Soil Erosion Prevention from Croplands- A Service or A Disservice?

Paper submitted by Ruchi Mishra[1], Sudeepta Ghosh[2] and Rakesh Kumar Maurya[3], NSO, India for the 29th London Group on Environmental Accounting

Abstract

Estimation of the 'soil erosion prevention services' is based on a counterfactual scenario of 'no service supply', and in the case of croplands, as per SEEA, bare land has been suggested to be taken as the counterfactual land cover. The method of estimation compares actual erosion rates to those for bare land, assuming the same soil type and erosivity, slope characteristics, rainfall characteristics and land management factors, with the bare land representing the worst-case scenario and maximum potential erosion rate. While bare land may be taken as a baseline case for evaluating soil erosion prevention services provided by natural habitats such as natural grasslands and forests with no anthropogenic influence, that may not be the case for croplands. Since the land would have been converted to provide cropland for the local population, there would still be natural vegetation in the absence of this conversion. Therefore, the most plausible counterfactual scenario would be land covered by natural habitat.

This paper attempts to highlight that in the steps leading to the estimation of ecosystem service flows, the choice of counterfactual scenario should be the starting point, lest a positive value is accorded to a likely 'disservice'.

[1] Deputy Director, Email: mishra.ruchi@gov.in
[2] Director, Email: sudeepta.ghosh81@nic.in
[3] Deputy Director General, Email: rakesh.maurya@gov.in
The views expressed in the article are authors' personal and not that of Government of India.

1. Introduction

1. The concept of ecosystem services, even though existing since ages, has gained the attention of policymakers in recent years. The ecosystem services are any benefits that are derived by humans and societies from the ecosystems. These are the contributions of the ecosystems to the benefits. Cropland Ecosystem is an important ecossytem providing multitude of services such as food production, air regulation, soil and water conservation, environmental decontamination, carbon sequestration etc. In terms of the SDGs, reaching the SDG targets simply will not be possible without a strong and sustainable agricultural sector. Along with its direct impact on hunger and malnutrition, management of our food system is also linked to other development challenges being addressed in the SDGs

2. One of the prime requirements for the cropland is the presence of soil. The daily needs of crops, fodder among others can only be fulfilled efficiently in the presence of healthy soil ecosystem. Soil is linked with several ecosystem services such as providing food, feed, fiber, wood, regulating carbon sequestration, supporting human habitat, regulating water and nutrient cycle etc. (Adhikari & Hartemink, 2016).

3. With the changing climatic conditions, this ecosystem can face multidimensional threats (Pal et. al. 2021) such as reduction in carbon capture and storage, high erosion rates dues to intensified rainfall for short duration, climate driven land use land cover change etc. In addition, with the growing population dynamics, there is a growing need for more and more land for crops and other pursuits which degrades the soil and makes soil erosion more likely. Soil erosion generally means the destruction of soil by the action of natural phenomena (e.g., water, wind, and snow) and man-made factors (e.g., intensive and extensive agriculture). Erosion of soil is viewed as a serious problem not only in India but globally too (Garcia-Ruiz et al., 2015; Pimentel & Burgess, 2013). The loss of soil from land surfaces by erosion is widespread and reduces the productivity of a number of ecosystems including croplands and forests. Soil erosion is the major constraint to agriculture that affects yield production and environmental sustainability (Ahmad et.al., 2020). Soil erosion in agricultural fields, does not only affect plant growth but also pollutes nearby waterbodies through sediment runoff.

4. The problem of soil erosion in the Indian context has been discussed along with possible mitigation strategies by several researchers. Narayan & Babu, 1983 provided the estimates of annual rates of soil erosion and percentage of soil dislocated and lost in sedimentation. Singh et.al., 1992 estimated soil loss using universal soil loss equation and deduced that annual erosion rate due to water is less than 5 Mg/ha/yr (2.2 tons/acre) for dense forest (above 40% canopy), cold desert regions, and arid regions of India. Dabral et.al., 2008 estimated the annual soil erosion rates to be 51 t/ha/year for selected hilly catchment in north eastern region, India. Mandal & Giri highlighted some policy initiatives that are linked to soil erosion in India. Pal et.al., 2021 in their

study attempted to highlight that climate change and anthropogenic land use are the main factors of soil loss in India. Other notable studies have provided spatial and quantitative information on soil loss in India (Jasrotia & Singh, 2006; Chatterjee et.al., 2014; Sharda et.al., 2013; Prokop & Poręba, 2012; Singh & Panda, 2017). The Department of Land Reforms, Government of India has several initiatives such as Integrated Watershed Management Programme in place which not only focuses on the assessment of land degradation due to erosion but also suggests some preventive measures such as regeneration of natural vegetation and rainwater harvesting which reduces soil erosion[4,5].

5. The impact of LULC on soil erosion has been well-documented in numerous studies. Globally, agricultural land yields the highest erosion rates, and shrubs or pastures show relatively low soil loss (Garcia-Ruiz et al., 2015). In contrast, bare land had the highest soil loss, followed by cropland, orchard, grassland, shrubland and forestland (Xiong et al., 2019).

6. To manage the off-site and on-site effects of soil erosion, researchers have assessed and suggested various control practices such as land management through tillage operation, mulching, cover crop etc. Ahmad et.al. (2022) systematically reviewed the literature to study the control practices that have been taken and tested to control soil erosion on agricultural land in Asia focusing on land management practices. The vegetation especially crop canopy provides protection against soil erosion.

7. With globalization and growing urban population, the croplands are being expanded to fulfil the need for food and fodder. Soil erosion and associated damage to agricultural land over many years have resulted in losses in cropland due to abandonment and reduced productivity of the remaining land. This loss of cropland often results in the creation of new cropland out of forests and pastureland and there arises the need to enrich these new croplands with inputs of nitrogen and phosphate fertilizers. In addition, soil erosion reduces the valuable diversity of plants, animals and soil microorganisms.

8. It is generally assumed that croplands are being converted from fertile lands such as forests to fulfil the needs of the growing population and had it not been the cropland there would have been natural vegetation on that land. Meiyappan et.al. (2017) concluded that cropland was the major source of forest conversion, contributing to ~39% of gross forest loss in 1985–1995, and ~35% during 1995–2005.

9. This paper attempts to see the soil erosion prevention services of the croplands from two perspectives, first when the baseline land cover is bare land and the second when the baseline land

[4] https://dolr.gov.in/sites/default/files/DoLR%20Activities%20version-2%2017-Mar-2016.pdf

[5] https://dolr.gov.in/en/programme-schemes/pmksy/watershed-development-component-pradhan-mantri-krishi-sinchai-yojana-wdc-pmksy

cover is forests or scrublands. The two scenarios are compared to see if the 'prevention of the soil erosion' service provided by the croplands is a service or a disservice as the baseline scenario changes.

2. Soil Erosion Prevention Services by Croplands: Service or Disservice

10. One of the ecosystem services supplied by the vegetation is the effect of vegetation cover on mitigation of soil erosion that makes it an effective tool in preventing the adverse effect of soil erosion. Vegetation cover plays very important role on protecting the soil surface from raindrop splashing, increasing soil organic matter, soil aggregate stability, water holding capacity, hydraulic conductivity, retarding and reducing surface water runoff, etc. However, this protection against soil erosion depends on several factors including type of vegetation cover, its density and other characteristics. The vegetation cover having less density will be less effective in preventing soil erosion in comparison to highly dense vegetation cover due to the presence of more bare soil exposed to erosion under these vegetation covers.

11. System of Environmental Economic Accounting (SEEA) defines Soil erosion control services as the ecosystem contributions, particularly the stabilizing effects of vegetation, that reduce the loss of soil (and sediment) and support use of the environment (e.g., agricultural activity, water supply)[6]. The factors affecting this ecosystem service are mainly topology; geology and soil type; type and condition of vegetation, especially structural state, rainfall patterns etc. The SEEA Ecosystem Accounts discusses that determining the baseline of no service supply independent of any land cover is difficult for estimation of Soil Erosion Prevention (SEP) services. To quantify the SEP services, such an approach is followed which compares actual erosion rates to those for bare land where the erosion rate in bare land is the maximum potential erosion rate (a worst-case scenario) in a given ecosystem, assuming other factors such as soil type and erosivity, slope characteristics, rainfall characteristics and land management factors as constant. Thus, the service supply is defined as the reduction in erosion rates compared to bare land and the baseline needs to be bare land since it represents the situation in which there is no ecosystem service (SEP service) supply.

12. As established above, the soil erosion prevention services can vary for different vegetation cover. Crops, serving as vegetation cover, provide protection against soil erosion for the land under crop cover. The croplands may provide protection against soil erosion compared to some of the other land cover categories but other practices such as tillage, ploughing associated with farming may contribute to soil erosion. In fact, soil erosion could be largest without proper management practices (Chen et.al., 2021). Studies suggest that soil erosion are relatively lower for vegetation

[6] https://seea.un.org/sites/seea.un.org/files/documents/EA/seea_ea_white_cover_final.pdf

cover having dense canopy such as forests and shrublands (Kumar & Hole, 2021; Shreshta, D.P., 1997). The agricultural plants such as rubber, coffee, palm oil etc. often cannot hold onto soil and sometimes can worsen the soil erosion. (Neyret, M. et.al., 2020) demonstrated that afforestation by rubber plantation is overall detrimental to soil conservation.

13. The soil erosion prevention services of crop cover would be service or disservice based on the fact that which type of land cover is being taken as the baseline condition. In other words, the soil erosion prevention services would be an ecosystem service if it positively contributes in mitigating the Soil Erosion owing to the structural impact. If due to change in land use, the land cover becomes more prone to erosion, then it will be a disservice of existing ecosystem rather than service.

3. Conceptual Background

14. In the current paper a comparison of the SEP services of croplands have been made under two baselines- bare land and forest lands. The conceptual approach for the same is provided in the subsequent paragraphs. The SEP is estimated for land cover categories for the State of Telangana of India for illustration.

15. First, the structural impact of soil erosion owing to the topography, (Guerra, Pinto-Correia, & Metzger, 2014) rainfall and soil structure of the land is assessed. The structural impact is defined as the erosion that would occur when vegetation is absent and therefore no ecosystem services of the vegetation cover is provided. This erosion is solely depending on the structural characteristics of a given place at a time and represents the potential soil erosion capacity. Although these factors are not entirely free from anthropogenic activities but these activities may affect them indirectly and the impact may not be visible immediately.

16. The erosion prevention service of vegetation cover be it cropland, forests or shrubland mitigates the structural impact of soil erosion and reduces the loss of soil of that place. The ecosystem service provision of vegetation cover is affected both by anthropogenic activities such as changing land use dynamics and other social and climatic factors.

17. For the estimation of the soil erosion prevention services provided by the croplands, two scenarios have been considered for baseline land cover

i. When the baseline landcover is bare land
ii. When the baseline landcover is the forest

18. To quantify the actual soil erosion prevention service of any ecosystem, it is important to determine what category is considered baseline land cover. For a region, the LULC change matrix gives an idea of the land cover change dynamics. If most of the croplands are converted from

forests or shrublands, it is only natural to consider forests as the baseline scenario. In one of the working papers of Food and Agriculture Organization (FAO), all transitions to and from the land use categories as well as the areas remaining in each category at global level show that forest has maximum share amongst the other land use categories converted to croplands[7]. An analysis of Indian land use land cover (LULC) change matrix depicts that out of other LULC categories that have been converted to croplands, forests and scrublands combined have the largest share (EnviStats India Vol. II 2018, 2022). Among the additional Agricultural Land in 2015-16 that has been converted from Forest in 2011-12, the share of forests converted to croplands in non-forest land use categories is 41% followed by barren/unculturable/ wasteland which is 34%.

19. The LULC dynamics from 2005-06 to 2011-12 shows that share of forest converted to croplands is around 64% out of total forest put to other land use in 2011-12. Change matrix also highlights that in the additional area of croplands, the maximum share of land was previously Fallow. The Fallow land includes Bare land, and land with spontaneous vegetation cover. Even under this scenario, considering whole of the cropland in baseline as bare land would be slightly misleading for estimation of soil loss.

4. Methodology Used

20. The revised universal soil loss equation (RUSLE), an empirical soil loss model is frequently used model amongst researchers to estimate soil loss. SEEA EA also mentions that the soil erosion control service is usually quantified using the RUSLE model. The RUSLE model is used to estimates the annual average rate of soil erosion. The model is expressed below:

$$A = R * LS * K * C * P$$

where A is mean annual soil loss (metric tons per hectare per year), R is the rainfall and runoff factor or rainfall erosivity factor (megajoule millimetres per hectare per hour per year), K is the soil erodibility factor (metric ton hours per megajoules per millimetre), L is the slope length factor (unitless), S is the slope steepness factor (unitless), C is the cover and management factor (unitless), and P is the support practice factor (unitless). Extensive reviews of RUSLE and its components have been published by several researchers including (Benavidez et.al., 2018; Ghoshal & Bhattacharya, 2020; Phinzi & Ngetar, 2019; Jahun et. al.,2015 etc.)

21. For any area, the factors $RLSK$ depends on the structural characteristics of the land such as the amount and intensity of the rainfall received, the soil structure, its organic carbon content, the topographical structure of land, its slope and depth. The other two factors CP are independent of

[7] https://www.fao.org/3/ag049e/AG049E03.htm#TopOfPage

structural characteristics and are highly dependent on land use and land cover dynamics and its management practices. These two factors are affected directly by anthropogenic activities.

22. The RUSLE model used to estimate soil erosion rates has factors representing impacts on soil erosion due to topography, rainfall, soil structure, land cover management and support practices. For the present analysis, the impact of support practices is not considered. The C factor provides the land cover impact on soil erosion. The synopsis of the study can be given as:

In the RUSLE model, the structural and land cover impact is represented by several factors.
Structural Impact= $R * LS * K$
Land Cover Impact= C
Support Practices Impact = $P(= 1)$

Let C_F represents C factor when the land cover is forest and C_C when land cover is Croplands. In the absence of any ecosystem service, the annual soil loss would be

$$SL = R * LS * K$$

which is also the soil loss for bare soil considering, maximum potential soil erosion for bare soil ($C = 1$). If the land cover is forest, then

$$\text{Soil Loss} = SL_F = R * LS * K * C_F$$

When the land cover is crops then

$$\text{Soil Loss} = SL_C = R * LS * K * C_C$$

23. The literature review of Soil Erosion in Indian Context shows that the C factor for Forests varies from 0.001 to 0.15 and C factor for croplands varies from 0.2 to 0.6 (Gansari & Ramesh, 2016; Thomas et.al., 2018; Shit et.al.,2015; Barman et.al., 2020; Sujatha & Sridhar, 2018; Biswas & Pani, 2015; Joshi et.al. 2016). Even for the degraded forests and scrublands the C factor is 0.03 which is lower than that of croplands (Jain and das, 2009). Several other reviews depict that the value of C factor for Crops varies from 0.01- 0.525 and for Forests it is 0.001-0.005 (Benavidez et. al., 2018; USDS-SCS, 1972; Wischmeier & Smith, 1978).

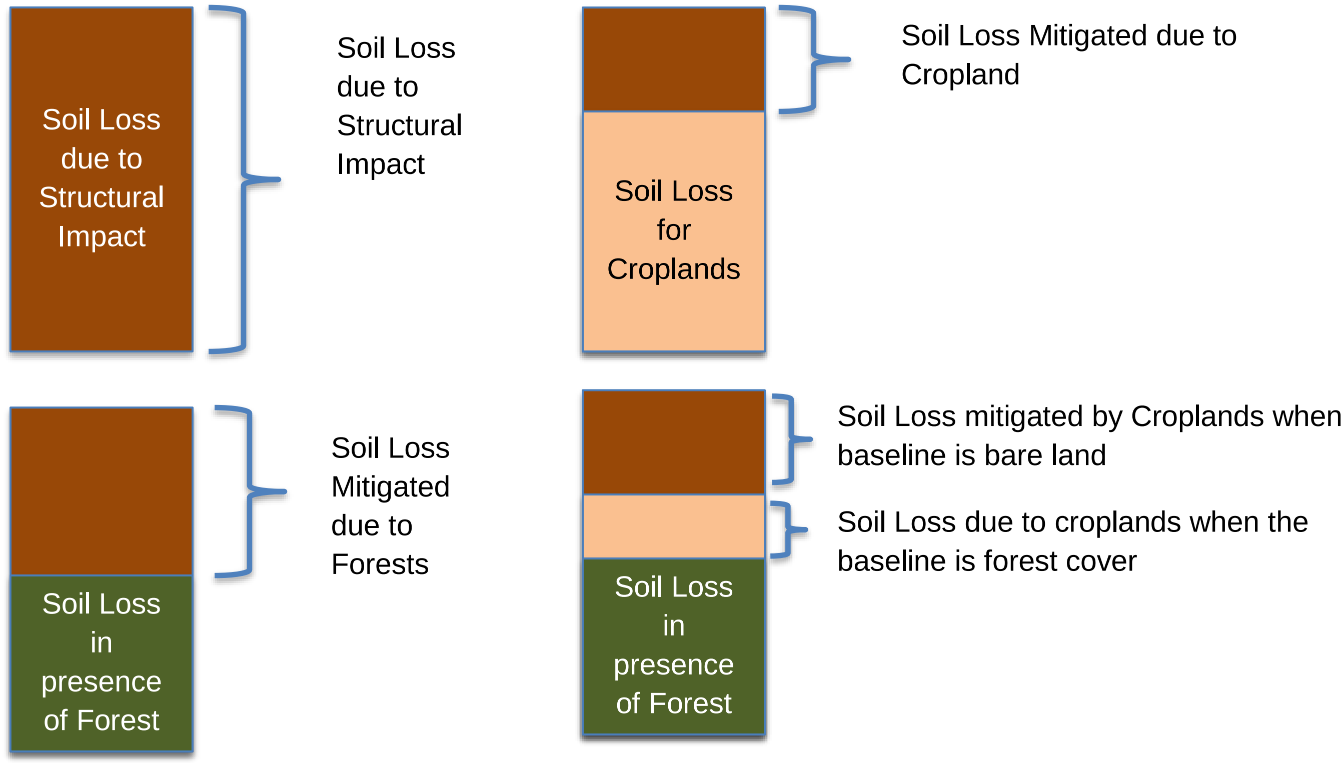
In light of the above, it would be fair to assume that

$$C_F < C_C$$

which implies

$$SL_F < SL_C, \text{ and}$$
$$SL_F < SL_C < SL$$

The following figure illustrates the differences in soil loss mitigation under various scenarios



24. In this case, if the soil erosion prevention services are calculated taking bare land as the reference or base scenario, then it is reflected that the SEP service of croplands contributes to mitigating the structural impact on soil erosion. Thus,

$$SL - SL_C > 0$$

and the soil erosion prevention service of crop cover would be a positive contribution and would be a service of crop ecosystem in protecting soil erosion.

25. However, in the case of the other scenario when the baseline is forest, the SEP of croplands would not contribute to the mitigation of soil erosion. The soil loss would be higher for cropland land cover compared to the forests. The other farming practices such as tillage, ploughing and harvesting would lead to disturb soil ecosystem and the risk of soil erosion may increase. When most of the croplands are being converted from erstwhile forests because the croplands require fertile and nutrient-rich soil, soil erosion prevention capacity of croplands would be compared to that of forest ecosystems. Thus,

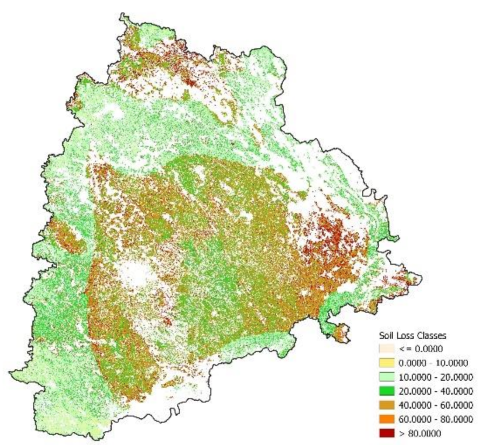
$$SL_F - SL_C < 0$$

and in this case, the SEP of crops would be a disservice as the earlier existing forests were providing more protection against soil loss occurring due to structural impact.

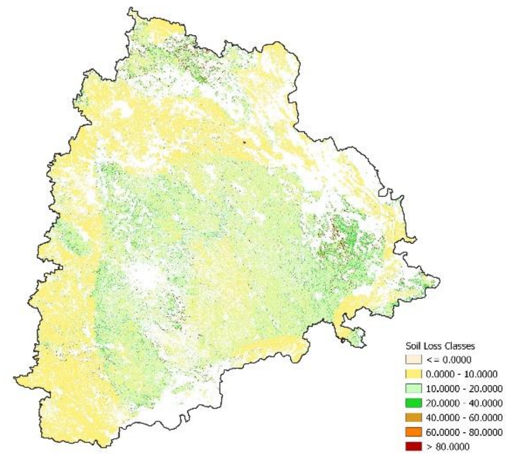
26. The above concept is illustrated by running the RUSLE model for the state of Telangana of India where SEP services of croplands are compared with that of forest. RUSLE is implemented in GIS environment using some local and global datasets. The GeoTIFF rasters of the *LS* factor

and K factor have been prepared with the RUSLE tool in the LUCI for SEEA toolbox, which processed these along with the global R factor layer produced by Panagos et al. (2017). For the C-factor parameterization, NRSC LULC datasets for 2015-16 have been taken. The area under croplands have been considered for this study. The C factor for croplands is taken as 0.23 and for forests it is taken as 0.005. Even if the land cover is sparse vegetation cover, the C factor can be taken as 0.15. The annual soil loss rates in each four cases, bare soil, croplands, forest cover and scrub vegetation are depicted in Fig. 1. The soil erosion prevented by cropland ecosystem under aforementioned scenarios are depicted in Fig. 2.

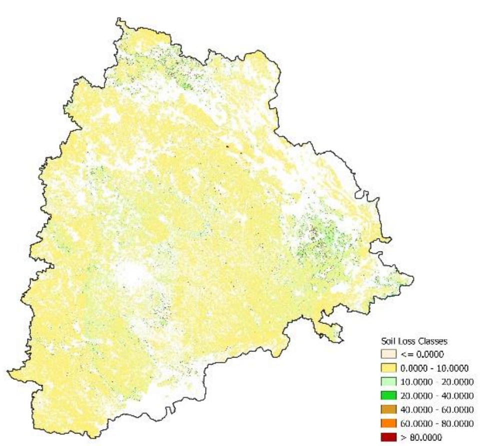
Fig. 1 Spatial Distribution of Soil Erosion in Telangana



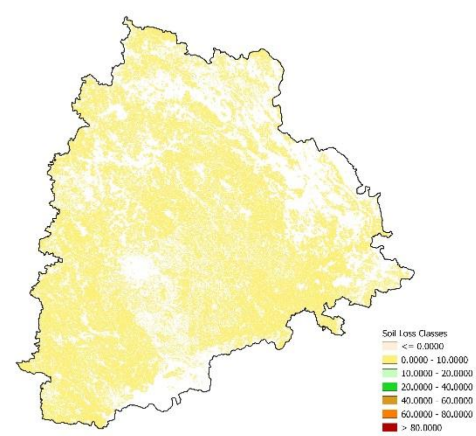
Soil Loss: Structural Impact



Soil Loss: Cropland Ecosystem

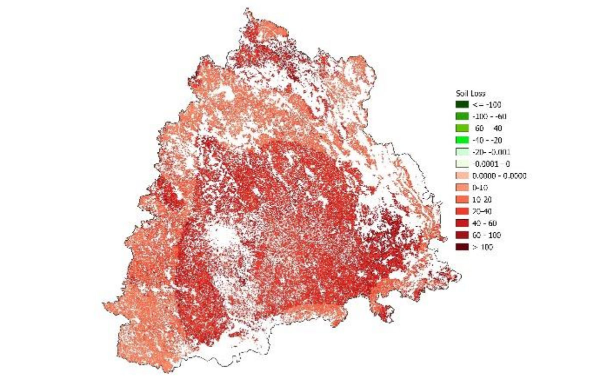


Soil Loss: Scrubland Ecosystem

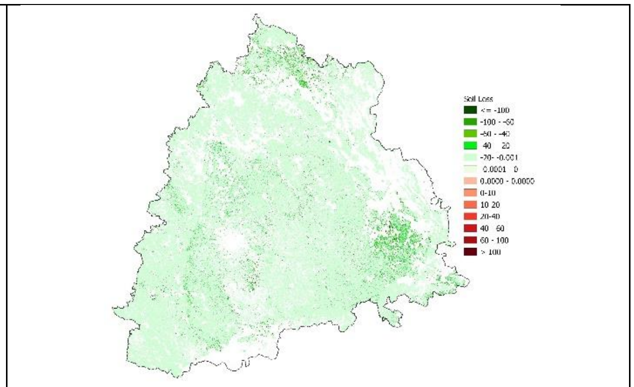


Soil Loss: Forest Ecosystem

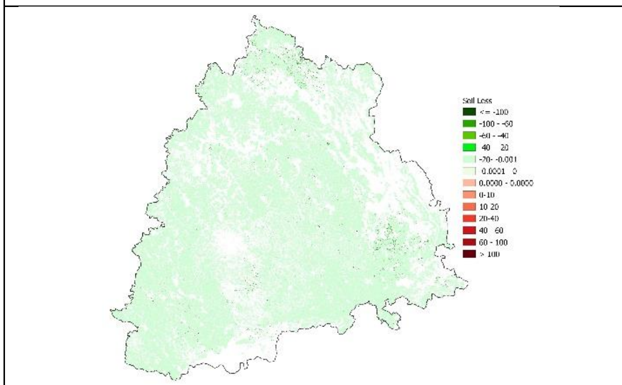
Fig. 2. Spatial Distribution of Soil Erosion Prevention Services under different scenario in Telangana



When baseline land cover is bare land



When baseline land cover is forests



When baseline land cover is scrubland

27. The estimate of mean soil loss due structural impact for the study area is 26 tonnes/ha/year. The mean soil loss for croplands is estimated to be 6 tonnes/ha/year and for forests & scrubland it is 0.13 tonnes/ha/year & 4 tonnes/ha/year respectively. When the baseline landcover is bare soil the estimates of mean SEP services of croplands is 20 tonnes/ha/year. The mean soil loss that could not be prevented when baseline land cover is forest i.e., croplands are converted from forests is 6 tonnes/ha/year, and when the baseline is taken as scrubland an additional mean soil loss due to croplands is 2 tonnes/ha/year. The GIS analysis shows that when SEP is calculated taking bare land as baseline, each cropland pixel has some positive value which denotes that the cropland ecosystem contributes positively in mitigating the soil loss owing to the structural impact. However, each pixel has negative values when forest and scrubland are taken as baseline which shows that same croplands ecosystem negatively contributes in preventing the soil loss due to structural impact. In the Fig. 2, the shades of green is indicative of negative SEP and shades of red indicates positive SEP.

28. The results show that for quantification of SEP services of croplands, the consideration of baseline land cover is crucial. The same ecosystem service when compared with different ecosystem under baseline may be service or disservice.

5. Limitations

29. In the discussed literature review, in most of the studies, the impact of cropland landcover is found to be greater than forests as well as scrublands. However, some of the studies for hilly areas in India, where the cover and support practices are incorporated in the RUSLE model, shows the mean soil loss for croplands is lower than forests as well as bare lands (Prashanth, M.,2023). This may be attributed to the characteristics of hilly plants and due to the fact that despite having vegetation much of the land is exposed to erosion. In such cases, the SEP of croplands may not be a disservice, but comparing it with forests would give a realistic estimate of SEP. Another study in the Western Ghats region of India estimated that mean gross erosion rates are relatively higher in open scrub, forest and Eucalyptus plantation, compared to agriculture, settlement/built-up areas and tea plantation (Thomas et.al., 2018). These studies reflect that the proper consideration of P factor i.e. land management is also crucial for estimating SEP services precisely. For certain land structure, such as hilly region, the properly managed croplands may produce relatively lessor soil loss than forests and plantations. Another limitation of the paper is the limitation of RUSLE model itself which has certain inadequacies regarding LS factor (Benavidez et.al., 2018; Kumar et.al. ,2022).

6. Conclusion

30. This paper is an attempt to highlight the fact that while calculating the SEP services of any ecosystem, it is crucial to have the precise knowledge about the land use land cover before deciding on the appropriate baseline land cover. The baseline land cover cannot be universally decided as there are plenty of other factors such as the changing dynamics of land over time, the management practices available, the vegetation that formed a part of the barren land etc. which needs to be taken into consideration. The LULC dynamics may help in identifying the land cover/ecosystem which contributes maximum to the converted land cover ecosystem. Therefore, the baseline condition for determining ecosystem services is pivotal.

31. The analysis again stresses on the fact that the subject ‘environment’ encompassing several ecosystems and the assets are interrelated with each other. In order to arrive at a just and robust conclusion, all the dimensions and their possible inter-linkages needs to be borne in mind.

References

1. Adhikari, K., & Hartemink, A. E. (2016). Linking soils to ecosystem services—A global review. Geoderma, 262, 101-111.
2. Ahmad, N. S. B. N., Mustafa, F. B., & Didams, G. (2020). A systematic review of soil erosion control practices on the agricultural land in Asia. International Soil and Water Conservation Research, 8(2), 103-115.
3. Barman, B. K., Rao, K. S., Sonowal, K., Prasad, N. S. R., & Sahoo, U. K. (2020). Soil erosion assessment using revised universal soil loss equation model and geo-spatial technology: A case study of upper Tuirial river basin, Mizoram, India. AIMS Geosciences, 6(
4. Benavidez, R., Jackson, B., Maxwell, D., & Norton, K. (2018). A review of the (Revised) Universal Soil Loss Equation ((R) USLE): With a view to increasing its global applicability and improving soil loss estimates. Hydrology and Earth System Sciences, 22(11),
5. Biswas, S. S., & Pani, P. (2015). Estimation of soil erosion using RUSLE and GIS techniques: a case study of Barakar River basin, Jharkhand, India. Modeling Earth Systems and Environment, 1, 1-13.
6. Chatterjee, S., Krishna, A. P., & Sharma, A. P. (2014). Geospatial assessment of soil erosion vulnerability at watershed level in some sections of the Upper Subarnarekha river basin, Jharkhand, India. Environmental earth sciences, 71, 357-374.
7. Dabral, P. P., Baithuri, N., & Pandey, A. (2008). Soil erosion assessment in a hilly catchment of North Eastern India using USLE, GIS and remote sensing. Water Resources Management, 22, 1783-1798.
8. EnviStats India Vol. II : Environment Accounts, 2018, Ministry of Statistics and Programme Implementation, India
9. EnviStats India Vol. II : Environment Accounts, 2020, Ministry of Statistics and Programme Implementation, India
10. Ganasri, B. P., & Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS-A case study of Nethravathi Basin. Geoscience Frontiers, 7(6), 953-961.
11. Ghosal, K., & Das Bhattacharya, S. (2020). A review of RUSLE model. Journal of the Indian Society of Remote Sensing, 48, 689-707.
12. Guerra, C. A., Pinto-Correia, T., & Metzger, M. J. (2014). Mapping soil erosion prevention using an ecosystem service modeling framework for integrated land management and policy. Ecosystems, 17, 878-889.
13. Jahun, B. G., Ibrahim, R., Dlamini, N. S., & Musa, S. M. (2015). Review of soil erosion assessment using RUSLE model and GIS. Journal of Biology, Agriculture and Healthcare, 5(9), 36-47.
14. Jasrotia, A. S., & Singh, R. (2006). Modeling runoff and soil erosion in a catchment area, using the GIS, in the Himalayan region, India. Environmental Geology, 51, 29-37.
15. Joshi, V., Susware, N., & Sinha, D. (2016). Estimating soil loss from a watershed in Western Deccan, India, using revised universal soil loss equation. Acta geographica Debrecina Landscape & Environment series, 10(1), 13-25.

16. Kumar, M., Sahu, A. P., Sahoo, N., Dash, S. S., Raul, S. K., & Panigrahi, B. (2022). Global-scale application of the RUSLE model: a comprehensive review. Hydrological Sciences Journal, 67(5), 806-830.
17. Kumar, S., & Hole, R. M. (2021). Geospatial modelling of soil erosion and risk assessment in Indian Himalayan region—A study of Uttarakhand state. Environmental Advances, 4, 100039.
18. Mandal, D., & Giri, N. (2021). Soil erosion and policy initiatives in India. Curr. Sci, 120, 1007-1012.
19. Meiyappan, P., Roy, P. S., Sharma, Y., Ramachandran, R. M., Joshi, P. K., DeFries, R. S., & Jain, A. K. (2017). Dynamics and determinants of land change in India: integrating satellite data with village socioeconomics. Regional Environmental Change, 17, 753-766
20. Narayana, D. V., & Babu, R. (1983). Estimation of soil erosion in India. Journal of Irrigation and Drainage Engineering, 109(4), 419-434.
21. Neyret, M., Robain, H., De Rouw, A., Janeau, J. L., Durand, T., Kaewthip, J., Trisophon, K. & Valentin, C. (2020). Higher runoff and soil detachment in rubber tree plantations compared to annual cultivation is mitigated by ground cover in steep mountainous Th
22. Pal, S. C., Chakrabortty, R., Roy, P., Chowdhuri, I., Das, B., Saha, A., & Shit, M. (2021). Changing climate and land use of 21st century influences soil erosion in India. Gondwana Research, 94, 164-185.
23. Pal, S. C., Chakrabortty, R., Roy, P., Chowdhuri, I., Das, B., Saha, A., & Shit, M. (2021). Changing climate and land use of 21st century influences soil erosion in India. Gondwana Research, 94, 164-185.
24. Phinzi, K., & Ngetar, N. S. (2019). The assessment of water-borne erosion at catchment level using GIS-based RUSLE and remote sensing: A review. International Soil and Water Conservation Research, 7(1), 27-46.
25. Pimentel, D., & Burgess, M. (2013). Soil erosion threatens food production. Agriculture, 3(3), 443-463.
26. Prashanth, M., Kumar, A., Dhar, S., Verma, O., Rai, S. K., & Kouser, B. (2023). Land use/land cover change and its implication on soil erosion in an ecologically sensitive Himachal Himalayan watershed, Northern India. Frontiers in Forests and Global Change, 6
27. Prokop, P., & Poręba, G. J. (2012). Soil erosion associated with an upland farming system under population pressure in Northeast India. Land Degradation & Development, 23(4), 310-321.
28. Sharda, V. N., Mandai, D., & Ojasvi, P. R. (2013). Identification of soil erosion risk areas for conservation planning in different states of India. Journal of Environmental Biology, 34(2), 219.
29. Shit, P. K., Nandi, A. S., & Bhunia, G. S. (2015). Soil erosion risk mapping using RUSLE model on Jhargram sub-division at West Bengal in India. Modeling Earth Systems and Environment, 1, 1-12.
30. Shrestha, D. P. (1997). Assessment of soil erosion in the Nepalese Himalaya: a case study in Likhu Khola Valley, Middle Mountain Region. Land Husbandry, 2(1), 59-80.

31. Singh, G., & Panda, R. K. (2017). Grid-cell based assessment of soil erosion potential for identification of critical erosion prone areas using USLE, GIS and remote sensing: A case study in the Kapgari watershed, India. International Soil and Water Conservation
32. Singh, G., Babu, R., Narain, P., Bhushan, L. S., & Abrol, I. P. (1992). Soil erosion rates in India. Journal of Soil and water Conservation, 47(1), 97-99.
33. Sun, D., Zhang, W., Lin, Y., Liu, Z., Shen, W., Zhou, L., Rao, X., Liu, S., Cai, X.A., He, D. & Fu, S. (2018). Soil erosion and water retention varies with plantation type and age. Forest Ecology and Management, 422, 1-10.
34. System of Environmental Economic Accounting Ecosystem Accounting, 2021
35. Thomas, J., Joseph, S., & Thrivikramji, K. P. (2018). Assessment of soil erosion in a monsoon-dominated mountain river basin in India using RUSLE-SDR and AHP. Hydrological sciences journal, 63(4), 542-560.
36. Thomas, J., Joseph, S., & Thrivikramji, K. P. (2018). Assessment of soil erosion in a tropical mountain river basin of the southern Western Ghats, India using RUSLE and GIS. Geoscience Frontiers, 9(3), 893-906.
37. Wischmeier, W. & Smith, D., 1978. Predicting rainfall erosion losses—A guide to conservation planning. Agriculture Hand-book No.537, pp. 3–4.