

Unravelling the Complex Relationship Between Climate Change and Soil Erosion: A Comprehensive Exploration of Soil Erosion Estimation Methods and Relevant Acts and Policies in India

Suraj Kumar Maurya¹, Vartika Singh², Kesar Chand³, Ashutosh Mishra⁴,
Ashutosh Acharya⁵, Ajay Sonawane⁶

^{1,2}Department of of Global Warming & Ecological Studies, Amity University, Noida, India

³G.B. Pant National Institute of Himalayan Environment, HRC, Mohal, Kullu, India

^{4,5,6}Law Centre-II, Faculty of Law, University of Delhi.

Abstract

Soil, a dynamic amalgamation of mineral and organic matter, is essential for plant growth and the sustenance of life on Earth. Formed over millennia through interactions among parent material, climate, biota, topography, and time, soil is a crucial resource that is increasingly threatened by both natural processes and human activities. This review examines the confluence of land use and climate change as primary drivers of soil erosion, with a focus on India's hilly terrain, where intensive agricultural practices, such as viticulture, are major contributors to soil loss and degradation. Widespread deforestation and unsustainable land management practices have further exacerbated erosion, affecting over 175 million hectares of land across the country. In addition to reviewing soil erosion estimation techniques, this paper highlights the complex interplay between climate change and soil erosion. Climate change amplifies soil degradation through shifts in rainfall patterns and extreme weather events, creating significant challenges for India's environment, agriculture, and rural communities. The paper also evaluates key soil conservation policies and initiatives implemented by India, including the Soil Health Card Scheme, Pradhan Mantri Krishi Sinchayee Yojana, and the National Mission for Sustainable Agriculture, which aim to promote sustainable land management, improve soil health, and mitigate climate-related soil degradation. By providing a critical assessment of erosion estimation models and evaluating India's policy efforts, this review offers valuable insights for researchers, policymakers, and land managers. Understanding the interlinkages between land use, climate change, and soil erosion is essential for developing and implementing effective strategies to conserve this vital resource and safeguard India's soils for future generations.

Keywords: Erosion, Erosion Estimation, RUSLE, Soil conservation Policy , global warming, climate change

1. INTRODUCTION

Numerous research has investigated the connection between land use and water erosion [1]. According to Sharma et al. [2], plant cover has a more significant influence than soil characteristics on soil runoff. In other words, the erosion rate in forested areas is much lower than in less vegetated areas like rainfed farming because the forest canopy effectively controls the runoff impact. Sharma et al. [2] find the same conclusion: that less forest cover in India

increases erosion risk, even though forests are often regarded as an efficient barrier against soil erosion.

More than rainfall variability or slope, land use is a major factor in soil erosion intensity. Since plants and plant cover residues tend to slow down the movement of surface runoff as well as allow the excess surface water to infiltrate into the ground, vegetation cover that is intrinsically related to land use [3] is considered to be effective in reducing the energy of erosion driving force, especially from rain drops. Furthermore, the plant structure layout profoundly affects water balances and erosion rates. Changes in land use or the percentage of vegetation cover affect the amount of soil loss since soil erosion is strongly correlated with land cover and land use. Multi-story forests are more effective at reducing the effect of rainfall energy than single-story vegetation. Soil erosion caused by a shift in land use is very context-dependent. Sedimentation due to soil loss may be reduced if land use changes lead to more vegetation/forest cover and less agricultural operations.

Said, soil degradation is a normal part of the environment [4]. Soil erosion is unbearable only when it is driven by humans or causes significant enough losses to soil quality and agricultural yield to be unsustainable. It becomes unbearable when it decreases agricultural yields, soil fertility, thickness, and water storage capacity. Acceptable soil loss (sometimes represented as a T value) provides a foundation for evaluating erosion risk, lost productivity, downstream sedimentation, soil quality, and erosion prevention. Information regarding soil loss tolerance limitations may serve as an early warning about the possible detrimental impact of ongoing soil erosion on land usage and agricultural yield due to its direct correlation with the soil erosion issue [5].

Nowadays, around 38% of the Earth's surface is used for farming, making it a cultivated planet where modern cultures exist [6]. Over ninety-five per cent of the world's food supply is derived from agricultural and animal production, which in turn relies heavily on the fertility of the earth's soils. It is important to note that the underlying agricultural systems are a significant source of considerable biogenic greenhouse gas emissions and a key cause of soil and environmental degradation. The newest United Nations (UN) report on the state of global soil resources emphasis that soil erosion is still a serious environmental and agricultural issue globally and notes that "...the majority of the world's soil resources are in only fair, poor, or very bad condition" [7]. Human activities such as inappropriate farming, ploughing methods, deforestation, and overgrazing are major contributors to soil erosion. This has knock-on repercussions in the ecosystem, such as depletion of essential nutrients, diminished carbon storage, loss of biodiversity, and weakening of the foundation upon which life depends. Globally, attempts to model the effects of climate and land use change on soils are growing but limited. This study aims to improve erosion forecasting capability in light of these factors. While we presently restrict its applicability to water erosion, excluding wind, gully, and river bank erosion, it nonetheless serves as a significant resource for policymakers at scales tailored to their decision-making requirements.

Land use and perhaps climate change, through an intensified hydrological cycle, are the principal human causes of erosion [8]. Although most studies have concentrated on arable farming [9], we showed in a recent publication that seminatural systems cannot be disregarded since they may be responsible for 50 percent of all soil lost to water erosion worldwide.

Because of the difficulty of modelling soil erosion on a global scale, the lack of available data, and the high computational requirements of physical models, a semiempirical method has been adopted as a practical means of informing policy. Only two studies have ever attempted to predict worldwide soil erosion in the future. Those estimates are too coarse (50 km or larger), based on outdated climatic forecasts, to be useful for informing policy. First performed by Yang et al. [10], the GIS-based Revised Universal Soil Loss Equation (RUSLE) modelling evaluation tended to overstate soil erosion because it used outdated assumptions of future climate and land use. Ito (14), in a study with implications for the carbon cycle, modelled the effects of water erosion on a grid of 55 km (1,901 to 2,100). The land use and climate prediction fields have come a long way since then. Improved processing of big datasets and developments in remote sensing and earth observation has led to the creation of new, more precise global vegetation indices and land cover products. (Additional Resources: Worldwide Maps of Land Use/Cover and Future Projections) Recent climate data, such as bias-corrected climate projections of numerous bioclimatic variables, may be used to calculate global estimates of rainfall erosivity, which is more closely related to rainfall intensity than rainfall volume [11]. For three different scenarios, this research assesses the Shared Socioeconomic Pathway and Representative Concentration Pathway (SSP-RCP), greenhouse gas trajectories, and a selection of General Climate Models (GCMs) at a resolution (sub km) that updates the output, making it more suitable for decision-making [12].

Incorporating environmentally friendly practices into land management and offering financial incentives are two ways to reduce soil erosion. Conservation agriculture (CA) is practised on an estimated 11–14% of the world's arable land or 1.42 billion hectares. Soil erosion is expected to be reduced by roughly 7.1% globally due to conservation efforts, compared to a scenario in which no such measures are taken. Humanity's actions have left an obvious imprint on the planet's landscapes. Erosion of soil also disrupts the cycles of nutrients and carbon in the soil. "Long-term consequences of nutrient losses such as nitrogen and phosphorus and organic carbon have been found to compromise the capacity of certain local soils to support agricultural output and ecosystem service requirements." The annual average growth rates for the global consumption of nitrogen (N), phosphorus (P), and potassium (K) fertiliser nutrients needed to maintain or increase soil fertility are 1.5, 2.2, and 2.4%, respectively. "Significant off-site environmental consequences and substantial onsite economic costs for land users to stem output losses." The growing population (expected to reach a high of 9.4 billion in 2070 [26]), shift toward meat-intensive diets, and a more robust hydrological cycle globally [13] all add to the burden on fertile soils via increased soil erosion and related environmental degradation impacts [14]. All of these things are the responsibility of policy groups.

Modern policymakers are keen on the need for a data-driven strategy. This modelling study is part of a larger United Nations-coordinated effort to provide useful information to governments worldwide. The effects of soil erosion are disproportionately felt in economically developing nations. This work aims to address this by providing a globally uniform evaluation that can be used to direct policy making. It will help governments, particularly those with less capacity for risk assessment, choose where to best allocate funds to prevent soil erosion and its accompanying deterioration. As a bonus, the United Nations has given its stamp of approval to the World Overview of Conservation Approaches and Technologies (WOCAT) database [15], which provides access to publicly accessible data on SLM strategies. When combined with

WOCAT SLMs, the model results provide policymakers with a robust suite of tools at the national scale to pinpoint causes of water erosion at the right scales for intervention planning at the local level. Insights into potential future patterns of global soil erosion by water about land use and climatic changes have been given by previous research, but no clear answer has been presented to guide policy action.

Climate change and soil erosion are two of the most significant environmental challenges confronting India today. These issues are deeply interconnected, as climate change directly affects the rate and intensity of soil erosion, which in turn has serious repercussions for ecosystem health, agriculture, water quality, and rural livelihoods. Rising global temperatures, changes in precipitation patterns, and more frequent extreme weather events accelerate soil degradation. In response, India has enacted various policies and initiatives aimed at mitigating soil erosion, many of which align with broader climate change and environmental conservation goals. This exploration focuses on the intricate relationship between climate change and soil erosion, highlighting key soil conservation strategies and policies in India, including national efforts and international collaborations.

Key Soil Conservation Policies and Initiatives in India- India has introduced a wide array of policies and initiatives aimed at combating soil erosion and promoting sustainable land use practices. One of the flagship programs is the Soil Health Card (SHC) Scheme, launched in 2015. This scheme provides farmers with detailed assessments of their soil, including information on nutrient deficiencies, soil type, and moisture levels. By offering these insights, the SHC enables farmers to make more informed decisions about fertilizer use and soil management practices, encouraging sustainable farming that preserves soil health and reduces erosion. Another key initiative is the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), which is focused on water conservation and improving irrigation efficiency to prevent soil erosion. Through measures such as rainwater harvesting, the regeneration of natural vegetation, and groundwater recharge, PMKSY not only helps mitigate soil erosion but also boosts agricultural productivity by ensuring a reliable water supply. The Watershed Development Project in Shifting Cultivation Areas (WDPSCA), introduced in 1955, is specifically targeted at regions practicing shifting cultivation, such as Jhum farming in hilly areas. This project employs soil and water conservation measures to protect vulnerable hill slopes and stabilize ecosystems that are particularly susceptible to soil degradation. India's National Mission for Sustainable Agriculture (NMSA) plays a vital role in promoting organic farming and traditional practices that reduce the dependence on chemical inputs. By enhancing soil fertility and structure through natural methods, NMSA helps mitigate soil erosion and supports sustainable agricultural practices that are better aligned with long-term soil health. Finally, the Rashtriya Krishi Vikas Yojana (RKVY) focuses on enhancing soil fertility and protecting topsoil by encouraging sustainable farming in watershed areas. This initiative aims to increase the productivity of degraded lands while promoting more efficient use of land and water resources, contributing to overall environmental sustainability.

India's Five-Pronged Strategy for Soil Conservation- India has adopted a comprehensive five-pronged strategy to address soil conservation, aimed at tackling soil degradation and ensuring long-term agricultural sustainability. The first element of this approach involves promoting

chemical-free soil by encouraging organic farming practices, which reduce reliance on chemical fertilizers and pesticides that can degrade soil health over time. This shift towards organic farming helps preserve the natural balance of nutrients in the soil and minimizes harmful chemical buildup. The second component focuses on enhancing soil organic matter (SOM), which is essential for maintaining soil structure, fertility, and its ability to retain moisture. By increasing SOM through sustainable farming practices, soil becomes more resilient to erosion and other forms of degradation. Complementing this, the third prong emphasizes preserving soil moisture through the implementation of techniques such as mulching, contour farming, and water harvesting. These methods are designed to protect the soil's moisture content, preventing it from becoming dry and susceptible to erosion. In addition to moisture preservation, India is actively working to save soil biodiversity. Efforts are made to maintain and improve the variety of organisms within the soil, which plays a crucial role in nutrient cycling, pest control, and overall soil health. Lastly, the fifth prong of the strategy focuses on mitigating soil degradation and erosion by implementing control measures like afforestation, reforestation, and sustainable land management. These initiatives help restore degraded lands and protect vulnerable soils, ultimately contributing to a more sustainable and productive agricultural system.

International Collaboration on Soil Conservation- India's efforts in soil conservation are strongly supported through partnerships with international organizations, particularly the Food and Agriculture Organization (FAO). The FAO collaborates closely with the Indian government to promote sustainable agricultural practices and strengthen soil conservation efforts. One of the key areas of collaboration is the development of data analytics and forecasting tools in partnership with India's National Rainfed Area Authority. These tools assist vulnerable farmers, particularly in rainfed regions that are prone to soil erosion, by providing them with information to make informed decisions regarding crop choices and land management. Additionally, the FAO plays a significant role in capacity building for farmers through initiatives such as the Deen Dayal Antyodaya Yojana-National Rural Livelihoods Mission (DAY-NRLM). Under this program, the FAO helps train Community Resource Persons, who in turn promote sustainable practices like organic farming and soil health management, along with the establishment of agri-nutri gardens. These efforts aim to empower farmers with the skills needed to maintain soil health and ensure sustainable agricultural practices. The FAO also partners with state governments, working in regions such as Madhya Pradesh, Odisha, and Andhra Pradesh to support agro-ecological transitions. These partnerships focus on implementing soil conservation strategies at the landscape level, ensuring long-term sustainability and resilience against soil erosion. In addition, India's Environment Protection Act of 1986 provides a broader legislative framework that encompasses soil conservation efforts, addressing land degradation and aligning national and international goals to protect this vital resource. India's Environment Protection Act (EPA) of 1986 was enacted after the Bhopal Gas Tragedy to provide a comprehensive framework for environmental protection. Although primarily focused on pollution control, the EPA includes provisions that address land degradation and soil conservation, making it an important legislative tool in India's efforts to combat soil erosion.

Our research represents the first comprehensive attempt to project global soil erosion patterns using the Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP) scenarios for land use and climate change, as outlined by the United Nations Intergovernmental Panel on Climate Change (IPCC). By integrating the latest scientific data, we aim to provide a forward-looking assessment of how climate change and evolving land-use practices will impact soil erosion on a global scale. Focusing particularly on India, where climate change and soil erosion are intricately linked, the study highlights the pressing environmental, agricultural, and socio-economic challenges that arise from soil degradation. Despite India's implementation of several soil conservation initiatives, such as the Soil Health Card Scheme, Pradhan Mantri Krishi Sinchayee Yojana, and the National Mission for Sustainable Agriculture, the country continues to face significant risks related to soil erosion. These programs, while promoting sustainable land management and soil health, are part of a broader national and international effort to mitigate the impacts of climate change. The objective of this research is to provide actionable insights for policymakers, researchers, and land managers by projecting future erosion risks under various climate and land-use scenarios. By examining both global trends and the specific case of India, we aim to inform the development of more effective soil conservation strategies that are resilient to climate change.

I. FACTORS AFFECTING SOIL EROSION

A. The topography

The catchment's terrain influences several elements, including its area and drainage density. Transport capacity and the shear stress on particles due to overland flow velocity are other important considerations [16]. Soil erosion is also affected by the slope. The slope's length, steepness, and contour all have an effect [17]. Many studies have shown that as slope gradients have grown, so has erosion's monetary worth [18].

B. The soil

Erosion is affected by several soil properties, including crust thickness, soil resistance, water content, infiltration capability, and so on. Soil erodibility is described as the soil's sensitivity to erosion factors [15]. Variables in the soil, such as its chemical make-up, physical characteristics, and even its structure and texture, affect how easily it erodes. Soil physical characteristics such as soil bulk density, water-stable aggregates, the water content of the soil, and particle composition may influence soil infiltration capability and shear strength, and hence rill erosion [16]. Soil erodibility [17] may be altered by the number of oxides and organic carbon, which may also affect soil tightness. Clay content, aggregate stability, soil texture, shear strength of soil, and cohesion strength are some of the soil parameters that may be evaluated precisely and used to calculate soil erodibility factors [1]. According to certain studies, soil erodibility may sometimes be estimated from shear strength [18]. Many studies have considered aggregate stability when assessing the erodibility of soil. According to their assessment, erosion prediction was seen as more feasible and simpler to model. [1].

C. The land use

Plants have been shown to slow the rate of soil erosion. Roots continuity, canopy height, and ground cover density increased due to its work. Roots significantly influence the pace of soil erosion by reducing the volume of soil and increasing the flow strength of soil [7]. Vegetation restoration has been widely used to slow water flow and strengthen the soil. It may improve

anti-erodibility, soil infiltration, and soil stability while decreasing erosivity from rainfall, flow speed, and runoff discharge [1].

D. The rainfalls

Raindrop size and location are the most important factors in determining erosion rates. Precipitation's latent energy onto soil erosion is known to be corrosive. The intensity, volume, and duration of rainfall all have a role in the rate and extent of soil erosion [1]. Rain plays several functions, which might affect erosion rates [2]. After crashing into the ground, raindrops convert their kinetic energy into potential flow energy, dramatically enhancing the dissociation of soil and easing its movement. [19].

E. The runoff

Runoff may degrade sediments and transport them directly. From the perspective of the dynamics of overland flow—including the flow pattern, the flow discharge rate, the flow depth, the flow velocity, the flow shear stress, and the flow resistance—it is not difficult to investigate the impacts of runoff functions on soil erosion. Several attempts have been made to estimate erosion quantities using hydraulic flow metrics like the Froude and Reynolds numbers. "Hydraulic features of the ground vary significantly as rills emerge, making rill flow distinct from river flow and overland flow [1]."

F. The tillage system

Erosion on farmland may be affected by a variety of tillage practices. Rill may be triggered by tillage implements, especially those with various cutting instruments and machinery. "Tillage processes have included tillage speed; tillage depth and frequency affect erosion during runoff discharge modification, soil credibility, and soil infiltrations [1]."

II. REVIEW OF LITERATURE

The forces of erosion break apart soil particles and carry them elsewhere. Water may function as an eroding force via raindrop action and surface runoff [17], but wind and ice are other possibilities. Conversely, erosion may be thought of as the process by which material from Earth's surface is removed, whether by wind, water, ice, or gravity. Extremely fast erosion and its risks have existed for over a million years on Earth's geologic timescale. However, modern times have seen a worsening of the issue due to the rising human impact on the environment. Soil erosion monitoring is also a time- and resource-consuming process [18,19].

Furthermore, soil erosion seems to provide a significant risk to human survival [20,21]. Soil degradation includes everything that causes soil's physical, chemical, and biophysical properties to deteriorate. In addition, many soil erosion study metrics have been produced, and it is generally agreed that the eroded land area is the most reliable predictor in this field [22]. Soil erosion, however, is the most important kind of land loss, both locally and internationally, endangering food security and the natural economy of areas [23,24]. Siltation is the result of soil erosion in catchment regions and along the shores of reservoirs and lakes.

Because of this, flood retention may be compromised, and turbidity and hydraulic structure blockage may rise [23]. Reservoir sedimentation is thus mostly attributable to soil erosion brought on by human activities in the watershed. Rivers pick up the sediment and transport it downstream, which may clog up reservoirs. "The volume and composition of sediment [24]

are affected by the drainage basin's geology, geographical character, climate, plant kinds, and land use". Land use is an essential factor that may have either a good or negative effect on the erosion process, as stated by Kastridis and Kamperidou (2015) [25]. Vacca et al. (2000) examined data from three hillslopes with different land uses to determine the effect of land use on runoff and erosion rates. Soil erosion is a constantly changing phenomenon that has far-reaching consequences for humans and the planet, many of which are still poorly understood [27]. Natural habitats, including woods, pastures, and rural ecosystems, degrade due to decreased soil fertility. The rate of soil erosion is used as a metric to evaluate the efficacy and longevity of soil preservation plans [28,29]. In today's world, however, poor soil conditions have a chilling effect on plant growth, threatening the integrity of the local water system and the surrounding vegetation [16].

The degree of soil erosion in a given area may be calculated using a suitable model of the phenomenon. To quantify soil deterioration and erosion risk in environmental planning, erosion modelling is a useful statistical technique [21]. As a result, soil erosion has repercussions not only on the environment and society but also on the economy [30]. (Brath et al., 2002, p. Information regarding the topography, atmosphere, soil, and land use was used in a regional application of RUSLE to determine land use's effect on erosion. Many research [32–35] have used remote sensing and GIS technologies to calculate the amount of soil lost due to erosion in various parts of the globe. Their research has shown that changes in land use significantly impact yearly soil loss. However, research that quantitatively sought to quantify these changes concluded that human impact in causing changes in sediment production was more relevant than climate change [4].

Furthermore, field expertise is required to determine the monetary worth of soil erosion. The soil loss models include the universal soil loss equation (USLE) [36] and the revised universal soil loss equation (RUSLE) [37]. Several studies [38–40] used GIS and remote sensing techniques along with erosion models to anticipate spatial maps of soil erosion risk better and increase the precision of erosion estimates. Also, erosive factors such as water, wind, gravity, and human disturbance play a role in the removal and movement of soil particles throughout the soil erosion process [41,42]. However, soil erosion has severe ecological and economic effects when it happens more rapidly due to human disturbance. Erosion modelling in Niger is challenging because of a paucity of data, particularly soil-related data. Soil erodibility, measured by its k-factor, is an essential yet elusive characteristic in erosion prediction models [43,44]. Despite widespread assumptions about wind and water erosion frequency and their destructive effects on agriculture in the Sahel, no data exist to support these claims [43]. This is why indirect methods are employed to estimate these variables to conduct such investigations [45]. There is still a need for a model that can reliably quantify soil loss due to all forms of erosion at a particular location.

A. Land cover and land use change

Biota, soil, terrain, water, and artificial buildings were the first things that sprang to mind when you heard the word "land cover." Land use, meanwhile, describes why people are digging up all that dirt [46]. So, land use may also be seen as the variable leading to land cover changes.

Expansion of agricultural use, unlawful cutting of trees, and increased urbanisation are all examples of land cover change. Proximate and underlying causes both have a role in causing

shifts in land use. Land cover change is often triggered by physical activity that is close to where it happens; hence this category is called "proximate" or "direct" influences (households or communities). Strengthening proximal factors are underlying forces which occur on a larger scale, such as regional or global reach. Various factors, including politics, technology, society, biology, and physics, may all play a role in its promotion.

Land cover changes may also occur due to processes independent of human activity. Natural causes may also trigger land cover shifts. However, human activity is the primary driver of land cover change. Land use and land cover change as a result of human activities are shown in Figure 1.

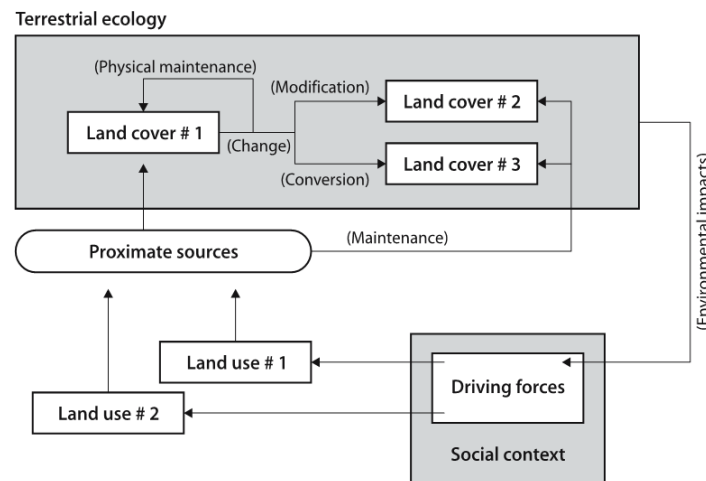


Figure 1. “Link between human activities and land cover/land use change Source[46]”

B. Soil erosion

The processes of dissociation, transport, and deposition lead to soil erosion. It is a risk that has long been connected with farming in tropical and semiarid regions, and it significantly impacts agricultural output and sustainability. The Latin verb "order," meaning "to eat away" or "to dig," is whence we get our modern English term "erosion." Later, the word erosion refers to any process by which water wears away at Earth's surface.

Willcocks [47] distinguished between erosion caused by natural processes and erosion caused by humans. Without human interference, soil production is stable, and erosion is balanced in its natural state (acceptable limit). Soil erosion may have no impact if human activities disrupt agricultural production but are mitigated via conservation measures (nil hazard). "However, the balance may be disturbed if extreme natural occurrences occur, such as high rainfall, an extended period of drought, earthquake, landslide, etc., abnormal erosion can be induced". Erosion rates are amplified when anomalous conditions collide with human-caused ones (such as deforestation, unsustainable agricultural practices, and other forms of earth-moving).

There are two main categories of erosional impacts: local and remote. "The loss of soil, damage to soil structures, the decline in organic matters, loss of soil moisture, which makes the area more prone to drought, reduction of soil fertility, which reduces cultivable land, limits plantation that can be grown, and increases expenditure for fertiliser are all on-site effects." Sedimentation downstream and downwind limits river and ditch capacity, increasing flood risk and soil erosion by breaking down soil aggregates and clods into their natural form of clay, silt,

and sand, which might end up as a contributor to climate change. This process releases carbon stored in sedimentation (soil) into the atmosphere as carbon dioxide (CO₂).

C. Erosion on Land-use/covers

About two-thirds of the world's farmland is used for grazing animals, while the other third is used for growing crops. About eighty per cent of the world's arable land experiences some degree of erosion, and ten per cent experiences moderate to severe erosion. Because the soil in croplands is continuously tilled and left without a protective layer of plants, it is particularly vulnerable to erosion. Overgrazing and subsequent erosion and deterioration of more than half of the world's pasturelands is a serious problem. Rates of soil erosion range from 30 to 40 tonnes per hectare per year in Asia, Africa, and South America, whereas they are only 17 tonnes per year in the United States and Europe, respectively. Rates of erosion in undisturbed woods are low, ranging from 0.004 to 0.05 tons ha⁻¹ per year⁻¹. Since steep slopes are frequently changing from forests to agricultural use owing to the rising human and land deterioration requirements, soil erosion is a major problem on these slopes. Vegetation loss is especially common in developing nations.

In China, over 60% of agricultural residues are collected annually and burnt for energy; in Bangladesh, this number rises to 90%. The Hindu-Kush Himalayas suffer from the same problem. So far, there have been very few investigations on the connection between land use and soil erosion in the Himalayas. There is a plethora of research on natural watersheds (those without land use or cover altered). The most illuminating study is that of the Lesser Himalaya and Shiwalik watersheds [48], which highlighted that the growing quantity of soil loss and run-off was connected to human pressure, deforestation, road cutting, etc. Generally, two tonnes per hectare per year was estimated to be the average soil loss. They calculated that the region's water output had been halved due to agricultural activities and tree felling. Both 9.13 and 4.69 tonnes per hectare were reported to be the average annual suspended loss in two investigations conducted in the Garhwal Himalaya. Run-off and sediment loss were highest in cultivated areas and lowest in the forest-dominated region in the Malay watershed of the Sikkim Himalaya, comprised of five micro-watersheds with varying land uses. Soil loss across micro-watersheds ranged from 0.18 to 5.71 tonnes per hectare per year. Despite their proven effectiveness, development agents, researchers, soil conservationists, and government employees have a widespread failure to recognise or appreciate the significance of indigenous SWC methods [49]. Achieving our goals of learning about indigenous SWC techniques allows us to comprehend farmers' perspectives on the measures [50]. In order to avoid the issue of soil erosion, farmers of the Papung-Ben Khola watershed employed a variety of indigenous SWC strategies, which are sustainably managing their land and food security.

III. SOIL EROSION MODELING

Applying models to evaluating soil erosion provides a chance and a cutting-edge tool for determining what actions should be made to maintain soil, especially at the river or regional levels. Moses[51] Estimates of soil loss in Kenya's catchments due to water erosion have been generated using various soil erosion models, from the straightforward empirical USLE and RUSLE to the more involved process-based European Soil Erosion Model, EUROSEM. Models for predicting the geographical distribution of soil erosion at catchment scale have been

developed thanks to advancements in geographic information systems, remote sensing, and digital elevation modelling.

Catchment zones may be found in a broad range of environmental conditions due to their adaptability to many topographical, geological, agricultural, and climatic factors. Therefore, because the catchment is characterised by a wide range of biophysical factors, estimating soil erosion at the watershed level is challenging. Soil erosion dynamics are further complicated by changes in watershed hydrology that occur at different spatial and temporal scales. The distributed approach considers the spatial variation and interplay of the catchment's land use, topography, and soil quality. Panagos et al. [52] suggested combining a geographic information system (GIS) framework with soil erosion models to address this issue. Long-term land management planning is aided by predictive soil erosion models, which consider both natural agricultural conditions and human activities. However, it is essential to stress that no one model can adequately cover many forms of soil erosion. However, models have been developed to identify potential sites where soil loss may be reduced by implementing a selection of established conservation practices.

Bringing a model's capabilities closer to real-world situations necessitates first simplifying or generalising a catchment's behaviour. Therefore, a raster GIS format accurately portrays the alterations associated with environmental landscape aspects and shows the magnitude to which these alterations occur. In a dynamic landscape, the RUSLE model can smooth out the effects of distance and time. Using a raster GIS to analyse the RUSLE variables requires the creation of separate layers for each region. Because of this GIS framework, the geographical and technological obstacles to the RUSLE model have been removed. The Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) are two of the most widely used soil erosion models that have been applied at the catchment level (RUSLE). Wischmeier and Smith's (1978) USLE empirical model was developed and adjusted for use in the United States and other countries. The Revised Universal Soil Loss Equation (RUSLE) model was developed to forecast soil erosion due to water in temperate settings. However, it was shown to adapt well in the tropics, where no other models had proven effective. The RUSLE empirical model (equation 1), developed from the USLE, offers various advantages. The model predicts annual mean soil erosion rates by considering agricultural trends, management practices, and erosion control strategies. The model may be used to predict soil erosion rates in ungauged catchments if the watershed's characteristics and its hydro-climatic conditions are known. We may estimate annual soil loss by doing a regional analysis of the RUSLE variables and then superimposing the corresponding raster layers [53].

$$A = R K L S C P \quad (1)$$

Using the following variables: annual soil loss (in tonnes per hectare), annual rainfall (in megajoules per square metre), soil erodibility (in hours per megajoule of water), slope length (dimensionless), slope steepness (dimensionless), soil cover and management (also dimensionless), and soil and water conservation practises (also dimensionless).

IV. CONCLUSION

The stability and productive potential of land use/covers are seriously threatened by soil erosion, a severe environmental issue. "More than 10 million hectares of farmland are lost

yearly due to erosion, which has caused a loss of one-third of the world's arable land in the last 40 years.” An important land-use/cover type in the current watershed is rainfed agriculture, intensive cropping techniques on open, unterraced slopes and agroforestry systems. “The open agricultural (cropped) areas in the watershed had the highest overland flow rates and soil loss.” The soil was maintained more effectively in large cardamom-based agroforestry and forest systems than in conventionally farmed open areas. The watershed may need to implement more soil and water conservation measures. Incorporating these measures would aid in preserving soil quality and nutrients, boosting soil fertility and production. “Both giant cardamom and broom grass have stronger soil and water conservation benefits than other crops”. In the case of a large-scale land use shift from forestry to agriculture, these perennial income crops with more conservation potential may be more helpful for massive planting. Consequently, the area requires cutting-edge technological methods of soil and water conservation. U.S. President Theodore Roosevelt issued the warning, "A country that destroys its soils, kills itself," which we should take to heart. Focused policies and acts are essential for effective soil and water conservation in India. A comprehensive national policy, akin to the U.S. Soil Conservation Act, should emphasize sustainable land management practices, soil health monitoring, and restoration initiatives. Incentives for agroforestry systems, particularly those incorporating crops like giant cardamom and broom grass, are crucial due to their proven benefits for soil conservation. Additionally, the government should support sustainable agricultural practices by providing subsidies and training programs on conservation tillage, cover cropping, and crop rotation, which enhance soil fertility and reduce erosion.

Integrated watershed management policies must focus on tailored soil and water conservation measures, ensuring community involvement and the incorporation of traditional knowledge. Increased funding for research into innovative soil and water conservation technologies is critical, including the development of drought-resistant crops and efficient irrigation systems. Public awareness campaigns are also vital to educate farmers and communities about the importance of soil health and sustainable practices. Establishing a robust monitoring and evaluation system for soil health and erosion rates will help assess the effectiveness of these measures. Finally, engaging local organizations and communities in policy formulation and implementation can ensure that strategies are context-specific and widely accepted. By adopting these focused policies, India can effectively combat soil erosion and promote sustainable land use, ultimately safeguarding agricultural productivity and environmental health.

REFERENCES

- [1] J. De Graff. “Soil conservation and sustainable land use: An economic approach” Amsterdam, The Netherlands: Royal Tropical Institute
- [2] P. Panagos, and A. Katsoyiannis, “Soil erosion modelling: The new challenges as the result of policy developments in Europe,” Environmental Research, vol. 172, pp. 470 – 474. 2019.
- [3] Smith D D and Wischmeier W H 1957 Factors affecting sheet and rill erosion Eos, Transactions American Geophysical Union 38 889-896

- [4] Wischmeier W H and Smith D D 1978 Predicting rainfall erosion losses: a guide to conservation planning (No. 537) Department of Agriculture, Science and Education Administration
- [5] Lei T W, Zhang Q, Zhao J and Tang Z 2001 A laboratory study of sediment tran
- [6] J. A. Foley et al., Solutions for a cultivated planet. *Nature* 478, 337–342 (2011).
- [7] L. Montanarella, Agricultural policy: Govern our soils. *Nature* 528, 32–33 (2015).
- [8] N. D. Mueller et al., Corrigendum: Closing yield gaps through nutrient and water management. *Nature* 494, 390 (2013).
- [9] K. Paustian et al., Climate-smart soils. *Nature* 532, 49–57 (2016).
- [10] D. Yang, S. Kanae, T. Oki, T. Koike, K. Musiak, Global potential soil erosion with reference to land use and climate changes. *Hydrol. Processes* 17, 2913–2928 (2003).
- [11] R. Amundson et al., Soil science. Soil and human security in the 21st century. *Science* 348, 1261071 (2015).
- [12] D. A. Robinson et al., Soil natural capital in europe; A framework for state and change assessment. *Sci. Rep.* 7, 6706 (2017).
- [13] M. A. Friedl et al., MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. *Remote Sens. Environ.* 114, 168–182 (2010).
- [14] B. Mora, N. E. Tsendbazar, M. Herold, O. Arino, “Global land cover mapping: Current status and future trends” in *Remote Sensing and Digital Image Processing*, I. Manakos, M. Braun, Eds. (Springer, 2014).
- [15] S. E. Fick, R. J. Hijmans, WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *Int. J. Climatol.* 37, 4302–4315 (2017).
- [16] Mahabaleshwara H and Nagabhushan H M 2014 A study on soil erosion and its impacts on floods and sedimentation *International Journal of Research in Engineering and Technology* 3 443-451
- [17] Li JL, Cai Q G and Sun L Y 2010 Reviewing on factors and threshold conditions of rill erosion *Progress in Geography* 29 1319-1325
- [18] Emmett W W 1978 Overland flow. In: Kirkby M J (ed). *Hillslope Hydrology* John-Wiely and Sons 145-176
- [19] Mhangara, P.; Kakembo, V.; Lim, K.J. Soil Erosion Risk Assessment of the Keiskamma Catchment, South Africa Using GIS and Remote Sensing. *Environ. Earth Sci.* 2012, 65, 2087–2102.
- [20] 20. Ravi, K.K.; Asadi, S.S.; Venkata Ratnam, K. Estimation of Soil Erosion Status for Land Resources Management Using Remote Sensing and GIS: A Model Study from A.P. *Int. J. Mech. Eng. Technol.* 2017, 8, 873–880.
- [21] Atoma, H.; Suryabhadgavan, K.V.; Balakrishnan, M. Soil Erosion Assessment Using RUSLE Model and GIS in Huluka Watershed, Central Ethiopia. *Sustain. Water Resour. Manag.* 2020, 6, 12.
- [22] Hurni, H. Land Degradation, Famine and Resource Scenarios in Ethiopia. In *World Soil Erosion and Conservation*; Pimentel, D., Ed.; Cambridge University Press: Cambridge, UK, 1993; pp. 27–62.
- [23] Maina, C.W.; Sang, J.K.; Raude, J.M.; Mutua, B.M.; Moriasi, D.N. Sediment Distribution and Accumulation in Lake Naivasha, Kenya over the Past 50 Years. *Lakes Amp. Reserv.* 2019, 24, 162–172

- [24] Iradukunda, P.; Bwambale, E. Reservoir Sedimentation and Its Effect on Storage Capacity—A Case Study of Murera Reservoir, Kenya. *Cogent Eng.* 2021, 8, 1917329
- [25] Kastridis, A.; Kamperidou, V. Influence of Land Use Changes on Alleviation of Volvi Lake Wetland (North Greece). *Soil Water Res.* 2016, 10, 121–129.
- [26] Parveen, R.; Kumar, U. Integrated Approach of Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for Soil Loss Risk Assessment in Upper South Koel Basin, Jharkhand. *J. Geogr. Inf. Syst.* 2012, 4, 588–596.
- [27] Yeshaneh, G.T. Assessment of Soil Fertility Variation in Different Land Uses and Management Practices in Maybar Watershed, South Wollo Zone, North Ethiopia. *Int. J. Environ. Bioremedi. Biodegrad.* 2015, 3, 15–22.
- [28] Chen, S.; Zha, X. Evaluation of Soil Erosion Vulnerability in the Zhuxi Watershed, Fujian Province, China. *Nat. Hazards* 2016, 82, 1589–1607.
- [29] Molla, T.; Sisheber, B. Estimating Soil Erosion Risk and Evaluating Erosion Control Measures for Soil Conservation Planning at Koga Watershed in the Highlands of Ethiopia. *Solid Earth* 2017, 8, 13.
- [30] Wynants, M.; Kelly, C.; Mtei, K.; Munishi, L.; Patrick, A.; Rabinovich, A.; Nasser, M.; Gilvear, D.; Roberts, C.N.; Boeckx, P. Drivers of Increased Soil Erosion in East Africa's Agro-Pastoral Systems: Changing Interactions between the Social, Economic and Natural Domains. *Reg. Environ. Chang.* 2019, 19, 1909–1921.
- [31] Brath, A.; Castellarin, A.; Montanari, A. Assessing the Effects of Land-Use Changes on Annual Average Gross Erosion. *Hydrol. Earth Syst. Sci.* 2002, 6, 255–265.
- [32] Ganasri, B.P.; Ramesh, H. Assessment of Soil Erosion by RUSLE Model Using Remote Sensing and GIS - A Case Study of Nethravathi Basin. *Geosci. Front.* 2016, 7, 953–961.
- [33] Fu, B.; Wang, S.; Liu, Y.; Liu, J.; Liang, W.; Miao, C. Hydrogeomorphic Ecosystem Responses to Natural and Anthropogenic Changes in the Loess Plateau of China. *Annu. Rev. Earth Planet. Sci.* 2017, 45, 223–243.
- [34] Tadesse, L.; Suryabhagavan, K.V.; Sridhar, G.; Legesse, G. Land Use and Land Cover Changes and Soil Erosion in Yezat Watershed, North Western Ethiopia. *Int. Soil Water Conserv. Res.* 2017, 5, 85–94.
- [35] El Jazouli, A.; Barakat, A.; Khellouk, R.; Rais, J.; El Baghdadi, M. Remote Sensing and GIS Techniques for Prediction of Land Use Land Cover Change Effects on Soil Erosion in the High Basin of the Oum Er Rbia River (Morocco). *Remote. Sens. Appl. Soc. Environ.* 2019, 13, 361–374.
- [36] Renard, K.G.; Foster, G.R.; Weesies, G.A.; McCool, D.K.; Yoder, D.C. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE); United States Government Printing: Washington, DC, USA, 1997.
- [37] . Kefi, M.; Yoshino, K.; City, T. Evaluation of the Economic Effects of Soil Erosion Risk on Agricultural Productivity Using Remote Sensing: Case of Watershed in Tunisia. *Int. Arch. Photogramm. Remote. Sens. Spat. Inf. Sci.* 2010, 38, 930.
- [38] Yoshino, K.; Ishioka, Y. Guidelines for Soil Conservation towards Integrated Basin Management for Sustainable Development: A New Approach Based on the Assessment of Soil Loss Risk Using Remote Sensing and GIS. *Paddy Water Env.* 2005, 3, 235–247.

- [39] Hacısalihoglu, S.; Oktan, E.; Yucesan, Z. Predicting Soil Erosion in Oriental Spruce (*Picea Orientalis* (L.) Link.) Stands in Eastern Black Sea Region of Turkey. *Afr. J. Agric. Res.* 2010, 5, 2200–2214.
- [40] Leh, M.; Bajwa, S.; Chaubey, I. Impact of Land Use Change on Erosion Risk: An Integrated Remote Sensing, Geographic Information System and Modeling Methodology. *Land Degrad. Dev.* 2013, 24, 409–421.
- [41] . Kefi, M.; Yoshino, K.; Zayani, K.; Isoda, H. Estimation of Soil Loss by Using Combination of Erosion Model and GIS. Case Study Watersheds Tunis. *J. Arid Land Stud.* 2009, 19, 287–290.
- [42] Anache, J.A.A.; Bacchi, C.G.V.; Panachuki, E.; Sobrinho, T.A. Assessment of Methods for Predicting Soil Erodibility in Soil Loss Modeling. *Geociências* 2016, 34, 32–40.
- [43] Chappell, A.; Warren, A.; Taylor, N.; Charlton, M. Soil flux (loss and gain) in southwestern Niger and its agricultural impact. *Land Degrad. Dev.* 1998, 9, 295–310. [
- [44] Panagos, P.; Meusburger, K.; Alewell, C.; Montanarella, L. Soil Erodibility Estimation Using LUCAS Point Survey Data of Europe. *Environ. Model. Softw.* 2012, 30, 143–145.
- [45] . Bonilla, C.A.; Johnson, O.I. Soil Erodibility Mapping and Its Correlation with Soil Properties in Central Chile. *Geoderma* 2012, 189, 116–123.
- [46] Warren, D.M. (1991) Using Indigenous Knowledge for Agricultural Development. *World Bank Discussion Paper*, 127, pp 46.
- [47] Willcocks, T. J., Twomlow, S. J., Ellis-Jones, J. and Critchley. W. R. S. (1992) Conserve Water to Save Soil and the Environment, Project Proposal Document, Overseas Division, AFRC, Silsoe Research Institute, Silsoe, UK.
- [48] Valdiya, K.S. and Bartarya, S.K. (1989) Landslide and erosion in the Catchment of Gaula River, Kumaun Lesser Himalaya, India. *Mountain Research and Development*, 9: 403-419.
- [49] IFAD (1992) Soil and water conservation in Sub-Saharan Africa: Towards sustainable production by the rural poor. Centre for Development Cooperation Services, Free University, Amsterdam
- [50] Hudson, N. (1992) Land Husbandry. B. T. Batsford Limited, London. pp. 192.
- [51] A.N. Moses, “GIS-RUSLE Interphase Modelling of Soil Erosion Hazard and Estimation of Sediment Yield for River Nzoia Basin in Kenya,” *Journal of Remote Sensing & GIS*, vol. 6, issu. 3, pp. 1 – 13. 2017.
- [52] P. Panagos, C. Ballabio, P. Borrelli, K. Meusburger, A. Klik, S. Rousseva, M.P. Tadic, S. Michaelides, M. Hrabalíkova, P. Olsen, L.M. Aalto, A. Rymaszewicz, A. Dumitrescu, S. Begueria, and C. Alewell, “Rainfall Erosivity in Europe,” *Science of the Total Environment*, vol. 511, pp. 801 – 814. 2018
- [53] W.S. Fwamba, S.S. China, and E.N. Masibayi, “Estimation of Spatial Distribution of Potential Soil Erosion Risk in Isiukhu River Catchment, Kakamega County, Kenya,” *International Journal of Engineering Research & Technology*, vol. 6, issu. 7, pp. 159 – 163. 2017.