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Application of Remote Sensing and GIS for Soil Erosion Analysis on Baitarani River Basin by RUSLE Model

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Abstract:* *Soil degradation in Odisha poses a significant conservation concern for the local environment. The present research focused on a region in central Odisha State, India, affected by drought conditions. Several models have emerged to assess soil loss, with the Revised Universal Soil Loss Equation (RUSLE) standing out as the most suitable option. The erosion computation process entails utilizing the Digital Elevation Model (DEM), Landsat-9 imagery, and soil data from several sources accessible in different forms and scales. The present analysis took into account various elements, namely crop management factor (C), practice management factor (P), slope length factor (LS), steepness factor of the slope (S), and rainfall factor (R). Multiplying these factors yielded the average rate of soil erosion. Areas with a high slope length factor, such as those in Keonjhar and Mayurbhanj have a high erosion rate. The study reveals that 57% of the land in the study area experiences very low to moderate soil erosion at a rate of 2-10 tons per hectare per year, while 43% faces moderately to very severe erosion at a rate of 10-25 tons per hectare per year. Erosion hotspots, covering 14,218 square kilometers, are mainly identified in agricultural and forested hilly areas where slopes exceed 100, such as those in Keonjhar and Mayurbhanj, which have a high erosion rate. These districts are especially vulnerable to soil loss and resulting climate action (Sustainable Development Goals-13) because of frequent and severe rainfall, shifting agricultural practices, a thin surface soil covering, natural erosion, and barren hills. The research emphasizes the urgent need for implementing conservation and management measures to protect high-risk areas from further degradation. In conclusion, the study underscores the effectiveness of the RUSLE-GIS model in conducting quantitative and spatial assessments of soil erosion on a river watershed scale. The model is deemed crucial in formulating conservation strategies to address the identified erosion issues in the tropical highlands of the area.
Keywords:* *Soil degradation, DEM, Arc GIS, Landsat 9, RUSLE.

I. INTRODUCTION

Soil is an irreplaceable useful resource that, once lost, cannot be retrieved. Historically, a loss of foresight and know-how, coupled with present-day negligence and over-exploitation, has ended in large land degradation with extreme implications. Soil erosion now not only removes the topsoil and plants but also depletes the entire productive soil layer, which incorporates important plant vitamins, humus, organic carbon, beneficial microorganisms, and other important components. This degradation reduces soil first-rate, diminishing herbal soil capital and soil-associated surroundings services, for that reason negatively impacting agriculture, forestry, and normal environment productivity. Consequently, biodiversity amongst vegetation, animals, and microorganisms is likewise affected (Steinhoff-Knopp et al., 2021).

Beyond agriculture, soil erosion has various indirect results, consisting of threatening hydrological systems. It degrades water exceptional and causes immoderate siltation in streams, channels, wetlands, and reservoirs, which diminishes their water-keeping and absorption capacities. These outcomes can lead to unfavorable floods, droughts, and enormous bad effects on the ecology and economic system tied to those natural assets (Schmidt, 2000; Poesen et al., 2003; Jamal et al., 2022a). Soil erosion and degradation are global troubles resulting from both herbal and human sports (Panagos et al., 2017). The growth of wastelands due to land degradation increases worries approximately environmental sustainability (Zhao et al., 2013; Dai et al., 2015; Prosdocimi et al., 2016; Behera et al., 2017).

Human-brought about elements including deforestation, agriculture, climate trade, city growth, and modifications in land use patterns have improved soil erosion (Ganaie et al., 2020; Borrelli et al., 2020; Jamal & Ahmad, 2020). It is estimated that around 84% of global land loss is due to soil erosion, with erosion charges ranging from 12 to fifteen lots in line with hectare per 12 months (Ashiagbor et al., 2013).

Vulnerable landscapes are mainly threatened by means of floor runoff leading to soil loss (Sahana et al., 2020). For example, northeast China's high-yielding black soil region has been critically affected by erosion (Liu, J. & Liu, H., 2020). Similarly, gully erosion drastically affects regions which include Calabria in South Italy and Ilam in western Iran (Terranova et al., 2009). The escalating soil erosion hassle reduces water availability and agricultural productiveness. The observe of soil erosion is essential for addressing geo-environmental degradation (Vanwalleghem et al., 2010; Marzolff et al., 2011). The Revised Universal Soil Loss Equation (RUSLE) is one of the maximum popular empirically-based fashions for assessing and predicting soil loss globally, valued for its enter parameter availability and simplicity (Perovic et al., 2013; Chalise et al., 2018). The RUSLE version requires enter parameters which includes topography, soil type, land use patterns, and weather. Combined with far flung sensing and GIS, this version is value-powerful, simple, and suitable for soil loss evaluation. Researchers globally observe this approach (Renard, 1997).Remote sensing and GIS are utilized to perceive, map, and estimate potential soil erosion hazard regions (Millward & Mersey, 1999). Remote sensing records is particularly useful in areas with confined human accessibility, assisting in aid control, rainfall-runoff modeling, soil erosion assessment, groundwater recharge, and reclamation potential (Thomas et al., 2018). Slope characteristics affecting soil loss are efficaciously assessed the usage of remotely sensed information and Digital Elevation Models (DEM) for comprehensive critiques (Gelagay & Minale, 2016). Soil loss tests at one-of-a-kind watershed degrees are conducted the usage of numerous calculation strategies (Ganasri and Ramesh, 2016).

The Baitarani River Basin has skilled great adjustments in recent a long time because of anthropogenic and herbal factors, impacting its organic productivity, water fine, and geomorphology (Sahu et al., 2014). Human sports on this watershed have caused unfavorable ecological effects, which includes promoting siltation, impeding water motion, and increasing nutrient stages (Pattnaik, 2008). Studies by using Jhingran and Natarajan (1966) and Satyanarayana (1999) highlight troubles like siltation, nutrient enrichment, reduced salinity, and weed infestation, which have altered the lake's shape and length, posing fundamental environmental concerns.

The objectives of the prevailing examine are to estimate the once-a-year common soil loss price of the Baitarani River Basin the use of remote sensing, GIS, and the RUSLE model, and to evaluate the land use and land cover to identify every category's role in contributing to soil capability values. This observe is novel as it's miles the primary of its type at the Baitarani River Basin, growing a methodological framework that combines the RUSLE version, far flung sensing, and GIS to estimate the spatial distribution of soil loss. The outcomes can aid policymakers in enforcing soil management practices to lessen erosion inside the Baitarani River Basin catchment place.

II. LITERATURE STUDY

1) Soil Potential Erosion Risk Calculation Assessment Using Geospatial Technique in Keonjhar District, Odisha, India

SK Singh, R Raza, S Kanga, SC Moharana, S Rao

Using a Revised Universal Soil Loss Equation (RUSLE) model combined with Geographic Information System (GIS) technology, this investigation examines soil erosion in Odisha's Keonjhar District. The ecology and economy are seriously threatened by soil erosion, particularly in regions with steep slopes that have an impact on topsoil and agricultural fertility. Due to deforestation and mineral exploitation, which disturb agricultural land, Keonjhar is experiencing an increase in soil erosion. Important conclusions consist of: 36.31% of the region is weakly severe in 0–10 t ha^{-1} $year^{-1}$. A very severe 27.69% of cases are 10–20 t ha^{-1} $year^{-1}$. Twenty to thirty t ha^{-1} $year^{-1}$: 16.57% is really severe. Thirty to forty t ha^{-1} $year^{-1}$: 11.82% is very high. More than 40 t ha^{-1} $year^{-1}$: 7.61% is very severe.

2) Estimation of Soil Erosion Using RUSLE Model and GIS Tools: A Study of Chilika Lake, Odisha

Dhiroj Kumar Behera1, Saleha Jamal2, Wani Suhail Ahmad3*, Mohd Taqi3 and Rajiv Kumar

A new entry causes considerable size variations and increasing siltation in Chilika Lake, the largest coastal lagoon on India's eastern coast. The ecosystem of the lake has been impacted by this siltation's reduction in water retention capacity. The study employed the RUSLE model linked with remote sensing and GIS techniques to quantify soil loss in the watershed of the lake. Crop management (C), soil erodibility (K), slope length (L), conservation practices (P), rainfall erosivity (R), and steepness (S) were among the aspects taken into consideration. Results: The watershed's low risk of soil erosion covers 73.16% (486.92 km2) of it. There is a moderate risk for 6.6% (44.17 km^2). The danger for 11% is substantial. 8.8% is quite dangerous. 0.043% is extremely vulnerable. It is calculated that the average yearly soil loss rate is 32.41t**one/ha/yr**. Recommendations: In order to solve the problems of soil erosion and siltation and stop more harm to Chilika Lake's environment, prompt conservation and management measures are required.

3) A systematic review of soil erosion control practices on the agricultural land in Asia

Nur Syabeera Begum Nasir Ahmad*, Firuza Begham Mustafa,

Asia plays such a large part in global agriculture, this study examines strategies for reducing soil erosion in agricultural areas throughout the continent. One of the main problems affecting crop yields and the sustainability of the environment is soil erosion, which is brought on by intensive farming, bad practices, rainfall, and terrain. To evaluate the body of knowledge regarding soil erosion prevention strategies in Asian agriculture, the review employs the PRISMA methodology. Principal discoveries consist of: 39 relevant studies were found by the review in the databases of Scopus and Web of Science. The three primary themes of control practices are mechanical (using physical structures to prevent erosion) and agronomic (relating to crop management). Agrostological practices are categorised under this category as well. These three themes are further divided into 11 specific subthemes, detailing various methods tested and implemented to mitigate soil erosion.

4) Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin

B.P. Ganasri, H. Ramesh*

The Revised Universal Soil Loss Equation (RUSLE) model combined with Geographic Information System (GIS) is used in this work to examine soil erosion in the Nethravathi Basin, southwest India. With rainfall erosivity ranging from 2948.16 to 4711.4 MJ/mm/ha/hr/year, soil erodibility from 0.10 to 0.44 t ha/MJ/mm, topographic factor from 0 to 92,774, and crop management factor from 0 to 0.63, the model's parameters were estimated using remote sensing data. The anticipated total yearly soil loss for the years 2002–2003 was around 473,339 tonnes, which is in close agreement with the recorded sediment production of 441,870 tonnes annually. An extra 14,673.5 tonnes of soil erosion are expected annually as a result of the expansion of agricultural land. Only a small percentage of the basin is located in high and very high probability zones, according to the probability zone map created using the weighted overlay index approach. The majority of the basin is located in low erosion probability zones. These findings demonstrate the necessity of conservation measures and efficient soil management to lessen erosion in the area.

5) Estimation of Soil Erosion and Identification of Critical Areas for Soil Conservation Measures using RS and GIS-based Universal Soil Loss Equation

Deepesh Machiwal • Pratibha Katara • H. K. Mittal

The study conducted in the Aravalli hills of Udaipur district, Rajasthan, aimed to estimate soil erosion potential and identify critical conservation areas in an ungauged catchment. Over a decade, the Universal Soil Loss Equation (USLE) model, integrated with GIS and remote sensing, was employed to assess soil erosion. Results revealed significant variability in parameters such as rainfall erosivity, soil erodibility, slope characteristics, and land cover, impacting erosion levels across the catchment. Notably, approximately two-thirds of the area experienced soil erosion exceeding 10 t ha-1 year-1, indicating severe erosion conditions. The study underscores the profound influence of rainfall patterns on erosion potential and highlights the effectiveness of the USLE model coupled with GIS and remote sensing for mapping critical erosion areas in ungauged catchments, particularly beneficial for developing regions.

III. RESULTS AND DISCUSSIONS

The variation in soil erosion rates is influenced by several factors:

1) Topography: Steeper slopes in the basin contribute to higher erosion rates.
2) Soil Type: Areas with sandy or loamy soils are more prone to erosion compared to clayey soils.
3) Land Use and Vegetation Cover: more vegetation cover less will be the soil erosion
4) Rainfall Intensity: High-intensity rainfall events increase then soil erosion rate also increased.

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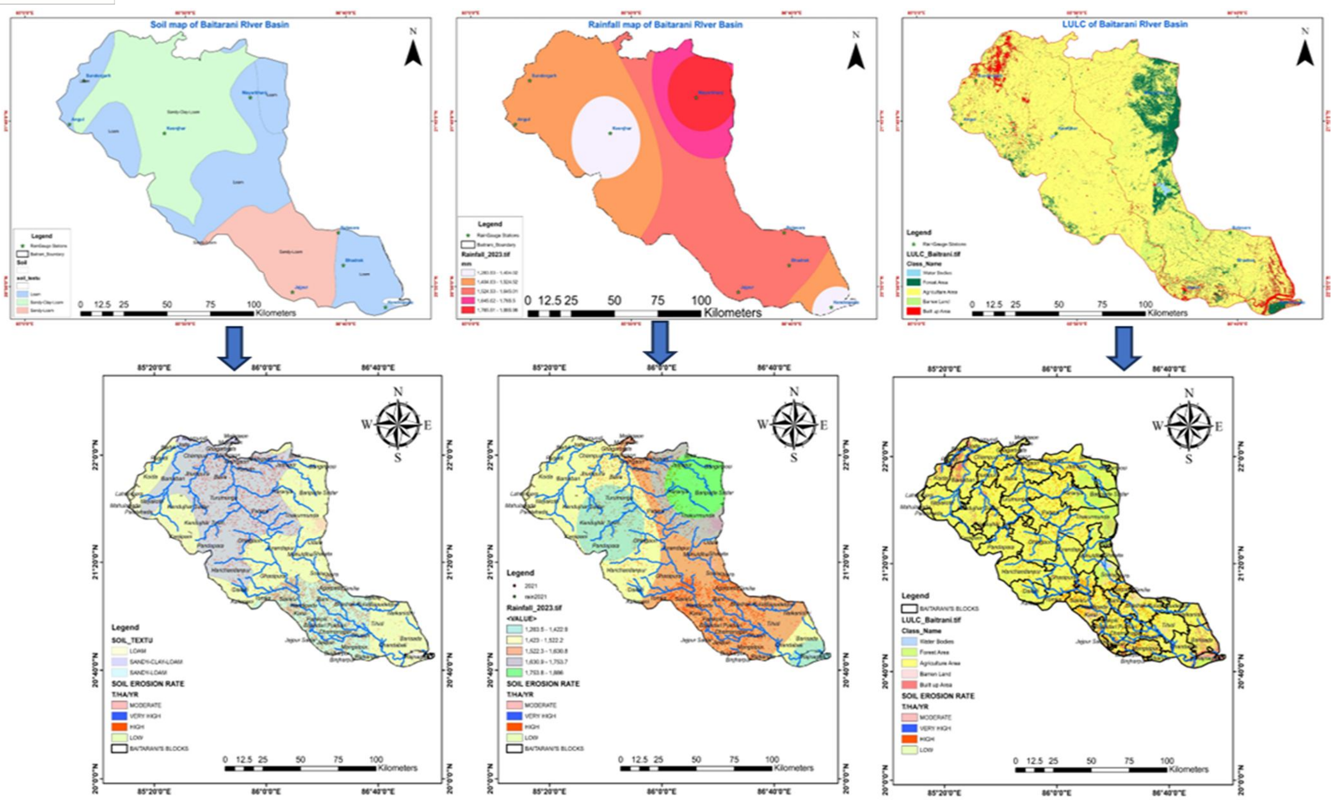


Images – Shows the graphical analysis of soil erosion factors with different maps of BRB
Source: Extracted from ArcGIS v10.5

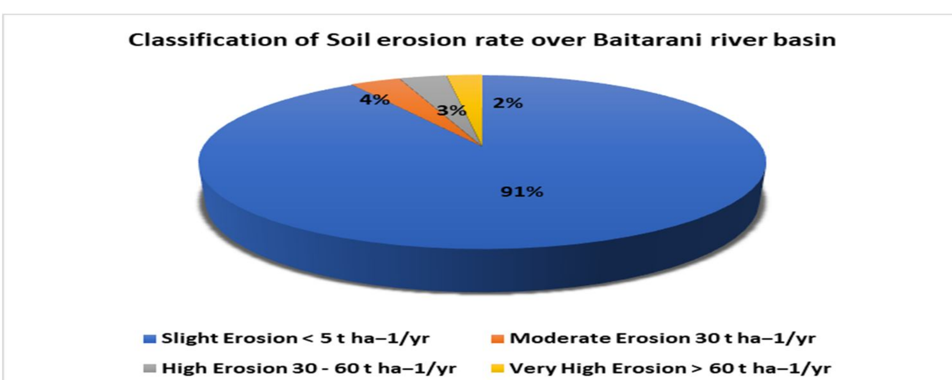
IV. MANAGEMENT STRATEGIES

To effectively manage soil erosion in the BRB, a combination of structural and non-structural measures should be implemented. These strategies are designed to reduce soil loss, enhance soil health, and promote sustainable land management.

The Baitarani River Basin (BRB) in Odisha, India has been studied for soil erosion using the Revised Universal Soil Loss Equation (RUSLE) and geospatial techniques. The analysis showed that the computed annual soil erosion in the BRB varies from 0.5 to 216.85 t ha−1/yr. The results indicate that:

1) 91% of the BRB area (12938.4km2) has soil loss < 5 t ha−1/yr, which is considered low soil erosion
2) 3.4% of the area (383.4 km2) is moderate soil erosion (5-30 t ha−1/yr)
3) 3.2% of the area (455 km2) is under high erosion (30-60 t ha−1/yr)
4) 2.4 % of the area (341.2 km2) is under very high erosion (>60 t ha−1/yr)

The study highlights the importance of soil erosion status information for planning and implementing conservation measures in the Baitarani River Basin. The RUSLE model combined with geospatial techniques provides a useful tool for assessing soil erosion at the basin scale.



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We referred to these places as high erosion hotspots because we studied locations where soil erosion exceeds 10 tons per hectare annually. These hotspots were found in almost 43% of the territory, or 13,848.15 square km, whereas tolerable values were found in 57% of the area (18,624.86 sq. km). Most hotspots were found on steep slopes (more than or equal to 10 degrees) with forests and agricultural areas. When we merged all the data, we could forecast the average annual soil loss for the entire region. Table 6 lists the various types of soil erosion. Two tons per hectare per year is the lowest, and 26 tons per hectare per year is the greatest. The greatest soil loss was seen in the areas with the steepest slopes, particularly in the upper sections. The primary reason for this is how the land is covered and exploited. In different areas, we have specific plans to control soil erosion based on how severe the erosion is. In places where erosion is "Low," we use methods like growing special grasses and building structures to prevent erosion. In areas with "Moderate" erosion, we encourage practices like covering the soil with mulch on farms. We have stricter rules for places with "High" erosion, like changing crops on farms and fixing damaged forests to act as natural shields. In the most severe case, the "Very High" erosion zone, we need a comprehensive plan with multiple steps, including changing crops, using mulch, planting more trees, and restoring forests (Table 7). These plans aim to protect the soil, reduce erosion, and promote good land management practices based on the specific erosion risks in each area.

TABLE 1: PREDICTED SOIL EROSION AND MANAGEMENT STRATEGIES

<table>
<tr><th rowspan="2">Soil Erosion zone</th><th rowspan="2">Predicted Soil Erosion Value (tone ha^{-1}y^{-1})</th><th colspan="2">Management Strategies</th></tr>
<tr><th>Non-structural</th><th>Structural</th></tr>
<tr><td>Low</td><td><5</td><td>Plantation of soil erosion controlling grasses like fallow and wastelands</td><td rowspan="3">Site-specific structures like check dams and gabion structures should be placed in areas with greater slopes.</td></tr>
<tr><td>Moderate</td><td>10-30</td><td>Mulching in the agricultural field,</td></tr>
<tr><td>High</td><td>30-60</td><td>Crop rotation in the agricultural field, Restoration of degraded forest</td></tr>
<tr><td>Very High</td><td>>60</td><td>Crop rotation, mulching, forestation, restoration of forest</td><td>Diversion channels, interception ditches, etc., will be constructed in the low-slope areas.</td></tr>
</table>

TABLE 2: STRUCTURAL MEASURES FOR PROPOSAL

Measure Structural Measures	Description	Implementation	Benefits
Terracing	Constructing terraces on slopes to reduce runoff velocity and soil erosion.	Suitable for hilly and steep slope areas.	Reduces surface runoff and soil loss, increases water infiltration.
Contour Ploughing	Ploughing along the contour lines to create natural barriers for water flow.	Applicable in moderately sloping agricultural lands.	Decreases runoff speed, minimizes soil erosion.
Check Dams	Small dams constructed across streams to reduce water flow and capture sediment.	Suitable for small streams in eroded areas.	Reduces downstream sedimentation, promotes groundwater recharge.
Afforestation and Reforestation	Planting trees and vegetation to stabilize soil.	Applicable in degraded and deforested areas.	Enhances soil structure, reduces runoff, provides habitat for wildlife.

TABLE 3: NON-STRUCTURAL MEASURES FOR PROPOSAL

Non-Structural Measures	Description	Implementation	Benefits
Crop Rotation and Cover Cropping	Rotating crops and using cover crops to improve soil health and reduce erosion.	Suitable for agricultural lands.	Enhances soil organic matter, reduces erosion.
Conservation Tillage	Reducing tillage intensity to maintain soil structure.	Applicable in agricultural practices.	Preserves soil moisture, reduces erosion.
Grazing Management	Implementing controlled grazing to prevent overgrazing.	Suitable for pasture lands.	Maintains vegetation cover, reduces soil compaction and erosion.
Community Participation and Awareness	Educating local communities about soil conservation techniques.	Through workshops, training programs, and community projects.	Encourages sustainable land management practices, increases community involvement.

V. CONCLUSION

The study of soil erosion in the Baitarani River Basin using the RUSLE method reveals a detailed picture of erosion risk across the region. While the majority of the basin experiences slight erosion, targeted management strategies are essential for areas with higher erosion rates. Implementing a combination of structural and non-structural measures will help mitigate soil erosion, enhance soil health, and promote sustainable land use in the BRB. Regular monitoring and community involvement are critical to the success of these management strategies, ensuring long-term environmental sustainability and agricultural productivity. The conclusion of an assessment of soil erosion using the RUSLE model with remote sensing and GIS integration typically highlights key findings and implications. It may include Erosion Hotspots Identification, Land Use and Land Cover Change Impact and Erosion Risk Assessment.

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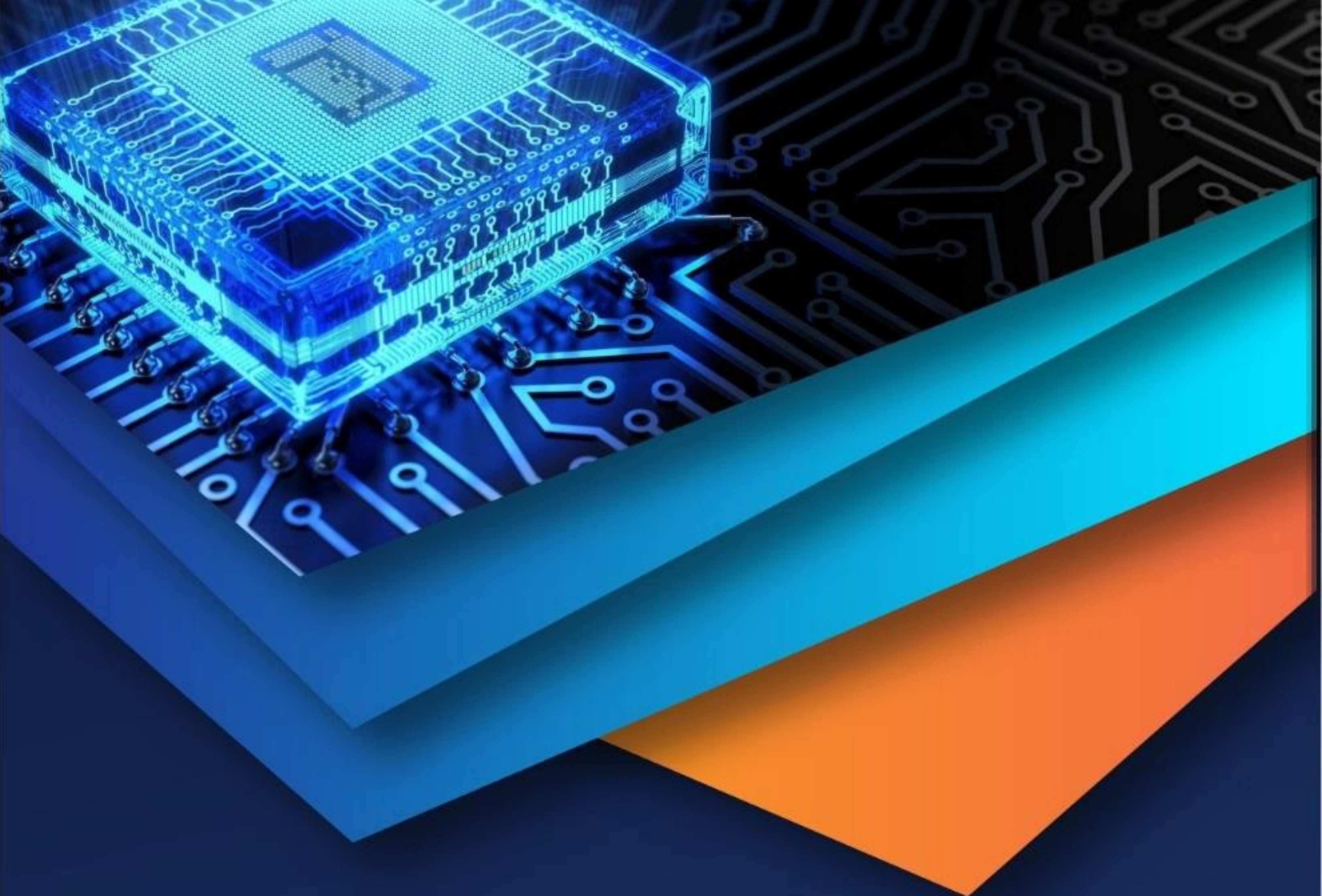

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