EnviStats India Explainer Series

THEME: CROPLANDS

Soil Erosion Prevention Services

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Access

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Revision Summary of this Document

Version Number	Date of Issue	Brief Description of Change
Ver1.0	**May, 2023**	**First Version**

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Introduction

1. Croplands[1] is the land used for the cultivation of crops, both temporary (annuals) and permanent (perennials), and may include areas periodically left fallow or used as temporary pasture. Croplands are critical, terrestrial man-made ecosystem and contribute to several ecosystem services such as food production, air regulation, soil and water conservation, environmental decontamination, etc. In India, the croplands support the agricultural sector which not only sustains the growing population of the country but also contributes more than 15% (National Accounts Statistics) of the total GDP. In addition, these croplands are a source of livelihood for nearly half of the workforce in the country.

2. The Indian Agricultural sector is facing a number of challenges and the soil erosion is one of the prime concerns. The loss of soil from land surface by erosion is one of the major factors responsible for degradation of land quality. Soil erosion involves the breakdown, detachment, transport, and redistribution of soil particles by forces of water, wind or gravity. Soil erosion of cropland is of particular interest because of its on-site impacts on soil quality and crop productivity, and its off-site impacts on water quantity and quality, air quality, and biological activity.

3. The nutrient rich topsoil erodes when the rain droplets hits the soil and the running water takes away the loose particles of soil with itself. With this runoff the fertile soil is lost and thus the agricultural production is affected. Not only this, the soil erosion increases pollution and sedimentation in streams and rivers which results in clogging of these waterways and decline in fish and other species. Soil erosion is a gradual process that occurs when the impact of water or wind detaches and removes soil particles, causing the soil to deteriorate. Soil deterioration and low water quality due to erosion and surface runoff have become severe problems worldwide. Sometimes, the severity can be judged by the fact that land becomes completely non-suitable for agriculture and hence is abandoned.

4. However, this runoff can be prevented if the rain water does not hit the soil directly, i.e. if there is some kind of vegetation on the land. The presence of vegetation on the land would reduce the kinetic energy of the raindrops reducing the forceful impact of the rain on the soil. This would eventually result in lowering the soil erosion. Having this fundamental theory in mind, it would be absolutely reasonable and just to acknowledge the fact that croplands, which has a major share in the Indian land, plays a significant role in the prevention of soil erosion.

5. To support the theory and assumption, an analysis on soil erosion prevented by the croplands termed as 'Soil Erosion Prevention Services by the Cropland', has been carried out in GIS interface using the RUSLE (Revised Universal Soil Loss Equation) model. This study will enable the quantification of the services provided by the croplands essentially for the prevention of soil loss.

[1] https://www.fao.org/sustainability/news/detail/en/c/1274219/

Soil Erosion Prevention Services

Objective

6. There is no denying the fact that croplands, a component of abiotic ecosystems, help in prevention of the soil erosion. In order to have an estimate of the amount of soil erosion prevented by the cropland, the erosion occurring owing to the local climate, topography and soil characteristics with no vegetation is estimated. This gives a fair idea about the amount of erosion taking place in the absence of vegetation. Thereafter, soil loss is estimated in the presence of the croplands and the difference of these is the estimate of 'Soil Erosion Prevention Services' provided by croplands. The study provides estimates of soil erosion prevention services for the 'Croplands' in the major States of India for the years – 2005-06, 2011-12 and 2015-16. The study is done on the entire geographic area of India.

Background

7. India is the seventh largest country in the world with total area of 3.287 million km^2 (Survey of India). India is primarily an agricultural economy with agricultural area of about 1.8 million km^2. Agriculture is undoubtedly the backbone of the nation. India is the second-largest producer of agricultural products in the world with production of more than 280 million tonnes employing around more than 50% of the total employed people. Agriculture plays a prime role in not only India's economy, but also provides food for the huge population. It therefore becomes all the more important to ensure its sustainability so as to meet the growing demands of the current as well as future population.

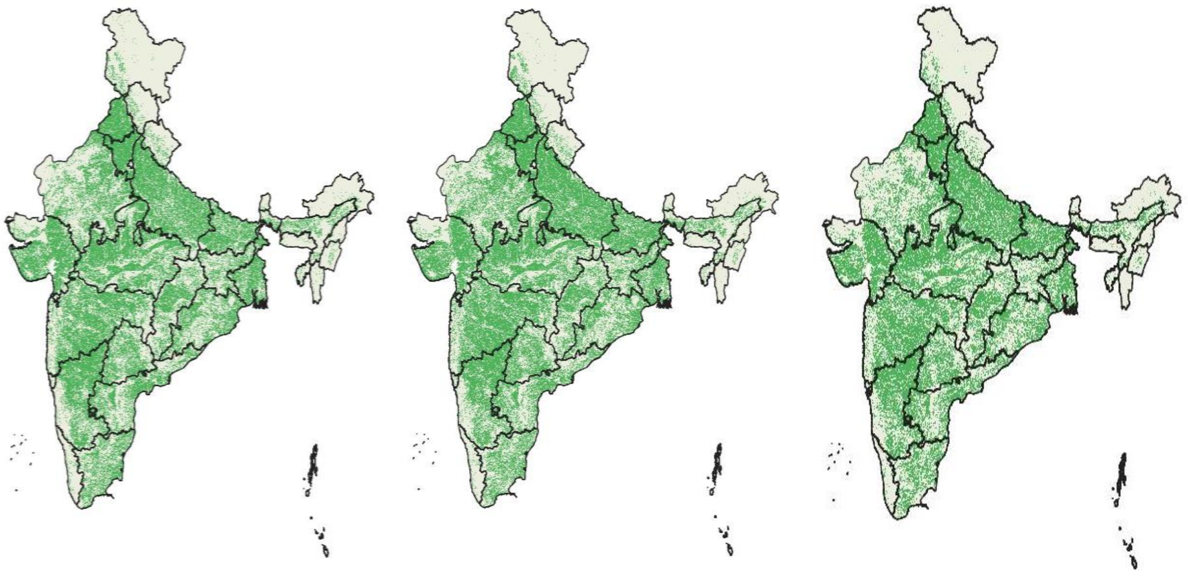
8. Sustainability is being hindered by a number of environmental threats such as degradation of land, water, forest etc. Among these, degradation of land (soil) is the major cause of concern especially towards achieving a sustainable agriculture. The remedial measure includes soil management in such a way that the natural form of the soil is maintained. Practicing soil conservation techniques so that the nutrient rich topsoil is always there for healthy growth of plants and crops is another preventive measure which will safeguard soils from being permanently damaged. But before starting these management and conservation practices, it is important to know the extent of the degradation/erosion that has occurred or is likely to occur in future to the soil and the practices which can prevent the degradation along with the extent of prevention of degradation. There are certain schemes of Government of India such as Soil Health Card, which provides an assessment of the quality of soil and which can quantify the extent of degradation till date. However, it provides no information about the conservation practice that is required to prevent soil erosion in a particular area.

9. In the study, croplands all over the India have been assessed to check the extent they can provide soil erosion prevention services.

Soil Erosion Prevention Services

Figure-1: Spatial Distribution of Croplands in India

(a) 2005-06 **(b) 2011-12** **(c) 2015-16**



10. From **Figure-1**, we can see that in India croplands are well distributed except for the hilly and arid areas. So, it is important to study the relevance of croplands on the soil erosion prevention.

Context

11. All economic activity and most of human well-being are based on a healthy, functioning environment. By focussing on the various benefits from nature i.e. ecosystem services – the direct and indirect dependence of human well-being on the natural environment becomes more evident. Ecosystems provide a variety of benefits to people, such as provisioning, regulating and cultural services. Provisioning services are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems, such as food, fuel, fibre, fresh water, and genetic resources. Regulating services are the benefits people obtain from the regulation of ecosystem processes, including air quality maintenance, climate regulation, erosion control, regulation of human diseases, water purification etc. Cultural services are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, aesthetic experiences etc.

12. Erosion regulation is an important ecosystem service that represents the ability of the ecosystems to prevent and mitigate soil erosion. Soil erosion is one of the most serious environmental problems in the India in current times, as it severely threatens agriculture,

natural resources and the environment. The land degradation caused by erosion may be attributed to inappropriate agricultural practices (Bhattacharya et al. (2016))[2].

13. Soil erosion is a natural process, occurring over geological time. Most of the concerns about erosion are related to accelerated erosion, where the natural rate of erosion has been significantly increased by human activity. Accelerated soil erosion is a serious concern worldwide, and it is difficult to assess its economic and environmental impact accurately because of its extent, magnitude, rate and the complex processes associated with it.

14. Vegetation acts as an ecosystem service provider by preventing the soil erosion and therefore mitigating the impact of soil erosion. To assess the soil erosion prevention services, it is important to first measure the soil loss in the presence and absence of the ecosystem, in the current case – the cropland. The Revised Universal Soil Loss Equation (RUSLE), commonly used empirical model for the determination of potential soil loss, has been used to calculate the Soil Erosion Prevention Service.

Literature Review

15. Among various land degradation processes, soil erosion is recognized as a major environmental concern causing a loss of topsoil and nutrients, reducing soil fertility and, as a consequence, lowering the crop yields. Soil erosion is not only a major threat to agricultural soil productivity (losses in yields, nutrients and plantations) but are also major cause for the generation of offsite impacts such as sedimentation, flooding, damage to properties, landslides, water eutrophication etc. A key element for ensuring a sustainable food production system is linked to effective soil management, which in turn depends on the reduction in soil erosion rates (Sartori *et al.* ,2019)[3]

16. In order to assess the soil erosion, the commonly used soil erosion model is the Universal Soil Loss Equation (USLE) and its family of models: The Revised Universal Soil Loss Equation (RUSLE), the Revised Universal Soil Loss Equation version 2 (RUSLE2), and the Modified Universal Soil Loss Equation (MUSLE). In the study by Benavidez and others (Benavidez *et al.*, 2018)[4], RUSLE model has been used to estimate the annual average rate of soil erosion (tons per unit area) for a given combination of crop system, management practice, soil type, rainfall pattern, and topography

17. As discussed above the RUSLE model has various sub-factors and information/ data and calculation are crucial for the correct estimation of soil loss. The various factors are studied by various researchers. A brief discussion is provided for values of C factor take in the Indian context.

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[2] R. Bhattacharyya, B.N. Ghosh, P. Dogra, P.K. Mishra, P. Santra, S. Kumar, et al. Soil conservation issues in India Sustainability, 8 (6) (2016), p. 565

[3] Sartori, M., Philippidis, G., Ferrari, E., Borrelli, P., Lugato, E., Montanarella, L., Panagos, P. 2019. A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion. Land Use Policy

[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. Hydrol. Earth Syst. Sci, 22(11), 6059-6086.

18. Rainfall erosivity accounts for the combined effect of rainfall duration, magnitude and intensity. In addition, it is also necessary to consider the frequency of erosive events over a longer time period. However global patterns of rainfall erosivity is poorly quantified and estimates have large uncertainties. This hampers the implementation of effective soil degradation mitigation and restoration strategies. Quantifying rainfall erosivity is challenging as it requires high temporal resolution (<30 min) and high-fidelity rainfall recordings (Panagos et al.,2017)[5].

19. Due to the detailed data requirements for the standard RUSLE calculation of rainfall erosivity, studies in areas with less detailed data have used alternative equations depending on the temporal resolution and availability of the rainfall data. These compiled studies have used long-term datasets with at least daily temporal resolution to construct their R-factor equation (Benavidez *et al.*, 2018)[4].

20. One key parameter for modelling soil erosion is the soil erodibility, expressed as the K-factor in the widely used soil erosion model, the Universal Soil Loss Equation (USLE) and its revised version (RUSLE). The K-factor, which expresses the susceptibility of a soil to erode, is related to soil properties such as organic matter content, soil texture, soil structure and permeability. Soil erodibility, together with management practices (P-factor) and vegetation cover (C-factor) can be influenced by agricultural practices. Therefore, the K-factor dataset can be a guide for applying better conservation practices (e.g., increase or preserve soil organic carbon in areas prone to high levels of soil erosion risk or adaption of soil management at areas of high risk) (Panagos et al., 2014)[5].

21. The C-factor measures the effects of all interrelated cover and management variables. (Jena et al., 2018). Crop management factor is the expected ratio of soil loss from a cropped land under specific condition to soil loss from clean tilled fallow on identical soil and slope under the same rainfall conditions (Dabral et al. ,2008)[6]. The value for C factor for agriculture / croplands has been taken as 0.20 in (Jasrotia and Singh, 2006)[7] and higher such as 0.28 in (Dabral et al. ,2008)[6], (Warwadhe et al., 2013)[8] etc to 0.50 in (Jena et al., 2018)[9].

22. Conservation practice factor (P) is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope cultivation. (Dabral et al. ,2008)[6]. In the study done by Dabral the P factor for the field under cultivation is taken to be 0.28 whereas

[5] Panagos, P., Borrelli, P., Meusburger, K., Yu, B., Klik, A., Lim, K. J., ... & Sadeghi, S. H. (2017). Global rainfall erosivity assessment based on high-temporal resolution rainfall records. Scientific reports, 7(1), 1-12.

[6] 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(12), 1783-1798.

[7] 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(1), 29-37.

[8] Warwade, P. R. A. T. I. B. H. A., Hardaha, M. K., Kumar, D. H. E. E. R. A. J., & Chandniha, S. K. (2014). Estimation of soil erosion and crop suitability for a watershed through remote sensing and GIS approach. Indian Journal of Agricultural Sciences, 84(1), 18-23.

[9] Jena, R. K., Padua, S., Ray, P., Ramachandran, S., Bandyopadhyay, S., Deb Roy, P., ... & Ray, S. K. (2018). Assessment of soil erosion in sub-tropical ecosystem of Meghalaya, India using remote sensing, GIS and RUSLE.

it has been taken as 0.5 in (Jena et al., 2018)[9] and in (Das et al.,2018)[10] and 0.34 in (Kumar et al., 2020)[11].

23. The factors have been studied from the above-mentioned studies, and accordingly used in the analysis.

Data and Methodology

24. RUSLE model estimates the average annual soil erosion using the following multiplicative model-

$$A = R * K * L * S * C * P$$

where,

A= average soil loss estimate

R= rainfall runoff erosivity factor

K= soil erodibility factor

L= slope length factor

S= slope steepness factor

C= cover management factor

P= support practice factor

25. **Rainfall Runoff Erosivity Factor (R) -** This factor quantifies the impact of rainfall along with the amount and rate of soil runoff associated with the rainfall. R factor is function of the mean annual EI_{30} that is calculated from long-term records of kinetic energy (E) of storms and maximum intensity of rainfall during the period of 30 minutes (I_{30}). Accordingly, the calculation of rainfall erosivity (EI_{30}) of a single event is based on the following equation:

$$EI_{30} = (\sum_{r=1}^{k} e_r v_r) * k \qquad (1)$$

where e_r is the unit rainfall energy (MJ ha^{-1} mm^{-1}) and v_r the rainfall volume (mm) during the r^{th} time period of a rainfall event divided in k-parts. I_{30} is the maximum 30-minutes rainfall intensity (mm h^{-1}). The unit rainfall energy (e_r) is calculated for each time interval as follows:

[10] Das, B., Paul, A., Bordoloi, R., Tripathi, O. P., & Pandey, P. K. (2018). Soil erosion risk assessment of hilly terrain through integrated approach of RUSLE and geospatial technology: a case study of Tirap District, Arunachal Pradesh. Modeling Earth Systems and Environment, 4(1), 373-381.

[11] Kumar, T., Jhariya, D. C., & Pandey, H. K. (2020). Comparative study of different models for soil erosion and sediment yield in Pairi watershed, Chhattisgarh, India. Geocarto International, 35(11), 1245-1266

$$e_r = 0.29 * [1 - 0.72e^{-0.05i_r}] \quad (2)$$

where i_r is the rainfall intensity during the time interval (mm h^{-1}).

R is the average annual rainfall erosivity (MJ mm ha^{-1} h^{-1} yr^{-1}):

$$R = \frac{\sum_{j=1}^{n} \sum_{k=1}^{m_j} (EI_{30})_k}{n} \quad (3)$$

where n is the number of years recorded, m_j is the number of erosive events during a given year j and k is the index of a single event with its corresponding erosivity EI_{30}.

26. For this study, the R factor for India has been derived from the global R factor raster layer produced by Panagos et al. (2017)[5].

27. Soil Erodibility Factor (K) - Soil erodibility factor represents the susceptibility of the soil to erosion. Erodibility is the function of soil texture, organic matter content and permeability thus impacting the rates of erosion in different types of soil. In practical terms, the soil erodibility factor is the average long-term soil and soil- profile response to the erosive powers of rainstorm. The parameter represents an integrated average annual value of the total soil and the soil profile reaction to a large number of erosion and hydrologic process. These processes consist of soil detachment and transport by raindrop impact and surface flow, localised deposition, rainwater infiltration. Higher K-factor values are indicative of soil's higher susceptibility to soil erosion. The soil erodibility factors for India is estimated using Harmonised World Soil Database (HWSD) data and the parameterisation is based on the soil texture class and organic matter content. The K factor ranges from 0 to 1, where 0 indicates least susceptibility of soil for erosion and 1 high susceptibility of soil for erosion

28. **Slope Length and Steepness Factor (LS Factor)-** LS factor accounts for the effect of the topography on erosion. As the slope length increases the erosion increases. The slope length factor is denoted by L. Slope length is defined by the horizontal distance between origin of overland flow and the point where either slope gradient decreases enough that deposition begins or runoff becomes concentrated. Erosion would normally be expected to increase with increases in slope steepness and slope length as a result of respective increases in velocity and volume of surface runoff. Further, while on a flat surface raindrop splash soil particle randomly in all directions, on sloping ground more soil is splashed downslope than upslope, the proportion of which increases as the slope steepens.

29. The slope steepness (S) factor reflects the influence of the slope gradient on the erosion. With increase in slope steepness, soil loss increases more rapidly than it does in slope length. The combined LS factor in RUSLE represents a ratio of soil loss under given conditions to

that at a site with the "standard" slope steepness of 9 % and slope length of 22.13 m. (Stone and Hilborn 2012). [12]

30. The *LS*-factor dataset for this exercise was generated using Digital Elevation Model (DEM) from NASA following the equation that uses slope length steepness only as shown below:

$$LS = \left(\frac{l}{22}\right)^{0.5} \times (0.065 + 0.045s + 0.0065s^2)$$

where:

l = Slope length or cell size (m)

s = Slope steepness (%)

31. **Cover management factor (C)-** The C factor indicates the effect of cropping and management practices on soil erosion. It reflects how the conservation plans will affect the average annual soil loss. In fact, the C factor can often be used to compare the impact of management option on conservation plans. The value of C ranges from 0 to 1, where the bare land gets the value 1 and the land covered with plants, trees open water gets the value close to 0. The existing literature review reveals in certain cases C factor can take value greater than 1. It is expected that the areas having C factor greater than 1 would generate significantly more erosion than a bare soil in crop fallow conditions. In the current exercise, the C value has been taken as 0.23 for croplands (based on previous studies in India). For others it has been considered to be 0 essentially to nullify the effect of other types of land.

32. **Support practice factor (P)-** The P factor is the ratio of soil loss with specific support practice to corresponding loss without. The practices affect the erosion by modifying the flow pattern, direction of surface runoff and rate of runoff. The support practice includes contouring, tillage or planting near the contour etc. The P factor ranges between 0 to 1, where the area with no conservation practices receives the value 1. For this exercise, the P factor for the croplands is taken as 1.

33. The RUSLE model was applied using QGIS interface, which allowed for combining the different remote sensing datasets, for estimating the soil loss and its spatial distribution. Detailed steps for the application of QGIS are given in **Appendix I**.

[12] Stone, R. P., & Hilborn, D. (2012). Universal soil loss equation (USLE) factsheet. Ministry of Agriculture, Food and Rural Affairs order, (12-051).

Data used for the estimation

Input	Dataset	Source	Resolution
Digital Elevation Model	Shuttle Radar Topography Mission 3 Arc-Seconds Global Dataset (SRTM)	NASA	~ 95 metres
Soil data	Harmonised World Soil Database v1.2 (HWSD)	FAO	30 arc-second (~1km at equator)
Rainfall erosivity	Global Rainfall Erosivity Database (GloREDa)	Panagos et al. (2017)	30 arc-second (~1km at equator)
Land cover data	Land Use Land Cover Datasets	NRSC, India	~20-25meters

Methodology

34. The basic idea of the study is to estimate Soil Erosion Prevention Services provided by the ecosystem service provider, which here is the cropland. In order to check the extent to which this ecosystem service provider can prevent this loss, two situations - one with bare land and other with cropland - are considered. For calculating the soil loss in both the cases, RUSLE model has been applied where the parameter like R, K, L, S and P have been used as discussed above and only C factor is varied.

35. C factor reflects the effect of cropping and for the study, this is the most important factor. When croplands are assumed to be replaced by bare lands, C factor for these areas is taken as 1, which represents the bare lands. For the alternative scenario, C factor for croplands is taken as 0.23. C-factor for all the other areas have been considered as 0, in order to nullify the effect of other types of land.

36. All the RUSLE parameters derived have been multiplied using a geographical information system to produce the spatial distribution map of annual average soil loss in the area, and the results are detailed in the following sections.

Results

37. Using the GIS environment, the annual soil loss estimates have been computed to assess the soil erosion in both the situations (with and without croplands) for three time periods- 2005-06, 2011-12, 2015-16. The state wise soil loss estimates (spatial distribution) for bare soil and croplands for all the three years are as given in **Table-1 to Table-3**. Figure-5 shows the spatial distribution of soil loss prevented due to croplands.

Figure 2: Spatial distribution of soil loss for 2005-06

(a) With croplands **(b) Without croplands**

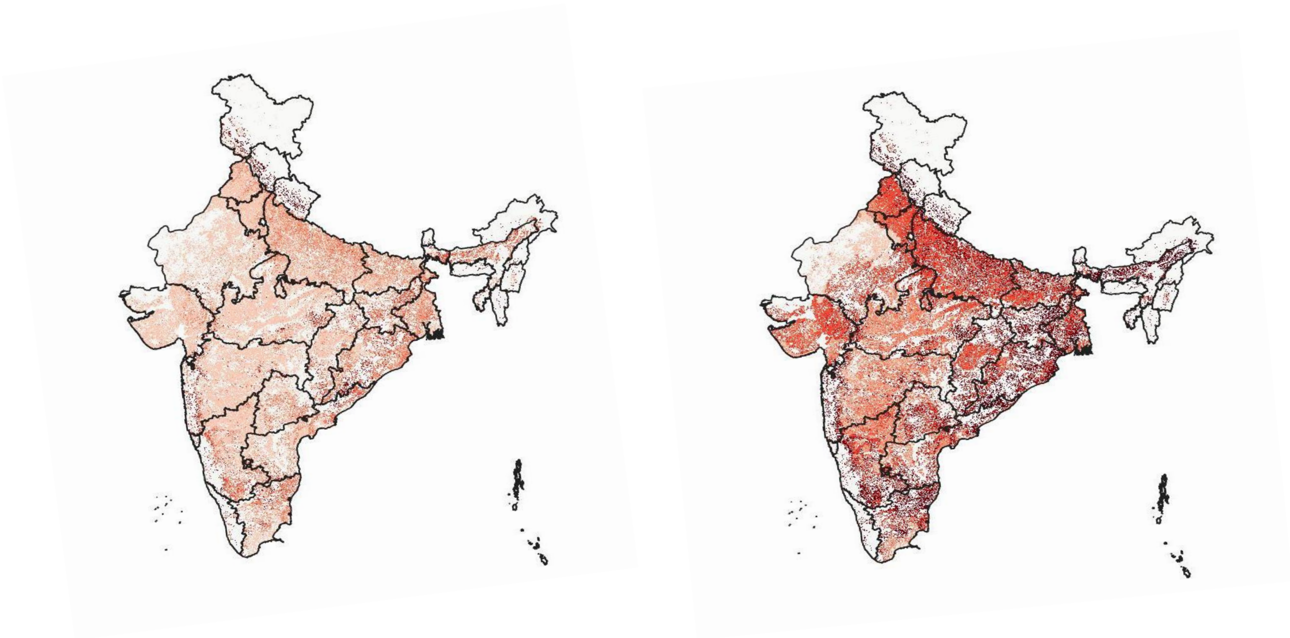


Figure 3: Spatial distribution of soil loss for 2011-12

(a) With croplands **(b) Without croplands**

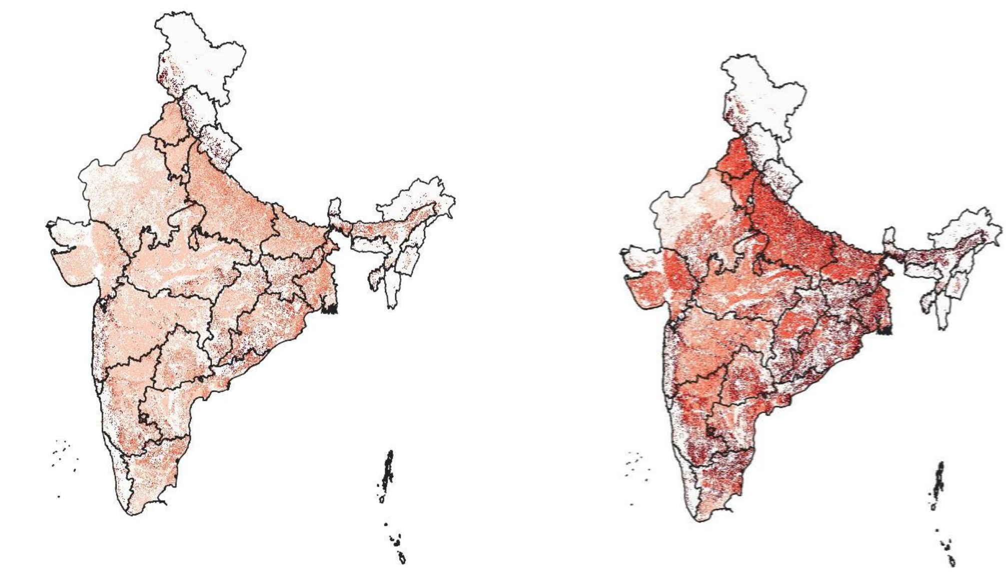


Figure 4: Spatial distribution of soil loss with croplands for 2015-16

(a) With croplands **(b) Without croplands**

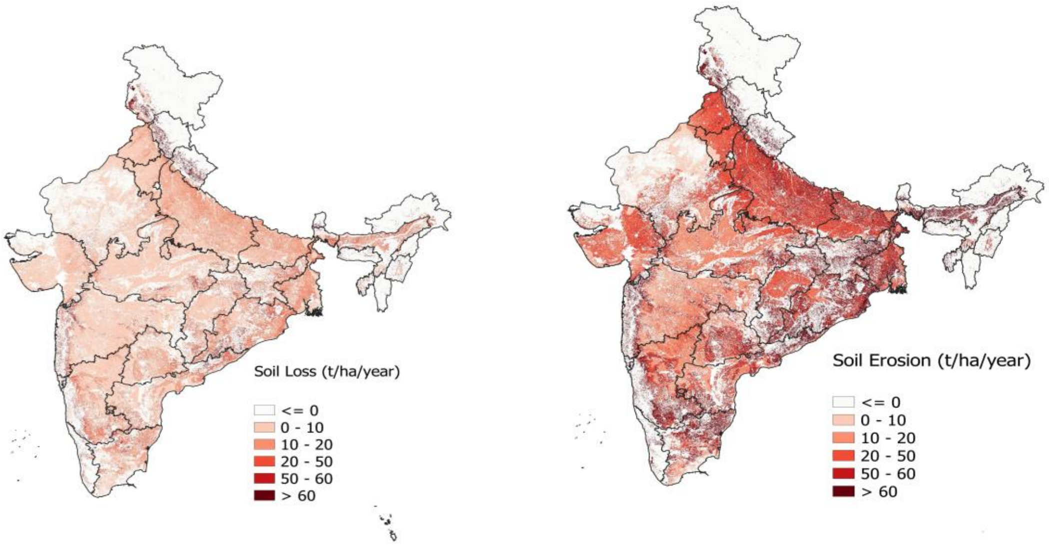
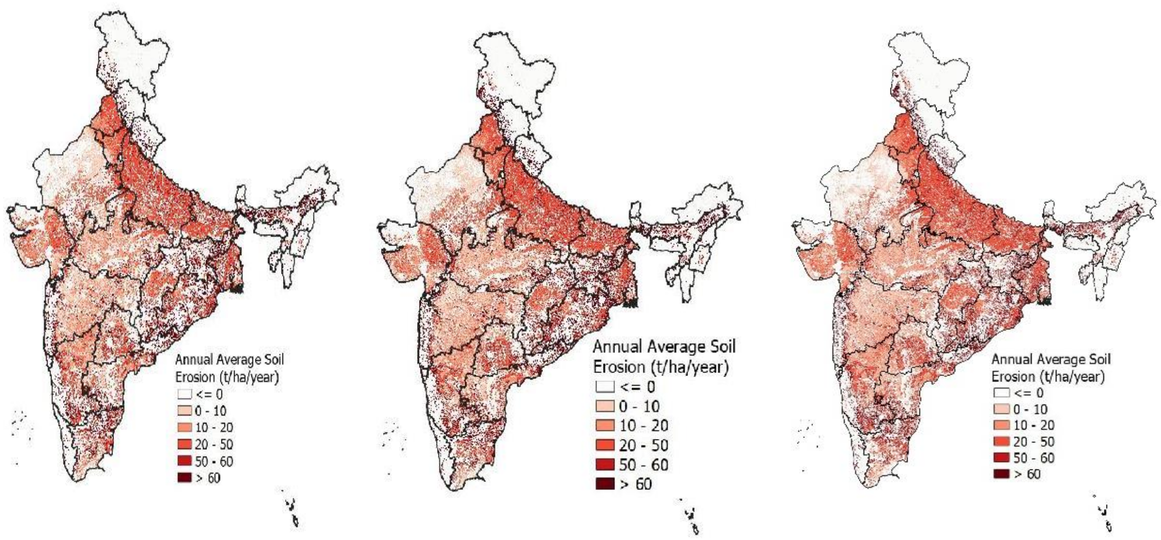


Figure 5: Spatial distribution of soil loss prevention service provided by croplands

(a) 2005-06 **(b) 2011-12** **(c) 2015-16**



38. From the above, it is seen that huge amount of soil loss is prevented by the croplands and the values are especially high for the hilly states like Uttarakhand, Himachal Pradesh and some of the north eastern states which may be attributed to steep slope.

Evaluation, Conclusions and Future Work

39. The estimates of 'soil erosion prevention services' given here are preliminary and further improvements in parameterization with expert knowledge and local datasets will enhance these estimates. Also, the future work can involve improving C factor parameterization for the specific crops and vegetation species present on the agricultural land provided detailed granular level data are available.

40. Another limitation of the analysis is that the report is focused over mainland India, excluding the Islands due to the coarseness of resolution and difference in the extent of global data for such small areas.

41. Estimation of the 'soil erosion prevention services' is based on a counterfactual scenario of 'no service supply', and in the case of croplands, 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. For croplands, a land covered with natural vegetation would have been converted to provide cropland for the local population and in absence of this conversion there would still be natural vegetation. Therefore, the most plausible counterfactual scenario for soil erosion prevention services by croplands would be land covered by natural habitat such as forest or grassland, which can be exercised as a way forward.

42. The cropland ecosystem accounts, as prescribed by the System of Environmental-Economic Accounts (SEEA) is an integrated approach for bringing together a wide range of cropland related statistics across domains – like soil condition, crop fragmentation, productivity and biodiversity - into one coherent information system that can inform on each of the aspects given above. Improved croplands can also help in an increased supply of ecosystem services like a clean and well-regulated water supply, biodiversity, natural habitats for conservation and recreation, climate stabilization, and aesthetic and cultural amenities. An assessment of these ecosystem services can further highlight the inter-linkages between the condition of croplands and the economy, thereby enabling interventions that can help achieve sustainable agriculture and conserve the resource base for future generation.

Soil Erosion Prevention Services

Table-1: Soil loss estimates for year 2005-06

State/UT	Mean Soil Loss Estimates in ton/ha/year for 2005-06		Soil loss prevented by Croplands(ton/ha/year)
	Without Croplands	With Croplands	
Andhra Pradesh	36.3	8.3	27.9
Arunachal Pradesh	31.1	7.2	24.0
Assam	37.5	8.5	28.8
Bihar	30.6	7.0	23.5
Chhattisgarh	27.6	6.4	21.3
Gujarat	19.4	4.5	15.0
Haryana	29.2	6.7	22.5
Himachal Pradesh	211	48.5	162.5
Jammu & Kashmir	27.3	6.3	21.0
Jharkhand	38.8	8.9	29.9
Karnataka	31.4	7.2	24.2
Kerala	18.9	4.3	14.5
Madhya Pradesh	21.5	5.0	16.6
Maharashtra	28.6	6.6	22.1
Manipur	48.1	11.1	100.0
Meghalaya	41.3	9.5	31.8
Mizoram	221.1	50.9	161.8
Nagaland	44.6	10.3	34.3
Odisha	64.9	14.9	49.9
Punjab	32.4	7.5	25.0
Rajasthan	9.4	2.2	7.2
Tamil Nadu	40.9	9.4	31.5
Tripura	29.9	6.9	18.3
Telangana	23.8	5.5	23.0
Uttar Pradesh	33.6	7.8	26.1
Uttarakhand	218.3	50.2	168.1
West Bengal	60.7	14.0	46.8

Soil Erosion Prevention Services

Table-2: Soil loss estimates for year 2011-12

State /UT	Mean Soil Loss Estimates in tons/ha/year for 2011-12		Soil Loss prevented by croplands (tons/ha/year)
	Without Croplands	With Croplands	
Andhra Pradesh	39.1	9.0	30.1
Arunachal Pradesh	34.2	7.9	26.3
Assam	36.0	8.3	27.7
Bihar	33.1	7.6	25.5
Chhattisgarh	29.4	6.8	22.6
Gujarat	18.9	4.3	14.5
Haryana	27.4	6.3	21.1
Himachal Pradesh	201.0	46.2	154.8
Jammu Kashmir	29.9	6.9	23.0
Jharkhand	40.7	9.4	31.4
Karnataka	31.5	7.2	24.2
Kerala	23.2	5.3	17.9
Madhya Pradesh	21.8	5.0	16.8
Maharashtra	29.1	6.7	22.4
Manipur	50.9	11.7	108.6
Meghalaya	41.5	9.5	32.0
Mizoram	16.4	3.8	149.5
Nagaland	44.9	9.7	34.6
Odisha	62.4	14.4	48.1
Punjab	31.8	7.3	24.5
Rajasthan	10.7	2.5	8.3
Tamil Nadu	43.3	9.9	33.3
Tripura	24.7	5.7	19.1
Telangana	29.3	6.7	22.6
Uttar Pradesh	36.3	8.4	28.0
Uttarakhand	212.3	48.8	163.5
West Bengal	60.9	14.0	46.9

Soil Erosion Prevention Services

Table-3: Soil loss estimates for year 2015-16

State	Mean Soil Loss Estimates in tons/ha/year for 2015-16		Mean soil loss prevented by Croplands (tons/ha/year)
	Without Croplands	With Croplands	
Andhra Pradesh	40	9.2	30.8
Arunachal Pradesh	38.6	8.9	29.7
Assam	36	8.3	27.7
Bihar	34.5	7.9	26.5
Chhattisgarh	30.5	7	23.5
Gujarat	18.5	4.3	14.3
Haryana	28.1	6.5	21.6
Himachal Pradesh	200.0	46.0	152.2
Jammu & Kashmir	31.7	7.3	24.4
Jharkhand	32.7	7.5	25.2
Karnataka	31.2	7.2	24.1
Kerala	24	5.5	18.5
Madhya Pradesh	21.9	5	16.8
Maharashtra	28.3	6.5	21.8
Manipur	115.9	26.7	89.3
Meghalaya	48.4	11.1	37.2
Mizoram	23.2	5.3	157.7
Nagaland	45.3	10.4	34.8
Odisha	63.1	14.5	48.6
Punjab	32	7.4	24.7
Rajasthan	9.2	2.1	7.1
Tamil Nadu	43.6	10	33.5
Tripura	29.0	6.7	19.9
Telangana	25.9	6.0	22.3
Uttar Pradesh	36.0	8.3	27.7
Uttarakhand	214.2	49.3	164.9
West Bengal	61.7	14.2	47.5

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Appendix I

Tutorial to Calculate Soil Loss Estimates in QGIS

This tutorial involves the steps that has been used in QGIS environment for performing the above computations. Along with the explanation of working with raster and vector data in QGIS, a brief knowledge to use certain tools of QGIS used in raster analysis is also mentioned in the tutorial.

Aim:

The aim of this tutorial is to generate raster files for soil loss estimates for different states of India.

Requirements:

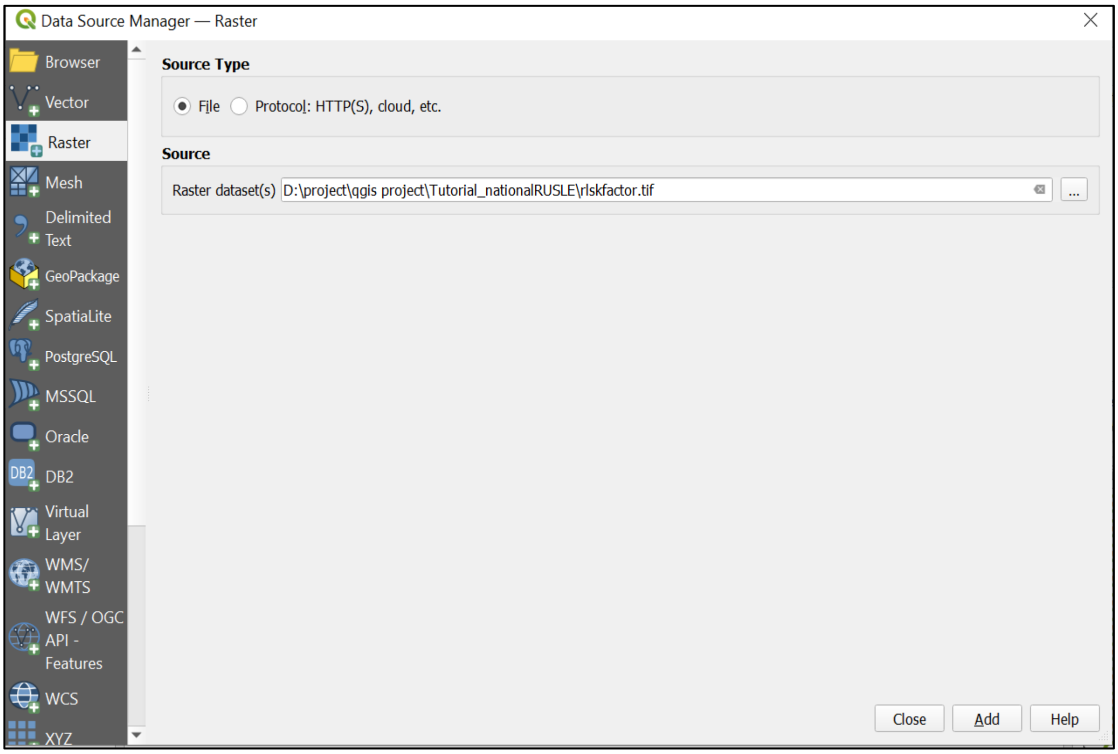
- Following files and Software are required for the analysis: Software: QGIS 3.10, MS Excel
- Datasets:
  - State Boundary shape files (Vector file) [Survey of India]
  - RSLK factor raster file named rlskfactor.tif (pre-processed geotiff file) [LUCI Team
  - LULC Raster datasets provided by NRSC.

Procedure:

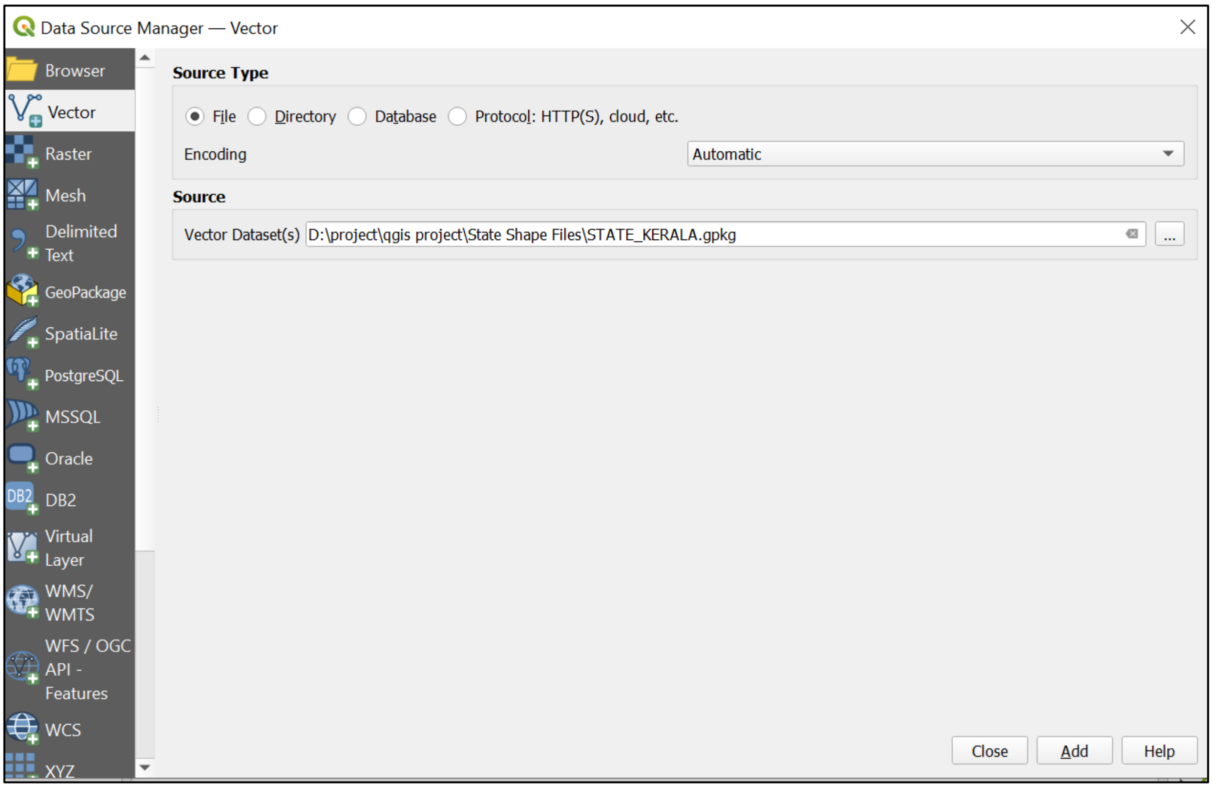
Here, the step-by-step procedure to calculate Soil Loss estimates for the state Kerala has been provided. Similar steps could be followed to derive soil loss estimates for other states as well. Steps to estimate the soil loss for Kerala:

1. Start QGIS 3.10.

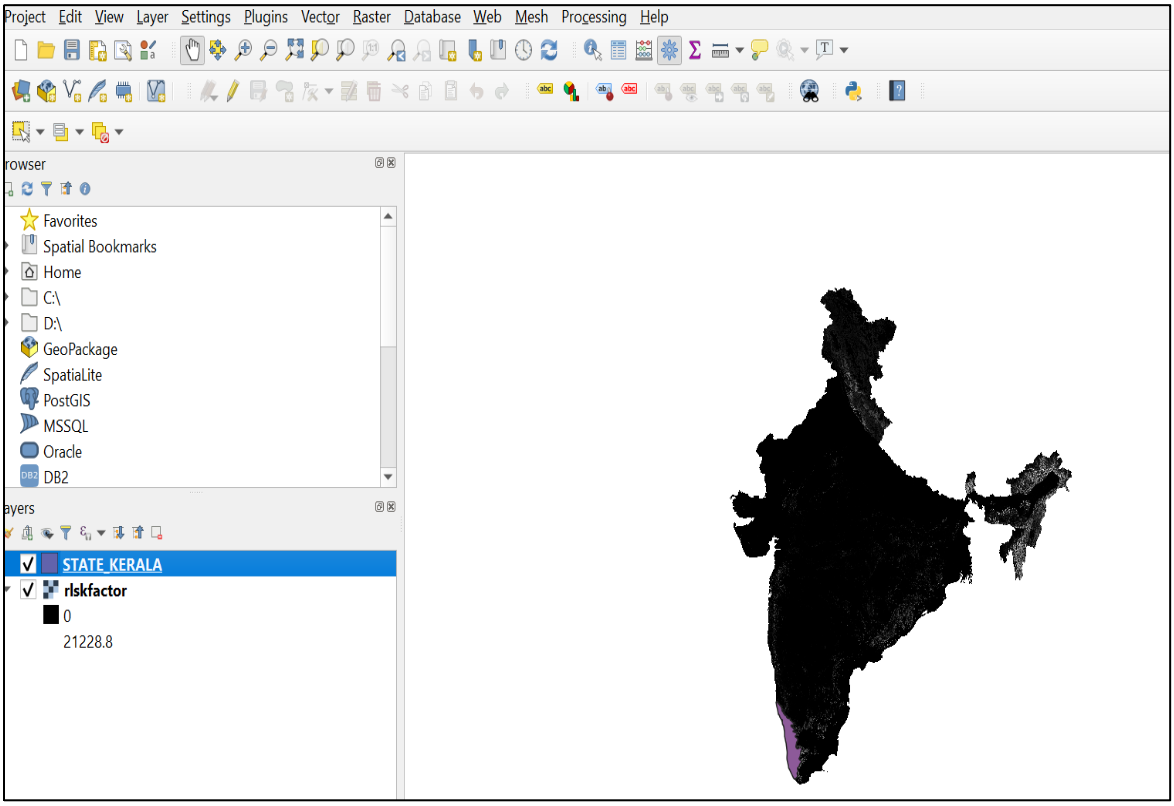
2. Load all of the datasets into QGIS through the Open Data Source Manager icon () or by hitting CTRL+L. Navigate to the Raster pane on the Data Source Manager dialogue box and import the *rlskfactor.tif* file.



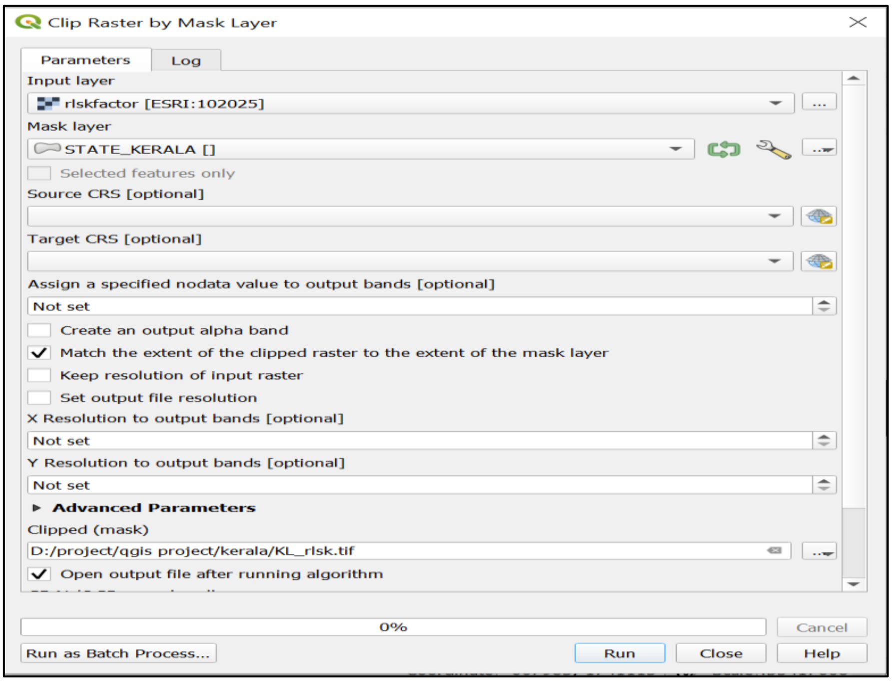
3. Click on *Add* and then close *Data Source Manager* window. The India raster file of rlsk factor will be shown on the QGIS environment.
4. Similarly, the vector pane is used to import the state boundary shape file for Kerala (STATE_KERALA.gpkg).



5. After importing both the files, the QGIS environment will appear like shown below.



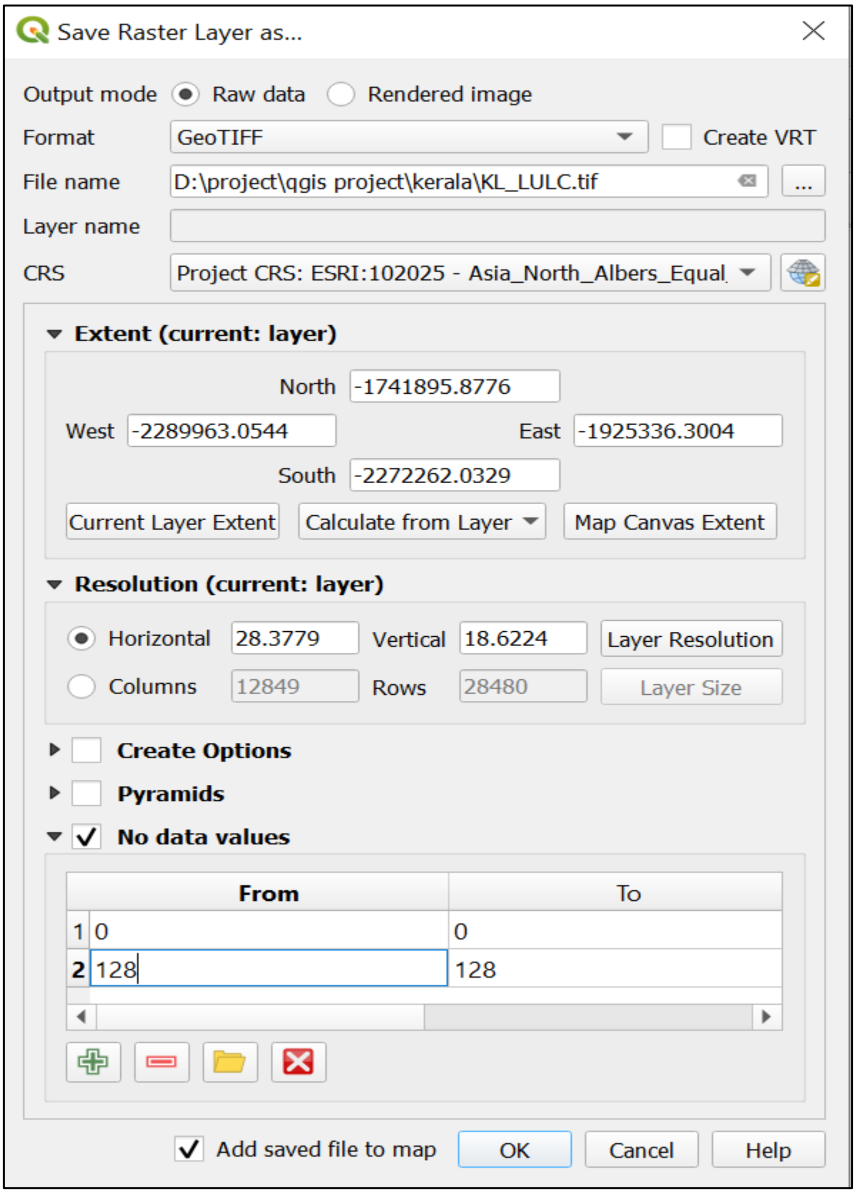
6. Now, the RLSK factor raster for Kerala is extracted using the following steps,: Click in Menu Toolbar ***Raster > Extraction > Clip by Mask Layer*.** Fill the opened dialogue box as shown below and save the file to an accessible path by clicking on '…' under *Clipped(mask)*. For this exercise, name it as KL_rlsk, this file will be used later. Run the process.



After the process is completed, *KL_rlsk* file will be visible on the QGIS Environment.

7. Now, LULC file for Kerala is imported in the same way as the rlskfactor.tif file was imported.

8. After importing, uncheck the KL_rlsk file from layer pane and click on . On right/left side of screen a box named Identity Results will provide the data points of current raster file (which in this case is LULC raster for Kerala). We need to remove the zero data points and the data points outside the boundary of state. For this right click on LULC file of Kerala and fill the dialogue box opened on clicking **Export > Save,** as below. Then click OK.



NOTE:

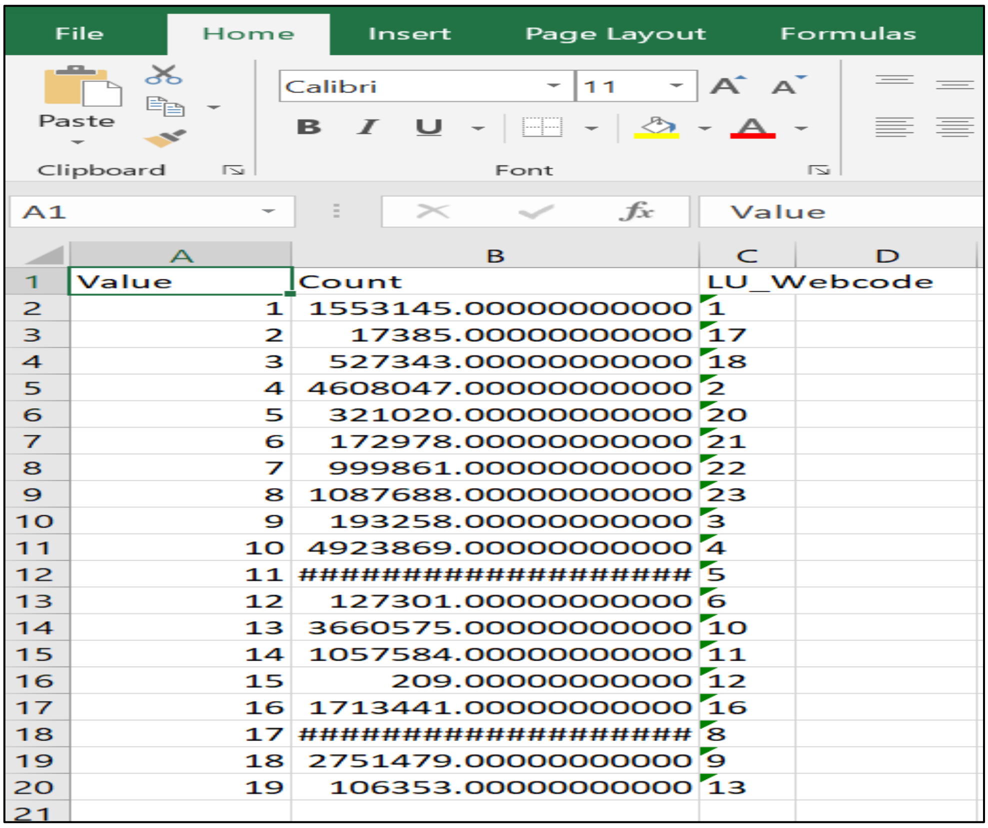
- Click on '…' to save the file to an accessible path. In this exercise, it is named as KL_LULC.tif.
- Set the CRS to **Project CRS: ESRI:102025 - Asia_North_Albers_Equal_Area_Conic.**

- To add the data point that would be removed from that raster, check the **No data value**s box and then click plus sign () for adding these data points. Here, 0 and 128 are the points which are outside the state boundary and where no LULC information is given, hence, these are treated as no data points.

9. Now, in order to set the same resolution of the LULC (KL_LULC.tif) and RLSK (KL_rlsk .tif) raster files, we open the properties of KL_rlsk file by **double clicking /right click> Properties** on KL_rlsk file. Then open the information block, from there copy the pixel size and close the properties window. Next, for KL_LULC.tif, fill the dialogue box opened by clicking **Raster> Projection> Warp (Reproject)**, as below. Save the file with name KL_LULC_p to an accessible path by clicking on '…' under Reprojected heading. Run the commands to get the re-projected raster file.

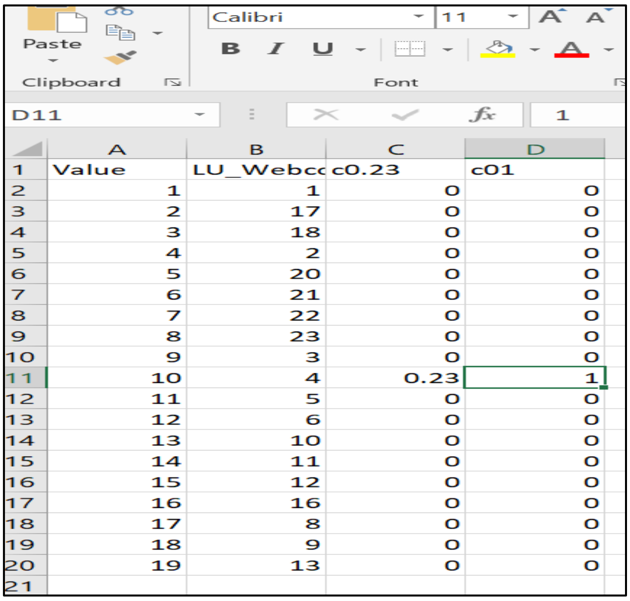
    Input layer: KL_LULC.tif
    Source CRS [optional]: ESRI:102025 - Asia_North_Albers_Equal_Area_Conic
    Target CRS [optional]: ESRI:102025 - Asia_North_Albers_Equal_Area_Conic
    Resampling method to use: Nearest Neighbour
    Nodata value for output bands [optional]: Not set
    Output file resolution in target georeferenced units [optional]: 94.430107
    Reprojected: D:/project/qgis project/kerala/KL_LULC_p.tif

10. Keep only KL_LULC_p.tif and KL_rlsk.tif file and remove all the files from the layer pane. Now, minimize the QGIS environment for a while.
11. Now, for C factor parameterization, an excel file is created for using NRSC data for Kerala. For this the Kerala file with extension .dbf using excel is opened. It will look like



	A	B	C	D
1	Value	Count	LU_Webcode	
2	1	1553145.00000000000	1	
3	2	17385.00000000000	17	
4	3	527343.00000000000	18	
5	4	4608047.00000000000	2	
6	5	321020.00000000000	20	
7	6	172978.00000000000	21	
8	7	999861.00000000000	22	
9	8	1087688.00000000000	23	
10	9	193258.00000000000	3	
11	10	4923869.00000000000	4	
12	11	######################	5	
13	12	127301.00000000000	6	
14	13	3660575.00000000000	10	
15	14	1057584.00000000000	11	
16	15	209.00000000000	12	
17	16	1713441.00000000000	16	
18	17	######################	8	
19	18	2751479.00000000000	9	
20	19	106353.00000000000	13	
21				

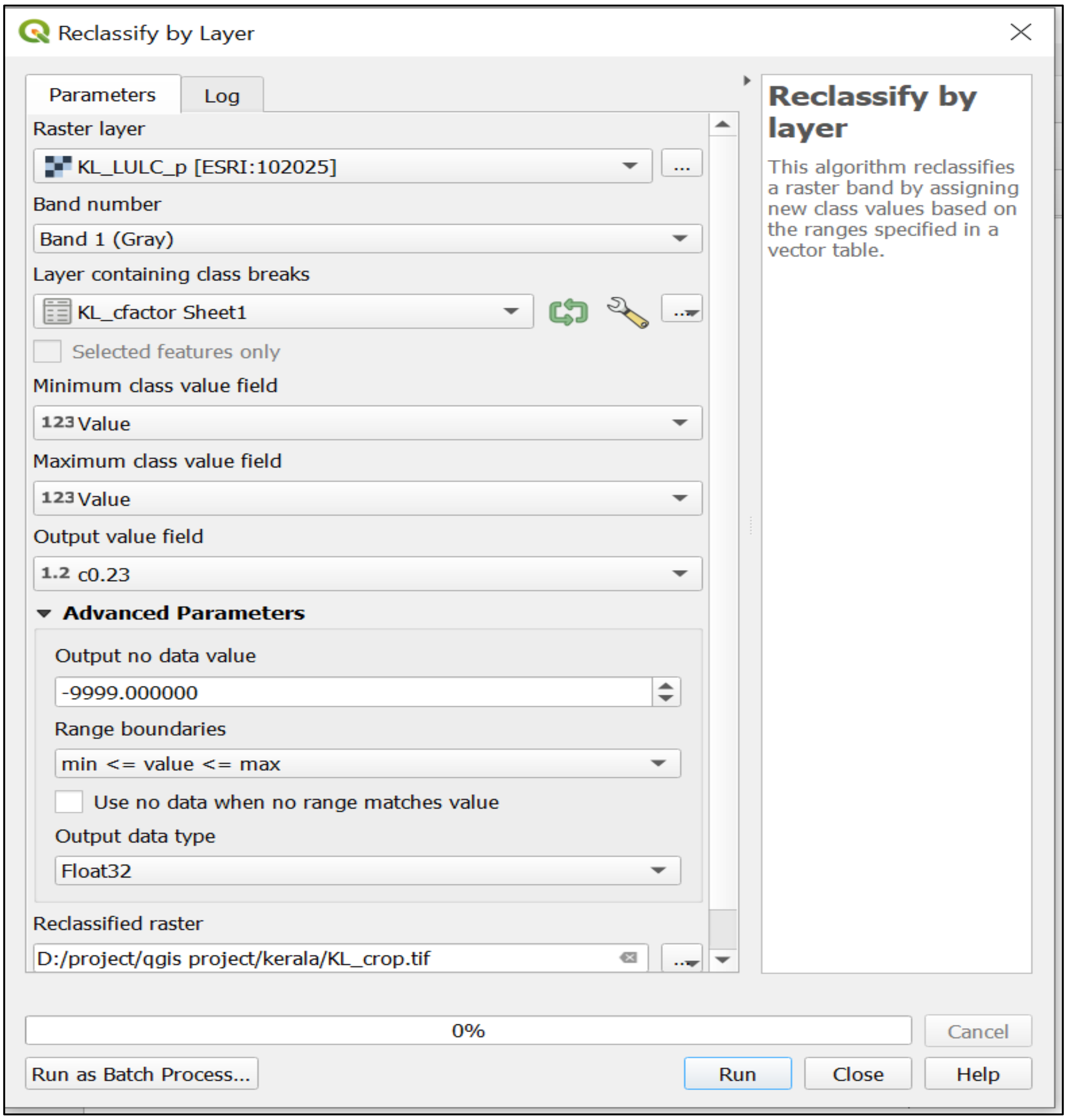
Copy the contents to some other excel file. Here add two columns with name c023 and c01. Fill zero (0) value in these columns except for LU_Webcode 4 which corresponds to Croplands in NRSC LULC layers. In LU_Webcode 4, give value 0.23 in c0.23 column and 1 in c01 column.



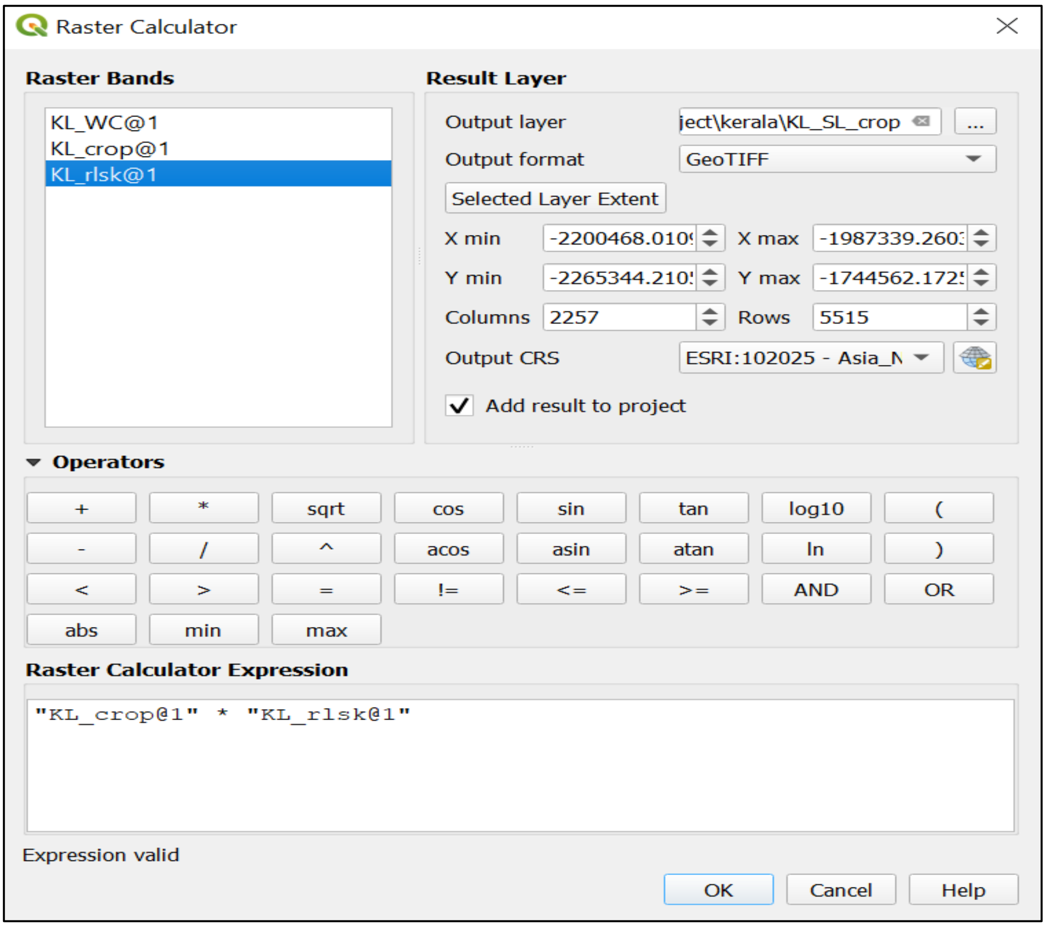
	A	B	C	D
1	Value	LU_Webcc	c0.23	c01
2	1	1	0	0
3	2	17	0	0
4	3	18	0	0
5	4	2	0	0
6	5	20	0	0
7	6	21	0	0
8	7	22	0	0
9	8	23	0	0
10	9	3	0	0
11	10	4	0.23	1
12	11	5	0	0
13	12	6	0	0
14	13	10	0	0
15	14	11	0	0
16	15	12	0	0
17	16	16	0	0
18	17	8	0	0
19	18	9	0	0
20	19	13	0	0
21				

12. Open QGIS and load this excel file using browser pane.
13. Now open the toolbox by clicking **processing > toolbox**. From toolbox (on right/left side of screen) select **raster analysis> reclassify by layer**. Fill the dialogue box as

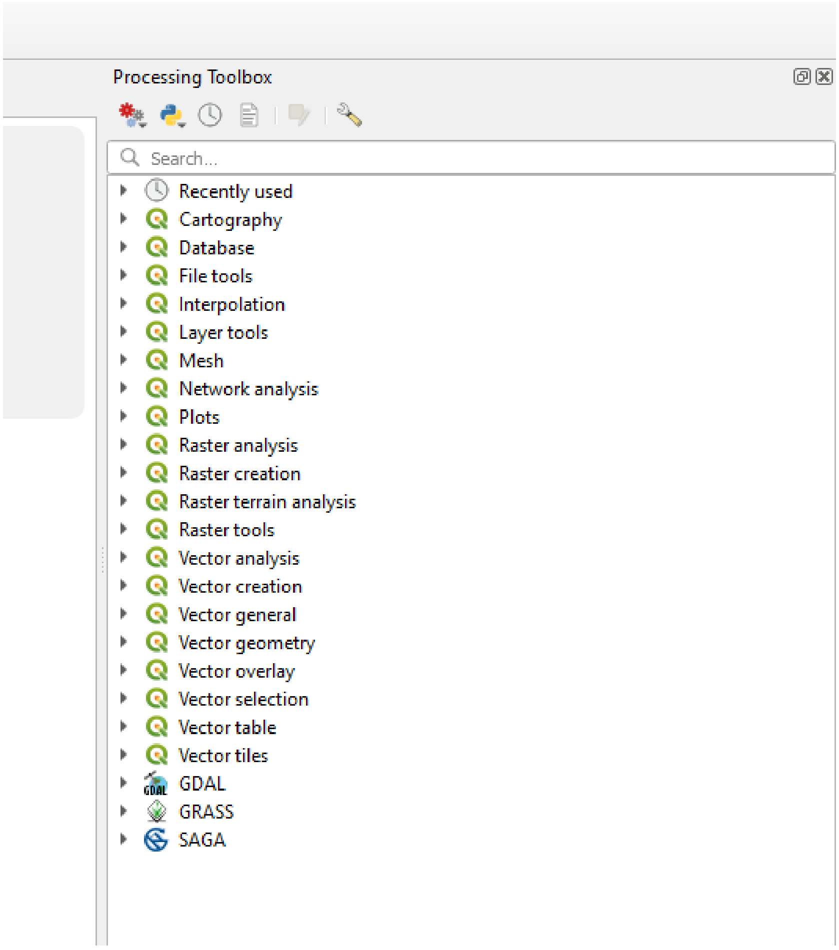
shown and save the file with name KL_crop to an accessible path by clicking on '…' . Then Run.



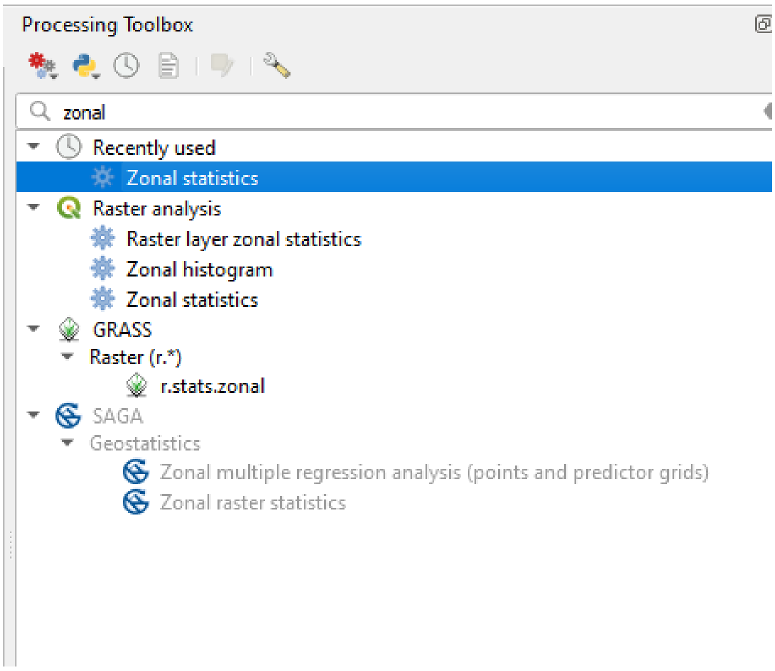
14. Again follow the step no 13, just change the Output value field as c01 and now save the file as KL_WC and Run.
15. Now keep only KL_crop , KL_WC, KL_rlsk files in layer pane and remove all other files.
16. Now to calculate the soil loss click on **Raster> Raster Calculator.** Select the file by double clicking on it and use the multiply operator given in it. To calculate soil loss for croplands, select KL_rlsk and KL_crop and multiply operator and save the file (with name KL_SL_crop) to an accessible path by clicking '…' in front of output layer. Output CRS should be
Project CRS: ESRI:102025 - Asia_North_Albers_Equal_Area_Conic.



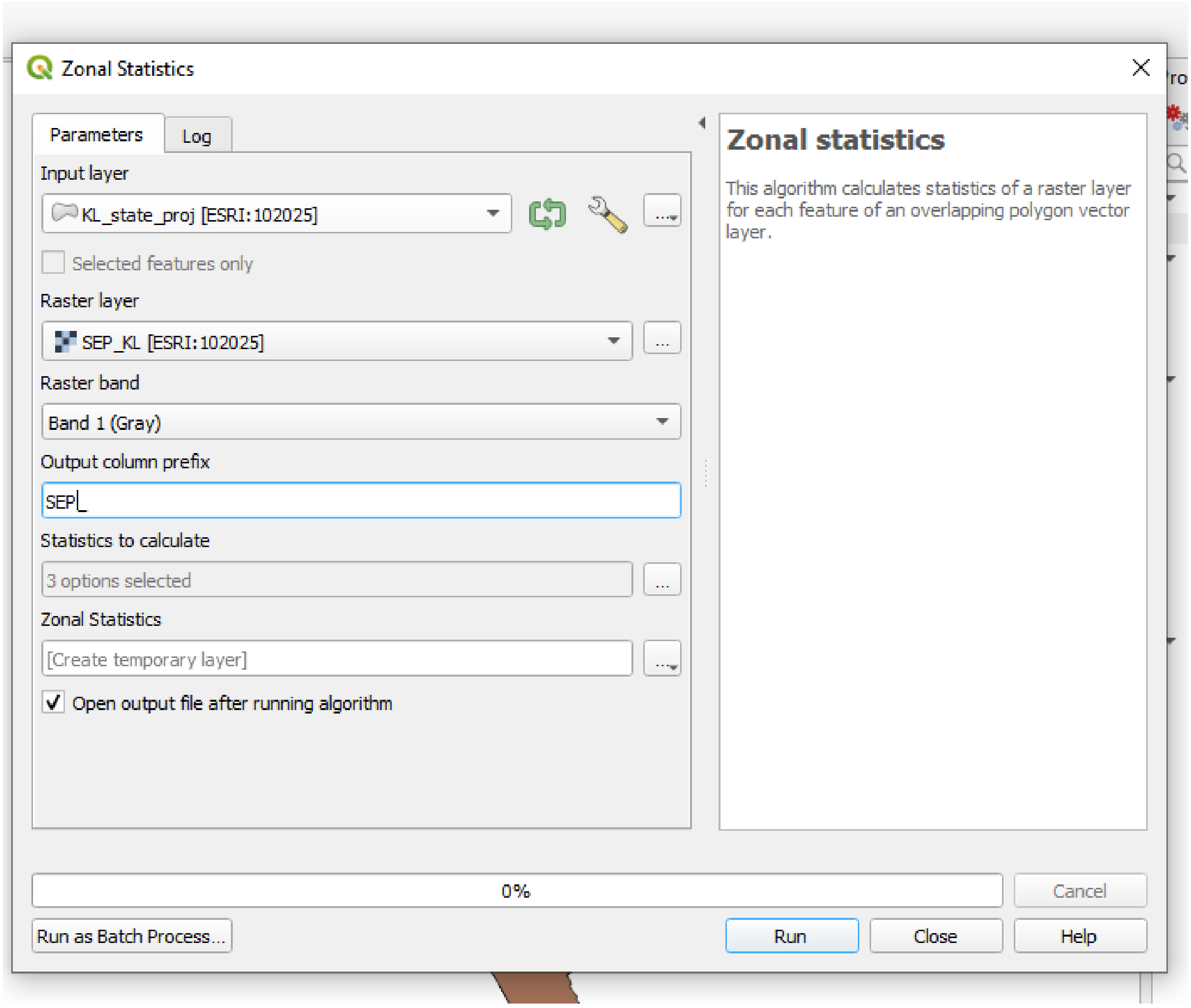
17. Calculate the Soil loss without cropland by multiplying KL_WC and KL_rlsk and soil loss prevention service by subtracting KL_SL_crop from KL_SL_WC.
18. The soil loss prevention raster file as obtained in previous step may be named as 'SEP_KL'.
19. For the next step, remove all other files, and keep only 'SEP_KL' and shapefile of state boundaries.
19. To calculate mean soil loss prevention services provided by croplands, go to '***Processing-> Toolbox'***. A pane will be displayed on the QGIS window (in the right corner) as follows:



19. Type 'Zonal' in the '*Search*' box of the above pane. Select 'Zonal Statistics'.



20. A 'Zonal Statistics' window will be opened as follows. Fill the parameters as shown below:

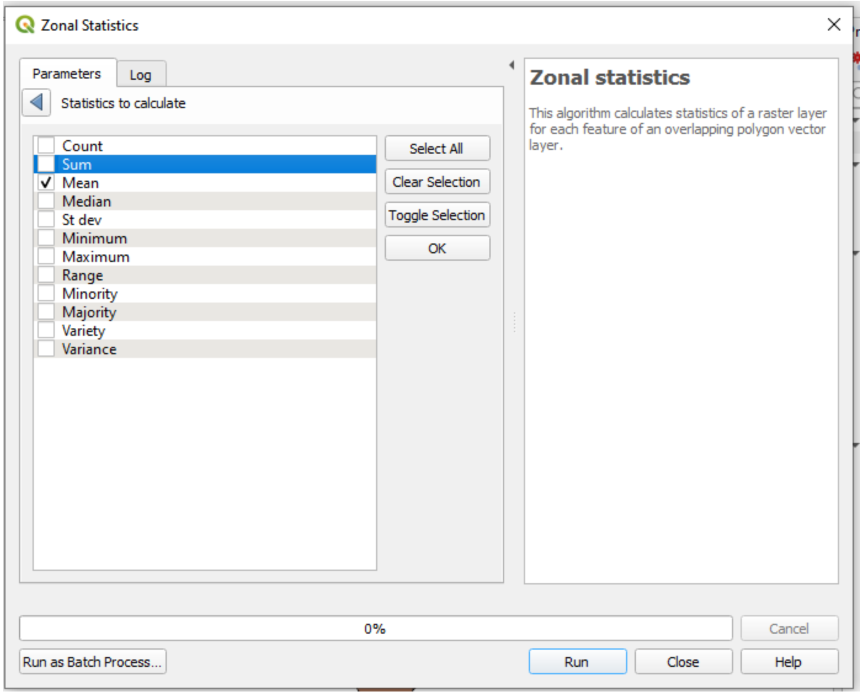


Input layer: Shapefile of state boundaries. Here it is 'Kl_state_proj.shp'

Raster layer: raster file having soil loss erosion prevention services estimates. Here, the file is 'SEP_KL.tiff'

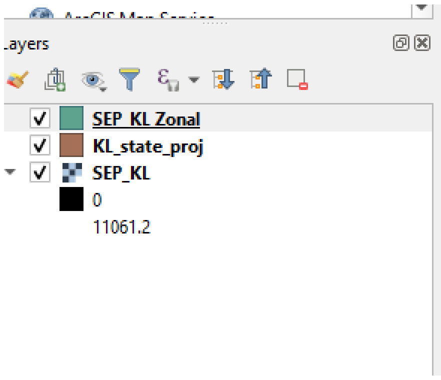
Output column prefix: Prefix of the column having desired statistics. Eg. Column having mean value would be shown as 'SEP_mean'

Statistics to calculate: Desired statistics to be calculated can be selected. Here we are calculating mean, so only 'mean' is selected as shown in the following.

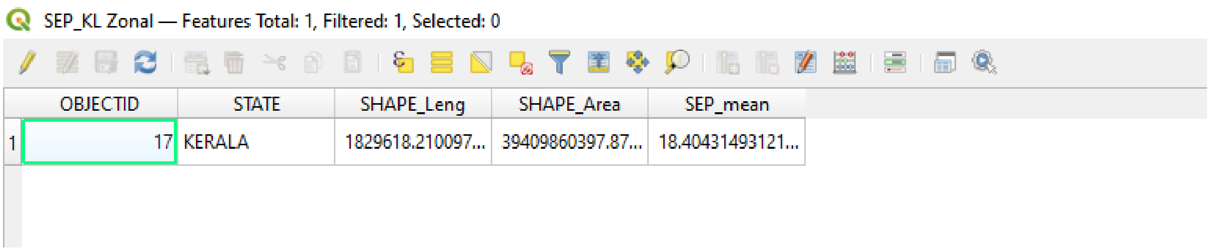


Zonal Statistics: The output file having zonal statistics can be saved. Click on '…' and select '*Save to file*' and name the output file as 'SEP_KL_Zonal'. Save the file as shapefile.

21. Now, the output file will be shown in layer pane.



22. Right Click on the 'SEP_KL_Zonal' and select '*Open Attribute Table*'. The following table will open. The last column 'SEP_mean' has the desired mean value of soil erosion prevention services by croplands for Kerala.



23. Same steps can be repeated to calculate Soil Erosion Prevention services for other States too.

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