Soil Erosion Prevention Services provided by the Forests

Chapter 5

Soil Erosion Prevention Services by the Forests

Trees listen to the breeze; & then, rustle its voice so beautifully.

-Summer Crosby & Angie Weiland-Crosby

Introduction

5.1 Forests have a deep cultural connect to civilization and its evolution in the Indian subcontinent. Since time immemorial, forests have been crucial for growth of the mind, a resource base and a sanctuary. Today, a global understanding is slowly emerging that there will be no healthy economy on an unhealthy planet[1]. Environmental deterioration is contributing to climate change, biodiversity loss and the emergence of new diseases. Forests and trees can play crucial roles in addressing these crises and moving towards sustainable economies.

5.2 In India, as per India State of Forest Report 2021[2], the total forest cover is 7,13,789 sq. km which is 21.71% of the total geographical area of the country. The tree cover of the country is estimated as 95,748 sq. km which is 2.91% of the total geographical area. Globally,[3] India has around 2% of the total world forest area. Forests provide a number of benefits to the mankind such as provide food and timber, poverty alleviation, tackle climate change, prevention of land and water degradation, preserving the biodiversity apart from providing the spiritual or the aesthetic pleasure. The major challenge forests pose is the deforestation.

5.3 Evidences suggests that halting deforestation would generate multiple other local and global benefits – such as biodiversity conservation, disaster reduction, the protection of soil and water and the maintenance of pollination services – that far exceed the cost of halting deforestation. It would also increase the adaptive capacity and resilience of people and ecosystems.

[1] https://www.fao.org/3/cb9363en/cb9363en.pdf
[2] https://fsi.nic.in/isfr-2021/acknowledgement-executive-summary.pdf
[3] https://fsi.nic.in/isfr-2021/chapter-1.pdf

Soil Regulation Services Provided by the Forests

5.4 Soil erosion i.e. the process that transforms soil into sediments is one of the major and most widely spread forms of land degradation. It encompasses the destruction of the physical structure that supports the development of plant roots. Moreover, surface soil removal may result in substantial nutrient and water losses, as well as in the decrease of productivity and increase the pollution of surface waterways. Soil erosion thus impacts the sustainability of the ecosystems and the provision of ecosystem services. Soil conservation efforts address concerns with these impacts and aims to meet the increasing needs for food and raw materials.

5.5 Soil erosion by water is linked to desertification processes[4]. Its severity is prone to increase as a consequence of changes in the amount of precipitation as well as in its temporal and spatial distribution under prospective climate scenarios (IPCC 2014a). This will exert further pressure on ecosystems' water balance and thus calls for adequate soil protection and conservation practices in the framework of ecosystems management.

5.6 The degradation of soil quality due to erosion has far-reaching economic implications, as it affects land productivity, water quality, and the overall health of the ecosystem. Estimating soil loss and evaluating its economic impact is crucial for effective land management, sustainable development, and informed decision-making in the fields of forestry and agriculture. The importance of estimating soil loss is given below:

(i) **Land Productivity:** Soil is a vital resource that supports plant growth, nutrient cycling, and water retention. Erosion reduces the topsoil layer, which contains essential nutrients and organic matter. Estimating soil loss helps to quantify the degradation of land productivity over time.

(ii) **Water Quality:** Soil erosion can lead to sedimentation of water bodies, impairing water quality and affecting aquatic ecosystems. Estimating soil loss helps to assess the potential impact on water resources and the cost of treating water for consumption.

(iii) **Economic Loss:** Soil erosion leads to direct economic losses through reduced crop yields, increased maintenance costs, and decreased land value. Accurate estimation of soil loss provides a basis for evaluating the monetary impact on agriculture and forestry sectors.

[4] file:///C:/Users/SSD/Downloads/s40663-020-00247-y.pdf

(iv) **Environmental Degradation:** Erosion can result in the loss of biodiversity, disruption of ecosystem services, and degradation of habitats. Estimating soil loss helps in understanding the broader ecological consequences.

5.7 The main factors influencing the amount of loss due to soil erosion are:

(i) **Soil Structure-** Soils with a medium to fine texture having low level of organic matter content and possessing a weak structural development are most easily eroded. Typically, these soils have low water infiltration rates and therefore are subject to high rates of water erosion and are easily displaced by wind.

(ii) **Status of vegetative cover-** Land areas covered by plant biomass, living or dead, are more resistant to wind and water soil erosion and experience relatively little erosion because rain drops and wind energy are dissipated by the biomass layer and the topsoil is held together by the biomass.

(iii) **Land Topography-** The topography of a given landscape, its rainfall and/or wind exposure all combine to influence the land's susceptibility to soil erosion.

5.8 Trees are widely known to impact the ecosystem's hydrological cycle and resultant water availability and quality. As vegetation cover plays a crucial role in erosion and runoff rates, afforestation is considered among the best options for soil conservation. Water-related forest ecosystem services include the provision, filtration and regulation of water, along with stream ecosystem support and water-related hazards control, e.g., soil protection from erosion and runoff. In this context, forest management practices that involve vegetation cover modifications may have a substantial impact on the provision of water-related ecosystem services. Moreover, forest ecosystem's interactions with water and energy cycles have been highlighted as the foundations for carbon storage, water resources distribution and terrestrial temperature balancing. Forest management thus plays a vital role in meeting climate change mitigation goals.

5.9 An important ecosystem services provided by the forests/croplands is the soil erosion prevention services, thereby mitigating several of the negative impacts of soil erosion. To begin the assessment, the first step is to evaluate the erosion that would occur when vegetation is absent and therefore no ecosystem service is provided. SEEA EA suggests taking bare land as the baseline scenario depicting the absence of any ecosystem and thereby denoting the maximum potential soil loss. The soil erosion in the presence of the ecosystem is then compared with the baseline scenario to quantify the SEP services. The choice of bare land as the baseline may be considered appropriate for natural vegetation such as forests and grasslands. The potential soil erosion in a given place and time is related to rainfall erosivity (i.e. the erosive potential of rainfall), soil erodibility (as a characteristic of the soil type) and local topography. Although external drivers can have an effect on these variables (for example, climate change), they are less prone to be changed directly by human action. The actual ecosystem service can then be determined by the difference between the soil erosion that occurs in two scenarios- in the presence of the ecosystem and in the absence of the same.

Revised Universal Soil Loss Equation (RUSLE)

5.10 The empirical soil loss model called the Revised Universal Soil Loss Equation Model (RUSLE), designed to predict long-term annual averages of soil loss, has been widely-used and applied around the world due to its relative simplicity and low data requirements compared to more complex soil erosion models. RUSLE is the most commonly used method for estimating soil erosion, and its input variables, such as rainfall erosivity, soil erodibility, slope length and steepness, cover management, and conservation practices, vary greatly over space. RUSLE offers a systematic methodology to estimate soil loss rates across diverse landscapes. The spatial erosion maps can serve as a useful reference for deriving land & forest planning and management strategies and provide the opportunity to develop a decision plan for soil erosion prevention and control in the country.

5.11 It is a multiplicative model that uses the information about the rainfall, topography, soil, land use and cover and support practices to estimate terrestrial rill/inter-rill erosion by the equation given below:

$$\boldsymbol{A = R * K * L * S * C * P}$$

where

A= Mean annual soil loss (metric tons/ ha/ year)

R= Rainfall erosivity factor (megajoules millimeter hectare / hour/ year)

K=Soil erodibility factor (metric tons hectare hour hectare/ megajoules/millimeter)

L= Slope-length factor (unit-less)

S= Slope-steepness factor (unit-less)

C= Cover and management factor (unit-less)

P= Support practice factor (unit-less)

5.12 A brief description of each of the factors used in the model for the RUSLE equation is provided in the following paragraphs:

(i) **Rainfall Erosivity (R) Factor:** This factor accounts for the erosive power of rainfall in the area. It is often calculated using rainfall intensity and distribution data. Rainfall data can be collected from local weather stations or interpolated from regional rainfall datasets.

(ii) **Soil Erodibility (K) Factor:** Soil erodibility represents how susceptible a particular soil type is to erosion. It depends on soil properties such as texture, structure, organic matter content, and permeability. Soil data can be obtained from soil surveys or databases.

(iii) **Slope Length and Steepness (LS) Factor:** This factor considers the combined effect of slope length and slope gradient on erosion. It is calculated based on the topography of the area. Digital elevation models (DEMs) can be used to determine slope characteristics.

(iv) **Cover and Management (C) Factor:** The C factor accounts for the land cover and management practices in the area. It quantifies the effect of vegetation and ground cover in reducing soil erosion. Different land cover types have different C values, and the factor can be adjusted based on conservation practices in place.

(v) **Support Practice (P) Factor:** The P factor represents the effectiveness of erosion control practices applied to the land. It accounts for the presence of terraces, contour farming, and other erosion control measures.

5.13 Geographic Information Systems (GIS) provide the spatial framework needed to implement RUSLE effectively. GIS technology allows the integration, analysis, and visualization of diverse geospatial data layers, enabling a comprehensive understanding of the spatial distribution of soil erosion risk. The capability to overlay various data sets—such as rainfall patterns, soil types, slope gradients, land cover and management practices, enables a holistic assessment that considers the intricate relationships between these factors.

5.14 National Statistical Office (NSO) of Ministry of Statistics and Programme Implementation (MoSPI) in collaboration with The Soil & Land Use Survey of India (SLUSI) under Integrated Nutrient Management (INM) division of Ministry of Agriculture and Farmers' Welfare attempted an assessment of the impacts of forest ecosystem on soil erosion protection, as presence of vegetation cover impacts soil erosion over the long-term. The Soil & Land Use Survey of India (SLUSI) is the apex organization in the country which deals with Soil Survey and Land Resource Mapping. SLUSI is primarily engaged in conducting soil survey of different intensities in order to provide scientific database for developmental programs encompassing soil and water conservation planning, watershed development, scientific land use planning etc.

5.15 The main objective of the analysis presented in the chapter is to estimate the soil erosion prevention service of the Forest Ecosystem by exploring the scenario of Soil Erosion Prevention Service in comparison to bare lands for two districts of India- Gondia in Maharashtra and Balrampur in Chhattisgarh on a pilot basis for the year 2021. The main reason behind the selection of these districts was that in both these districts the area under the forest cover is more than 50% of the area of the districts. It has been assumed that the changes in the land use land cover have not been significant since 2015. (Last available data of NRSC that has been used for the analysis is for the year 2015-16).

5.16 In order to assess the regulating Ecosystem Services, provided by the forests to mitigate the soil loss, first the soil erosion owing to the local climate, topography and soil characteristics with no vegetation present is estimated; i.e. the erosion that would occur in the absence of the associated ecosystem services provided by the forests. Thereafter, soil loss is estimated in the presence of the forests and the difference of these is the estimate of the 'Soil Erosion Prevention Services' provided by the forests.

Data Sets Used

5.17 The data sets used in the estimation of the soil erosion prevention services by the forest are summarized in **Table 5.1** below. Most of these datasets are spatial data (raster and feature classes/shapefiles) that can only be viewed within the ArcMap or ArcCatalog interface.

Table 5.1: Summary of the sources for the input data used

Input	Dataset	Source	Resolution
Digital Elevation Model **Format: raster**	CARTOSAT_1 DEM (30 mts vertical resolution) downloaded BHUVAN Portal	Indian Space Research Organization (ISRO))-CARTO-DEM	**~30 meters**
Soil data (K value) **Format: raster**	Soil resource Mapping layer (1:50k scale) harmonized with 1:50k soil dataset (Entire district)	Harmonized Data of Soil and Land use Survey of India & National remote Sensing Centre (SLUSI & NRSC-ISRO)	**1.5 arc-second (~.05km at equator)**
Land cover data (NRSC 2015-16) **Format: feature layer (same as shapefile)**	Land Use Land Cover datasets NRSC 2015	NRSC-ISRO	**1:50k scale**
Rainfall erosivity (R- factor) **Format: raster; ESRI grid**	Global Rainfall Erosivity-2017	Panagos etal. (2017) https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity	**30 arc-second (~1km at equator)**
Masks of the study area **Format: shapefile**	District Boundary Datasets	Admin layer from NIC and SOI	**1:50K scale**
K-factor dataset (Stewart 1975) (K-values used here are expressed in SI metric units. To convert to the SI metric unit, it was multiplied by 0.1317)		**Harmonized Soil data (NRSC & SLUSI) localdataset** **https://mepas.pnnl.gov/mepas/formulations/source**	
C-factor dataset ((November 2022) [Normalized Difference Vegetation Index (NDVI) in forest land cover]		**NDVI based C-values in forest land as per vegetation cover derived from LISS -III, Resourcesat-2 Data, Nov-2020**	

5.18 For the analysis, the software used on LUCI_SEEA[5] is ArcMap 10.4 and the computation of soil loss using RUSLE has been done using two processes listed in the tool- Pre-process data and calculate soil loss (RUSLE).

Assumptions of the Study

5.19 Assessing soil loss using the Revised Universal Soil Loss Equation (RUSLE) with remote sensing and GIS involves several assumptions and considerations. Detailed key assumptions in respect of RUSLE model are given below:

i. **Steady-State Conditions:** RUSLE assumes that the landscape is in a relatively steady-state condition, meaning that soil, land cover, and climate factors remain relatively constant over the assessment period. In the present study, the land use categories in the two scenarios assumes a fairly steady distribution of forest over the entire area of the district.

ii. **Correlated Rainfall:** It assumes a uniform rainfall distribution across the study area, the values of which are correlated with the averages from the last few decades. Varying precipitation patterns in different places in the district have not been taken into account.

iii. **Constant Slope:** In the present study, the DEM data from NRSC -ISRO has been used for measuring slope angles by assuming that that slope does not change much over time. It does not take into account the changes in slope due topographical changes owing to erosion or human activities.

iv. **Homogeneous Soil Properties:** It assumes uniform soil properties across the study area although variability in soil types and properties can significantly affect erosion rates.

v. **Conservation Practices:** In the present study, it is assumed that conservation practices (e.g., terracing, contour farming) are not in place. If such practices exist, they should be duly considered in the erosion assessment.

vi. **Time Scale:** RUSLE typically assumes a long-term erosion rate, usually on an annual basis. Short-term weather events like storms can lead to more erosion than the long-term average suggests.

vii. **Forest Definition**: In the current study the Forest Area has been taken from the NRSC-Land Use Land Cover data which includes all patches with canopy

[5] https://www.lucitools.org/using-luci/

density of more than 10% greater than 0.5 hectares in size, which are not categorized under any other predominant land use. This differs from the definition used by the Forest Survey of India (FSI) which includes all lands having trees more than 1 hectare in the area with tree canopy density of more than 10% irrespective of ownership, legal status of the land and species composition of trees. The estimates do have a chance of improvement if the Forest cover from FSI is used for the analysis. The note detailing the conceptual differences in the definition of 'forests' across India's official data sources is provided in Annexure 5.1.

5.20 Similarly, assumptions in respect of use of remote sensing and GIS are given below:

i. **Remote Sensing Data:** Remote sensing data, such as LISS III sensor satellite imagery from Resourcesat satellite and CARTO-DEM (30 mts.) downloaded from BHUVAN-ISRO portal have been used to gather information about land cover, land use, and vegetation. Assumptions here include the accuracy and availability of remote sensing data for the study area.
ii. **GIS Data:** Geographic Information Systems (GIS) are used to integrate and analyze various spatial data layers, including topography, land use, and soil types. Assumptions include the quality and availability of GIS data.
iii. **Spatial Variability:** Remote sensing and GIS help capture spatial variability within the study area, which can be crucial for accurately estimating erosion rates. However, due care has been taken while making assumptions about the spatial distribution of erosion factors.
iv. **Scale:** The scale of remote sensing and GIS data must match the scale at which erosion is being assessed. Assumptions about scaling and the representativeness of data at different scales are important. In the present study, the availability of information in a single resolution is ensured through downscaling/upscaling of various data.
v. **Data Accuracy:** Assumptions are made regarding the accuracy of remote sensing and GIS data, as errors or inaccuracies can propagate into erosion estimates.

5.21 Assessing soil loss using RUSLE with remote sensing and GIS involves some other assumptions, including those related to the natural environment, data accuracy, and the technology itself. Careful consideration of these assumptions and potential sources of error have been worked out in order to generate reliable erosion estimates.

Gondia District, Maharashtra

5.22 Gondia district is located in the north-eastern part of the state of Maharashtra with topographic features including a mix of flat and undulating terrain with forested areas, agricultural lands and water bodies. The land use in Gondia district includes agricultural activities, forested areas and settlements. The district has various soil types contributing to its agricultural productivity and also potential for erosion. The district has a mix of forest types including:

- **Tropical Moist Deciduous Forests:** These forests are characterized by a variety of deciduous tree species that shed their leaves during the dry season. Teak, Sal, Tendu, and Bamboo are common species found in these forests.
- **Bamboo Forests:** Bamboo is a prominent component of many forests in Gondia district. Bamboo is used for various purposes, including construction, handicrafts, and as a source of income for local communities.
- **Mixed Forests:** The district also has mixed forests with a combination of both deciduous and evergreen species.

5.23 For the current analysis, as far as the geographic area of Gondia district is concerned, the date range November (post-monsoon) has been taken.

Results

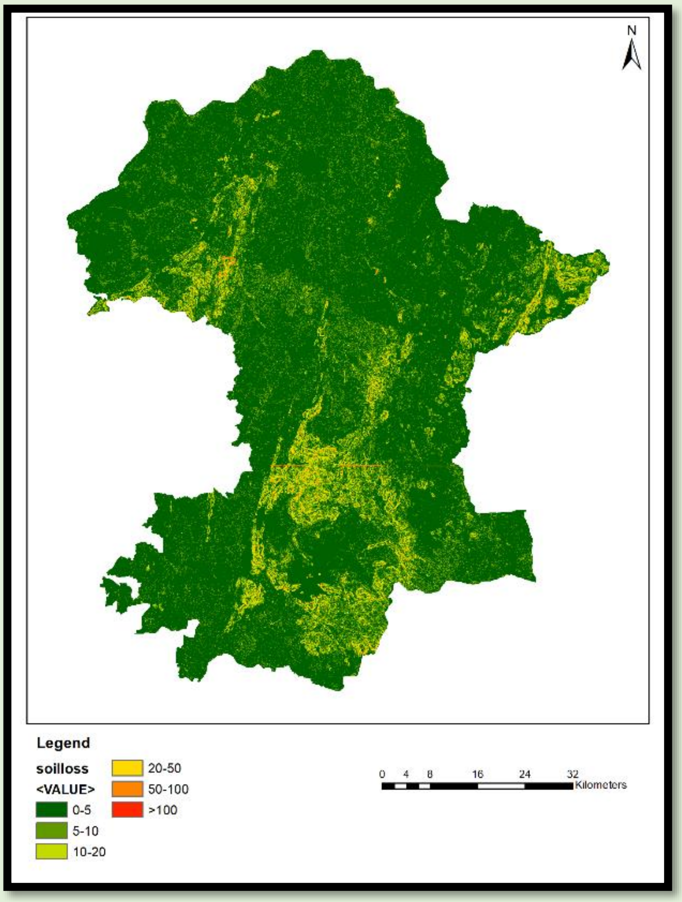
5.24 The analysis of the distribution of the soil loss in the Gondia districts indicates that a major part of the district area shows very low, low and medium soil loss (83.5%). Moderately high loss categories cover around (9.75%) land area while 6.88% area shows high to very high loss categories in the district. The distribution of area under different soil loss categories is presented in the **Table 5.2** below. The spatial distribution of the soil loss in the Gondia district of Maharashtra is shown in the **Map 5.1.** In the presence of various ecosystem cover, the estimated soil loss lies in the range varying from 0 - 113 T/Ha/year.

Table 5.2: Distribution of area under different soil loss categories (Tonnes/hectare/year)

Soil Loss Classes	Area (%)	Area hectare
0 - 5	39.74	208,541.90
5 - 10	25.27	132,670.05
10 - 20	18.36	96,333.17
20 - 50	9.75	51,203.74
50 - 100	3.65	19,200.65
>100	3.23	16,861.30
Total	**100**	**5,24,810.84**

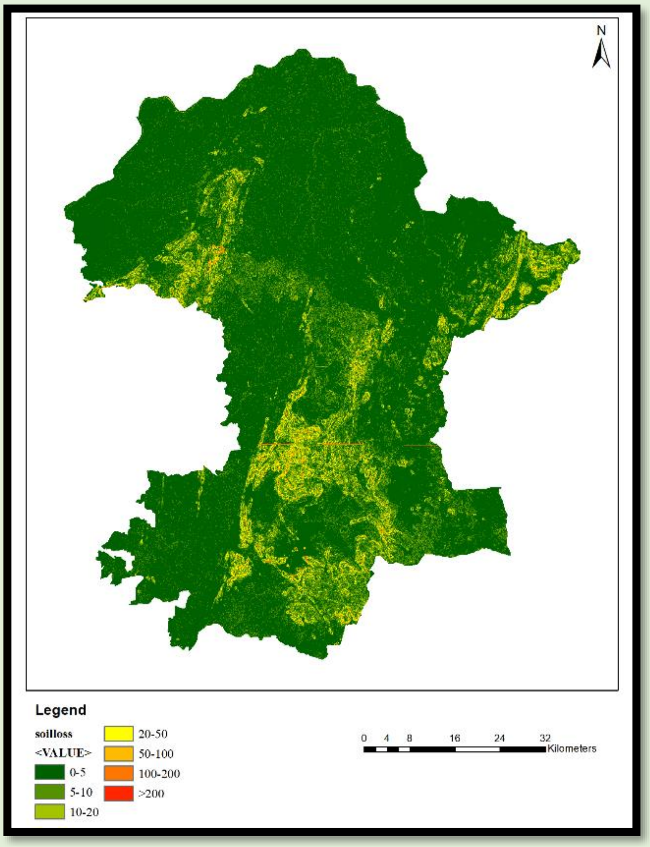
Values calculated with the support of SLUSI

Map 5.1: Distribution of Soil Loss in presence of various ecosystem in Gondia



5.25 The spatial distribution of the soil loss under the scenario of bare land (C=1) in Gondia district of Maharashtra is shown in the following **Map 5.2**. Under this scenario the estimated soil loss ranges between 0 -227 Tonnes/ Ha/Year.

Map 5.2: Distribution of Soil Loss under Bare Land Scenario in Gondia



Balrampur District, Chhattisgarh

5.26 Balrampur district is located in the Northern part of the state of Chhattisgarh in Central India with topographic features including a mix of flat and undulating terrain with forested areas, agricultural lands and water bodies. The land use in Balrampur district includes agricultural activities, forested areas and settlements. The district has various soil types contributing to its agricultural productivity and also potential for erosion. The district has a vast range of forests. These forests play a very important role in the economy of the district. There are different types of flora available in the district like Saja, Sal, Mango, Mahua, Sisham, Gamhar, Harra, Jamun, Tendu, Khair, Kusum, Imli, Bija, Aurjun, Sandan, Palas and others.

5.27 For the current analysis, as far as the geographic area of Balrampur district is concerned, the date range November (post monsoon) has been taken.

Results

5.28 The analysis of the distribution of the soil loss in the Balrampur districts indicates that a major part of the district area shows very low, low and medium soil loss (99.59%) under the presence of ecosystem cover and moderately high loss categories covers around (0.37%) land area, whereas, around 0.03% area shows high to very high loss categories in the district. The distribution of area under different soil loss categories are presented in the **Table 5.3** below. The spatial distribution of the soil loss in the Balrampur district of Chhattisgarh is shown in the **Map 5.3.**

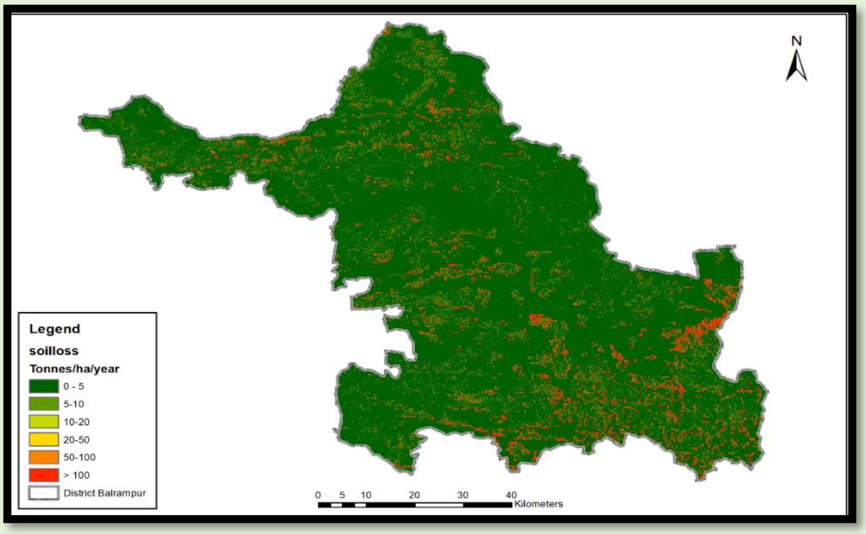
Table 5.3: Distribution of area under different soil loss categories (Tonnes/hectare/year)

Soil Loss Classes	Area (%)	Area in Hectare
0-5	95.98	6,02,336
5-10	2.58	16,249
10-20	1.02	6,409
20-50	0.38	2,378
50-100	0.028	174
100-200	0.003	16
200-300	0	0
Total	**100**	**6,27,562**

Values calculated with the support of SLUSI

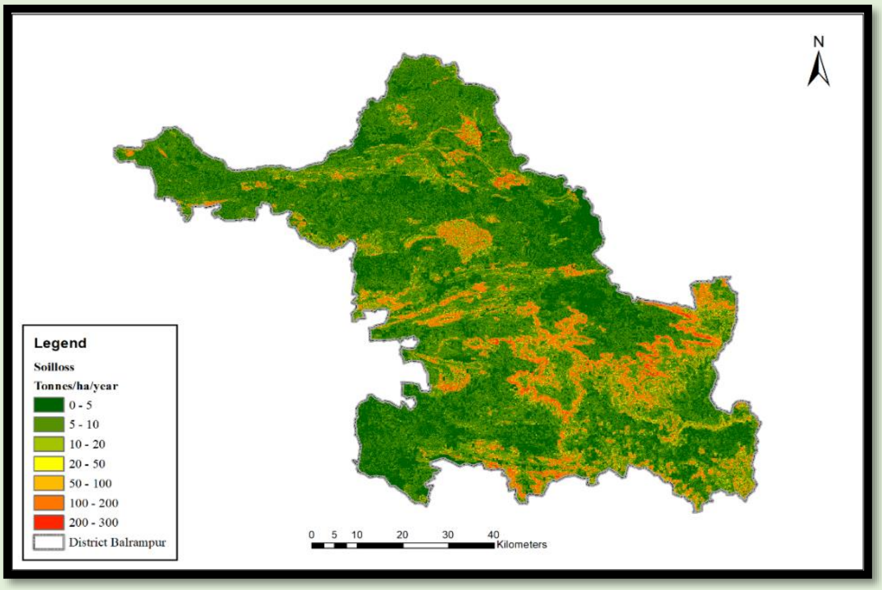
5.29 The spatial distribution of the soil loss in the Balrampur district of Chhattisgarh is shown in the **Map 5.3 as** given below:

Map 5.3: Distribution of Soil Loss in presence of various ecosystem in Balrampur



5.30 The spatial distribution of the soil loss under the scenario of bare land (C=1) in the Balrampur district of Chhattisgarh is shown in the **Map 5.4 as** given below:

Map 5.4: Distribution of Soil Loss under Bare Land Scenario in Balrampur



5.31 The estimates of soil loss under scenario of land use being 'bare land' and land use being 'forests' along with the soil erosion prevention services provided by the forests has been shown in the Table 5.4 below.

Table: 5.4 Estimates of Soil Erosion Prevention Services by Forests

Sr. No.	District	Soil Loss (Bare Land Scenario) (Tonnes/Ha/Year)	Soil Loss (Forests) (Tonnes/Ha/Year)	Estimates of Soil Erosion Prevention Services by Forests (Tonnes/Ha/Year)
1.	Gondia	5.79	2.89	2.9
2.	Balrampur	33.18	0.83	32.5

Values calculated with the support of SLUSI

5.32 The high SEP in Balrampur may be attributed to high potential soil loss under no vegetation cover due to steep slope in hilly areas and low soil loss due to thickly forest cover.

Limitations of the Study

5.33 The limitation of the study on soil erosion prevention services by the forest in Gondia District, Maharashtra and Balrampur District, Chhattisgarh are given below:

i. **Validation Challenges:** It can be challenging to validate RUSLE predictions with ground- truth data, making it difficult to assess the accuracy of the model's results.

ii. **Uncertainty:** Like all models, RUSLE has inherent uncertainties due to data errors, assumptions, and natural variability. Users should be cautious about interpreting results without considering these uncertainties.

iii. **Hydrological Factors:** RUSLE primarily estimates sheet and rill erosion but does not explicitly consider hydrological factors. In areas with significant runoff or complex hydrology, additional modelling may be necessary.

iv. **Vegetation Dynamics:** Changes in vegetation cover and density can affect erosion rates, and RUSLE may not capture these dynamics adequately.

v. **Model Calibration:** Calibration of RUSLE parameters can be challenging, and the choice of parameters can impact the accuracy of the model's predictions.

5.34 In summary, while RUSLE with RS and GIS are a valuable tool for soil erosion assessment, it is not without limitations. Users should consider these while interpreting and using the results. Combining RUSLE with other erosion models, ground- based measurements, and local knowledge can help improve the accuracy of erosion assessments, especially in complex or changing environments.

Conclusion

5.35 Human activities, severe climatic events, fire, pests, diseases and other environmental disturbances may degrade forests and thereby reduce the provision of forest goods and services, biodiversity values, productivity and health. Forest degradation may also negatively affect other land uses (e.g. by causing a loss of downstream water quality and affecting groundwater recharge) and cause the emission of greenhouse gases (GHG). With the population growing at a rapid pace, more and more forest land is converted into cropland to address the dietary requirements.

5.36 It is important to understand the fact that the Forest Ecosystems provide a number of services to mankind and the soil erosion prevention services is one such service. The forest pathways can contribute to building inclusive, resilient and sustainable economies. Doing so optimally will require shifts in policies to maximize synergies among the pathways and between agriculture and forestry across agri-food systems and to encourage private-sector investments.

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