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Estimation of soil loss by using remote sensing and geographical information system

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Abstract
Soil loss is the total amount of soil particles that reaches the watershed outlet due to erosion and deposition processes within a watershed. It results in the erosion of nutrient-dense topsoil in elevated regions, leading to a decline in agricultural production in such areas. Also on bed of river and lakes due to increase in sedimentation reduces the capacity of river, which increases velocity of the water leading erosion downstream and in coastal zones and cause damage to coastal and marine ecosystems and human settlements. Hence, soil loss is needed to estimate for studies of reservoir sedimentation, river morphology and soil and water conservation planning.
The present study aimed at estimating soil loss USLE equation using remote sensing and GIS technique in Urun Islampur watershed, located in Walwa tehsil, Sangli district of Maharashtra, occupying an area about 67.66 km^2. Watershed boundary and LULC were generated in GIS platform by using existing soil map. The slope is derived by using “Show Slope Profile” in “Google Earth” software by using boundary of watershed. The ultimate soil loss is determined by multiplying all derived and computed parameters utilizing the USLE equation.
The estimated soil loss of the Urun Islampur watershed using USLE equation in 2001 was 4.148 t/ha/yr. However, it was found 0.712 t/ha/yr for year 2008 with a decrease of 3.436 t/ha/yr. USLE equation is suitable for the Urun Islampur watershed for estimation of soil loss. The decreased soil loss was observed to the extent of 3.436 t/ha/yr (82.83%) in seven years i.e. from 2001 to 2008.

Keywords: Urun Islampur, Estimation, soil loss, remote sensing, geographical, information system

Introduction
Soil erosion is the process involving the detachment, movement, and deposition of soil particles due to the influence of wind, water, or gravity. This triggered a very fast pace of erosion of soil from land surface due to the action of two fluids, wind and water. Soil erosion resulting from natural occurrences is referred to as geological erosion, whereas erosion induced by excessive land utilization is considered accelerated erosion. Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function.
In nearly every instance, the primary necessity is to predict future conditions; however, the material presented herein emphasizes hind casting a historical period. This focus arises because land use, rainfall, and runoff are established for hindcasting, whereas forecasting future yields necessitates the estimation of these parameters. Furthermore, hindcasting is the requisite technique for validating that the methodology will be applicable to the proposed study area. Estimating erosion is crucial for land and water management issues, encompassing sediment transport and storage in lowlands, reservoirs, and irrigation and hydropower systems. Soil erosion rates can be estimated using erosion prediction equations developed over the past four decades.
Shifting cultivation on hill slopes, the failure to implement soil conservation practices, and the overexploitation of land for agricultural production owing to population pressure result in significant soil erosion. Water-induced soil erosion is a significant land degradation issue and a crucial environmental threat globally in contemporary times. This issue is critical since it depletes nutrient-rich soil and elevates sedimentation levels in rivers and lakes, hence diminishing their storage capacity; around 5,334 million tons of soil is eroded annually in India for various causes.

Suggested that sheet erosion is the most critical concern among India's soil erosion challenges. Soil erosion is acknowledged as a serious threat; nonetheless, research on this issue in India remains scarce.

Issues related to soil erosion, sediment transport, and deposition in rivers, lakes, and estuaries endure over geological epochs in nearly all regions of the Earth. However, the situation has deteriorated recently due to humanity's escalating interference with the ecosystem. The scientific management of soil, water, and vegetation resources on a watershed level is crucial for mitigating erosion and preventing fast siltation in rivers, lakes, and estuaries. Soil erosion is a significant issue that needs appropriate remedies. Soil erosion is seen as a significant danger to human well-being globally.

The primary reasons for selecting one of the aforementioned models are: intended application, available data, time constraints, and cost considerations. Most erosion models are designed to forecast localized soil loss, as they were created at a field size.

Soil erosion modeling can account for several intricate interconnections that affect erosion rates by simulating erosion processes within the watershed. Numerous parametric models, including empirical (statistical), conceptual (semi-empirical), and physical process-based (deterministic) models, are available for calculating soil loss. The Universal Soil Loss Equation (USLE) is the most often utilized model. The United States Agricultural Research Service designed the USLE. Wischmeier (1978) [7] developed the Universal Soil Loss Equation (USLE) to forecast soil erosion due to sheet and rill processes under particular agricultural situations. The Universal Soil Loss Equation (USLE) calculates soil loss by multiplying rainfall erosivity (R), soil erodability (K), slope length in meters (L), slope gradient in percent (S), cover management factor (C), and support practice factor (P). A disadvantage of the USLE is the requirement for extensive long-term data to establish the parameters for climate (R factor) and erodibility (K factor) for regions and soils outside the initial dataset.

Geographical Information Systems (GIS) is a contemporary instrument that offers data on many geographical factors and is commonly utilized in soil erosion research. Remotely sensed satellite imagery is crucial in producing current land use and cover maps of the Earth's surface, aiding in the identification of erosion-prone regions. De Roo and Jetten (1999) [2] elucidated that the primary rationale for employing a GIS is the geographic variability of the erosion process, necessitating the usage of grid cells to accommodate this variation. This study aimed to ascertain the geographical distribution of soil loss and to investigate the impact of land use, slope orientation, and terrace farming on soil erosion, as well as to evaluate the use of GIS and USLE in quantifying soil loss.

This study emphasized the generic USLE/GIS methodology for semiarid environments. The model was constructed using existing data, including soil maps, topographic maps, precipitation records, land use maps, and satellite imagery. This study aims to estimate the yearly soil loss for the region across two distinct years and to compare the results to determine the variation in soil loss.

Material and Methods

Study Area: Urun Islampur watershed (Latitude: 17˚02’N and Longitude: 74°22’E) Dist. Sangli, Maharashtra is the study area of this project (Figure 1). This watershed occupied area of the Walwa Tehsil and situated near the Krishna River. The area of watershed is 67.66 km^2 having relatively flat topography.

Climate

- The average temperature of this region is 29°C and average rainfall is 599.9 mm.
- Average wind speed in the region is 10 km/hr eastward.
- The temperature of the region is about 32°C in summer and 22.6°C in winter.
- The average humidity of the region is about 31%.
- The climate of the region is warm and temperate.

Data used in the study

The data required for study as follows:

- Remote sensing imagery: Landsat 4-5 for year 2001 and 2008.
- Survey of India top sheet (1:2,50,000)
- Mean annual rainfall (mm) for year 2001 and 2008.
- Monthly (only June to November) rainfall data (mm) for year 2001 and 2008.
- Soil data (% silt,% sand,% clay and soil properties).

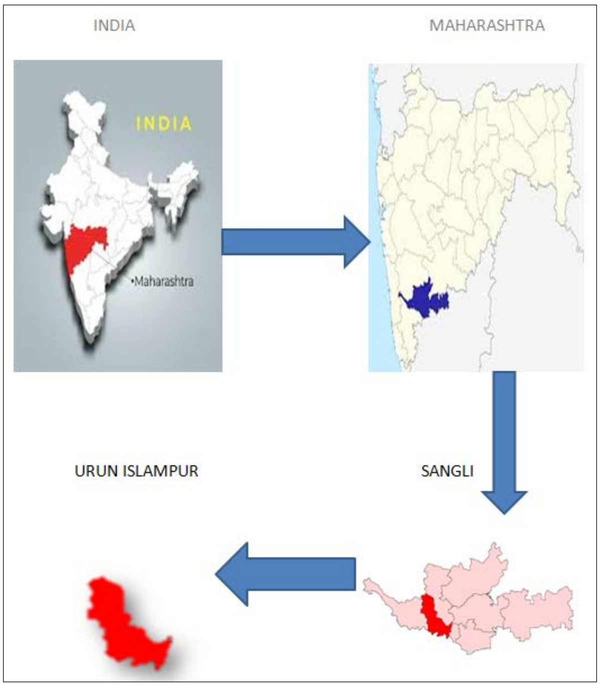

Fig 1: Location of study area

Thematic maps

Thematic maps such as land use map, soil map, slope map, digital elevation model (DEM), watershed delineation and meteorological data based rainfall maps are the main inputs for hydrological studies.

- Land use map was prepared using Landsat 4-5 images downloaded from *(https://earthexplorer.usgs.in)* and validated through field observations during present study period
- Rainfall data for the year 2001 and 2008 was taken from Data Portal *(https://chrsdata.eng.uci.edu).*

These thematic maps were prepared using remote sensing data and rainfall data. Methodology adopted and database used are described in subsequent sections of this chapter.

Methodology

USLE Equation

The Universal Soil Loss Equation (USLE) calculates soil loss by accounting for sheet and rill erosion caused by rainfall and the resultant runoff in a landscape profile. The soil erosion is calculated as follows

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

Where,
A = Average soil loss per unit area byerosion (t ha^{-1} $year^{-1}$).
R = Rainfall erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$).
K = Soil erodibility factor (t h MJ^{-1} mm^{-1}).
L = Slope length factor.
S = Slope steepness factor.
C = Cover management factor.
P = Support practice factor.

The methodology flow chart of soil loss estimation using USLE equation with remote sensing and GIS inputs is shown in Figure 2.

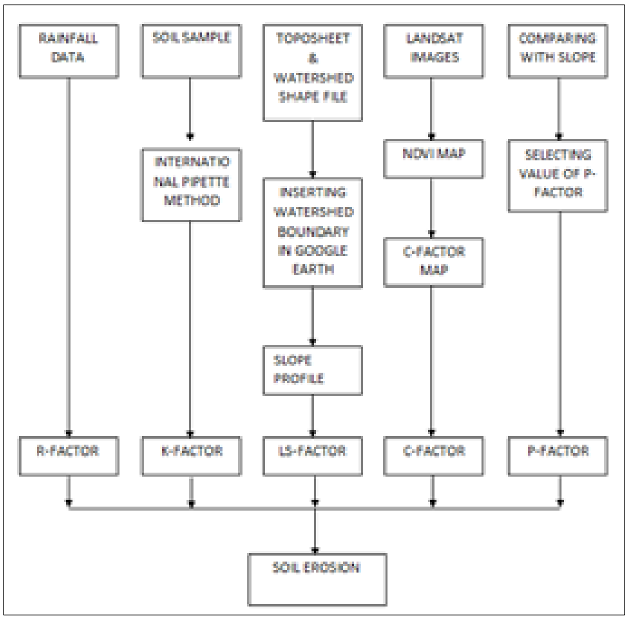

Fig 2: Flow chart of soil loss estimation using USLE equation with remote sensing and GIS inputs

Rainfall erosivity factor (R)

Rainfall erosivity refers to the capacity of precipitation to induce erosion. This study necessitates annual and monthly rainfall data to determine the R factor. This is a crucial factor for evaluating soil erosion risk in the context of future land use and climate change. Notwithstanding its significance, rainfall erosivity is typically included into models with inadequate spatial and temporal resolution.
The R-factor (rainfall erosivity), quantified in MJ.mm.ha^{-1} h^{-1} yr^{-1}, represents the cumulative total of erosive events over a specified time frame (year). Renard *et al.* (1997) [5] delineate the criteria for identifying an erosive event.

- The total rainfall of an occurrence must exceed 12.7 mm, or
- The event features a peak above 6.35 mm within 15 minutes, and
- A rainfall threshold of less than 1.27 mm over 6 hours is employed to segment an extended storm duration into shorter intervals.

The Rainfall erosivity index was calculated by using Fournier index formula (Arekhi *et al.* 2012) [1]. Fournier index (F), is as follows:

$$F = \frac{\sum Pi^2}{\sum P} \qquad (2)$$

Where,
P_i = Mean rainfall depth in mm of month 'i' and
P = Mean annual rainfall in mm.

If F < 55, then

$$R - Factor = \frac{0.07397xF^{1.847}}{17.2} \qquad (3)$$

If F > 55, then

$$R - Factor = \frac{\left((95.77) - (0.68\ x\ F) + (0.47\ x\ F^2)\right)}{17.2} \qquad (4)$$

Soil erodibility factor (K)

The soil erodibility factor (K) quantifies the rate of soil loss per unit of rainfall erosion index, as assessed on a conventional soil plot, and is often derived from intrinsic soil characteristics. This factor is contingent upon many soil features, including soil texture, organic matter content, soil structure, and the fundamental permeability of the soil profile. Numerous approaches have been proposed for the measurement of the K-factor.
The K values are usually estimated using the soil erodibility nomograph method, which uses% silt,% sand and% clay to calculate K (Renard *et al.* 1997) [5]. The equation for K factor is

$$D_g = \exp\left(0.01\ x \sum f_i\ x \ln(m_i)\right) \qquad (5)$$

$$D_g = \exp\left(0.01\ x \sum f_i x \ln\left(\frac{d_i + d_{i-1}}{2}\right)\right) \qquad (6)$$

Where D_g = Geographical mean diameter

$$K = 7.594\left(0.0034 + 0.0405 \exp\left(-0.5\left(\frac{\log D_g + 1.659}{0.7101}\right)^2\right)\right) \qquad (7)$$

Where,
i= Particle sizes (sand, silt and clay), mm
D_g = Geometric mean particle diameter, mm
f_i= Primary particle size i, fraction,
m_i= Arithmetic mean of particle size limits for size i, mm.

LS (Slope length & Slope gradient / steepness) factor (LS)

The L factor denotes the slope length factor, indicating the influence of slope length on erosion. The ratio of soil erosion from the field slope length compared to that from a 72.6-foot (22.1-meter) segment of identical soil type and gradient.
This project utilizes Google Earth software to calculate the region's slope. Google Earth is valuable for determining the heights of various locations within the watershed map and for identifying distinct topographic features. This module supports several hydrological functions. The current study

involves converting the watershed border, previously created using ArcGIS 10.3, from ".TIFF" format to ".kml" and subsequently embedding it into Google Earth.
L and S variables are often regarded in conjunction. LS factors represent the slope length factor, where L assesses the impact of slope length on erosion, and S evaluates the influence of slope steepness on erosion. The slope length and% slope of the area are obtained using the "Show Slope Profile" application of "Google Earth" and calculated using the method established by Wischmeier and Smith (1962) [6].

$$LS = (L)½ \ (0.76 + 0.53\ S\ + 0.076\ S^2) \ / \ 100 \quad (8)$$

Where,
L = length of slope (feet),
S = slope (percentage).

Cover management factor (C)
The C factor denotes the influence of cropping and agricultural management methods, together with the impact of ground, tree, and grass covers, on mitigating soil loss in non-agricultural contexts. As plant cover expands, soil erosion diminishes. The C-factor quantifies the influence of crops and management strategies on erosion rates.
The Universal Soil Loss Equation (USLE) employs a sub-factor methodology to calculate soil loss ratios, which represent the ratios at any specific moment throughout a cover management cycle relative to soil loss from the unit plot. Soil loss ratios fluctuate over time due to alterations in canopy, ground cover, surface roughness, soil biomass, and consolidation. The C factor value is an average soil loss ratio, weighted by the annual distribution of R. The sub-factors utilized to calculate soil loss ratio values include canopy, surface cover, surface roughness, previous land usage, and antecedent soil moisture.
The USLE incorporates surface roughness in the computation of the C value. Surface roughness retains water in depressions and diminishes the erosive effects of raindrop impact and water movement. If the deposits are sufficiently profound, considerable deposition transpires inside them. As time progresses, roughness diminishes as depressions are filled with silt and soil settles following the tillage activities that created the depressions.
The predominant indicator of plant growth utilizing remote sensing technology is the Normalized Difference plant Index (NDVI). It serves as a biophysical indicator of soil erosion. It illustrates the spread of plant and soil cover based on distinctive reflectance patterns. The NDVI for Landsat-ETM is represented by the subsequent equation (Lin *et al*. 2002) [3].

$$NDVI = \frac{NIR-R}{NIR+R} \quad (9)$$

Where,
NIR = Near Infrared.
R =Red bands.
Landsat 4-5 images are used for this research work.

The NDVI values are utilized to compute the spectral ground-based data, demonstrating the strongest association with above-ground biomass. Initially, it is necessary to normalize the distribution of NDVI values ($-1 \leq NDVI < 1$) due to potential variations in satellite data across multiple picture dates or vegetation seasons. Secondly, the vegetation cover index was obtained using linear inverse NDVI transformation (Lin *et al*. 2002) [3]. The distribution of flora and soil coverage. The NDVI for Landsat-ETM is represented by the subsequent equation (Lin *et al*. 2002). After a reversal linear transformation derived from training samples, the relationship between C and NDVI is as follows

$$C = \frac{(1-NDVI)}{2} \quad (10)$$

The C value in each grid cell can be designated. The C factor varies from 0 to 1, with a value of 0 assigned to certain pixels with negative values and a value of 1 assigned to pixels with values exceeding 1.

Support practice factor (P)
It is the ratio of soil loss resulting from specific conservation techniques to the soil loss measured from both the upper and lower sections of the slope. It articulates the impact of conservation strategies, including contouring, buffer strips of dense vegetation, and terracing, on soil erosion at a specific location. An effective conservation technique leads to less runoff volume, velocity, and reduced soil erosion. The USLE P-factor denotes the influence of support methods on the average yearly erosion rate. The conservation practice factor (P) value varies from 0.0 to 1.0 based on land slope. The values of P-factor for different values of slope are given below (Table 1):

Table 1: Values of P-factor for different slope values

Lin	Lin	Lin
Lin	Lin	Lin
	Lin	Lin
	Lin	Lin
	Lin	Lin
	Lin	Lin
	Lin	Lin
Lin	Lin	Lin

(Wischmeier and Smith 1978) [7]

Results and Discussions
Soil loss estimation using USLE equation
R (Rainfall erosivity) factor
The value of R-factor for year 2001 was 639.43 MJ mm/ha/yr and for year 2008, 112.3 MJ mm/ha/yr.

K (Soil erodability) factor
From International pipette method, the values of sand, silt and clay in per cent were obtained as 36, 41 and 23 respectively. After putting the all above values and particle size ranges and their per cent content in soil, the value of K factor for study area obtained was 0.0467.

LS (Slope length& Slope gradient / steepness) factor
The LS factor was computed via Google Earth. The watershed has the point of maximum elevation of 1996 ft (Figure 7) and lowest elevation of 1788 ft (Figure 8) with the length of run i.e. length of slope is 46918.68 feet (14.23 km), (Figure 9). The value of slope obtained in percentage is 0.427%. The value of LS factor is obtained as 2.16.

C (Cover management) factor
Vegetation cover safeguards the soil by attenuating the energy of raindrops prior to their impact on the soil surface.

The ratio of soil loss under given cropping to that from bare soil is represented as C factor. The C factor was computed via NDVI through the raster calculator in ArcGIS. The value of NDVI ranged from -1 to +1.

Normalized Difference Vegetation Index (NDVI)

Remote sensing methodologies are utilized for delineating the vegetative status of a watershed. Vegetation cover may be assessed with vegetation indices obtained from Landsat 4-5 images. Vegetation indices enable the delineation of vegetation and soil distribution based on the distinctive reflectance patterns of green vegetation. The disparity in spectral reflectance between Near Infrared (NIR) and Red (R) was utilized to compute NDVI. The NDVI map was prepared by using NIR and IR band combination for two different years. As mentioned in Figure 3, the value of NDVI for year 2001 ranged from -0.278 to 0.596. As mentioned in Figure 4, the value of NDVI for year 2008 ranged from -0.250 to 0.547.

C (Cover management) factor for year 2001 and 2008

The value of C factor for year 2001 ranged from 0.201 to 0.639 (Figure 5) and the value of C factor for year 2008 ranged from 0.226 to 0.625 (Figure 6). The maximum C factor value for year 2001 was 0.639 and for year 2008 was 0.625.

P (Support practice) factor

The supporting practice component arises from contouring, strip cropping, terraces, and similar techniques. Supporting activities often influence erosion by channeling runoff around the slope, so reducing its erosive potential, or by decelerating the flow to facilitate deposition. A lower P-factor value indicates a greater efficacy of the conservation strategy in mitigating soil erosion. In present study, Conservation practice factor (P) was taken as 0.1 from Table 3.2.

Soil loss estimation using USLE equation

The Soil loss was computed by multiplying the developed and estimated factors using equation $\{A = R\ K\ LS\ C\ P\}$. As per the calculations, maximum soil loss for year 2001 was 4.148 t/ha/yr and for year 2008 was 0.712 t/ha/yr.

Change detection in soil loss estimation using USLE equation

The soil loss for the watershed for year 2001 using USLE equation was found to be 4.148 t/ha/year. The soil loss for the watershed for year 2008 was found to be 0.712 t/ha/yr. The soil loss is decreased from 2001 to 2008 by 3.436 t/ha/yr (Table 2).

As mentioned in Table 2, it is clear that USLE method is suitable for estimation of soil loss of Urun Islampur. The decreased soil loss was observed to the extent of 3.436 t/ha/yr (82.83%) in seven years i.e. from 2001 to 2008.

Table 2: Increase in soil loss in 2008 over 2001 of Urun Islampur watershed using USLE equation

Year 2001	Year 2008	Decrease in Soil loss in 2008 over 2001 (t/ha/year)
Soil loss (t/ha/year)	**Soil loss (t/ha/year)**	
4.148	0.712	82.83

The soil loss is decreased considerably due to increase in land under vegetation; ultimately decrease in area under barren land. The high vegetation is one of the most important factors that are responsible to reduce soil erosion from the open land.

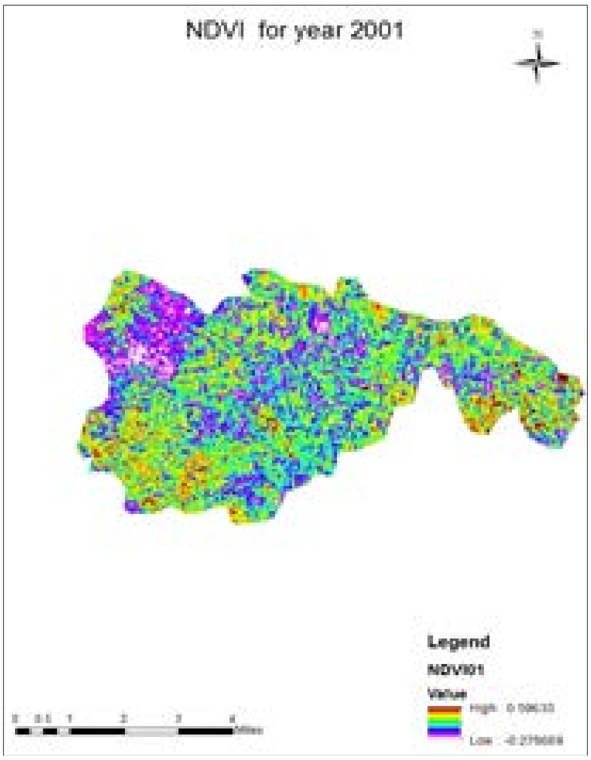

Fig 3: **N**DVI map for Urun Islampur watershed for year 2001

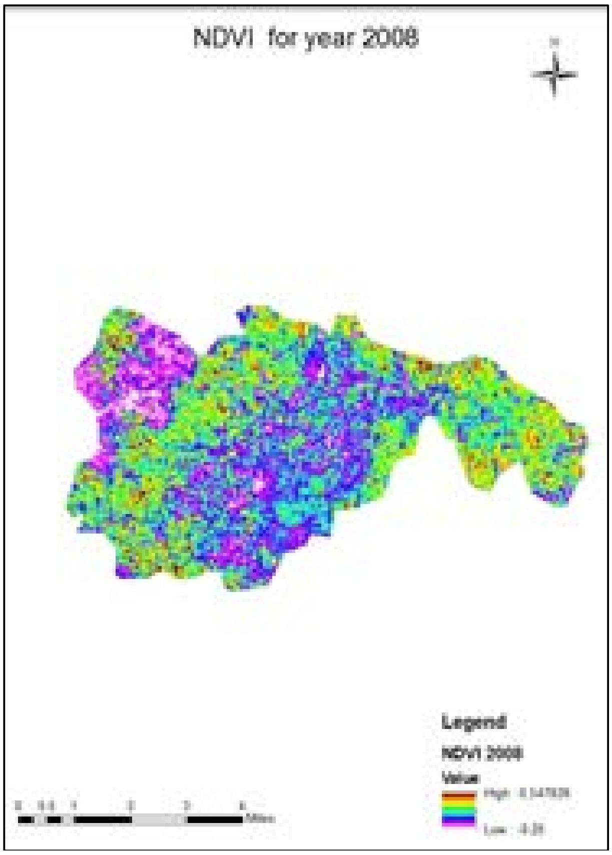

Fig 4: NDVI map for Urun Islampur watershed for year 2008

Fig 5: C factor map for Urun Islampur watershed for year 2001

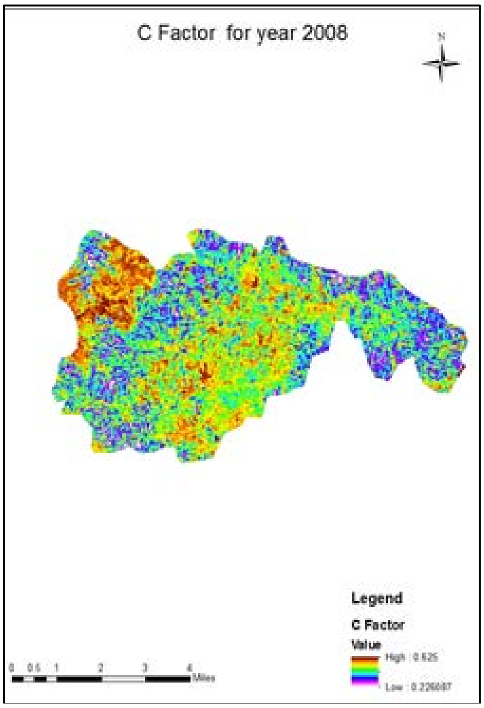

Fig 6: C factor map for Urun Islampur watershed for year 2008

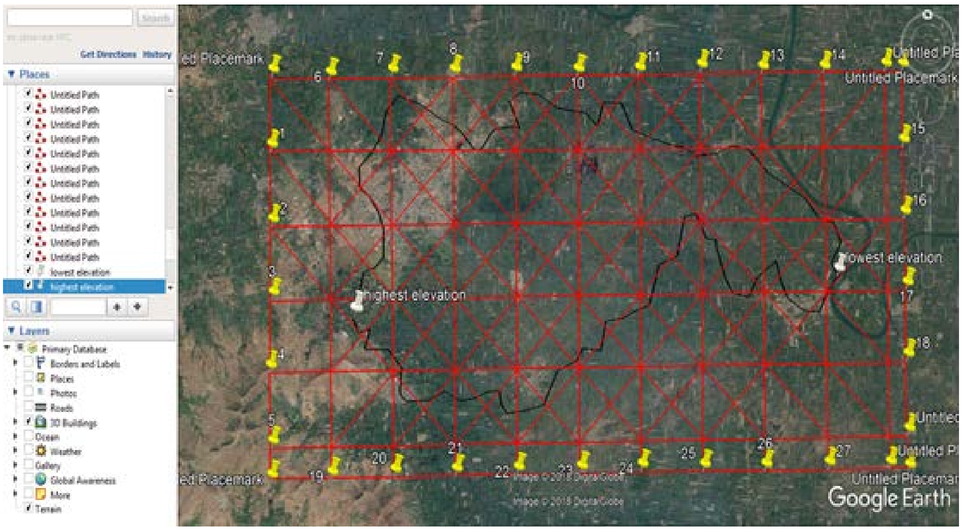

Fig 7: Maximum Elevation for Urun Islampur watershed

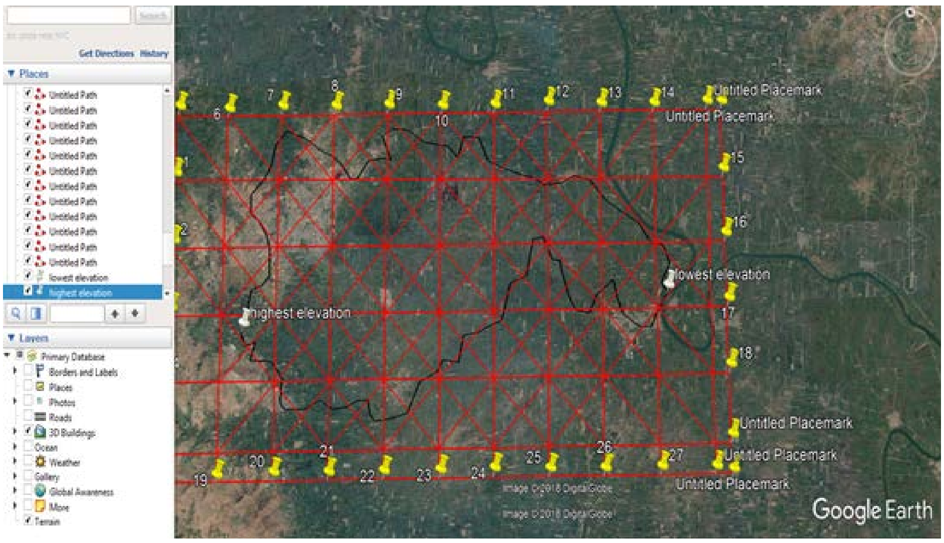

Fig 8: Minimum Elevation for Urun Islampur watershed

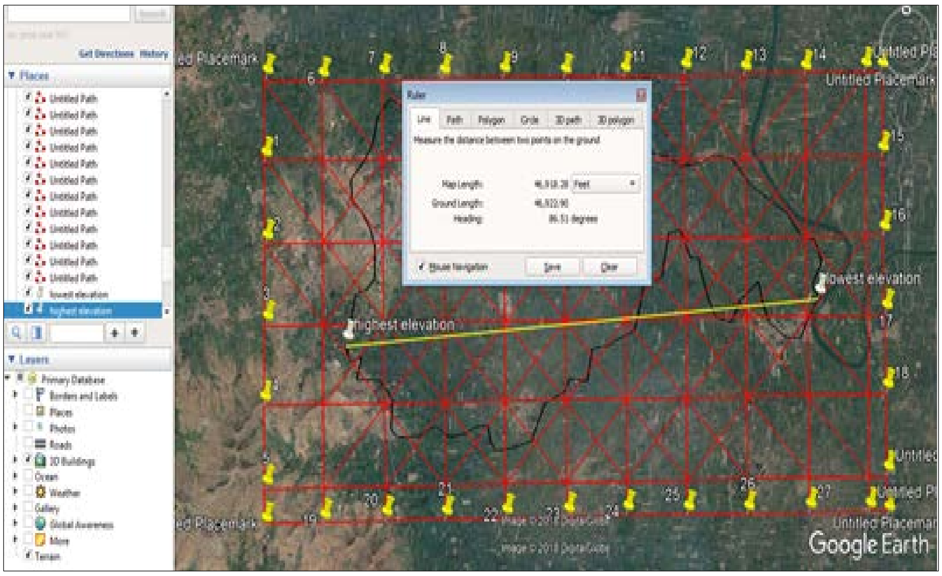

Fig 9: Slope length for Urun Islampur watershed

Summary and Conclusions

Summary of Results

Following results are obtained from the study undertaken in Urun Islampur watershed.

The estimated soil loss for the watershed for the year 2001 using USLE equation was found to be 4.148 t/ha/year. The estimated soil loss of the watershed for the year 2008 using USLE equation was found to be 0.712 t/ha/year.

Conclusions

Based on the results of the study, conclusions obtained are as follow

- The per cent change shows the USLE equation gives accurate results for soil loss estimation. USLE equation is suitable for the Urun Islampur watershed for estimation of soil loss.
- The projected soil erosion calculated using the USLE equation indicates a reduction in soil loss from 2001 to 2008, attributable to an expansion of vegetative cover and a decline in bare land within the watershed.
- As per the results, soil loss was reduced from 2001 to 2008 and also area under vegetation increased but water body was reduced from 2001 to 2008. Hence proper diversion and storage structure is required to increase storage of water.

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