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RESEARCH ARTICLE

Estimation of Soil Loss in the Nanoi River Basin using Geospatial Techniques

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Abstract

Objectives: The main purpose of this research is to identify severe soil loss areas in the Nanoi river basin of Assam, India to suggest appropriate soil management planning in the river basin. **Methods:** The Revised Universal Soil Loss Equation (RUSLE) integrates geospatial technologies to assess overall soil loss in the Nanoi river basin which provides a faster and more accurate estimation. It is possible to understand soil erosion patterns more thoroughly using RUSLE which makes sustainable soil management easier. **Findings:** According to the RUSLE equation, the Nanoi river basin experiences an estimated total soil loss of 18,562.5 tons per year, with an average annual soil loss of 0.32 t/h/y. This suggests that approximately 0.64 km^2 of the area falls into the Moderate, high and Extreme soil erosion sensitivity zones. Furthermore, a final map is generated to display different areas with varying levels of soil loss rates. **Novelty:** The geospatial approaches used produce precise findings at a reasonable price and demonstrate the severity of soil loss in the river basin. If soil loss continues at the current rate, there is a high likelihood that certain areas on both sides of the river, particularly in the downstream region of the basin, will experience fluvial hazards, such as drainage congestion and floods. Hence, the results generated will be helpful in the management practices of the river basin.

Keywords: Soil loss; Soil erosion; Geospatial; Revised universal soil loss equation; River basin

1 Introduction

Soil erosion is caused by activities like deforestation, poor farming, and unchecked grazing which is a persistent and challenging issue. For agricultural production and the management of natural resources, estimating the rate of soil erosion is essential [1]. The conversion of grasslands and forests into agricultural land aggravates soil erosion [2]. Amidst our evolving landscape, promoting the adoption of sustainable mechanical and biological practices becomes imperative for soil and water conservation [2]. Integrating computer-based soil erosion modelling with Geographic Information Systems (GIS) and the RUSLE model emerges as a versatile approach, facilitating precise estimation of erosion across diverse conditions, while aiding in strategic soil protection and hotspot identification[3].

Over time, many studies have explored the complex nature of soil loss[4–7], leading to the development of different models to estimate it; in our research, we utilize the advanced Revised Universal Soil Loss Equation (RUSLE) model to assess soil loss in the Nanoi river basin, creating a detailed map. More frequent studies are needed in the region with multiple methods to compare and ensure accurate data availability to get more precise outcomes[6]. The application of RUSLE in conjunction with GIS has attracted the attention of several researchers, especially in India, where it has been utilized to estimate soil loss in specific regions[5–10] and beyond. But despite the substantial advancements in soil loss estimation, there are still major holes in the body of knowledge. Many previous works have focused on broader regional assessments or utilized outdated models that may not adequately capture the complexities of soil loss dynamics. Using the results generated by advanced RUSLE model in the Nanoi river basin which occupies a smaller area of Assam is useful to policymakers as it helps to mitigate the damages caused by soil loss. The issues posed by soil loss in Assam are quickly addressed by this research with a practical answer.

2 Methodology

2.1 Study area

The Nanoi River is a tributary of the mighty Brahmaputra oozes from the Bhutan-Himalaya Tangchar, hill (1220m). The terrain characteristics of this river basin are quite typical. The slope of the river basin is steep upstream, whereas the slope is significantly decreasing towards the downstream part of the river basin. The river flows from the Bhutan Himalaya to the plain of the mighty Brahmaputra in the south, encompassing two districts Udalguri and Darrang from north to south. With many small tributaries, the length of the Nanoi River is 104.275 kilometers with a basin area of 577.927 sq. km (Figure 1). The basin extends from 26^0 $15^{/}$ $45.14^{//}$ N to 27^0 $04^{//}$ $57.84^{//}$ N latitude and 91^0 $48^{//}$ $59.66^{//}$ E to 91^0 $58^{//}$ $42.536^{//}$ E longitude. The total population of the river basin area is 3,00,486 in 1991 and 3,28,339 in 2011, based on census data.

The running water, altitude and the adjacent sub-tributaries dominate the basin's nature and play a significant role in making an unstable river basin in the region. Due to the heavy downpour during the monsoon (Annual Mean Rainfall 210 cm.) it carries a huge amount of discharge along with sediments. The entire Brahmaputra valley is composed of alluvial soil. Therefore, the middle part of the basin is highly volatile to bank erosion and channel shifting during the rainy season. The Nanoi River basin, a part of the riverine built-up plain of Brahmaputra valley composed of fine alluvial sediments, has been washed by sheet flood causing riverbank erosion and channel shifting almost yearly due to hydro-geomorphic factors. The hydro-geomorphic characteristic of the river basin has caused serious geomorphic, hydrologic, and environmental problems in the southern part of Darrang district. The Assam part of the Nanoi river basin is considered for soil loss estimation in the RUSLE model.

2.2 Material and methods

A wide range of data from reliable sources has been utilised to evaluate the extent of soil loss in the Nanoi River. Table 1 lists the many data sets that were used for the study along with their sources. All relevant layers have been converted to the raster framework through software and converted into universal transverse Mercator spheroid with datum WGS1984. Other related maps are generated from ASTER GDEM using appropriate spatial analysis tools. The raster files used in the model are resampled to 30m spatial resolution for further analysis. The drainage networks of the basin are then digitized to identify hydrologic and morphometric characteristics and behaviour along with areas of the river and associated problems.

Table 1. Details of data used in the model

Year	Type of data	Source	Title
1999	Thematic maps	Department of agriculture, Assam	Soil Types map with Soil bulletin
2020	Rainfall data	Tea estates (rain gauge data)	Daily rainfall data
2011	Topography data	United States Geological Survey, EarthExplorer' website	Aster DEM, 30 m
2020	Remote Sensing data	United States Geological Survey, EarthExplorer' website	Landsat OLI-TIRS
1959-60	Topographical Maps	Survey of India (SOI)	78N/10, 78N/11, 78N/12, 78N/13, 78N/14, 78N/15, 78N/16

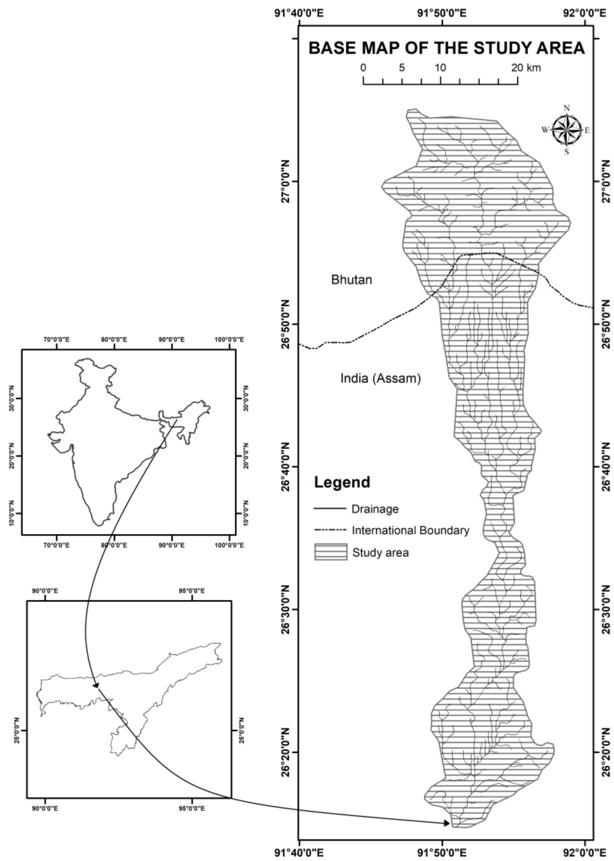

Fig 1. Nanoi river basin

The soil loss prospective model is prepared based on the Revised Universal Soil Loss Equation (RUSLE) can be expressed as[11].

$$A = LS * R * K * C * P \tag{1}$$

Where, A = yearly soil loss (tons/ha/year); LS = slope length and gradient factor; R = rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}); K = soil erodibility factor (ton/MJ/mm); C = land cover and management factor (dimensionless, ranging between 0 and 1); P = conservation practice factor (dimensionless, range between 0 and 1). Among the factors the LS, C, and P factors are dimensionless.

2.2.1 ***Rainfall erosivity factor***

The R factor signifies constraints of the sheet and rill erosion process, and differences in R values represent differences in the erosivity of the climate. The rainfall erosivity factors suggested by[12].

$$RE = 79 + 0.363 * P \tag{2}$$

Where RE is the Rainfall erosivity, P is the Average annual rainfall (mm) enumerates the impact of rainfall on the variability and intensity of runoff in the region. The rate of runoff and flow variability determines the erodibility of soil in a river basin of or in the wet region. Estimation of soil erosion rate, the degree of the R factor and it's recurring distribution must be concentrated on the cropping structure. In the case of Nanoi River, the value of R varies from 106 MJ mm ha^{-1} h^{-1} $year^{-1}$ to 164.901 MJ mm ha^{-1} h^{-1} $year^{-1}$ (Figure 2).

2.2.2 ***Soil erodibility factor***

Soil erodibility (K) is the innate soil vulnerability to loss by surface runoff and rainwater, and is an operation of structure, texture, hydraulic properties, organic matter content and soil wettability[13]. To calculate the K factor the equation, **EPIC** (Erosion

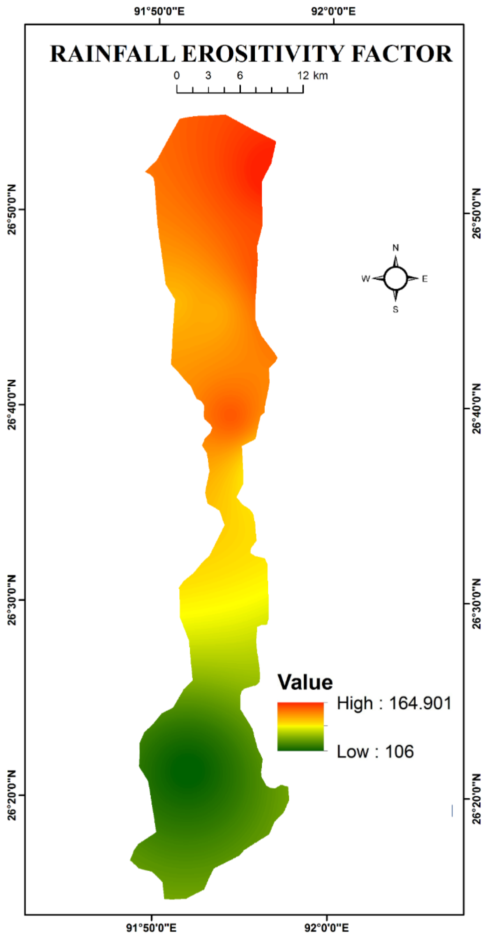

Fig 2. Rainfall Erosivity Factor

Table 2. Calculated R factor for the Nanoi River basin

Station	R-factor
Bhergaon TE	149
Dimakuchi TE	145
Paneery TE	147
Kherkheria TE	165
Hatigarh TE	158
Majuli TE	174
Nanoi Para	158
Mekelikanda H.W. Site	133
Mangaldoi E/DCampus	118
Khandajan Camp	106

productivity impact calculator) is used[13].

$$K = \{0.2 + exp\,[-0.0256SAN\,(1 - SIL/100]\} * [SIL/(CLA + SIL)]0.3* \\ \{1.0 - 0.025C/[C + exp\,(3.72 - 2.95C)]\} * \{1.0 - 0.7SN1\,/[SN1 + exp\,(-5.51 + 22.9SN1)]\} \quad (3)$$

The lower K factor value is linked with the low permeability of soils, low antecedent moisture content (AMC), etc. Here, SAN is sand in percent, SIL silt in percent, CLA is clay in percent, C is organic carbon in percent and SN1=1-SAN/100[12].

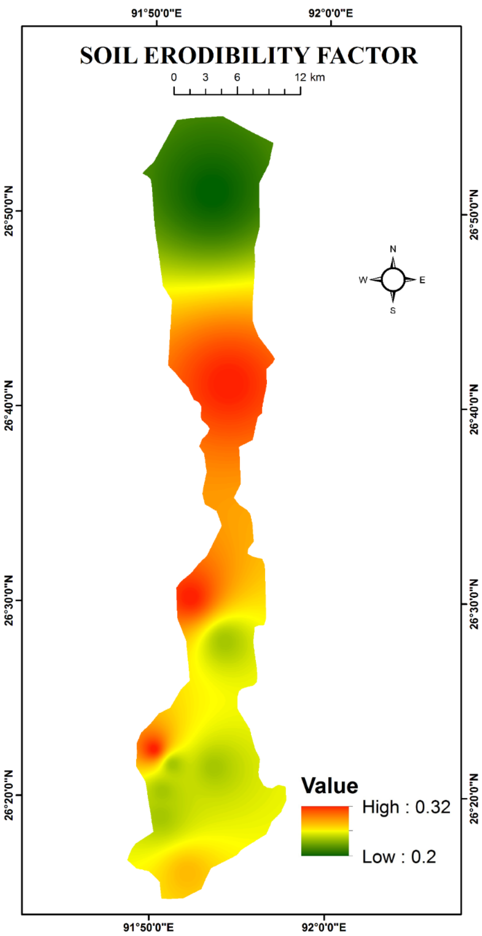

Fig 3. Soil erodibility factor

2.2.3 ***Length and steepness factor***

The slope length and steepness factor (LS) affect the total sediment yield from the site. The formula to calculate LS is[13].

$$LS = (AS/22.13)^{\,m} * (Sin\,l/0.09)^{\,n} \quad (4)$$

here, AS is an upslope contributing area per unit width of the pixel spacing **m** and **n** are exponential slope aspects for length and gradient.

The equation of RUSLE representation developed the rate of estimation for choosing the slope length values which helps to provide adequate information to the users. The L-factor, the soil loss is not as much of susceptible to the slope length as to any other USLE factor. In ideal slope conditions, if there is a 10% error in measuring the length of the slope, it will lead to a 5% error in the calculated soil loss. RUSLE uses four separate slope-length relationships. Slope steepness as in USLE, and of the susceptibility of the soil to rill erosion relative to inter rill erosion.

Soil loss is more prone to changes in slope steepness than to changes in slope length. Thus, special consideration should be drawn to the assessment of slope steepness. RUSLE has a more practically linear slope steepness relationship and also gives a slope steepness relationship for inter-rill erosion. LS factor is calculated by using flow accretion and slope in degree as inputs. When slope and flow accretion enhance, LS factor also enhances. A higher LS factor has been observed in the north-upstream area of the basin (Figure 4). It indicates the rate of erosion is high in the upstream part of the basin so it accumulates a high rate of sediments from the upstream and finally deposited in the downstream region and caused high to medium flood in the lower part of the basin.

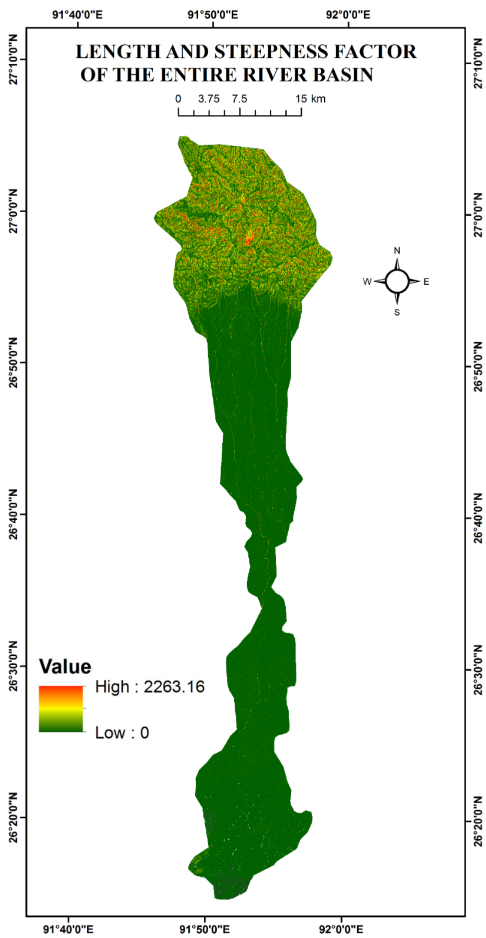

Fig 4. LS factor

2.2.4 ***Crop cover management factor***

The C factor is the crop cover management factor which is derived from the NDVI map with the following formula[14]

$$C = EXP[-\alpha(NDVI/\beta - NDVI)]. \quad (5)$$

The values for C can range from almost zero, indicating a highly protected soil, to 1.5. Values for C are a weighted mean of soil loss ratios (SLRs) that gives information about soil loss in a region at a given time. The C factor is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow. Where α and β are the parameters that determine the shape of the NDVI-C curve. α value of 2 and β value of 1 were taken[14]. The highest mean C-factors, i.e., 1.3 are found in the downstream part of the river basin (Figure 5) namely the villages Ptharighat, Chengeliajhar, Dumunichowki, Khandajan, Kurua, etc. for many fluvio-geomorphological regions. Among them, Chengeliajhar and Kurua have the highest shares of arable lands. The lowest C-factor values (<0.05) were identified in the upstream part of the basin (Tangla, Bhutia Chang and Khaleng Douwar R.F.) where the Tea Garden and vegetation are the dominant land use.

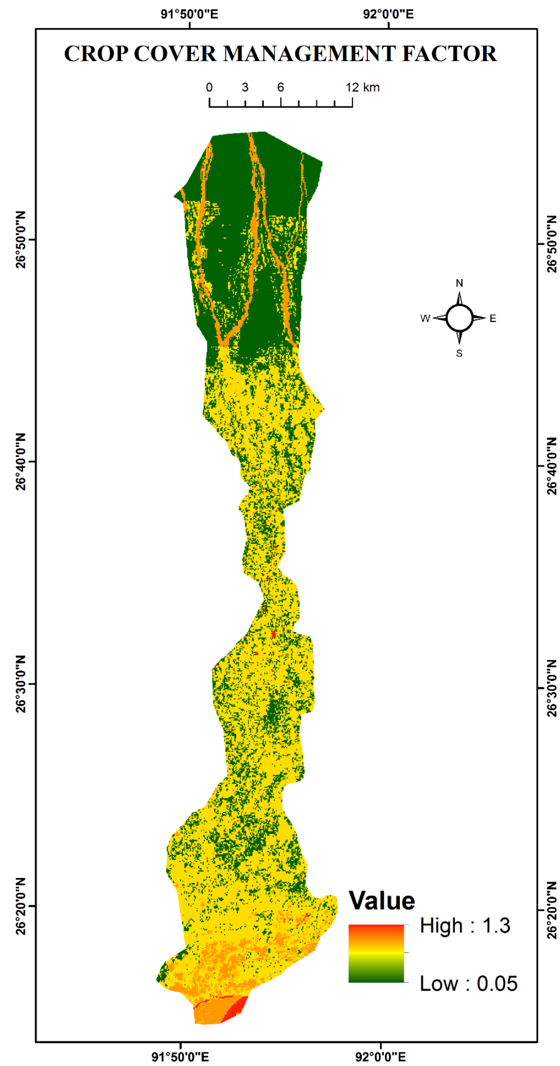

Fig 5. Crop cover management factor

2.2.5 ***Support practice or P factor***

The support practice factor P accounts for the impact of various practices, such as contouring, strip cropping, terracing, etc., which mitigate soil erosion by decreasing the rate of water runoff. In the Nanoi river basin no supporting practice such as strip cropping, terracing, contouring etc. was witnessed thus the value of 'P' was taken as 1.

3 Results and Discussion

In the case of Nanoi river basin it is pointed out that the estimated total soil loss is 18562.5 ton/y and average annual soil loss is 0.32 tons/ha/yr as per RUSLE equation (Figure 6). The quantity of soil erosion range varies on the various topographic zone in Nanoi basin. Relevant findings were observed in various river systems within India, including Godavari Middle Sub Basin[9], Amravati watershed of Tamil Nadu [10], Chambal River basin[11], Sadiya region[12], Panchnoi river basin[13], lower Kulsi basin[14] and many more. The average annual soil loss rates varied across different regions and higher than Nanoi river basin, the Godavari Middle sub-Basin having 9.88 t/h/y, the Amravati watershed is 280.2 t/h/y, the Chambal River basin is13.44 t/h/y, the Sadiya region encountering 5.45 t/h/y, the Panchnoi river having 5.63 t/h/y and Kulsi river basin is 0 to 6.453 thousand t/h/y.

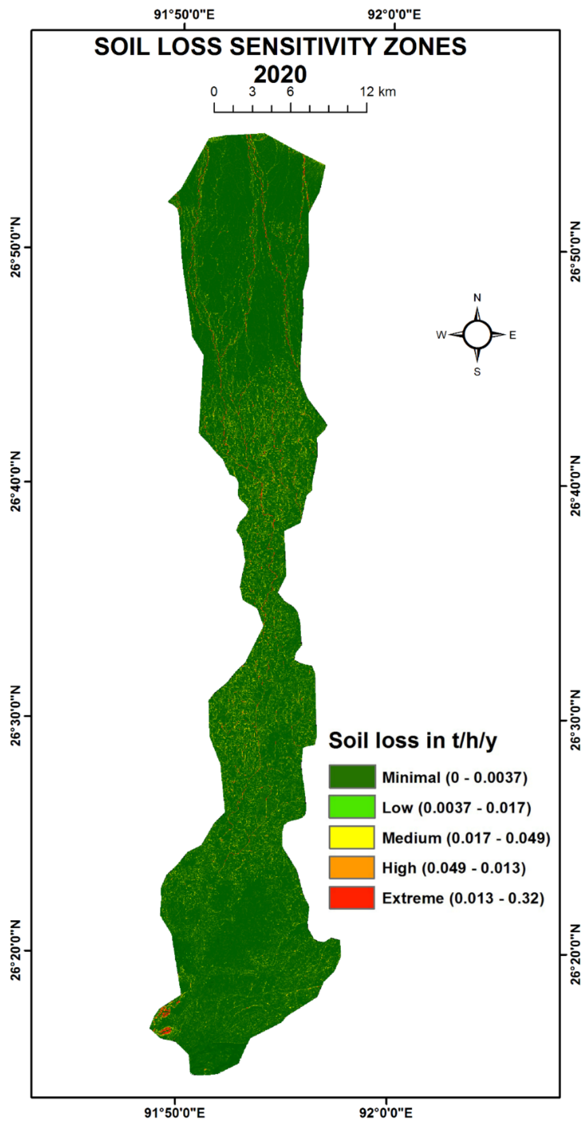

Fig 6. Soil loss sensitivity of Nanoi river basin of Assam

Table 3. Soil loss sensitivity classes of Nanoi river basin

Soil loss (ton/ha/yr)	Soil erosion sensitivity zone	Area (km^2)	Percentage
0 - 0.0037	Minimal	567	99.334
0.0037 - 0.017	Low	3.2	0.5606
0.017 - 0.049	Moderate	0.55	0.0964
0.049 - 0.013	High	0.081803	0.0143
0.013 - 0.32	Extreme	0.006876	0.0012

The Assam region of the river basin is characterized by mostly flat topography, and the amount of rainfall recorded shows a relatively consistent pattern over the years. The map generated reveals that areas with high and extreme erosion sensitivity are primarily found near the riverbanks, agricultural lands, and areas where deforestation has taken place. The LS factor plays a vital role in evaluating soil loss. Table 3 provides an overview of the various classes of soil loss sensitivity, indicating that the moderate, high, and extreme soil loss sensitivity classes together covered an area of 0.64 km^2, accounting for 0.1% of the total basin area.

4 Conclusion

This study is the first attempt to estimate soil loss in the Nanoi river basin using RUSLE model in GIS integrating local factors of soil loss like R, K, LS, C and P. The measurement of the soil erosion impact across different land use and cover areas (Figure 5), facilitates the implementation of suitable soil erosion control measures. However, planners often ignore the importance of addressing this issue, risking downstream fluvial hazards such as floods and bank erosion. The study estimates about 18562.5 tons of soil loss annually in the Nanoi river basin with an average rate of 0.32 t/h/y. Moreover, the study reveals that although areas with high soil loss sensitivity occupy a smaller portion of the study area, but they are concentrated in densely populated and intensively cultivated regions in turn imposing significant pressure on the rural economy. This study applies RUSLE model in a smaller river basin compared to many regional and larger watershed studies, but it can help formulate sustainable development measures to safeguard the environment and economy of the rural population of this smaller area. The model is a quick estimation of soil loss in the study area which not only save time but also the results can be served as information for further investigation.

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