and the Netarhat Plateau [20].

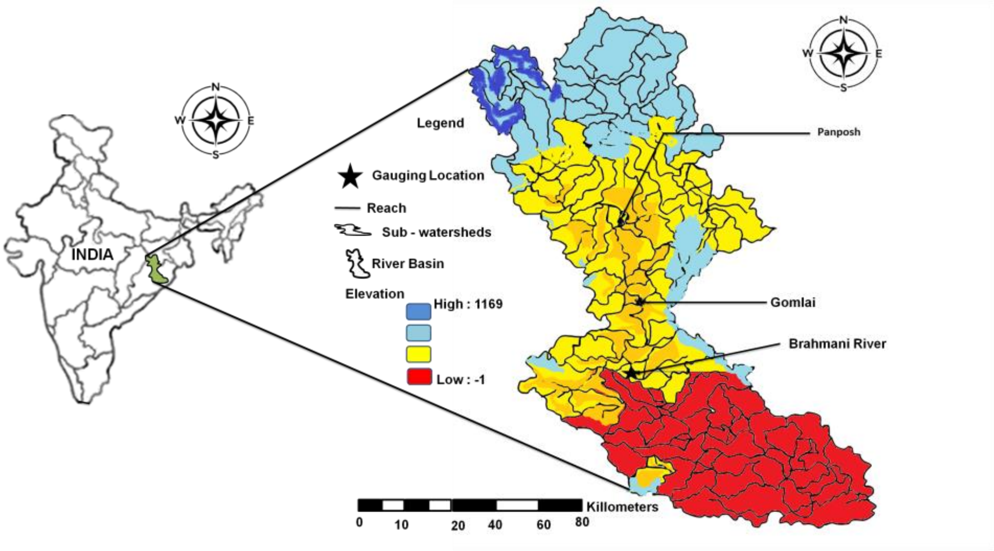

Figure 1: Study Area

Land use and cover geographical information, daily rainfall data, soil hydraulic parameters, and digital elevation model (DEM). For the purpose of stream network withdrawal and watershed delineation, five 30-m high-resolution Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) ASTERDEM tiles covered the complete study tropical regions. For all of the BRB's sub-basin, the India Meteorological Department (IMD) supplied monthly average rainfall data for the years 1951 through 2014. The necessary soil in sequence is providing by in Nagpur, and Maharashtra. Additionally, the DEM was used to characterize the topography, including the basin's steepness and length of slope [20].

3.2 Measurement of degradation with the radiological tracer (Cesium-137)

To measure erosion, the organic matter (OM), pH, and particle size of the soil were analyzed. According to the soil analysis (Table 1), the slope's bottom (sedimentation zone) has a clayey texture, while the slope itself is mostly made of silt. At a sloping level, the SOC is 0.48 to 0.64 in the middle 30 cm of the surface and 1.45 at the bottom of the slope. The mid-slope (core 2) exhibits the greatest and most consistent levels of sediments and SOC, depending to the findings. This was discovered during the examination of the 100 m^2 plots all throughout a 10-year period of observations.

Table 1: Soil Analysis of Core 1 and Core 2

Cores of Soil	Core -1		Core -2	
Depth	0-30	30-40	0-30	30-40
pH	9.38	9.26	9.18	9.23
SOC	0.56	0.64	0.40	0.77
Soil Organic Matter	1.04	1.24	0.62	1.26
Limestone	24.86	27.36	25.29	26.57
Clay	25.35	32.65	11.71	39.53
Slit	46.25	50.42	72.81	52.37
Sand	25.22	19.86	18.79	11.40

3.3 Vertical dispersion of 137Cs

The gamma spectrometry analysis was used to ascertain the distribution of 137Cs in the hydrographic basin under study and the reference location. The concentration of 137Cs is highest in the top couple of centimeters of untouched dirt and decreases substantially with depth. The reference site's 137Cs activity values range from 13.5 to 0.12 Bq/kg. Throughout the soil layer down to the profile bottom, the measurements show a decrease in 137Cs in the different samples. The 137Cs readings in the cores intended for crosses of the leaning topography are uniformly lower than the reference values, indicating erosion zones. Additionally, the most significant erosion is observed halfway down the slope. Conversely, the center's 137Cs production is somewhat greater in the vicinity of the places which have the lowest gradient.

3.4 Rate of Erosion

In the 45 years since the previous 137Cs fallout, the rate of erosion has varied, ranging from 3.94 to 42.61 $t \cdot h^{-1} \cdot year^{-1}$ based on simulations conducted at certain sites located in sloping terrain. From the result we analyzed that the slope buildup ranged from 7.49 to 55.62 $t \cdot h^{-1} \cdot year^{-1}$, according to the mathematical framework chosen.

3.5 MUSCLE Soil Corrosion Model

The modified soil loss equation (MUSLE) which was developed especially for the biological features of forests was employed to calculate soil loss; the USLE was kept for application in the context of agriculture. In the MUSLE approach, the soil cover management factor (C) and the soil preservation management factor are replaced with vegetation management (VM). It is written as:

$$A = R * K * LS * C * P \qquad (1)$$

Where A= Tons of soil lost roughly per acre annually

R = Variable erosivity of precipitation

K = Measure regarding soil erodibility

LS = Length of the descent and the slope component

C = Factors related to coverage and leadership

P = Encourage the habitual component

In the project region, elements that affect soil erosion have been identified and mapped, including vegetation management, rainfall, steepness, slope length and soil erodibility. After that, the various factor maps were overlayed using GIS in a grid cell format, with the MUSLE acting as the foundation, to compute the sedimentation levels for every identified watershed in the study region.

4. Results and Discussion

Two 4 L (10.16 × 10.16 × 50.8 cm) Thallium doped sodium iodide crystal (NaI(Tl)) detectors attached to Odisha Brahmani River photomultiplier tubes comprised the mobile gamma-ray spectrometer structure, which was supplied with electricity and controlled by a Digibase multimedia analyser. Every detector was protected by sturdy plastic Pelicases and operated using Ortec's Maestro software over a USB interface.

4.1 Specialization of Erosion

The goal of the study is to evaluate erosion using both a spatial and quantitative characterization. This methodology made it possible to highlight the significance of the erosion issue while also shedding light on the components of the environment under study. This area has moderate to extremely high erosion rates, ranging from 1 to 33 $t \cdot h^{-1} \cdot year^{-1}$, according to the MUSLE technique shown in **Fig. 2**. Table 2 presents the findings of the gamma spectrometry analysis.

Table 2: Gamma Spectrometry Analysis

Depth (cm)	0-2	2-4	4-6	6-8	8-10
Reference site	14.17 ± 0.62	13.72 ± 0.60	9.38 ± 0.54	6.26 ± 0.28	4.02 ± 0.22
Core 1	6.18 ± 0.55	5.91 ± 0.53	5.91 ± 0.53	5.94 ± 0.43	5.66 ± 0.47
Core 2	5.95 ±0.46	6.78±0.46	8.32±0.51	5.88 ±0.53	0.75 ± 0.33

Table 3 presents the outcomes that were achieved through the utilization of the conversion models.

Table 3: Erosion Rate Analysis

Transect	Cores	Inventory of Celsium -137	Proportional model	Mass bal. 1	Erosion/deposition
Transect 1	Core 1	546.81	2.84	3.22	Erosion
	Core 2	181.20	21.15	27.84	Erosion
Transect 2	Core 1	450.81	6.84	3.22	Erosion
	Core 2	310.20	12.63	15.53	Erosion
Transect 3	Core 1	384.79	7.10	8.03	Erosion
	Core 2	711.26	-15.02	-10.15	Depletion

The K factor thematic layer has been generated using the procedures previously described in the subsection focusing on the earth's erodibility component (K factor) and the geographic distribution of K component values displayed in **Fig. 2**. The BRB's downstream sections had higher values of the K factor, which had an observed mean of 0.031 $t \cdot h \cdot ha \cdot MJ^{-1}ha^{-1}mm^{-1}$. The application of finer declaration soil distinctiveness in this illustration resulted in a standard divergence value of 0.0029 $t \cdot h \cdot ha \cdot MJ^{-1}ha^{-1}mm^{-1}$ across the geologically circulated K factor values. The K factor, or 0.04057 $t \cdot h \cdot ha \cdot MJ^{-1}ha^{-1}mm^{-1}$, was found to be higher for loam soil, meaning that it was more vulnerable to the risk of soil erosion.

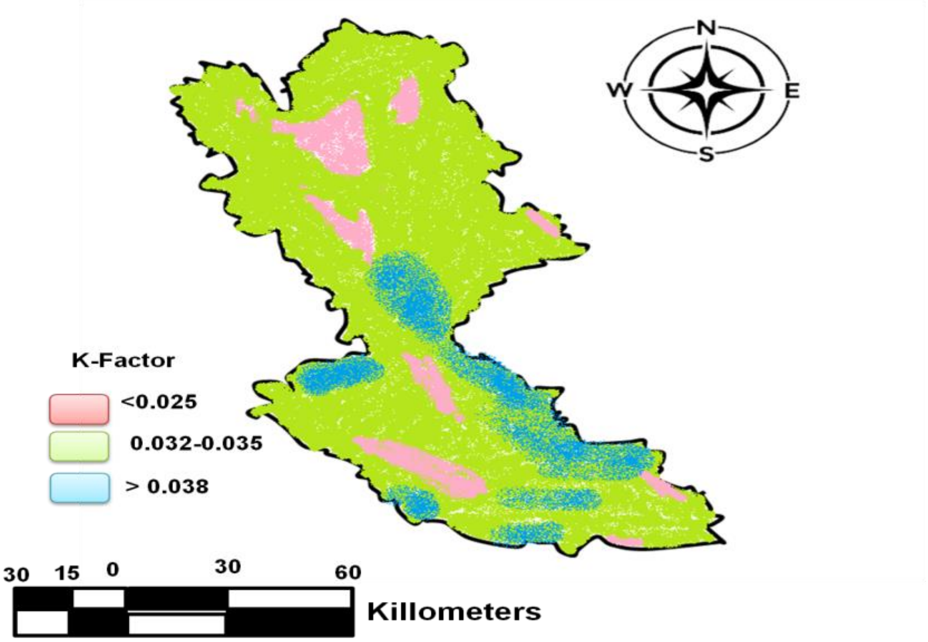

Figure 2: Soil erodibility map

5. Conclusion

This study set out to evaluate the possibility of soil loss in the Brahmani River-basin, and this spans large parts of both states of Odisha and has recently seen a number of extreme weather events, including droughts, floods, and tropical cyclones, due to warmer temperatures. This study examines the possibilities for soil dissolution and erosion production in the Brahmani River-basin using the MUSLE simulator in conjunction with satellite imagery and GIS techniques. we recommended this method especially for central african countries to reduice poverty because Utilizing nuclear methods can help with sustainable land management by providing an effective means for determining and assessing the dynamics underlying the erosion of soil in tropical areas. Techniques are evaluated competitively to determine which is more effective for quantifying erosion and characterizing the area. Our results demonstrate the value of nuclear approaches as useful adjuncts to conventional methods for mitigating the risks associated with soil erosion.

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