 Original Research Article

ESTIMATION OF RAINFALL EROSIVITY AND SOIL ERODIBITY FACTOR FOR THE OZAT RIVER BASIN USING REMOTE SENSING AND GIS

ABSTRACT

In India, soil erosion is a major problem that lowers water availability and agricultural land production. Detachment, transportation and deposition of soil particles from one place to another under the influence of wind, water or gravity forces is known as soil erosion. Therefore, Revised Universal Soil Loss Equation (RUSLE) with Remote Sensing and GIS study was found easy for estimation of soil loss in river basins. The selected watershed for this study was Ozat river basin is situated in Gujarat, having the catchment area 3410 km^2. The rainfall erosivity factor (R) was estimated using monthly and annual rainfall data. Sand, silt, clay and organic matter of soil were used to determine the soil erodibility factor (K). The highest and lowest estimated rainfall erosivity factor were found 144.45 $MJ.mm.ha^{-1}.h^{-1}.y^{-1}$ to 147.37 $MJ.mm.ha^{-1}.h^{-1}.y^{-1}$ respectively. The soil erodibility was found in the range of 0.139 tonnes-ha-hr/ha-MJ-mm to 0.172 tonnes-ha-hr/ha-MJ-mm.

Keywords: Rainfall Erosivity, Soil Erodibility, Remote Sensing and GIS, Ozat River Basin

1. INTRODUCTION

Soil is the upper most weathered and disintegrated layer of the earth's crust which is composed of minerals and the organic substances with the capability of sustaining plant life. The top layer of soil is continuously exposed to the actions of atmospheric activities. Wind and water are the two main active forces which are responsible for the dislodging of the top soil layer and transportation of them from one place to another which can be referred as soil erosion. There are various negative impacts of soil loss on agriculture. Soil degradation limits the soils' ability to retain water and nutrients. This leads to the deposition of silt in lower areas of the watershed, which ultimately reduces the production capacity of upland areas and also reduces the nutrients level of topsoil of soil erodible area.

Though soil erosion is a naturally occurring process, this has been accelerated by human activities such as intensive agriculture, improper land management, deforestation, and cultivation on steep slopes. Removal of vegetation cover and shaping of surface topography induce or accelerate soil displacement and movement. Serious soil erosion is occurring in most of the world's major agricultural regions (Pimentel *et al.*,1987) due to the expansion of agriculture without adequate soil conservation practices. Moreover, crop residues are removed for fodder, biofuel, and industrial uses leaving the soil surfaces bared from a protective cover enhancing the vulnerability to lands for erosion. The resulting runoff ultimately transports sediments, organic material, nutrients, and pesticide residues off-site impacting both water and soil quality. When lands are left as fallow to recover, the erosion problem is worsened due to minimal vegetative cover (Bashir *et al*., 2018). Soil erosion is reported to increase with higher magnitude of rainfall and frequent occurrences of heavy precipitation (Panagos *et al.,* 2012).

Gujarat is located in Western part of India covering total geographical area of 19.6 Mha, which is about 6% of the total geographical area of the country. Analysis of soil erosion data revealed that soil erosion rates vary enormously across the state, ranging from less than 5 tha^{-1}yr^{-1} in 0.01% area to very severe (>40 tha^{-1}yr^{-1}) in 10.64% area. Percentage of area under slight (<10 tha^{-1}yr^{-1}), moderate (10-20 tha^{-1}yr^{-1}) and severe (20-40 tha^{-1}yr^{-1}) soil erosion classes are 16.07, 61.23 and 10.99, respectively. Analysis of the data also revealed that nearly 82.96% area across the state has erosion rates of more than 10 tha^{-1}yr^{-1}, which indicates that soil erosion is a serious problem in major parts of the state. The severity of soil erosion is due to aggressive climatic conditions coupled with steep topography and erodible soils (Kumar *et al.*, 2021).

In recent years, advancements in Remote Sensing and Geographic Information System (GIS) technologies have provided valuable tools for assessing and monitoring soil erosion on a larger scale. Remote sensing involves the acquisition of data about the Earth's surface from air borne or satellite sensors, while GIS integrates and analyses spatial information to derive meaningful insights.

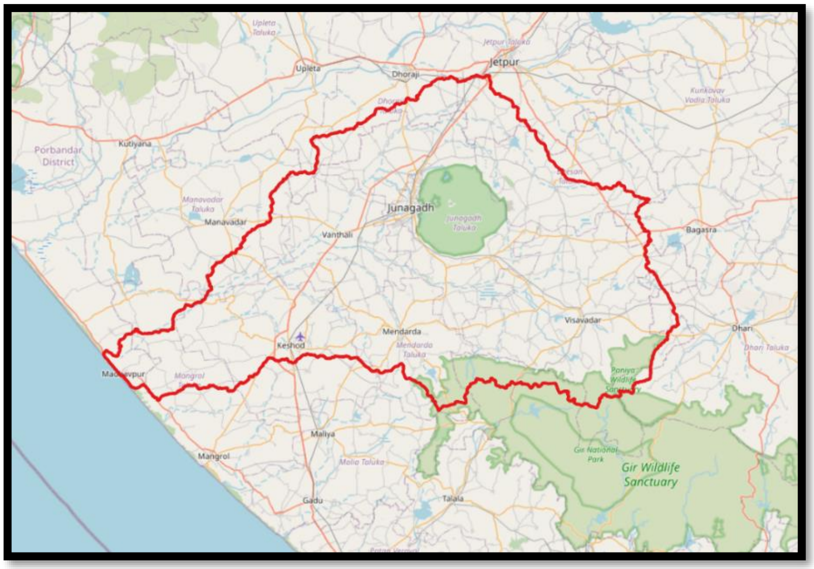
Keeping this in view present study has been planned with following objective i.e.,

To estimate the rainfall erosivity and soil erodibility factor of Ozat river basin.

2. MATERIAL AND METHODS

2.1 Location

Ozat river originates from Visavadar and meets in Arabian sea. It is situated between latitude of 21° N to 22° N and longitude of 70° E to 71° E. The perimeter of a basin is 390.11 Km having catchment area 3410 sq.km. Dhrafad & Ozat dams are located on this river having 169 sq.km. & 1138 sq.km. catchment area respectively. Abajal & Popatdi are right bank tributaries, and Uben & Utavali are left bank tributaries of this river. Agriculture is the main occupation in the area. Groundwater is the main source of irrigation on study area.



map. .1 Base map of Ozat river basin

2.2 Data collected

a. Rainfall data (monthly and annual)

CHRS data portal

https://chrsdata.eng.uci.edu/

b. Soil data

FAO Digital Soil Map of the World (DSMW)

https://www.fao.org/land water/land/land governance/land resources-planning toolbox/category/details/en/c/1026564/

2.3 Software

ArcGIS is a geographic information system (GIS) used to create, manage, analyze, and map all types of data. ArcGIS connects maps, apps, data, and people in ways that help empower organizations to make data-driven decisions more efficiently. ArcGIS accomplishes this by making it easy for everyone in an organization to discover, use, make, and share maps from any device, anywhere, at any time.

2.4 Rainfall erosivity factor (R)

Soil erosion is closely related to rainfall through the combined effect of detachment by raindrops striking the soil surface and by the runoff. According to USLE method, soil loss from the cultivated field is directly proportional to a rain storm parameter, if other factors remain constant.

Rain gauge stations are not present everywhere in India due to the high cost of installation. Yet, because rainfall is the key contributor to soil erosion and is uneven in both time and area, it is essential to study the variation in rainfall. Rainfall is unequal with time and space; to vanquish this issue the following formula was used in this study to estimate the R factor. The Equation, below developed by Wischmeier and Smith (1978) and modified by Arnoldus (1980) will be used in the computation:

$$\boldsymbol{R} = \sum_{i=1}^{12} \mathbf{1.735} \times \mathbf{10} \times \left\{\mathbf{1.5} \times \mathbf{log}\left\{\frac{\boldsymbol{Pi}^{2}}{\boldsymbol{P}}\right\} - \mathbf{0.08188}\right\}$$

Where,

R is the rainfall erosivity factor (MJ. mm. ha $^{-1}$. h^{-1}.y^{-1}),

P_i is the monthly rainfall (mm), and

P is the annual rainfall (mm)

2.5 Soil erodibility factor (K)

The physicochemical characteristics of soil are used to determine soil erodibility (K), which is an evaluation of the susceptibility of soil particles to be removed from soil aggregates by any erosive agent. The soil erodibility factor is the measure of the vulnerability to soil erosion as they are built-in soil properties. The K factor value ranges from 0 to 1, where the value near to 0 indicates least susceptibility to soil erosion and whereas the value closer to 1 indicated that they are very high susceptibility to soil erosion.

An equation for estimating K_{RUSLE} values given by Wiliams (1995):

$$\mathbf{K_{RUSLE} = Kw = F_{csand} \times f_{cl\text{-}si} \times f_{orge} \times f_{hisand}}$$

Where,

f_{csand} is a factor, that lowers the K indicator in soils with high coarse-sand content and higher for soils with little sand;

$f_{cl\text{-}si}$ gives low soil erodibility factors for soils with high clay-to-silt ratios;

f_{orgc} reduces K values in soils with high organic carbon content while,

f_{hisand} lowers K values for soils with extremely high sand content:

$$f_{csand} = \left\{0.2 + 0.3 \times \exp\left[-0.256 \times m_s \times \left(1 - \frac{m_{slit}}{100}\right)\right]\right\}$$

$$f_{cl\text{-}si} = \left(\frac{m_{slit}}{m_c + m_{slit}}\right)^{0.3}$$

$$f_{orgc} = \left(1 - \frac{0.25 \times orgC}{orgC + [3.27 - 2.95 \times orgC]}\right)$$

$$f_{hisand} = \left(1 - \frac{0.7 \times \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 \times \left(1 - \frac{m_s}{100}\right)\right]}\right)$$

Where,

m_s – the sand fraction content (0.05- 2.00 mm diameter) [%];

m_{silt} – the silt fraction content

(0.002-0.05 mm diameter) [%];

m_c – the clay fraction content (<0.002 mm diameter) [%];

org C – the organic carbon content [%]

3. RESULTS AND DISCUSSION

3.1 Rainfall erosivity factor (R)

The rainfall erosivity factor (R) values for the study area were calculated by using the equation given by the Wischmeier and Smith (1978) and modified by the Arnoldus (1980). For the preparation of R factor map monthly and annual rainfall data were used for the year 2003 to 2022. These data were downloaded from the CHRS data portal (Center for Hydrometeorology and Remote Sensing at the University of California) in which Persian CDR (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Network- Climate Data Record) was used having the resolution of 0.25^{o}× 0.25^{o}. It was given in tiff format. R -factor map was calculated by using the raster calculator in the

ArcGIS 10.4 software. After finding the R factor for 20 years, the raster file was converted into the point format by using the ‘rater to point’ tool in conversion toolbox in ArcGIS. Interpolation was done for the study area. For the Interpolation IDW (Inverse Distance Weighted) was used. It interpolates a raster surface from points using an inverse distance weighted technique. The output value for a cell using the IDW is limited to the range of the values used to interpolate. Because IDW is a weighted distance average, the average cannot be greater than the highest or less than the lowest input.

For the present study area R factor values ranges from 144.46 $MJ.mm.ha^{-1}.h^{-1}.y^{-1}$ to 147.37 $MJ.mm.ha^{-1}.h^{-1}.y^{-1}$.The R factor was calculated for the 20 years and average R factor map for the study area is shown in fig. 1. And the values of R factor for the period 2003 to 2022 are given in table.1.

Table: .1 Rainfall erosivity value for year 2003 to 2022

Year	R factor Value ($MJ.mm.ha^{-1}.h^{-1}.y^{-1}$)
2003	136.49-156.13
2004	144.41-149.14
2005	158.03-168.30
2006	158.84-164.00
2007	179.90-182.28
2008	144.85-152.87
2009	104.65-122.18
2010	153.47-162.34
2011	161.58-167.62
2012	114.71-120.44
2013	154.90-165.42
2014	70.01-122.75
2015	113.25-130.28
2016	138.00-141.64
2017	157.75-160.49
2018	89.13-110.38
2019	170.19-174.75
2020	168.02-173.60
2021	133.81-146.51
2022	155.37-163.20

3.2 Soil erodibility factor (K)

Sand, silt, clay and organic matter content data were used to evaluate the Ozat river basin's soil erodibility factor (K) map. For DSMW FAO data was used. DSMW FAO (Digital Soils Maps of the World) (Food and Agriculture Organization of the United Nations) provides the digital soil map of the world which is given in ESRI (Environmental Systems Research Institute) shapefile format. Study area was extracted from the world data and sand, silt, clay and organic matter content were tabulated as given in table 2 for the study area.

From the values in above table, sand fraction content (m_s), silt fraction content (m_{silt}), the clay fraction content (m_c) and organic carbon content were found out by using the equation proposed by the Williams (1995). The soil type found in the study area were Lithosols, Calcaric Fluvisols and Chromic Vertisols. The values of m_s, m_{silt}, m_c and orgc for the soil type Chromic Vertisols, Calcaric Fluvisols and Lithosols are given in table .3.

The K factor value was estimated by substituting all the above value in equation and the K factor value for the study area ranging between 0.139 tonnes-ha-hr/ha-MJ-mm. to 0.172 tonnes-ha-hr/ha-MJ-mm. K factor value for different soil type is given in table .4.

It was found that the clay content has low K factor values 0.0139 tonnes-ha-hr/ha-MJ-mm. and 0.140 tonnes-ha-hr/ha-MJ-mm, because the clayey soils are highly resistant to detachment of soil particles. The medium textured soils such as loam have K factor value 0.172 tonnes-ha-hr/ha-MJ-mm. The similar K factor value was found in results given by Machiwal *et al.* (2015).

Table: .2 Sand, silt, clay and organic matter content in soil types of study area

Soil sample	m_s (sand) Top soil %	m_{silt} (silt) Top soil %	m_c (clay) Top soil %	Orgc Organic carbon %
Vc	22.8	24.5	52	0.69
Jc	39.6	38.9	20.8	0.70
I	57.9	16.3	24.9	0.90

Table: .3 Sand fraction content (m_s), silt fraction content (m_{silt}), the clay fraction content (m_c) and organic carbon content of study area

Soil sample	F_{csand}	F_{cl-si}	F_{orgc}	F_{hisand}
Vc	0.20	0.71	0.97	0.99
Jc	0.20	0.88	0.98	0.98
I	0.20	0.76	0.93	0.97

Table:4 K factor values for different soil types of the study area

Sr. No.	Soil	FAO soil class	K factor value tonnes-ha-hr/ha-MJ-mm.
1	**Vc**	**Chromic Vertisols**	**0.140**
2	**Jc**	**Calcaric Fluvisols**	**0.172**
3	**I**	**Lithosols**	**0.139**

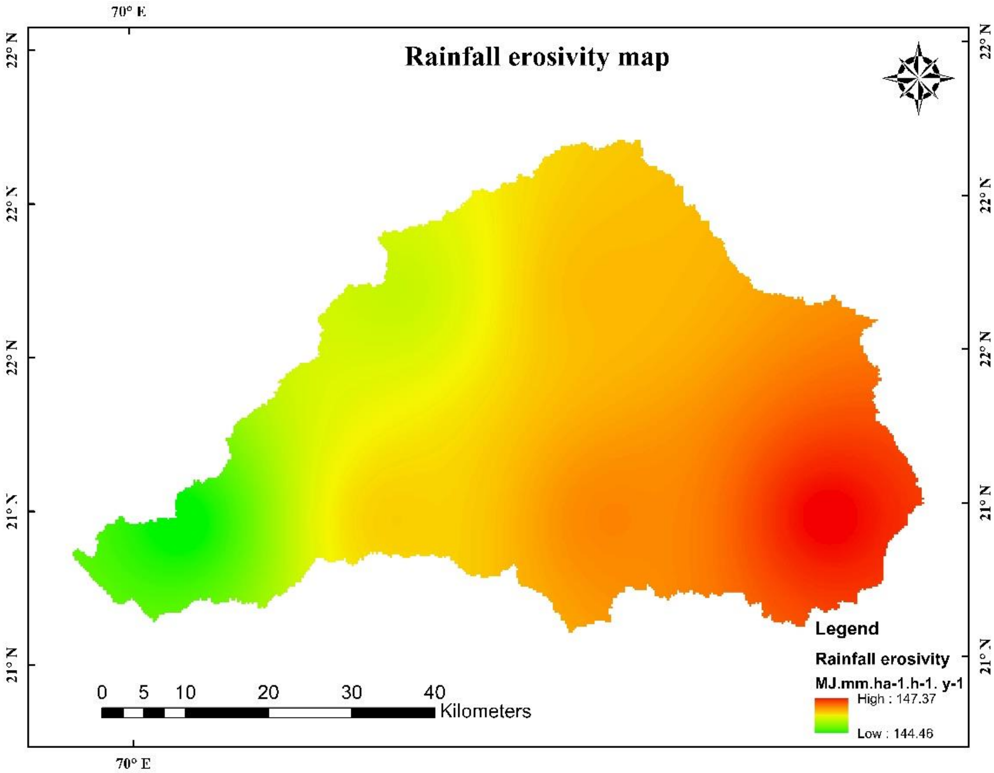


Fig. .1 Rainfall erosivity map of Ozat river basin

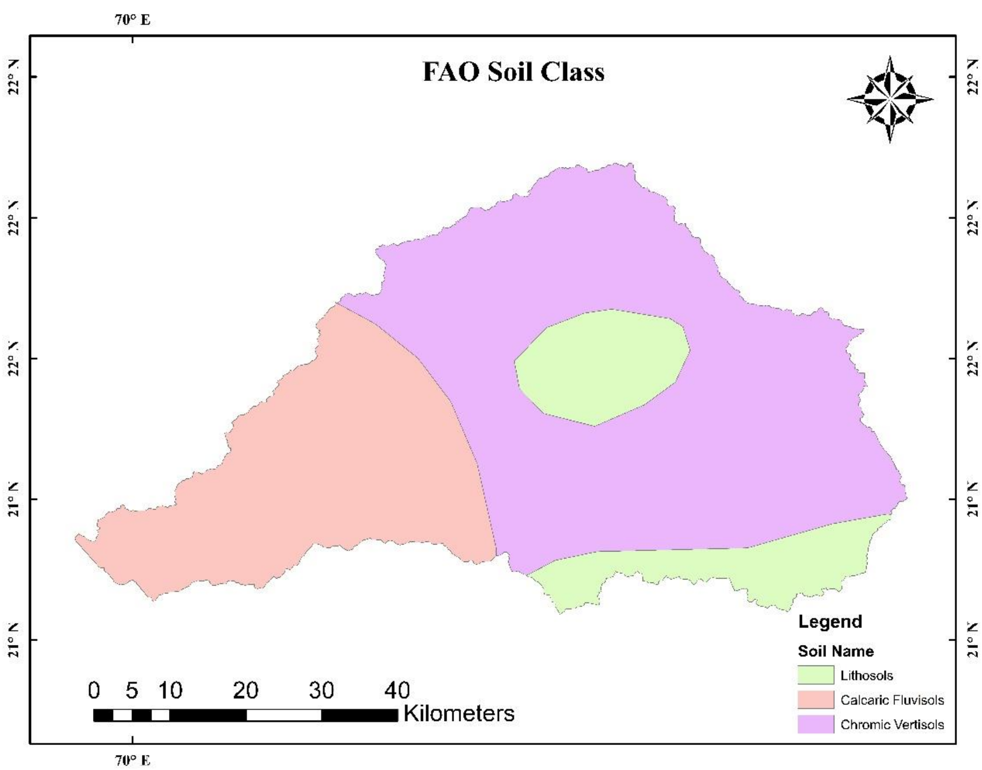


Fig. 2 FAO soil class map of Ozat river basin

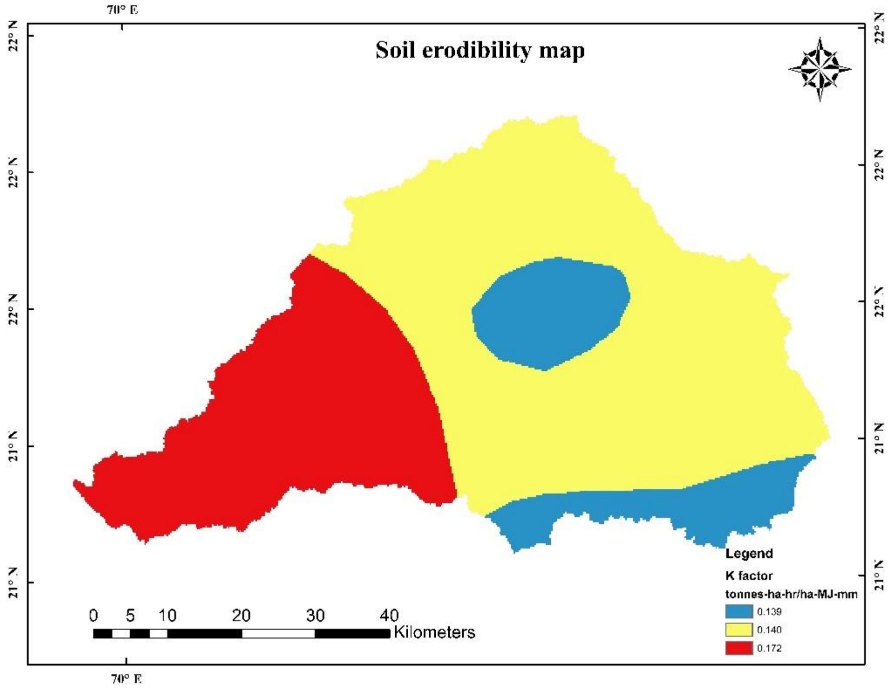


Fig. .3 Soil erodibility map of Ozat river basin

4. CONCLUSION

Based on the results of the study following conclusions are drawn-

The rainfall erosivity factor for the Ozat river basin was ranging between 144.46 MJ.mm.ha^{-1}.h^{-1}. y^{-1} to 147.37 MJ.mm.ha^{-1}.h^{-1}. y^{-1}.The soil erodibility factor of Ozat river basin was ranging between 0.139 tonnes-ha-hr/ha-MJ-mm to 0.172 tonnes-ha-hr/ha-MJ-mm. It was found that the clay content has low K factor values 0.139 tonnes-ha-hr/ha-MJ-mm. and 0.140 tonnes-ha-hr/ha-MJ-mm, because the clayey soils was highly resistant to detachment of soil particles. The medium textured soils such as loam have K factor value 0.172 tonnes-ha-hr/ha-MJ-mm.

REFERENCES

Arnoldus, H. M. J., de Boodt, M. and Gabriels, D. (1980). An Approximation of the rainfall factor in the Universal Soil Loss Equation; John Wiley and Sons Ltd.: Chichester, UK.

Bashir, S., Javed, A. and Bibi, I. (2018). Soil and water conservation. University of Agriculture, Faisalabad, Pakistan.

FAO/ Unesco. Soil Map of the World 1:5,000,000 South Asia; Food and Agriculture Organization: Rome, Italy, 1977; Volume 7, ISBN 92-3-101344-0.

Kirthigaa, C. and Sakthive,l R.(2022). Estimation of soil erosion risk using rusle and debris flow susceptibility mapping using bivariate spatial models, Palakkad district, Kerala. *International Research Journal of Modernization in Engineering Technology and Science*, **4** :8.

Kumar, R., Bhardwaj, A. K., Rao, B. K., Vishwakarma, A. K., Kakade, V., Dinesh, D., Singh, G., Kumar, G., Pande, V. C., Bhatnagar, P.R. and Bagdi, G. L. (2021). Soil loss hinders the restoration potential of tree plantations on highly eroded ravine slopes. Journal of Soils and Sediments, 21, pp.1232-1242.

Machiwal, D., Katara, P. and Mittal, H. K. (2015). Estimation of soil erosion and identification of critical areas for soil conservation measures using RS and GIS-based Universal Soil Loss Equation. *Agricultural Research*, **4(2):** 183–195*.*

Panagos, P., Karydas, C. G., Gitas, I. Z. and Montanarella, L. (2012). Monthly soil erosion monitoring based on remotely sensed biophysical parameters: a case study in Strymonas river basin. **5**:461–487.

Pimentel, D., Allen, J. and Beers, A. (1987). World agriculture and soil erosion. *Bioscience*, **37**:277–283.

Williams, J. R. (1995). Chapter 25. The EPIC Model. In Computer Models of Watershed Hydrology; Singh, V.P., Ed.; Water Resources Publications: Littleton, CO, USA.

Wischmeier, W. H. and Smith D. D. (1965). Predicting rainfall-erosion losses from cropland east of Rocky Mountains: guide for selection of practices for soil