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GEOINFORMATICS IN SOIL EROSION RISK AND VEGETATIVE COVER LOSS ASSESSMENT OF YETTHINAHOLE CATCHMENT, KARNATAKA

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ABSTRACT

Soil erosion is a significant environmental issue, adversely affecting soil productivity, agriculture, and water resources. Detailed mapping is essential, particularly in ecologically sensitive areas like Yetthinahole catchment area, which faces severe erosion risks. Erosion depletes fertile soil, leads to sediment deposition in water bodies, and alters watershed hydrology, impacting water availability and quality. The Yetthinahole catchment area, located in the Western ghats of Karnataka, India, spans 292 km^2 and is characterized by steep slopes, intense monsoonal rainfall, and anthropogenic activities. These factors contribute to its vulnerability to soil erosion. This study employed the Revised Universal Soil Loss Equation (RUSLE) model in Google Earth Engine (GEE) platform to assess soil erosion trends from 2001-2020. GEE platform facilitated the processing of large scale satellite imageries, enabling high resolution mapping of erosion hotspots and trends. The analysis revealed that significant soil erosion trends, with peaks corresponding to high rainfall years such as 2010, where the highest soil loss was observed (1095.39 T/ha/yr). Land use/land cover changes, notably the reduction in vegetative cover loss and increased impervious surfaces, exacerbated erosion risks. The erosin hotspots were identified in areas with steep slopes and significant land use transitions. The study concludes that the sustainable land management practices, particularly forest conservation, are essential for mitigation of soil erosion in the Yetthinahole catchment area.

Keywords: Soil erosion, RUSLE, Google Earth Engine, land use change, rainfall erosivity and vegetative cover

1. INTRODUCTION

Soils are the basic primary resource on which all terrestrial life depends **[1]** every land use has a soil implication **[2]**. It acts as the foundation of the life support system of our planet **[3]**. Erosion reduces the productivity of the soil and contributes to environmental pollution **[4]**. It is a natural phenomenon occurring always, but human activity can greatly increase the erosion process by stripping off vegetation, plowing, construction of roads, etc. **[5]**. Erosion problems occur in all countries of the world **[6]**. It is a significant environmental issue that not only depletes fertile top soil but also drives critical changes in geomorphology and hydrology **[1]**. In the Yetthinahole catchment area, it is a soil erosion is a issue of concern because of its steep slope, intense mansoon rainfall, human activities like deforestation and agricultural expansion **[4, 7]**. This leads to deposition in water bodies, reduction in agricultural production and alterations in watershed hydrology impacting water availability and quality **[3, 5]**.

Because of the region's ecological sensitivity and its importance as a water source, there is an urgent need for detailed soil erosion mapping to sustainable land and water management strategies **[6, 8]**. The study uses geoinformatics techniques, specifically the Revised Universal Soil Loss Equation (RUSLE) model implemented in Google Earth Engine (GEE) JavaScript coding, to analyse soil erosion trends from 2001-2020. GEE's cloud-based platform allows for efficient processing of vast satellite datasets, facilitating high-resolution soil erosion mapping over time **[9, 10]**. This approach provides critical insights into erosion hotspots, helping to effectively conserve soil erosion in the Yetthinahole catchment **[11, 12]**.

2. LITERATURE REVIEW

Soil erosion is a critical environmental issue with far-reaching implications for soil productivity, agricultural output, and ecosystem health. As **[1]** highlights, soil is a fundamental resource vital for sustaining terrestrial life, serving as the foundation of the Earth's life support system **[3]**. Erosion, a process where soil is removed by natural forces such as water and wind, leads to significant environmental degradation by reducing soil fertility and contributing to pollution **[4]**. While erosion is a natural phenomenon, anthropogenic activities like deforestation, agricultural practices, and infrastructure development can accelerate soil loss, thereby exacerbating its impact **[5]**. The global prevalence of soil erosion underscores its significance as an environmental issue affecting diverse regions **[6]**.

The Revised Universal Soil Loss Equation (RUSLE) is a prominent model used for soil erosion prediction and management. RUSLE builds upon its predecessor, the Universal Soil Loss Equation (USLE), by incorporating improved parameters and methodologies to estimate soil erosion rates more accurately **[13, 14]**. The RUSLE model evaluates soil erosion using factors such as rainfall, soil type, topography, and land cover. While RUSLE has been widely adopted due to its robustness and applicability across different regions, it has limitations, including the need for accurate input data and assumptions that may not hold in all contexts **[15]**.

The advent of geoinformatics techniques has revolutionized soil erosion mapping and modeling. Google Earth Engine (GEE) offers a cloud-based platform that enables the efficient processing of large-scale satellite data, facilitating high-resolution and temporal soil erosion analysis **[9]**. The integration of RUSLE with GEE enhances the precision of soil erosion assessments by leveraging extensive satellite imagery and remote sensing data. Studies utilizing this approach have demonstrated its effectiveness in identifying erosion hotspots and informing conservation strategies **[10, 11]**.

Detailed soil erosion mapping is particularly crucial in ecologically sensitive regions, such as the Yetthinahole catchment area. This region faces challenges due to its steep slopes, intense monsoonal rainfall, and anthropogenic pressures like deforestation and agricultural expansion **[4, 7]**. Soil erosion in such areas can lead to sedimentation in water bodies, reduced agricultural productivity, and disruptions in watershed hydrology, affecting water availability and quality **[3, 5]**. The need for comprehensive soil erosion studies in these regions is supported by literature emphasizing the importance of sustainable land and water management strategies **[6, 8]**. Hence, the integration of RUSLE with GEE represents a significant advancement in soil erosion modeling, providing valuable insights for managing soil resources and mitigating environmental impacts. This approach is essential for addressing the challenges posed by soil erosion, particularly in sensitive and crucial regions like the Yetthinahole catchment. The existing studies lack detailed long-term erosion trend analysis and integration of localized factors, such as land cover and regional topography. This study aims to evaluate soil erosion trends in the during (2002-2022) using RUSLE and Google Earth Engine and map erosion hotspots and their drivers using geoinformatics techniques.

1. **Study area**

The Yetthinahole catchment area is situated in the southwestern part of Sakleshpur taluk in Hassan district, Karnataka, within the Western Ghats. It stretches between 76°34′E and 76°45'E longitude and 12°44'N and 12°58'N latitude, covering an area of 292 square kilometers. The elevation ranges from 171 to 1130 meters above sea level, creating a landscape with a dense network of streams and rolling terrain.

2. **Data and methodology:**

The study employed a Google Earth Engine (GEE)-based approach to estimate Average Annual Soil Loss (A) using the Revised Universal Soil Loss Equation (RUSLE) within the Yetthinahole catchment area, Hassan District, Karnataka. Several critical factors, including rainfall–runoff erosivity (R) **[14]**, soil erodibility (K) (Renard *et al*. Rainfall erosivity (R) was calculated using long-term precipitation data **[14]**, while soil erodibility (K) was estimated through GEE, considering local soil characteristics specific to the catchment **[16]**. The LS factor, cropping management (C), and supporting conservation practices (P) were also computed using GEE and satellite data, ensuring spatial precision. Additionally, the Normalized Difference Vegetation Index (NDVI) was incorporated into the C factor to account for seasonal changes in vegetation cover **[17]**. The slope of the terrain was a critical component of the analysis due to its significant influence on erosion dynamics **[14]**. This GEE-based methodology facilitated a spatially detailed analysis of soil erosion potential, highlighting its scalability and efficiency in managing large geospatial datasets **[16]**. The findings offer key insights for promoting sustainable land management practices in the Yetthinahole catchment area, considering the diverse factors that contribute to soil erosion susceptibility **[17]**.

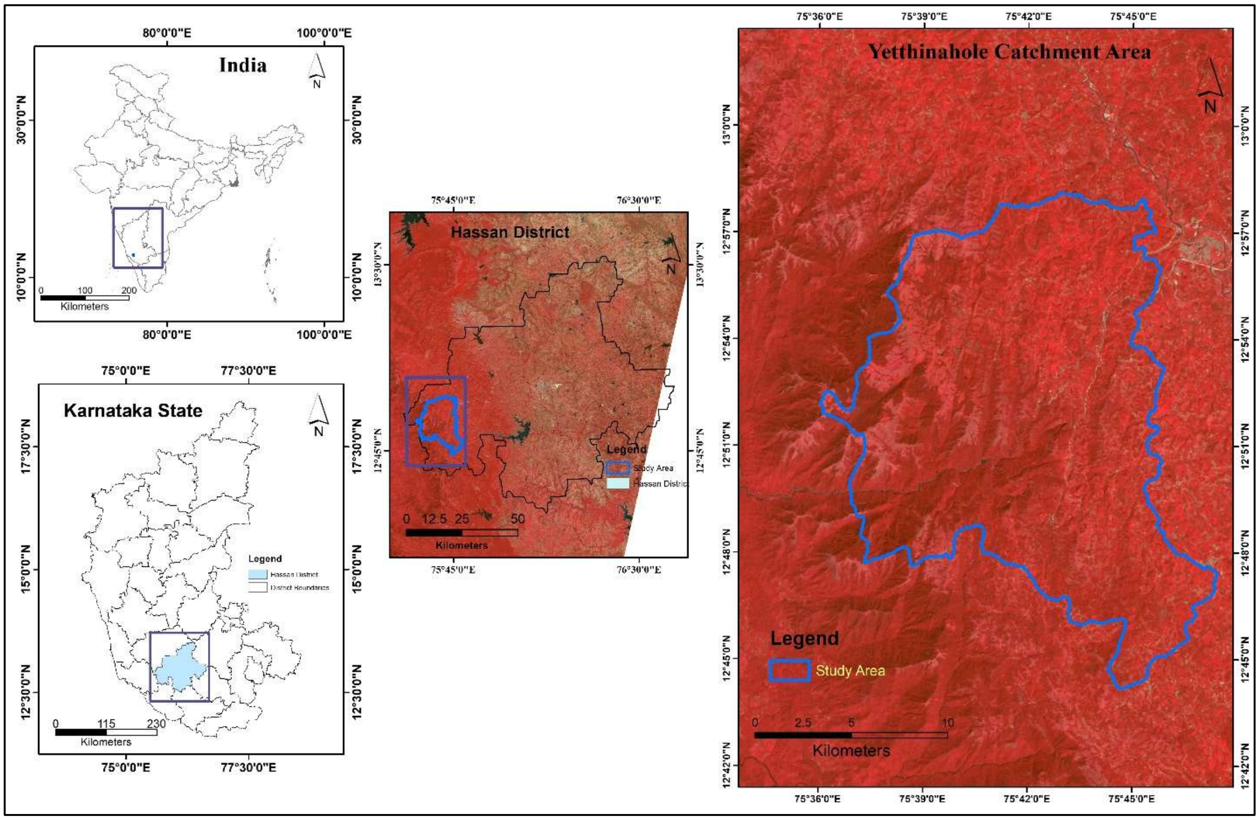


Figure 1: Location map of the study area

4.1 RUSLE Formulae adopted

R = R*K*L*S*C*P (1)

A – average annual soil loss (ton/ha/yr)

R- Rainfall runoff erosivity factor (Megajoules. mm/ha/h/yr)

K – soil erodibility factor (ton.ha.h /megajoules/ha/mm)

L – Slope length factor (unitless)

S – Slope gradient factor (unitless)

C- Cropping management factor (unitless, ranging between 0 to 0.5)

P – Supporting conservation practice factor (unitless, between 0 and 1).

The GEE -based methodology brings various thematic spatial layers derived from open-source datasets. Each factor of RUSLE equation is represented by thematic layers which are prepared and analyzed thoroughly. The output gives a understanding of soil erosion potential across the study area, contributing for the need of action to prevent its effects on region.

4.2 R- Rainfall runoff erosivity factor

In the present study, the rainfall erosivity (R) factor is essential in deterning the soil erosion potential. The intensity of rainfall significantly influences soil erosion, as higher rainfall rates and larger raindrops increase runoff flow, which enhances the detachment and transport of soil particles through sheet and rill erosion **[13]**. As rainfall rates rise, the energy applied to the soil surface increases, leading to greater soil displacement **[14]**. To calculate R factor, we utilized the sum of the monthly rainfall data for each year (2001-2020). The equation used for this calculation is well – established and widely applied in soil erosion studies across the globe **[8]**.

$$R = P * 0.363 + 79 \quad (2)$$

Here P – annual rainfall(mm), which is calculated by using Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) data summed for each year from for the study i.e., 2001-2020.

4.3 Soil Erodibility (K) factor

The soil erodibility factor is a critical element for assessing soils vulnerability to erosion from rain and runoff, influenced by its mineral, physical and morphological features **[18]**. In this study, GEE platform was used to estimate K values derived from soil texture data classified according to the USDA texture triangles **[19, 20]**. We utilized the function of GEE to calculate K-factor based on soil values. The conditional statement assigns different K-factor values depending on the soil value. This method includes the local variations and characteristics, accurately representing soil erosion factors within the catchment area.

4.4 Topographic (LS) factor

The LS factor is a crucial parameter of assessing soil erosion, which integrates slope length and slope steepness into a unified index **[21]**. In this study we utilized GEE platform and SRTM DEM data for the generation of slope (%) by applying equation (3).

$$\text{Slope \%} = \left(\tan\left(\frac{\boldsymbol{Slope(deg)} * \boldsymbol{\pi}}{\mathbf{180}}\right)\right) * 100 \quad (3)$$

The LS represents the combined slope steepness factor and slope length, which is computed by equation (4).

$$LS = \left(\frac{L}{22.1}\right)^m * \left(\frac{\sin\theta}{0.0896}\right)^n \quad (4)$$

Where, L – slope length (m), θ is the slope angle in degrees, *m* and *n* are empirical parameters of values 0.5 and 1.3 respectively.

4.5 Cropping management (C) factor

The C factor is essential for accurate soil erosion assessment, reflecting the impact of land cover on erosion rates **[13]**. It assigns lower values to areas with better vegetation cover, indicating effective soil protection **[14]**. In this study MODIS land cover type product used, which includes 17 land cover classes based on IGBP classification scheme, generated based on supervised decision-tree algorithm. These classes include natural vegetation, developed land and nonvegetated areas. Values range from 0 to 1; lower values indicate less soil loss susceptibility; higher values indicate more susceptibility to soil loss. Utilization of Geoinformatics and GEE enhances C factor estimation by providing detailed, large-scale cover data and efficient analysis capabilities **[9]**.

4.6 Conservation practice (P) factor

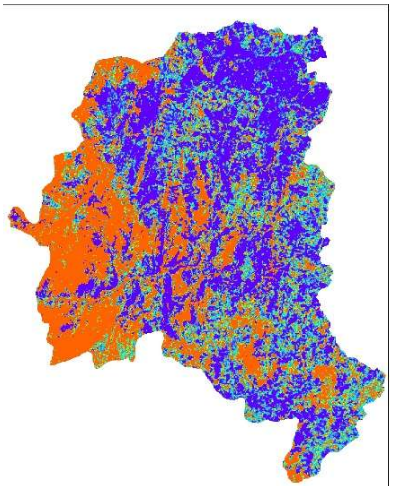
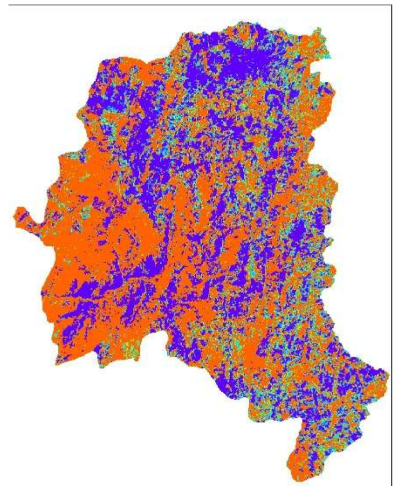
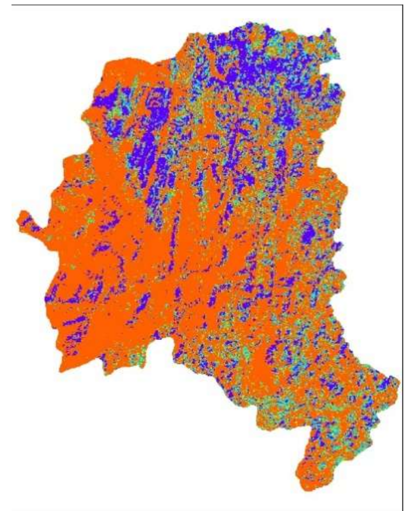
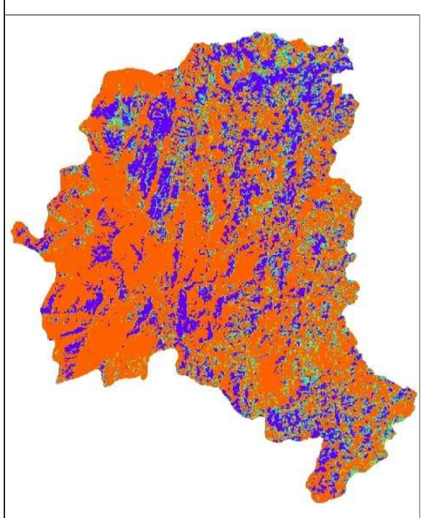
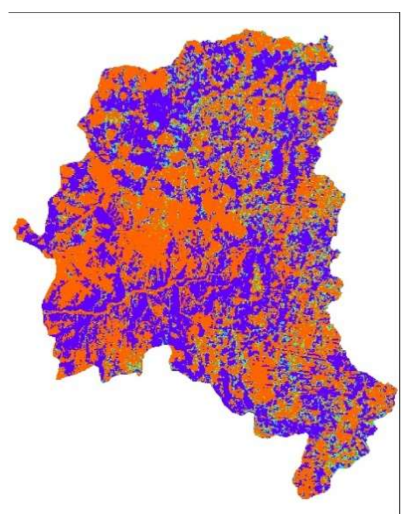
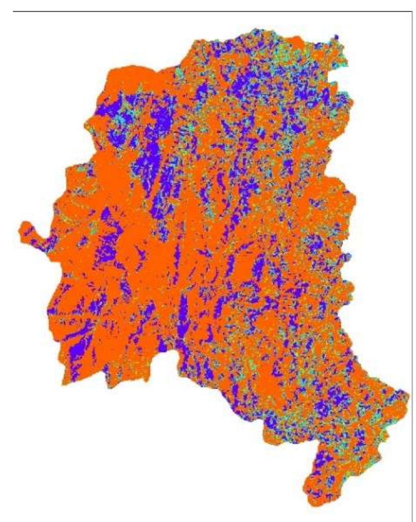
The P factor in RUSLE accounts for land management role in reducing soil erosion **[14]**. Using GEE, large-scale Factor estimation is efficient through remote sensing and GIS data **[9]**, providing critical insights int land cover, slope and conservation practices in the Yetthinahole catchment area. This approach helps optimize soil erosion control strategies, making it essential for accurate loss prediction **[8]**. The value ranges between 0 to 1; where P =1, means no conservation practice and P<1 indicates conservation practices with lower values reflecting more effective erosion control **[8]**.

3. RESULTS AND DISCUSSION

The relationship between soil loss and land use land cover (LULC) changes in the Yetthinahole catchment area is closely intertwined with annual rainfall patterns. Over the2001-2020 period, fluctuations in soil loss appear to correlate with both LULC transitions and variations in total annual rainfall. For example, the clear increase in soil loss observed in 2010 (1095.39 T/ha/yr) coincides with the highest rainfall recorded in the region (3717.25 mm). High rainfall intensities can intensify soil erosion, especially in the areas where LULC changes have reduced vegetative cover and increased runoff potential **[3, 22]**.

The progressive depletion in dense forest cover 110.56 km^2 in 2001 to 96.06 km^2 2020, coupled with increase in plantation and built-up areas, which reduces the natural protective mechanisms against soil erosion. Forested areas are critical for intercepting rainfall, enhancing infiltration, and reducing surface runoff, which helps to mitigate soil loss **[23, 24]**. Additionally, the expansion of impervious surface also increases the runoff, reducing soil infiltration and increasing soil erosion risks **[25]**.

The results of LULC change, combined with years of high rainfall, likely intensified erosion rates, particularly in 2010 and subsequent years where rainfall was consistently above average. The interplay between reduced forest cover, increased impermeable surfaces, and variable rainfall underscores the complex dynamics influencing soil erosion in this region. Sustainable land management considering LULC, and climate is crucial for reducing soil loss in Yetthinahole **[2, 8]**.

2001	2002	2003
		
2004	**2005**	**2006**
		
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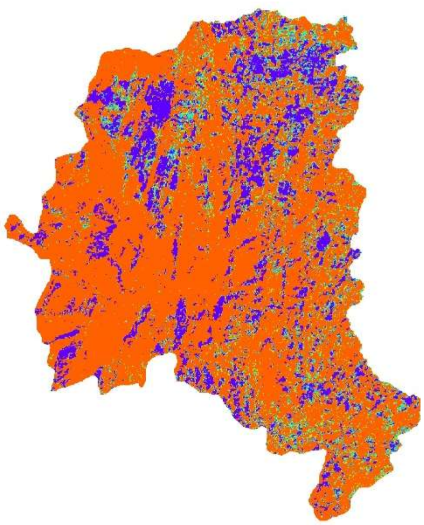
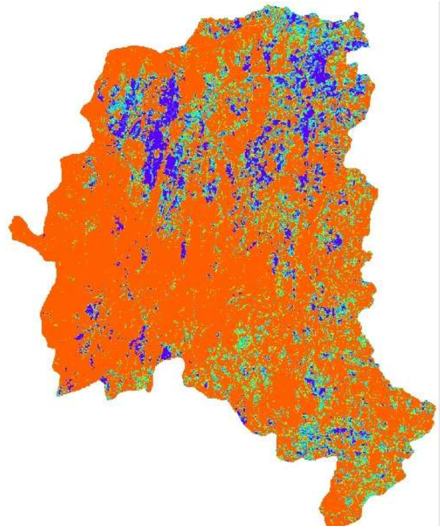
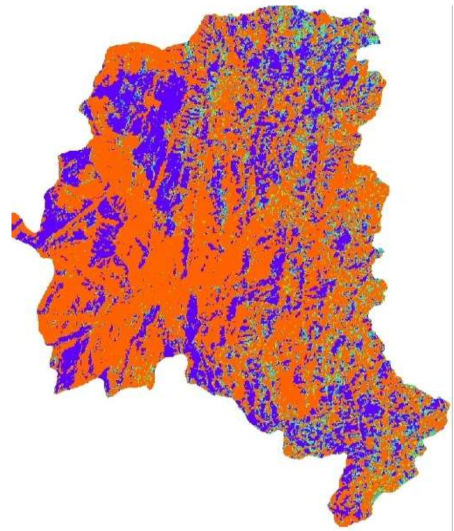
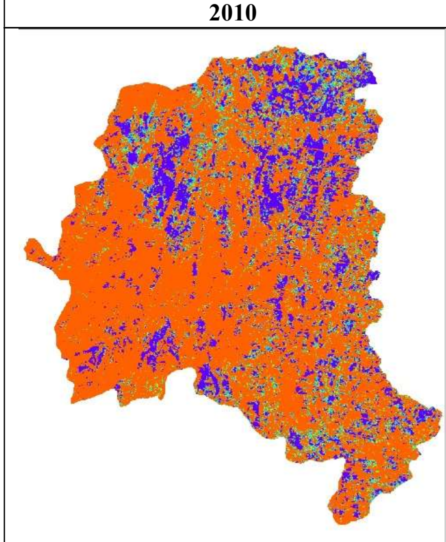
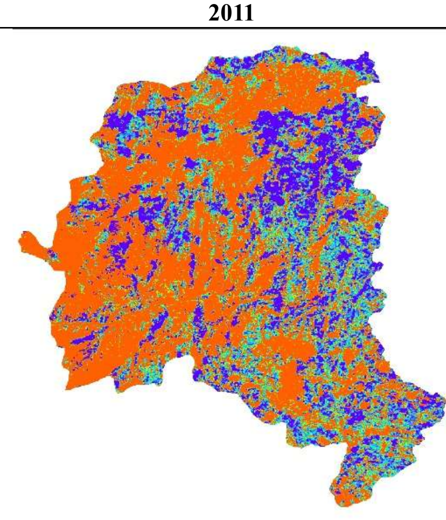
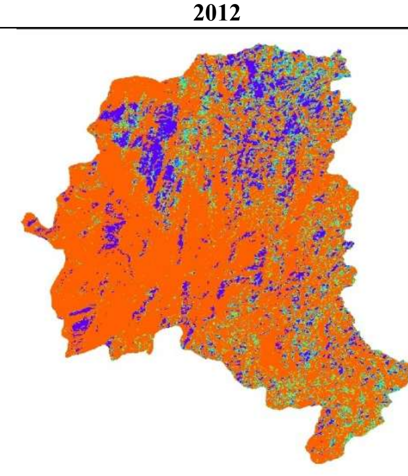
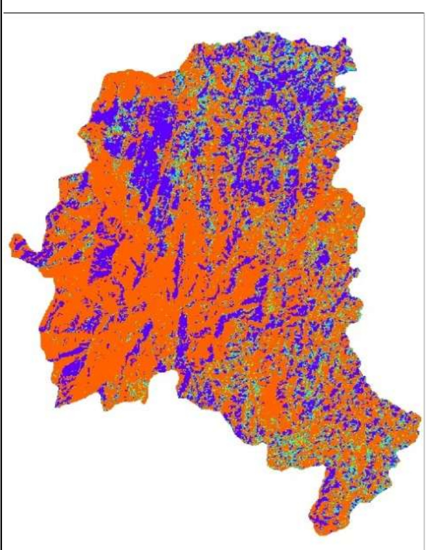
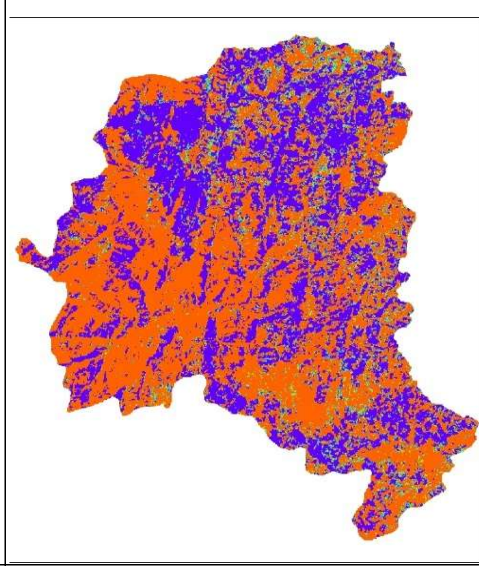
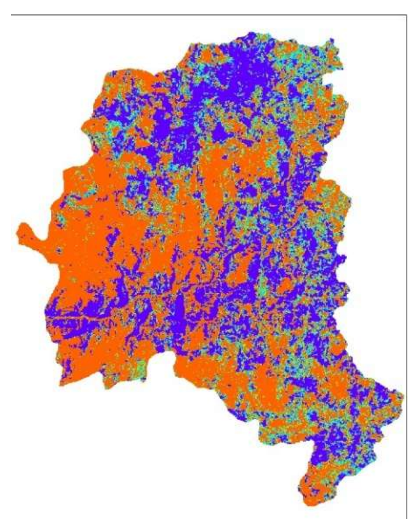
		
2010	**2011**	**2012**
		
2013	**201**	**2015**
		

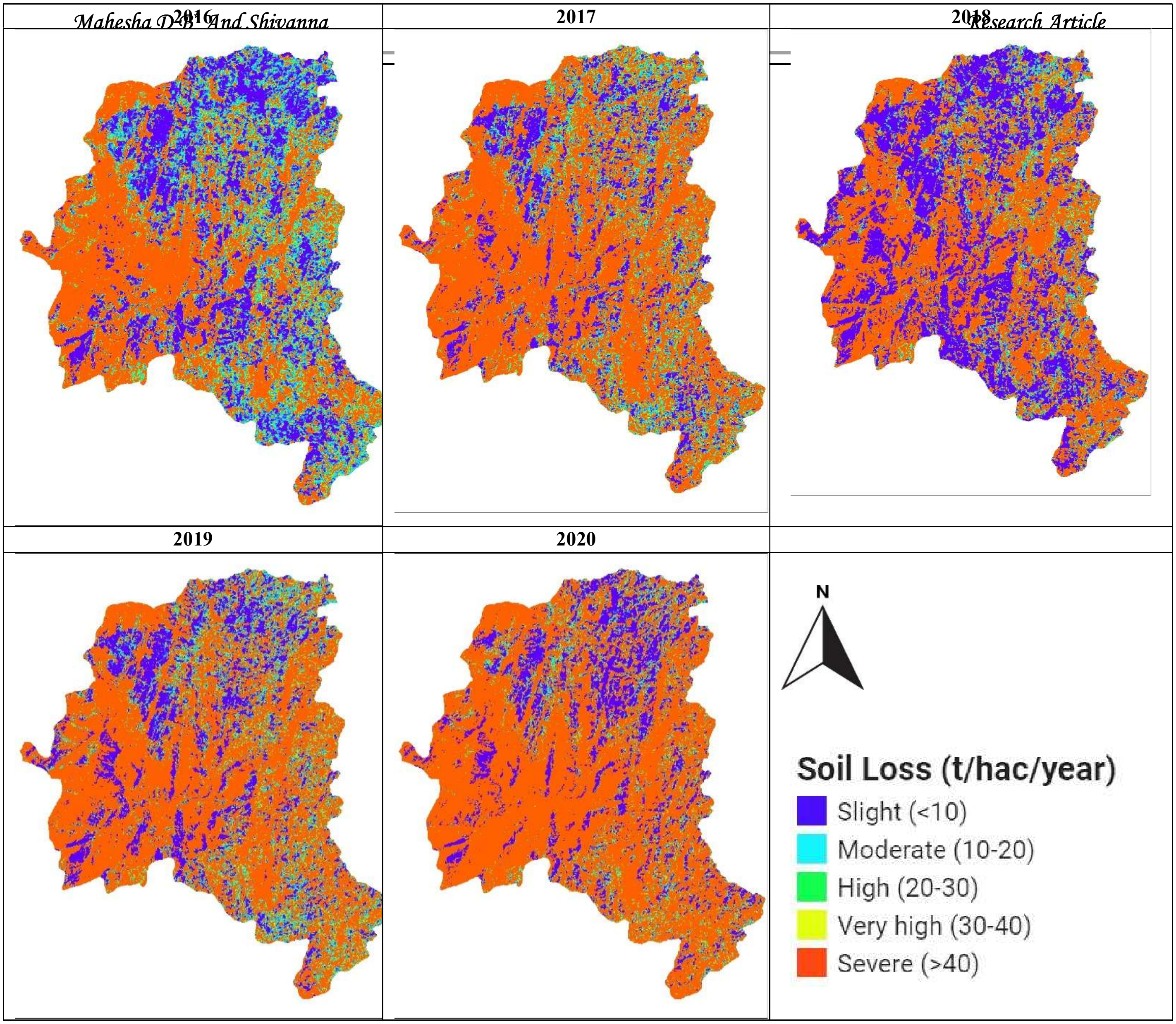


Table 2: Land Use/Land Cover Changes Over Five Decades

Class	2001	2011	2023
Dense Forest	110.56	107.26	96.06
Plantation	84.23	88.27	90.04
Grassland	53.90	52.78	50.46
Cropland	35.53	34.26	39.43
Built-up	3.21	4.70	6.70
Waterbody	0.80	0.80	0.78
Other (Road/Railway)	3.69	3.93	8.53
Area (km^2)	292	292	292

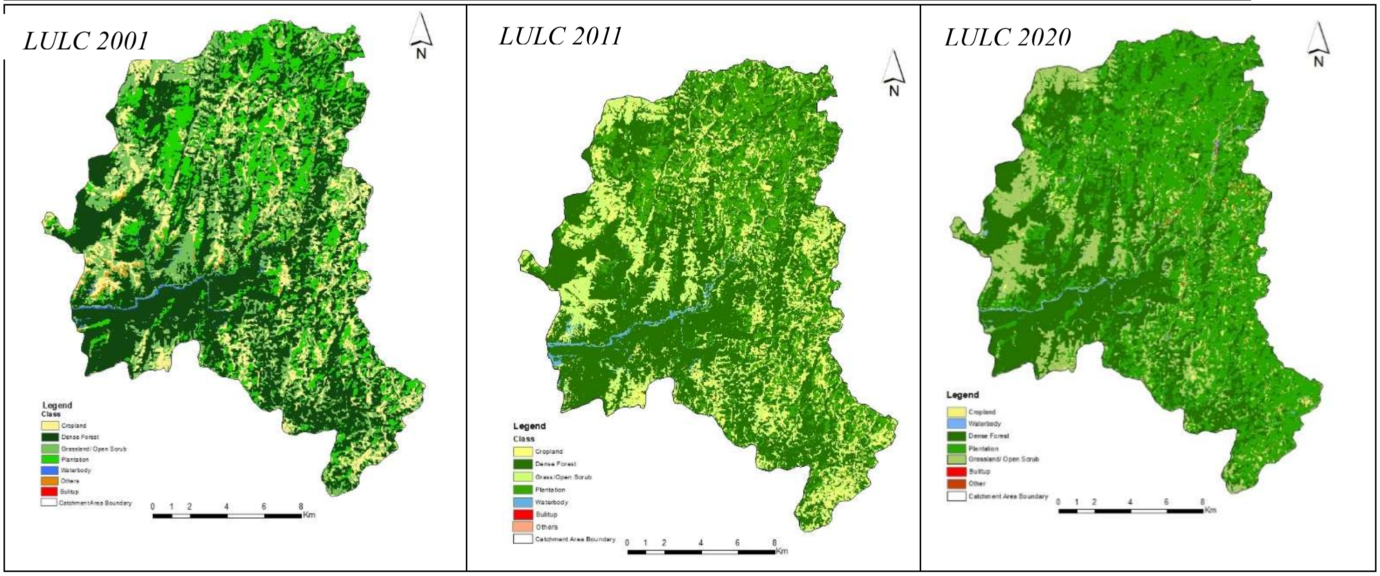


Figure 3: Land use land cover map

Table 3: Yearly rainfall and mean soil loss

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Rainfall (mm)	2612.46	2043.46	2252.81	2512.79	2652.01	2952.6	3231.56	2557.62	3150.88	3717.25	3059.12	2674.69	3933.46	3364.45	2133.63	1471.82	1653.22	1595.74	1926.39	2407.32
Mean Soil Loss (T/Ha/Yr)	354.45	491.03	652.73	626.73	385.17	658.11	715.44	621.26	567.55	1095.39	422.83	710.86	612.29	582.00	597.47	226.74	767.69	504.22	496.55	564.47

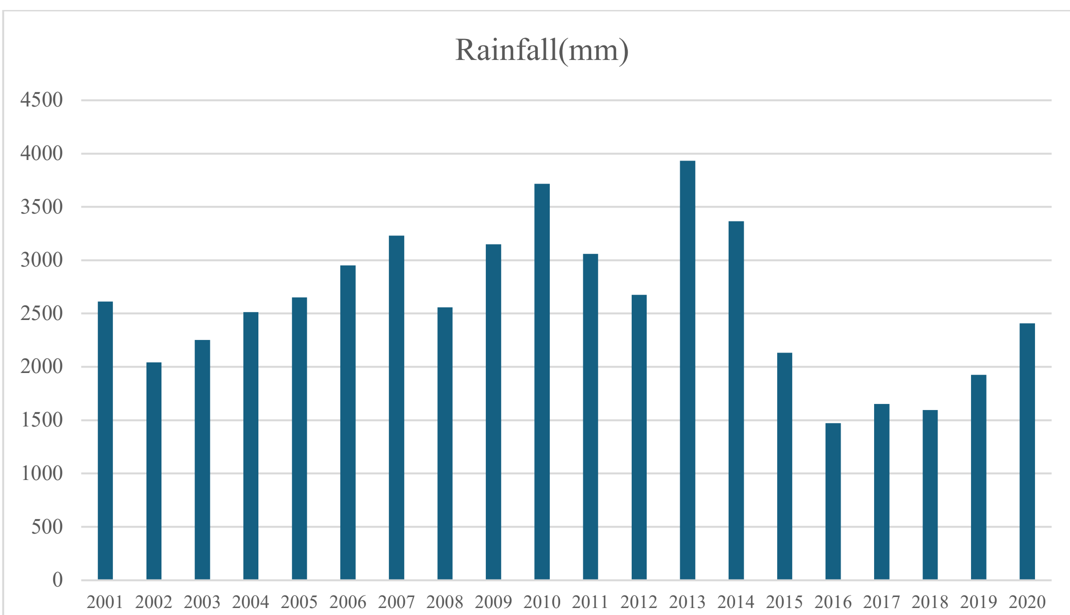


Figure 5: Annual total Rainfall(mm) graph from 2001-2020. (Source: NASA power)

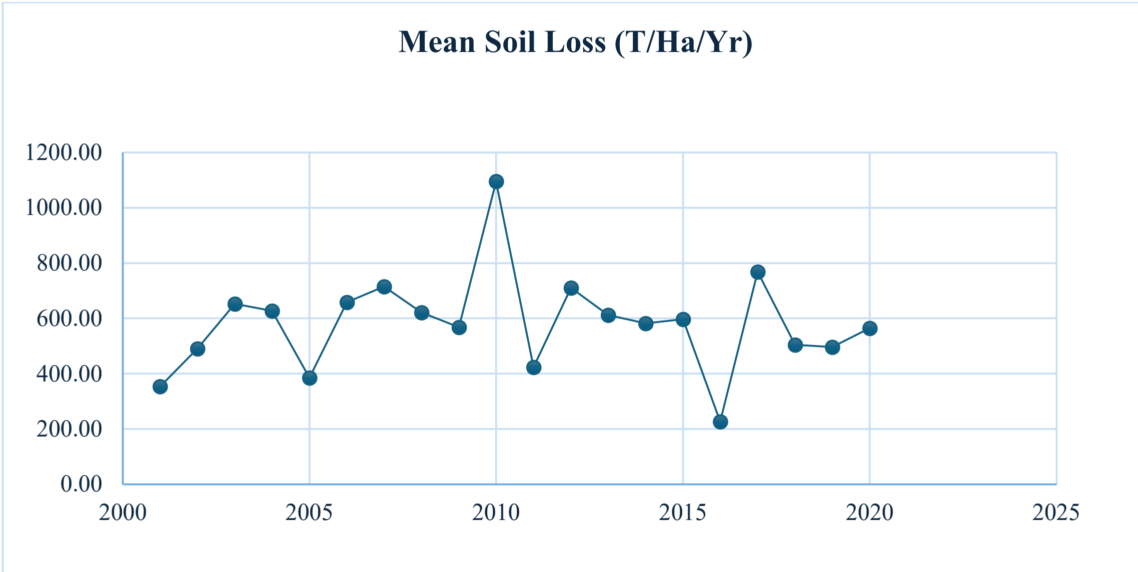


Figure 6: Mean Soil Loss (T/Ha/Yr) graph from 2001-2020

4. CONCLUSIONS:

Significant soil erosion is a problem in the Yetthinahole catchment area due to shifting land uses, erratic rainfall patterns and a decline in plant cover. By utilizing the Google Earth Engine platform and geoinformatics tools, our study leverages accessible data to evaluate these dynamics. Determining the amount of lost vegetative cover was essential to comprehending erosion trends in the study area. Effective land management measures, with a focus on forest preservation, restoring vegetative cover and implementing sustainable practices, are crucial for minimizing erosion and guaranteeing environmental sustainability.

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