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Soil Erosion and Sediment Yield Assessment of Nilwande Dam Watershed using RUSLE, GIS, and Remote Sensing Techniques

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Abstract: Soil erosion and sediments movement have become a serious problem which affects agriculture production, watershed sustainability, and water holding capacity of reservoirs. This study examines to assess soil erosion and sediments yield in Nilwande Dam watershed, Ahilyanagar district of Maharashtra State, India based on Revised Universal Soil Loss Equation (RUSLE) with Remote Sensing (RS) and Geographic Information Systems (GIS). RUSLE is composed of Rainfall Erosivity Factor (R), Soil Erodibility Factor (K), Slope Length and Steepness Factor (LS), Cover Management Factor (C), and Conservation Practice Factor (P) obtained from rainfall, soil, Digital Elevation Model (DEM), and Sentinel-2 land use/land cover data. Soil erosion per year was quantified through a raster-based analysis within ArcGIS software environment, whereas the sediment yield was calculated through the use of the Sediment Delivery Ratio (SDR). Soil erosion varied between almost 0 to 28,720.4 t ha^{-1} yr^{-1}, whereas sediment yield showed differences between 0 to 8,369 t ha^{-1} yr^{-1}. The hilly areas located to the northwest and southwest parts of the study area were found to suffer most erosion and sediment yield as a result of steep slopes, high rainfall erosivity, and sparse vegetation cover. The validation of the developed model based on the receiver operating characteristic (ROC) curve and area under the curve (AUC) showed satisfactory predictive power.
Keywords: Soil Erosion, Sediment Yield, RUSLE, Remote sensing, GIS, Sediment delivery ratio.

I. INTRODUCTION

Sediment yield refers to the volume of eroded sediments carried out of the watershed outlet in a certain period, plays an important role in the determination of watershed condition. Too much sediment yields have negative impacts on reservoir storage capability, irrigation facilities, river life, and hydro-electric power production. Sediment deposition in reservoirs has become a significant problem around the world since it makes water storage less efficient, limits the life of the reservoir, and creates high maintenance costs. Therefore, correct calculation of sediment yield is crucial for proper management of watersheds and sustainable use of natural resources. The field-based conventional techniques employed in evaluating soil erosion and sediment yield are normally cumbersome, tedious, and expensive, particularly when the area under investigation is huge. With developments in Remote Sensing (RS) and Geographic Information System (GIS), the effectiveness in analyzing spatial patterns of soil erosion and sediment transport has greatly been boosted. The incorporation of geospatial techniques with empirical soil erosion models makes it possible to analyze large areas quickly, with the added advantage of obtaining reliable information concerning soil erosion. Of all the available empirical soil erosion models, the Revised Universal Soil Loss Equation (RUSLE) is among the widely used approaches for soil erosion prediction. In estimating soil erosion, the RUSLE technique depends on five factors, namely rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and conservation practices (P). The flexibility, ease of use, and compatibility of RUSLE with geographical information system applications have made it possible for this method to be employed in varied climatic and physiographic conditions. Many researchers have applied RUSLE along with satellite-based data and digital elevation models to predict erosion hotspots and conservation efforts (Prasannakumar et al., 2012; Borrelli et al., 2017). However, the amount of soil loss estimated through RUSLE does not equate to sediment yield in a particular watershed. Sediment Delivery Ratio (SDR) indicates the amount of eroded soils that are moved from hillslope surfaces to streams via drainage network. Using RUSLE equation soil losses estimates with SDR based sediment delivery method offers a good technique for computing sediment yields in a watershed.

This sediment estimation methodology has gained increasing attention in watershed management studies as it allows determination of sediment generation sites and application of appropriate management techniques (Williams & Berndt, 1977; Jain & Korthyari, 2000).

Soil erosion issues in India are prevalent because of the heterogeneous topography of India, its high intensity rainfall during monsoon, its rapid process of urbanization, and agricultural development. Many river basins and reservoir catchments in India have been observed to be experiencing accelerated rates of sedimentation due to which there is a risk of water insecurity and un-sustainable agriculture. Two such regions which have shown vulnerability towards accelerated erosion and sedimentation are Western Ghats and Deccan Plateau regions.

In the current research, an effort is made to determine sediment yield in the Nilwande Dam watershed in Ahilyanagar District, Maharashtra, through the combined usage of RUSLE-GIS methodology. Satellite imagery and DEM data have been used to prepare various inputs necessary to calculate RUSLE factors comprising rainfall, soil properties, land use/land cover, and topography. Following that, the total soil erosion per year was calculated, which was then linked with Sediment Delivery Ratio (SDR) to compute the amount of sediment yield in the study watershed. The results obtained from this study have contributed to a better comprehension of the erosion processes that occur in the watershed and shown the efficacy of combining Remote Sensing, GIS, and modelling approaches for estimating sediment yields. The spatial information produced through this process will be useful for making decisions for soil and water conservation to prevent further land degradation.

II. STUDY AREA

This research work is conducted in the upper Pravara river basin, situated within the district of Ahilyanagar (formerly Ahmednagar) of Maharashtra state in India. The basin forms one of the crucial sub-basins of the Godavari river system and holds much significance for regional water management, agriculture, and power generation. The region studied here comprises the catchment areas that drain into the Bhandardara and Nilwande dams, both forming one of the largest artificial reservoirs in western Maharashtra. The dams have been providing water for irrigation, drinking purposes, and industries in the neighboring districts of Ahilyanagar. The region has come under the increased anthropogenic impacts like land-use changes, deforestation, and agricultural activities, making the watershed prone to soil erosion and sediment transport. The study has varied topography, uneven rainfall pattern, varied land use systems, and different soil properties. These factors have a great effect on the processes of runoff formation, soil erosion, and sediment transport in the watershed. Combining remote sensing (RS), geographic information system (GIS), and the revised universal soil loss equation (RUSLE) offers a good methodology for determining soil erosion susceptibility and sediment yield in such areas (Renard et al., 1997; Ganasri & Ramesh, 2016). The study area ranges between 19°26′N to 19°40′N latitude and 73°38′E to 74°06′E longitude. The watershed is located within the upper region of the Pravara River catchment and contains the drainage basin upstream of the Nilwande and Bhandardara dams. It should be noted that being located within the Western Ghats, the area is extremely vulnerable to monsoon rains. Location of the watershed under consideration is significant from a strategic point of view since the region lies in the northwestern part of the Deccan Plateau. In addition, the region forms a part of the Godavari Basin, which is one of the largest river basins of peninsular India. Geography of the study area makes a notable contribution to high diversity in terms of slope, elevation, land use/cover pattern, and hydrology, thus becoming highly suitable for soil erosion and sediment yield studies. The location map of study area is present in Figure 1.

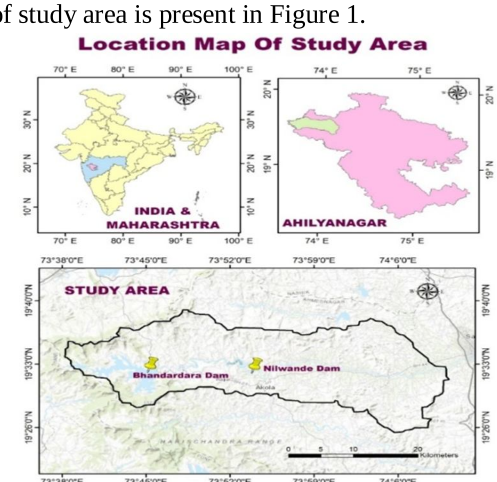

Fig. 1: Location Map of Study Area

III. MATERIALS USED AND METHODOLOGY

A. *Materials used*

The present study employed different datasets gathered from various sources (Table 1). Such data sets include topography data, precipitation data, soil data, and satellite data. The data sets gathered were then combined in a GIS system for erosion modeling.

Table 1: Dataset used for the Analysis

Data Layer	Sources	Resolution / Scale	Purpose
DEM	SRTM	30 m	Slope and LS factor
Rainfall Data	CHRS Data portal	4 x 4 km	R factor
Sentinel 2 Imagery	ESA	10 m	LULC mapping
Soil Map	FAO	250 m	K factor
Watershed Boundary	Derived from DEM	Vector	Spatial Analysis

B. *Methodology*

1) *GIS Database Development:*

Development of GIS databases is an important part of spatial modeling and analysis. Projections of all datasets were conducted to bring them on to a uniform coordinate system (WGS 1984 UTM Zone 43N). Further, datasets were clipped by means of the watershed boundary to make sure that analyses could be conducted only within the study area. There were three major datasets in the GIS database, which included topography, rainfall, soil, and land-use conditions. Thematic layers of these factors were grouped according to themes in thematic folders. The following steps were involved in GIS database preparation:
Projection transformation - Clipping of rasters – Resampling - Creation of mosaics – Reclassification - Hydrological correction - Delineation of watersheds

2) *Revised Universal Soil Loss Equations (RUSLE):*

Revised Universal Soil Loss Equation (RUSLE) is among the most commonly used empirical equations for predicting average soil erosion by rainfall and surface runoff in a year. RUSLE was designed to be an advanced version of USLE and integrates scientific advancements in soil erosion, GIS, and remote sensing technology, offering more accurate predictions of soil erosion under different environmental settings (Renard et al., 1997). This equation has found extensive use in the field of watershed management, land degradation monitoring, and reservoir sedimentation, among other applications, owing to its easy adaptability in a spatial environment. According to the RUSLE model, soil erosion is estimated on the basis of the combination of rainfall erosivity, soil erodibility, topographic factors, land use, and conservation practice. The RUSLE model in the current research is applied to 1251nalyse the soil erosion at the Nilwande Dam watershed using ArcGIS software.
The general form of the RUSLE equation is:

$$A = R \times K \times LS \times C \times P$$

Where:
A = Average annual soil loss (t ha^{-1} yr^{-1}), R = Rainfall erosivity factor, K = Soil erodibility factor, LS = Slope length and slope steepness facto, C = Cover and management factor, P = Support practice factor
This represents the calculated soil loss in terms of tons per year per hectare (t ha^{-1} yr^{-1}), which indicates the amount of soil that is detached and carried by water from an area.
Erosion is one of the environmental issues, causing soil losses leading to decreased land productivity and reduced capacities of dams due to siltation in the reservoir. Soil erosion is a severe threat to agricultural productivity and ecosystems since excessive erosion leads to soil degradation and fertility loss. RUSLE helps in locating the areas where erosion takes place and thus prioritizes efforts to conserve such areas. In conjunction with GIS and remote sensing techniques, RUSLE allows an effective way to map and estimate erosion rates accurately. For this analysis, separate thematic layers were created based on the R, K, LS, C, and P factors. These layers were then integrated using raster multiplication in the GIS software ArcGIS to prepare the final map of soil erosion.

3) *Rainfall Erosivity Factor (R):*

The Rainfall Erosivity Factor (R) is an indicator of the erosion capability of rainfall and one of the key variables used in the Revised Universal Soil Loss Equation (RUSLE).

The R factor measures the ability of rainfall to detach and move soil particles by means of raindrop impact and overland flow. Locations receiving intense rainfall and storm events typically register high levels of rainfall erosivity and therefore high potential for soil erosion (Renard et al., 1997). The R factor is an indicator of rainfall kinetic energy and maximum 30-minute intensity. In view of the lack of precise pluviograph records in many places, particularly in developing countries, various empirical equations have been devised to calculate the erosivity from annual rainfall totals. In this particular study, rainfall data for the Nilwande Dam catchment area was sourced from the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks - Cloud Classification System (PERSIANN-CCS). Rainfall data was then analyzed through ArcGIS software to create a rainfall distribution map that was later used to compute the rainfall erosivity factor.

The rainfall dataset for the year 2024 was then extracted from the portal and clipped using the Extract by Mask tool in ArcGIS according to the study area, namely the Nilwande Dam. Given that the original rainfall raster had coarse spatial resolution, rainfall values were first converted into point data and later resampled using the IDW interpolation method. After extracting the rainfall data from the rainfall raster using the watersheds boundaries, the rainfall values were extracted as points. This layer was then projected to the coordinates of the study area before performing IDW interpolation. The IDW method of interpolation is an example of deterministic interpolation that works under the premise that points near each other have more effect than points that are far apart, as described below:

$$Z\,(x) = \frac{\sum_{i=1}^{n} \frac{z_i}{d_i^p}}{\sum_{i=1}^{n} \frac{1}{d_i^p}}$$

Where: Z (x) = Estimated Rainfall Value, Z_i = Observed Rainfall Value at Point, d_i = distance between sample point and prediction location, p = power parameter, n = number of neighbouring points

A power value of two and a cell size of 30m were used for the interpolation process. There have been several empirical formulas for the estimation of rainfall erosivity from annual rainfall. The formula suggested by Singh et al. (1981) and used in various RUSLE models thereafter was chosen to be applicable to India's tropical climate.

Rainfall erosivity index can be calculated from:

$$R = 0.0483\, P^{1.61}$$

Where: R = Rainfall Erosivity Factor (MJ mm ha^{-1} h^{-1} yr^{-1}), P=Mean annual Precipitation (mm)

4) Soil Erodibility Factor (K):

K-factor (Soil Erodibility) refers to the tendency of the soil to be detached from its position and transported due to rainfall and surface runoff. This factor is among the core determinants in the calculation of the Revised Universal Soil Loss Equation. This factor mainly considers the natural resilience of the soil against erosion. The factors that influence the value of K-factor include the nature of soil texture, soil content of organic matter, soil structure, soil permeability, soil infiltration, and soil aggregate stability. High levels of soil silt content and low soil aggregation lead to increased soil erodibility (Wischmeier & Smith, 1978; Renard et al., 1997).

K factor units are measured in: t·ha·h/(ha·MJ·mm), representing the mean soil loss by unit of rainfall erosivity under normal conditions. In this research, the Soil Erodibility Factor was calculated based on data provided by the FAO Digital Soil Map of the World (DSMW) and soil texture in the Nilwande Dam catchment area. GIS methodologies were applied in creating a map with spatially distributed K-factor values in the context of RUSLE application.

The values of K-factor were assigned based on soil textures using the guidelines provided by Wischmeier & Smith (1978), Renard et al. (1997), and several RUSLE GIS applications from India.

Soil Texture	K value
Clay	0.15
Clay Loam	0.30
Loam	0.45

5) Slope Length and Steepness Factor (LS):

Slope Length and Steepness (LS) is another critical parameter in RUSLE. Slope Length and Steepness is an integration of slope length (L) and slope steepness (S). With an increase in slope length, runoff builds up and increases its ability to cause soil detachment and transport. Likewise, the steeper the slope, the faster the flow of water, hence more erodibility and transportation capability (Renard et al., 1997; Wischmeier & Smith, 1978).

The Slope Length and Steepness (LS) factor is a non-dimensional quantity, which has relatively larger values in hills and smaller values in flat regions. Topography plays a significant role in controlling erosion processes, therefore, the need for proper LS estimation. LS factor was obtained from a DEM using ArcGIS spatial analysis tools. It included DEM processing, filling sinks, determining flow direction, flow accumulation computation, and calculating slopes, followed by raster-based application of the RUSLE LS formula.

LS factor was estimated based on the raster form of the equation by Moore & Burch (1986).

$$LS = \left(FA \times \left(\frac{cell\ Size}{23.13}\right)^{0.4} \right) \times \left(\frac{\sin(Slope \times 0.01745)}{0.09}^{1.3} \right) \times 1.6$$

Where: LS = Slope Length and Steepness Factor, FA = Flow Accumulation, Cell Size = DEM resolution (30 m), Slope = Slope angle in degrees, 0.01745 = Degree-to-radian conversion factor, 23.13 m = Standard USLE slope length, 0.4 and 1.3 = Empirical exponents, 1.6 Calibration coefficient

6) LULC Classification and Cover Management Factor (C):

LULC plays an important role as one of the parameter inputs in the RUSLE as it regulates the cover management factor (C). The factor C indicates the influence of vegetative cover, condition of the crops, surface protection, and other types of land management practices on soil erosion. This factor is a ratio between the amount of soil erosion by water on a particular land use/cover condition and the amount of soil erosion under bare soil condition with the same rainfall, soil, and slope. Small values of C imply that there is good soil erosion protection, while large values mean high vulnerability to soil erosion. The LULC data was acquired from the ESRI Sentinel-2 10 m Land Use/Land Cover dataset. This dataset offers annual land use/cover classification based on Sentinel-2 satellite images that can be used in environmental analysis of watershed scale. The dataset was downloaded for the year 2024 and imported into the ArcGIS environment. The LULC data was initially overlain with the watershed boundary of Nilwande Dam, after which the clipping process was carried out through the Extract by Mask feature.

The derived LULC layer was categorized into six main types: water, trees, agricultural land, built-up land, bare soil, and rangelands. The raster attribute table indicated the following land use types: water, trees, agriculture, built-up land, bare soil, and rangeland. Based on this categorization, C factor values were selected according to the RUSLE reference and local land uses conditions. Land use with dense vegetation cover and water bodies had very low C values, as they offer good surface protection and minimize raindrop impact. On the other hand, agricultural lands and rangelands had moderate C values because of the varied erosion risks posed by different crop cover and seasonality.

The clipped LULC raster was first converted into polygons using the Raster to Polygon tool. Dissolution of the resulting layer by LULC class was done using the Dissolve tool. A new attribute, C Code, was added to the attribute table and the respective C-factor values were assigned to each LULC class. The resulting dissolved layer was finally converted back to raster form using the Feature to Raster tool, with C Code as the value field.

Below are the C-factors used in the study:

LULC Class	C-Factor Value
Water	0.01
Tree	0.05
Crops	0.28
Rangeland	0.50
Built Area	1
Bare Ground	1

The values generated for the C factor map varied from 0.01 to 1.00. Low values were mostly found in areas with water features and forests, particularly in the western part of the watershed. Moderate values were seen in crop fields, while high values were found in rangelands, bare soil, and built-up land cover types. The C factor map was then combined with other factors (R, K, LS, and P) using the Raster Calculator to determine annual soil loss.

7) P Factor

Support Practice Factor (P-Factor) is among the important factors used in the RUSLE model. It reflects the capability of soil and water conservation techniques and farming practices to minimize soil losses due to surface runoff and soil erosion. The P-factor is described as the ratio between the soil loss due to soil support practice to the soil loss due to cultivation along the slope (up and down). Its value ranges between 0 and 1; the closer the value, the better the erosion prevention technique. For the Nilwande Dam catchment, there was no information available regarding the presence of any kind of conservation practices like contour cultivation, terracing, strip farming, and bunding. Thus, the value for P-factor was determined through the slope method, which is usually applied while conducting watershed RUSLE. For the calculation of P-factor values, a map of slope from the DEM was used.

Firstly, using the Slope tool within the ArcGIS Spatial Analyst extension, the slope map was created from the DEM map. The slope values varied from very flat terrain to very steep hill slopes, where the slope values exceeded 70°. Then, the slope raster map was divided into five classes. Different support practice values were attributed to each class according to RUSLE standards and erosion studies of the watershed. Reclassification was done using the Reclassify function by assigning each slope category a class code from 1 through 5. After reclassification, the resulting slope raster was converted into polygons by use of the Raster to Polygon function. The polygons were dissolved depending on the slope class to ensure that the data became homogeneous. An additional attribute name was created as P_Factor and the appropriate values assigned for each slope category. Finally, the polygons were converted back to raster using the Polygon to Raster function to create the P-factor raster.

The following table summarizes the slope classes and their corresponding P-factors:

Slope Class	Slope Range (degree)	P factor
Class 1	0 -7	0.55
Class 2	7-11.3	0.60
Class 3	11.3 – 17.6	0.80
Class 4	17.6-26.8	0.90
Class 5	>26.8	1.00

The derived P-factor map had values that ranged between 0.55 and 1.00. Areas having low P-factor values were mainly characterized by gentle slopes and farmlands, implying that such areas were relatively conducive to controlling the flow of water. However, high P-factor values were found on steeper hills found on hill crests, escarpments, and highly dissected regions. Finally, the P-factor map was used together with the maps for the R, K, LS, and C factors in order to estimate soil loss using the RUSLE approach.

8) Sediment delivery Ratio (SDR):

The Sediment Delivery Ratio (SDR) is described as the ratio of sediment that moves through the drainage network and eventually arrives at the outlet of the watershed to the total amount of soil erosion within the watershed. The reason for using SDR is that not all sediment eroded will reach the outlet because there will be deposition on hillslopes, channel systems, and floodplains.

In this study, the SDR estimation equation is based on the empirical relationship taken from sediment transport studies in watersheds:

$$SDR = (0.51 \text{ x } A^{-0.11})$$

Where, A= area of each SW (km^2) and SDR= SDR of each SW or the entire watershed

The watershed area was determined using the delineated watershed boundary using ArcGIS. The resultant SDR gives an indication of how efficient is the sediment transfer through the watershed. In most cases, large watersheds tend to show low SDR because there is plenty of chances for the sedimentation process to occur before the point of outflow. Small watersheds show high SDR because the distances covered are small.

This particular SDR value was then used for sediment yield determination.

9) Sediment yield estimation:

The sediment yield can be defined as the total amount of eroded sediment that is carried out of the watershed to the outlet point. This value is significant for evaluating the sedimentation of reservoirs, the stability of channels, watershed degradation, and conservation programs.

Sediment Yield = Annual Soil Erosion X Sediment Delivery Ratio (SDR), using the formula:

$$SY = \sum_{i=1}^{n} SDR \ X \ SE$$

Where, SE = mean annual soil erosion (tonnes/ha/year) and SY = mean annual sediment yield (tonnes/ha/year).

The map of sediment yield was developed using ArcGIS software with the help of Raster Calculator, where the annual soil loss layer was multiplied by the SDR factor. The high sediment yield in specific places shows that these places produce significant sediment quantities and are responsible for transporting the sediment load into the drainage system or reservoir. These kinds of places usually have slopes and less vegetative cover and thus produce more runoff.

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IV. RESULTS AND DISCUSSION

A. Spatial Variation of the Rainfall Erosivity Factor (R Factor):

The rainfall erosivity factor (R factor) is an indicator of the erosive potential of rain and shows the contribution of rainfall intensity and volume in terms of the detachment and movement of soil particles (Fig. 2 and 3). The R-factor map of the Nilwande Dam catchment area shows considerable variation in values, which range between about 49.93 and 75.69 MJ mm ha-1 h-1 year-1. Higher erosivity levels are recorded in the western and northwest regions of the catchment area, while lower values are registered in the central and eastern regions. Western parts of the watershed receive higher rainfall due to the presence of higher elevations that cause orographic effects related to the Western Ghats. Higher impacts of rainfall are registered in these areas as a result of higher kinetic energy of soil particle detachment. Erosivity levels in the eastern parts are relatively low due to lower rainfall. Spatial variation of rainfall erosivity in the area under study conforms to other similar studies done in tropical and semi-arid watersheds in which it was found that rainfall intensity is among the key determinants affecting soil erosion process (Panagos et al., 2015).

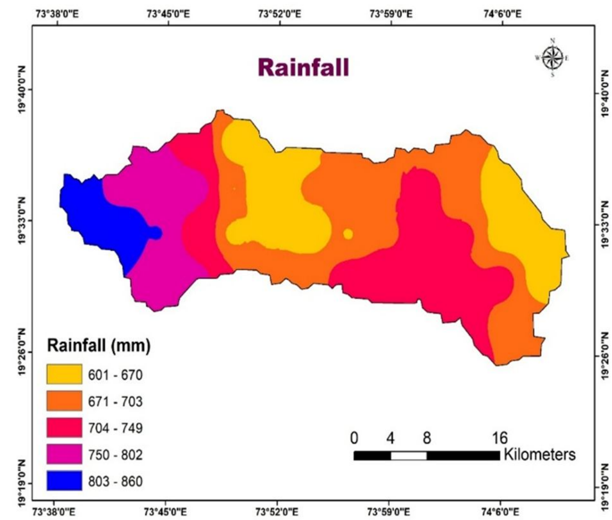

Fig. 2: Rainfall Map

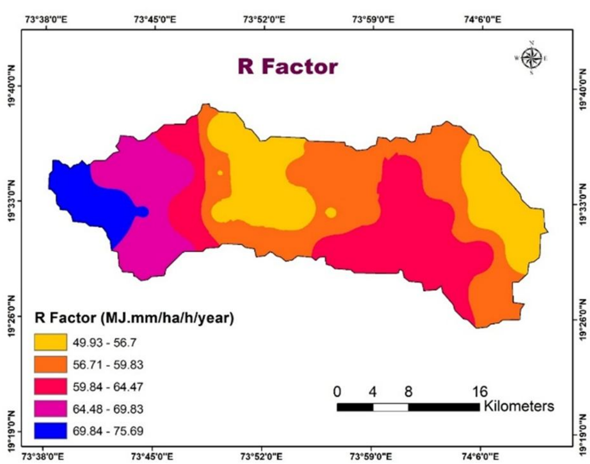

Fig. 3: R Factor Map

B. Soil Erodibility Factor (K Factor)

Soil erodibility (K-factor) refers to how easily the soil is susceptible to erosion by raindrops and runoff water (Fig. 4 and 5). Three types of soil erodibility are observed on the K-factor map, whose values range between 0.15 and 0.45. Values of the K-factor that are higher can be observed in the western part of the watershed while those of lower values occupy the center and eastern parts.

The soil type map shows that the dominant soils found in the watershed are loam and clay loam soils. These soils have moderate permeability, thus are susceptible to erosion due to their vulnerability to detachment by high intensity rainstorms.

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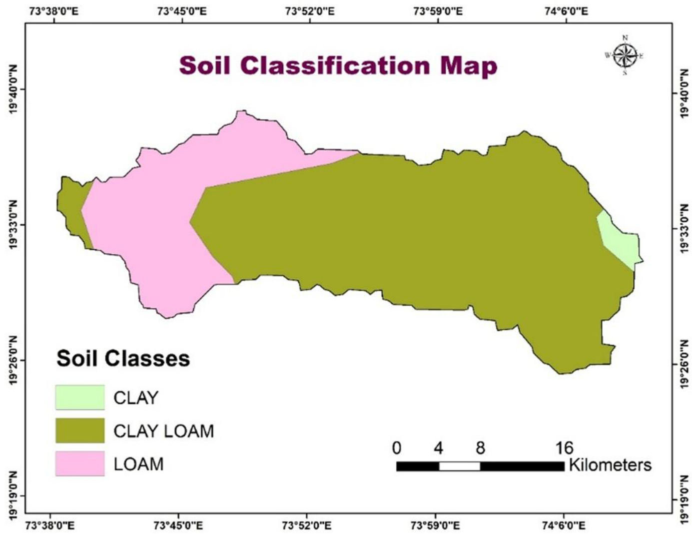

Fig. 4: Soil Class Map

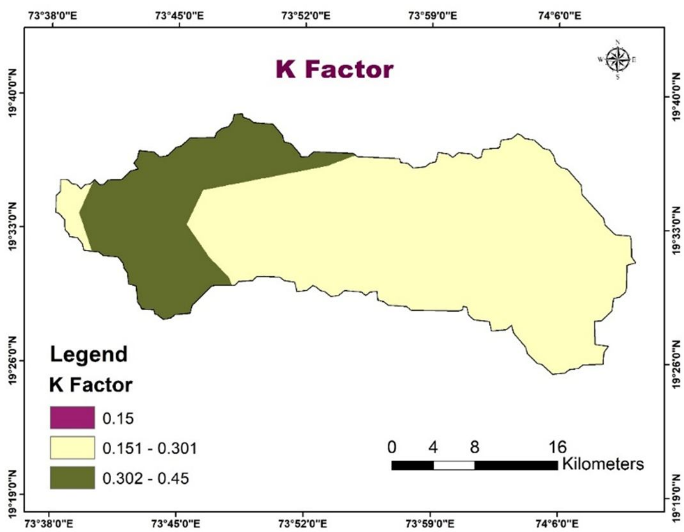

Fig. 5: K Factor Map

The regions that are marked with high K-factor value are those that have loamy soils wherein finer particles can easily be separated from the mass and be carried away through runoff. On the other hand, regions having clay loam soils show less erosion susceptibility due to the greater stability of their aggregates. This was similarly observed by Wischmeier and Smith (1978) and Morgan (2005).

C. Length and Steepness Factor (LS factor)

LS-factor is the combination of L and S that shows the effects of the morphological aspect of the terrain on the degree of erosion. The LS-factor varies between 0 and 1,910 in the watershed, which implies that the landscape has significant variation in topography. Areas with high values of LS-factors are mainly found in the northwestern and southwestern sections of the watershed (Fig 6 and 7). These areas have steep hillsides, dissected topography, and drainage lines where flow velocity and soil detachment processes can easily take place. Lower LS factor values are evident in the central and eastern parts where the slopes tend to be less steep. It can be seen that the distribution of LS values matches closely the slope distribution. Indeed, several researches confirmed that the degree of slope was among the main parameters determining the rate of soil erosion due to an exponential increase in runoff velocity with increasing slope degree (Moore & Burch, 1986; Desmet & Govers, 1996).

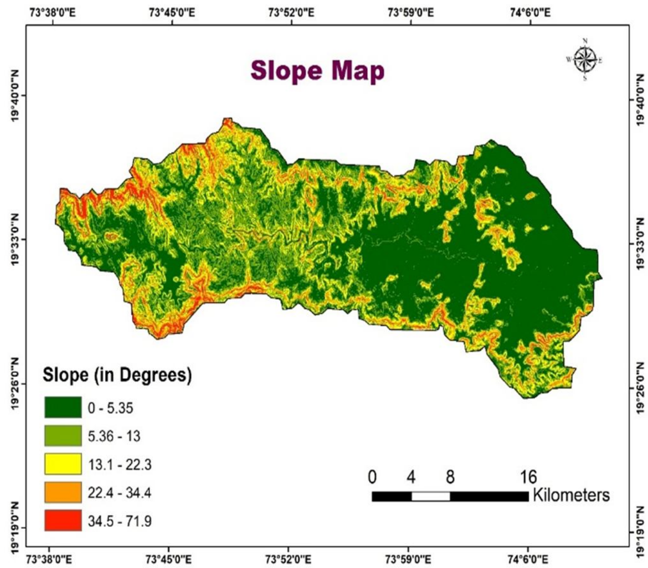

Fig. 6: Slope map in Degrees

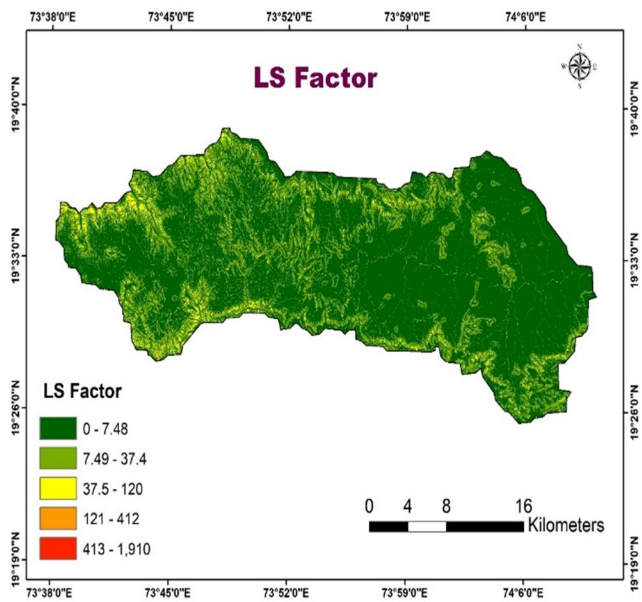

Fig. 7: LS Factor Map in Degrees

D. Land Use/Land Cover and Cover Management Factor (C Factor)

Land use/land cover (LULC) shows six dominant classes, which are water, tree cover, cropland, built-up land, bare land, and rangeland. From these LULC classes, the C factor was developed, indicating vegetation cover and its management concerning soil erosion. Values for the C factor vary from 0.01 to 1.0. Low C factor values correspond to densely covered vegetation with forests situated in the western area (Fig 8 and 9). This is due to the fact that vegetation cover plays an important role in intercepting rainfall and reducing surface runoff. The values for the C-factor are found to be moderate on agricultural land as soil surface is exposed due to the cultivation practices performed seasonally. High values of the C-factor can be seen in case of barren land, sparse vegetation, and exposed land where the soil surface is exposed to rainfall. It is clear from the above discussion that vegetation helps in reducing the chances of erosion. This is also supported by the work of Nearing et al. (2005).

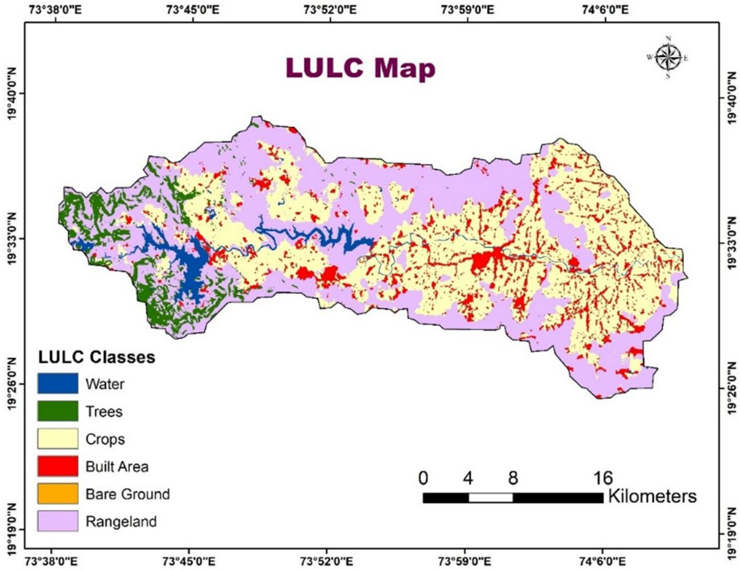

Fig. 8: LULC Map

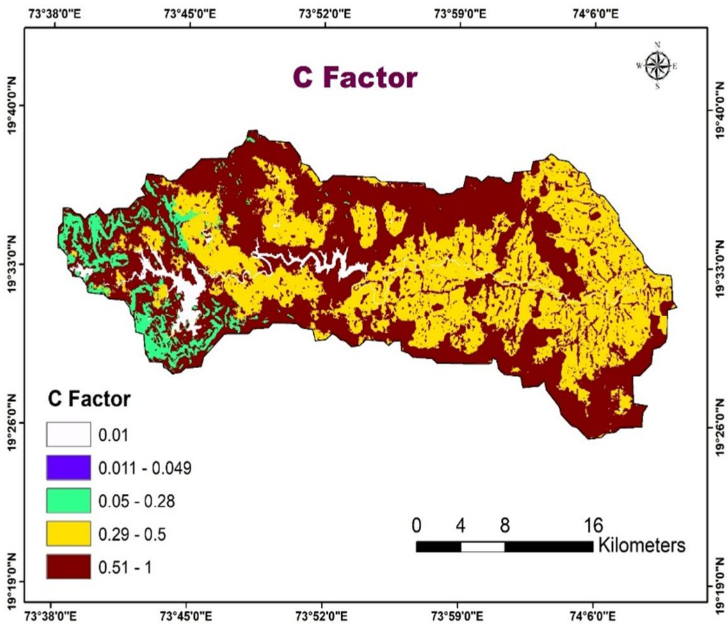

Fig. 9: C Factor Map

E. Conservation Practice Factor (P Factor)

This factor is the level of efficiency in using soil conservation methods like farming on contours, terracing, strip farming, and others. The P-factor values for the watershed area vary between 0.55 and 1.0. Low P-factor values can be found in regions of gentler slopes as well as in areas that practice agriculture. High P-factor values occur in hilly areas with steeper slopes (Fig. 10). Based on the distribution pattern, it can be concluded that a significant part of the watershed is without any conservation practices, making it susceptible to soil erosion. High values of the P-factor, which indicates this problem area, need to be taken up by watershed management practices like contour bunding, check dams, and afforestation.

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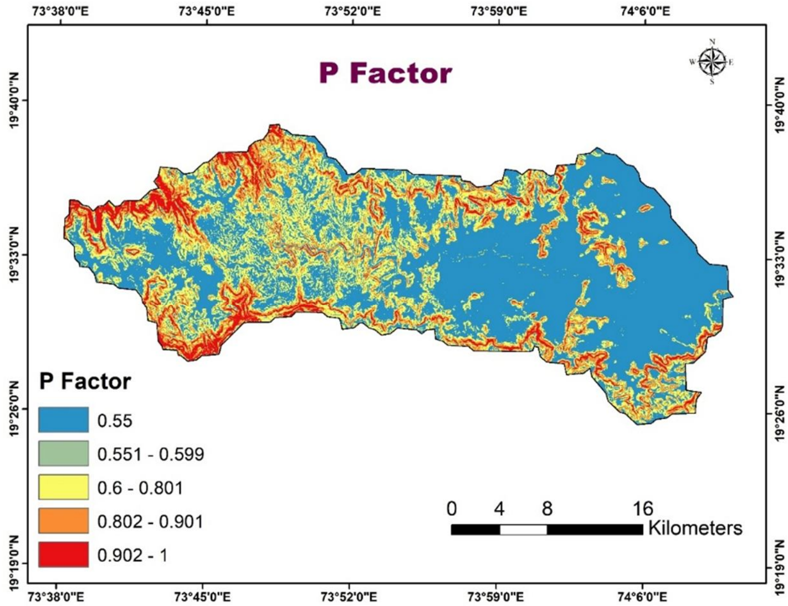

Fig. 10: P Factor Map

F. Soil Loss Estimation

The average soil erosion per year for the Nilwande Dam catchment was determined using the RUSLE. It uses five variables; rainfall erosivity (R), soil erodibility (K), LS factor which includes slope length and slope steepness, cover and management factor (C), and conservation practice factor (P) to determine the rate of erosion in the GIS setting. The soil erosion map indicates that erosion occurs spatially, with soil loss rates varying from 0 to 28,720.4 tons per hectare per year (Fig 11).

Most of the catchment area belongs to the very low and low erosion categories, indicated in dark and light green colors, respectively, in the erosion map. This is because the areas belong to the central and eastern part of the catchment where the slopes are less steep, have low LS values, and stable conditions that hinder the rate of soil detachment. The agricultural lands within the area are mostly located within gently rolling terrain that reduces the rate of erosion due to low topographic effects.

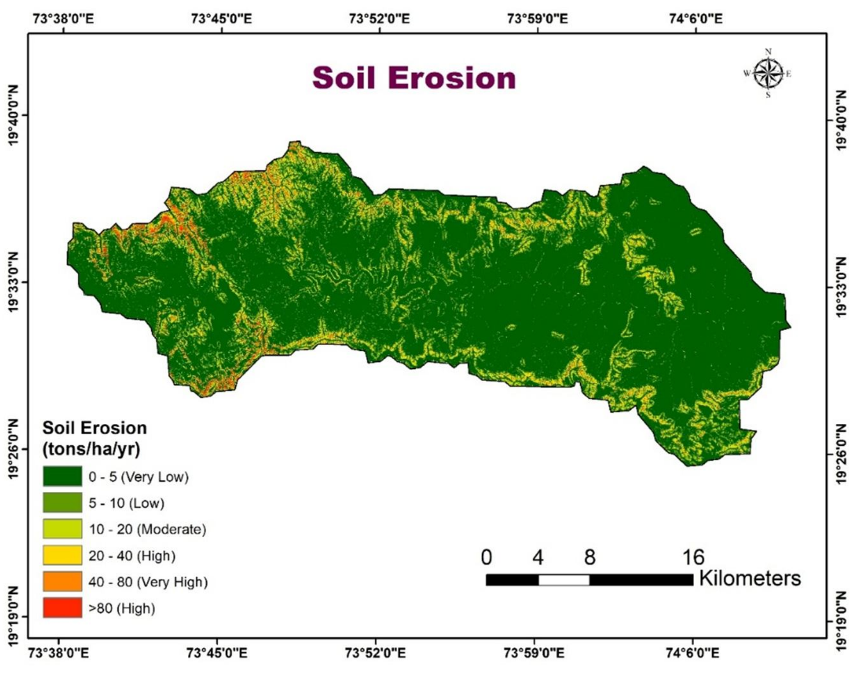

Fig. 11: Soil Loss Estimation

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Soil erosion areas of medium intensity (10–20 tons ha^{-1} yr^{-1}) are prevalent primarily in transitional zones between the upland region and valley bottom. This area is characterized by relatively steep slopes and fragmentation of vegetation cover, where accumulation of runoff starts to become significant. While at present there are moderate rates of erosion, in the future they might increase because of anthropogenic influences.

Very High (20-40 tons/ha/yr) and High (40-80 tons/ha/yr) soil erosion areas can be found mainly within the northwestern and southwestern parts of the watershed. These areas are characterized by steep slopes as highlighted by the slope and LS-factor maps. Due to the increased slope, focused flow channels, and bare soils, the power of running water in eroding soil is greatly enhanced. From the LS-factor map, it is evident that these areas exhibit the greatest topographic effect in promoting soil detachment and movement.

Areas of intense soil erosion (>80 tons ha^{-1} yr^{-1}) happen at ridges, drainage heads, and highly dissected hill slopes. These areas represent zones of superimposition of several factors contributing to soil erosion, such as high precipitation erosion index, steep slopes, moderate-high soil erodibility index, low vegetation cover, and lack of protective measures. High LS-factors in relation to soil erosion is evidence for the importance of topography as a controlling factor for erosion processes. This fact has been proved by Renard et al. (1997), Panagos et al. (2015), and Borrelli et al. (2017) when identifying slope features among major erosion parameters.

The findings show that while a considerable part of the basin is characterized by low levels of erosion, the impact of local erosion spots is disproportionately high in relation to the total amount of soil loss. It is necessary to urgently apply soil and water conservation techniques like contour bunds, terracing, vegetative barriers, check dams, and afforestation.

G. Sediment yield estimation

The sediment yield refers to the proportion of sediment produced that actually moves through the hydrological system and ends up being discharged at the end of the watershed. Unlike soil erosion, which estimates the total amount of soil lost from the land, the sediment yield takes into account not only the movement but also deposition of sediments in the watershed. The sediment yield mapping has been done by considering the predicted soil erosion rates and sediment delivery ratios (SDR).

Sediment yield values range from about 0 to 8,369 tons/ha/yr, indicating substantial spatial variation across the watershed. According to the classification used in this study, sediment yield falls into the following categories: low (0 – 1 tons ha^{-1} yr^{-1}), moderate (1 – 7 tons ha^{-1} yr^{-1}), high (7 – 19 tons ha^{-1} yr^{-1}), very high (19 – 40 tons ha^{-1} yr^{-1}), and extremely high (>40 tons ha^{-1} yr^{-1}) (Fig 12). It forms a significant part of the watershed area because it is common on flat lands, agricultural plains, and areas where there is minimal erosion of the soil. This implies that the water flowing through such land will have less energy to move the detached sediment since it will settle in its immediate environment.

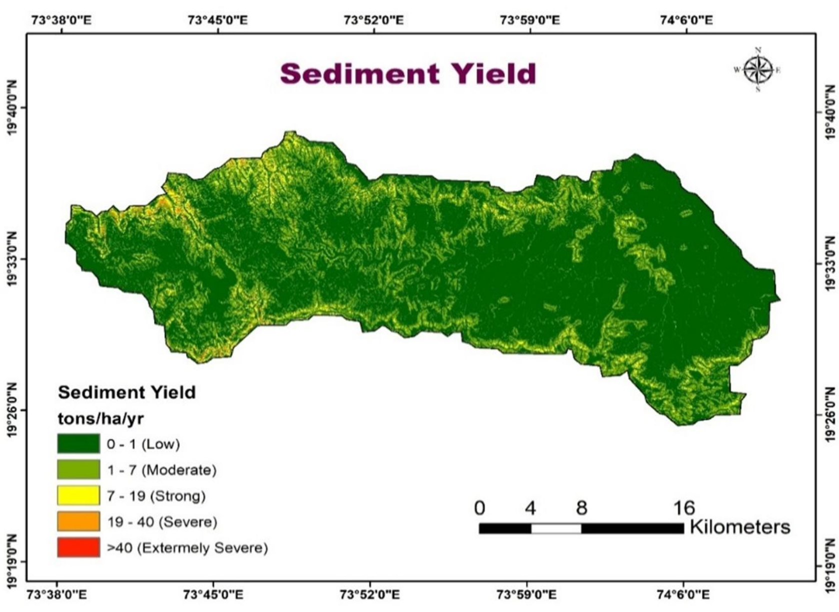

Fig.12: Sediment estimation

Moderate sediment yield zones exist mainly within gently sloping uplands and transitional zones. These zones have relatively high soil erosion levels, as well as enough energy in their runoff systems to carry some detached sediments to the drainage systems. While sediment discharge from these zones is still relatively low, further degradation of these lands can cause higher levels of sediment discharge in the future.

The strong and severe sediment yield zones exist mostly in the northwestern hilly zones and drainage systems. These zones are very similar to those zones which have high values of the LS-factor, hence high soil erosion rates. The presence of steep terrain in these zones causes the formation of quick runoff streams, thereby increasing the sediment transport capacity.

Extremely high sediment yield zones are confined to specific spots which occur in highly dissected mountainous terrains and upper catchments slopes. They act as important sources of sediments in the basin and have a very high contribution to sedimentation in the reservoirs. The distribution shows clearly that there is strong control on sediment transport by drainage and topographic factors. Steeply sloping and hydraulically connected landscapes to streams have higher sediment yields than their surroundings. it can be observed that sediment generation does not occur evenly throughout the watershed. Rather, only a small fraction of the watershed provides a considerable number of sediments in the total sediment load. These critical sources require special attention in the implementation of management activities in the watershed since it is very effective in minimizing sedimentation.

V. CONCLUSION

This study shows the efficiency of using RUSLE, Remote Sensing, and GIS approaches in assessing soil erosion and sediment production of the Nilwande Dam Watershed, Maharashtra. Results from spatial analysis have shown that there was significant variation in the erosion susceptibility of the watershed due to factors such as rainfall erosivity, topography, land use/land cover, and soils. The soil loss estimate map shows the large part of the watershed is subject to erosion risks ranging from low to moderate, some localised areas in the north-western and south-western hilly portions of the watershed appear highly prone to serious soil erosion problems. The sediment production evaluation results show important sediment producing regions in relation to sediment delivery downstream and possible sedimentation in the reservoir. The high level of spatial association between soil erosion and sediment production suggests that topography, vegetation, and watershed management are essential factors in determining sediment dynamics. This investigation proves the effectiveness and practicality of using the RUSLE-GIS model in the identification of erodible zones and prioritization of conservation strategies at the watershed level. The resulting maps of soil erosion and sediment production can be effectively used by planners and watershed managers to select suitable measures of soil and water conservation. Implementation of these measures, which include planting of trees, contour cultivation, vegetative cover, and construction of check dams in erodible zones, would help control sediment production and improve watershed conditions.

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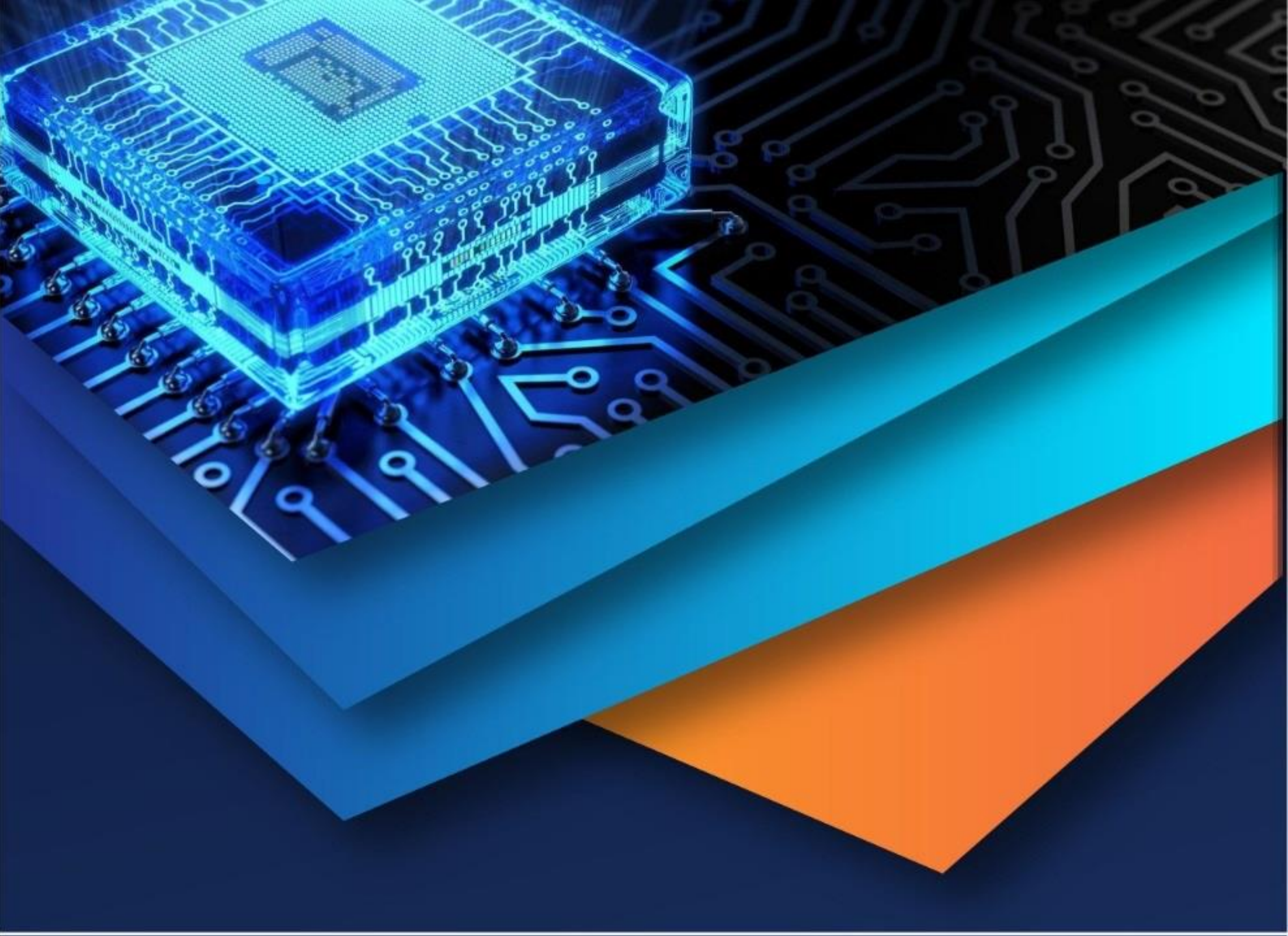

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