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Climate Change Impacts on Land Surface Temperature and Vegetation Health: A Case Study of Henry Island, Sundarbans Region

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Abstract: ***The research focuses on annual and decadal variations of LST over Henry Island, West Bengal, for the year 2023. LST datasets derived from MODIS satellites processed in Google Earth Engine were used for the analysis. Spatiotemporal changes of LST were studied by observing seasonal dynamics. This research offers essential knowledge regarding the thermal behavior of the area, thus important in explaining the local microclimate and possible ecological impacts. Results have significant annual and decadal variations of LST with peaks in summer and troughs in winter. Spatial analysis reveals hotspots in some parts of Henry Island, meaning that heat retention occurs in those localized areas through land cover or human activity. The study demonstrates the utility of MODIS LST data and GEE for monitoring thermal dynamics in Henry Island, providing valuable insights for ecological conservation and sustainable land use planning. The findings of this study have significant implications for understanding the impacts of climate change on the Sundarbans region and inform strategies for mitigating these impacts.***

Keywords: Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), Henry Island, Sundarbans, Climate Change, Thermal Dynamics, Ecological Conservation, Sustainable Land Use Planning, MODIS Satellite Data, Google Earth Engine (GEE), Remote Sensing, Geographic Information Systems (GIS), Spatial Analysis, Temporal Analysis, Environmental Monitoring, Ecosystem Health, Land Surface Temperature Variations in Coastal Ecosystems, Impact of Climate Change on Sundarbans Ecosystem, NDVI Analysis for Vegetation Health Assessment, Thermal Dynamics and Ecological Conservation in Henry Island, Sustainable Land Use Planning for Coastal Regions.

I. INTRODUCTION

The region spanning approximately 10,000 km² of Bangladesh and India, the Sundarbans has been classified as a UNESCO World Heritage Site and it is home to the largest mangrove forest on the planet. On the western boundary of Sundarbans exists Henry Island, a delicate coastal ecosystem that is vulnerable to climate change. The rising temperatures, increasing levels of sea water and changing precipitation patterns are endangering the rich biodiversity and ecosystem services of these coasts. An important sign of climate change is the Land Surface Temperature which is forecasted to vary significantly on an annual and decadal basis in this region. Coastal ecosystems are especially sensitive to climate changes and the impacts are gradually worsening over time and the decadal LST trends can pinpoint those impacts. Li et al. (2019) explain that The Normalized Difference Vegetation Index (NDVI), which is a measure of vegetation health, can estimate the adaptation of the mangrove forests to climate changes. This research attempts to study the decadal and annual patterns of NDVI and LST of Henry Island which is located in West Bengal by using MODIS satellite datasets available on Google Earth Engine (GEE). An understanding of the effects of climate change on estimation of the relations between LST, trends in decadal LST and NDVI would be helpful to improve understanding of the effects of climate change on coastal systems.

II. OBJECTIVE

The risks that climate change holds for Sundarbans and Henry Island include temperature increase, rise in sea levels due to melting ice caps, and alteration in the patterns of rainfall in the area that affects the rich variety of plant and animal as well as ecosystem services. Not only does the mangrove ecosystem of the Sundarbans support diverse plant and animals but it also sustains livelihood millions, providing fishing industry, forestry, and travel. These factors such as thermal conditions, vegetation dynamics, and ecosystem health, can be inferred from the analysis of LST, NDVI, RTM, and LULC. LST is extremely significant tounderstand surface energy balance;

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NDVI is a measure of vegetation health, accepted widely with its two-band infrared and red-channel assessment, RTM is an 'efficacious tool' to interrogate surface radiative properties; and LULC study helps to look into changes of land use pattern and impacts on environment. It investigates the changes of LST, NDVI, RTM, and LULC since the time of Henry Island, Sundarbans. The analysis of these variables will help understand the health and biodiversity of this area's ecosystem and develop the best possible solutions for conservation and The Sundarbans have gone through huge land use changes including logging, urbanization, and agricultural expansion. These changes are currently affecting the most important aspects of the biotic services which include carbon isolation, water adjustment, and biological diversity conservation. Thus, better understanding of the dynamics involved in the LST-NDVI-RTM-LULC changes can make it possible for the policy makers and conservationists to come up with strategies for natural resources management and adaptive mitigation to climate change.

III. PROBLEM STATEMENT

The Sundarbans region, covering Henry Island, is under enormous ecological stress with climate change. Changes in the temperature regime and altered precipitation pattern, along with increasing frequency of extreme weather events, are affecting the balance of this sensitive ecosystem. The lack of comprehensive studies on LST variation in Henry Island hampers our understanding of the thermal behaviour of the region, which is essential for ecological conservation and sustainable land use planning. The goal of this research is to bridge the knowledge gap by studying annual and decadal LST changes in Henry Island.

IV. LITERATURE REVIEW

Existing Research on LST Variations in the Sundarbans Region Several studies have investigated LST variations in the Sundarbans region, highlighting the importance of understanding thermal dynamics in the context of climate change. 4.2 Relationship between LST and Meteorological Factors Research has shown that LST is strongly influenced by temperature, humidity, and wind speed. Understanding these relationships is crucial for predicting LST variations and their impacts on the local ecosystem.

V. METHODOLOGY

A. Data Source

MODIS/061/MOD11A2 LST data for 2023 were acquired from the Google Earth Engine platform. Normalized Difference Vegetation Index (NDVI) analysis utilized Landsat 8 or Sentinel-2 data, collected from platforms like USGS Earth Explorer or Copernicus Open Access Hub.

B. Data Preprocessing

The study utilized the GEE platform for data preprocessing and analysis. The region of interest (ROI), Henry Island, was manually defined using polygon geometry. LST data were filtered spatially and temporally to extract relevant datasets for 2023.

C. Algorithms/Models Implemented

NDVI calculation was performed using the normalized difference between the near- infrared (NIR) and red bands of the satellite imagery.

TABLE 1.
WORKFLOW OF LST, DECADAL LST, AND NDVI ANALYSIS

STEPS	TOPIC	INPUT	OUTPUT	CONNECTIONS
1	LandSurface Temperature (LST)	Satellite Data (MODIS/Landsat)	LST Image	Provides data for Decadal LST Analysis
2	Decadal LST Analysis	LST Data (from multiple years)	Decadal LST Trend Analysis	Uses LST from Step 1 for trend analysis
3	Normalized Difference Vegetation Index (NDVI) Analysis	Satellite Imagery (Landsat/MODIS)	NDVI Image	Provides input for further vegetation analysis

VI. RESULTS AND DISCUSSION

Land Surface Temperature (LST) Analysis This section presents an analysis of the Land Surface Temperature (LST) patterns for Henry Island, focusing on seasonal variation, mean LST, and spatial distribution. Annual LST Trends The MODIS Land Surface Temperature (MOD11A2) dataset provided daily LST values (°C) for 2023. Using the formula: LST (◦C) = (LSTraw (Kelvin) × 0.02) − 273.15 (1) we interpreted trends based on day-of-year (DOY) values. – Peak LST:

The highest temperature of 34.22°C occurred around DOY 113 (mid-April), likely due to summer heating. – Lowest LST: The lowest temperature of 21.39°C occurred around DOY 1 (January), reflecting winter conditions. – Monsoon Dip: A drop in temperatures was observed during DOY 193 (mid-July), consistent with the monsoon season. – Post-Monsoon Rise: Temperatures increased again post- DOY 241 (end of August). [2]

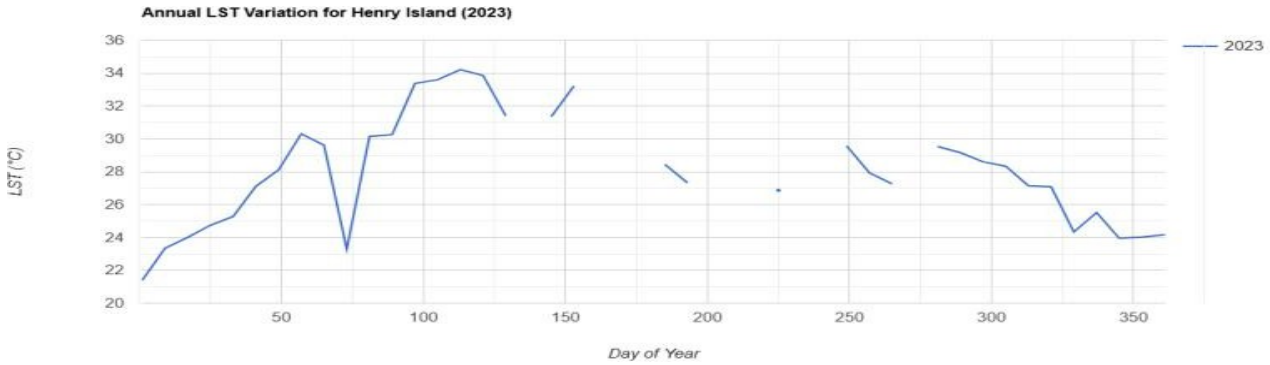

Figure 1. Annual LST Variation Throughout 2023

Completing Missing Values Using the daily LST dataset, we can interpolate missing values (e.g., DOY 137, 161, etc.) via linear interpolation. The formula for missing DOYx: LST(x) = LSTprev + LSTnext − LSTprev DOYnext − DOYprev × (x − DOYprev).

Spatial Distribution of LST The spatial distribution of LST was analyzed using the MODIS dataset. – Raw LST (Kelvin): The unprocessed spatial patterns of temperature for Henry Island ranged from 14,000 to 16,000 Kelvin. – Mean LST for 2023 (°C): The average temperature values for the entire year 2023 were clipped to the Henry Island boundary, with a palette indicating values from 10°C to 45°C.

High and Low LST Zones The high and low LST zones were identified by thresholding the Mean LST (°C) map and interpreting spatial patterns. – High LST Zones: Typically occurred in areas with less vegetation, such as open sandbanks, bare soil, or built-up regions. These zones were concentrated in the western parts of Henry Island, closer to exposed land and low vegetation cover. – Low LST Zones: Observed in vegetation-dense regions, water bodies, or shaded areas. These zones were primarily found in the eastern parts of Henry Island, near mangroves and vegetated zones. [4]

Figure 2. Map showing Distribution of LST

Statistical Summary A statistical summary of the LST data is provided below:

Decadal LST Analysis A decadal analysis of the LST data was performed to examine the seasonal variations and trends. Seasonal Variations The decadal analysis revealed the following seasonal variations: – Summer: Peaks in April-May. – Winter: Drops in January. [12]

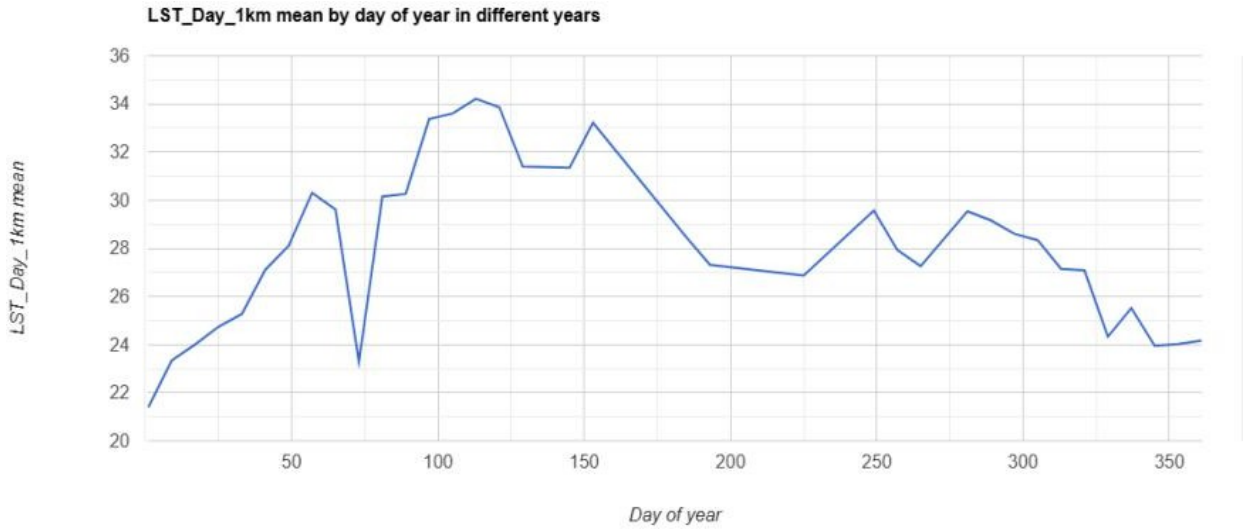

Figure 3. Seasonal Variations of Decadal LST

Figure 4. Map Showing Decadal LST Analysis for Henry Island

TABLE 2.
SUMMARY OF LST AND DECADAL LST METRICS

Statistical Distribution The statistical distribution of the LST data showed: – Peak Clustering: Around 28-32°C. – Outliers: During extreme weather events (e.g., April heatwave).

Metric	Value (°C)
Annual Mean LST	28.9
Annual Median LST	28.6
Annual Std. Deviation	3.2

Warmest Period (DOY)	34.22(113)
Coolest Period (DOY)	21.39
Warmest Month	April(33.8)
Coolest Month	January(22.5)

1) *Normalized Difference* Vegetation Index (NDVI) Analysis the NDVI analysis for Henry Island in 2023 reveals significant insights into vegetation health and temporal patterns. The key observations are summarized below: – The minimum NDVI value of 0.413 was recorded at the beginning and end of the year, indicating sparse vegetation cover during these periods. – The maximum NDVI value of 0.656 occurred during mid-year (Day of Year 16-20), coinciding with peak vegetation growth. – The NDVI values exhibited a gradual increase from the start of the year, peaking during mid-year, and then declining gradually toward the end of the year.
2) *Vegetation Health Assessment* – Higher NDVI values (>0.6) represent regions with dense and healthy vegetation. – Lower NDVI values (<0.5) indicate areas with sparse or stressed vegetation.
3) *NDVI Time-Series Chart* A line chart was generated to display the temporal variation of NDVI values over the Day of Year (DOY) in 2023.
4) *NDVI Map Visualization* The spatial distribution of NDVI values was visualized using Google Earth Engine (GEE), highlighting regions with varying vegetation densities. [10]

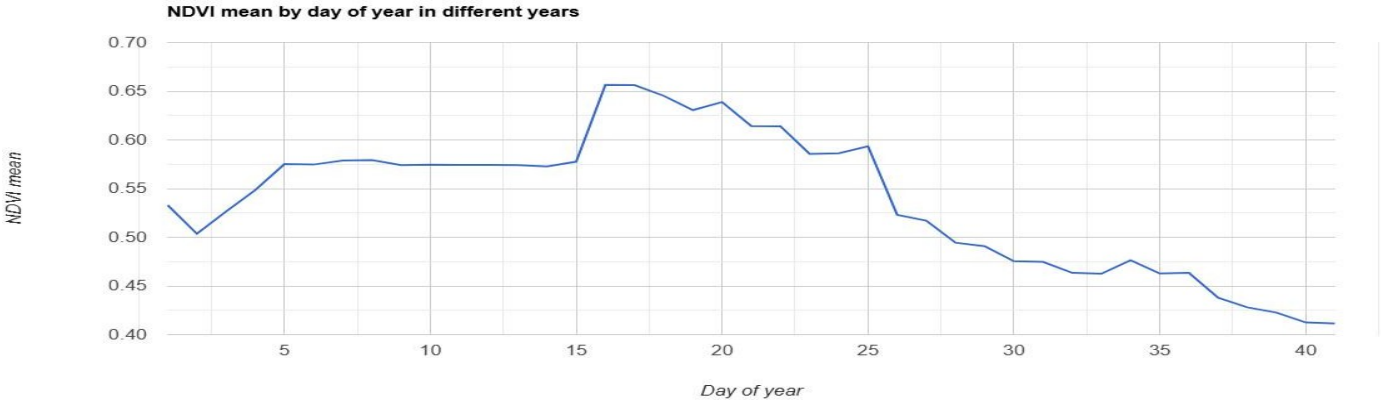

Figure 5. NDVI mean by day of year

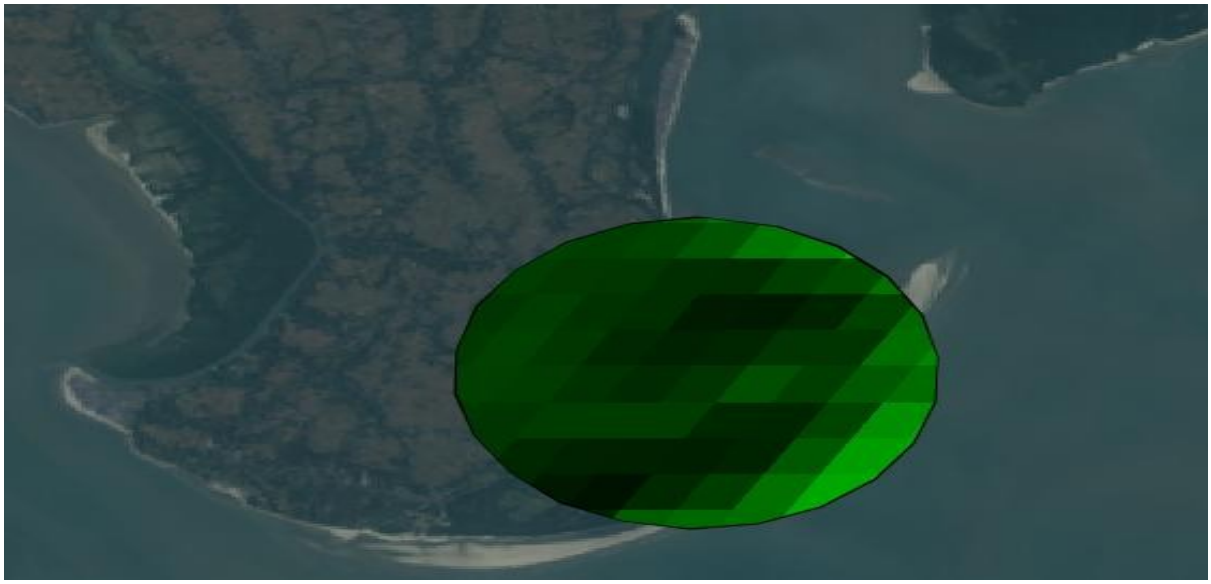
Figure 6. Sapital distribution of NDVI

TABLE 3.
TABLE SHOWING STATISTICAL SUMMARY OF NDVI VALUES FOR 2023

Statistical Summary of NDVI: A statistical summary of the NDVI data is provided below:

Statistic	Value
Minimum NDVI	-1
Maximum NDVI	1
Mean NDVI	Row 0.350

VII. IMPLICATIONS AND RECOMMENDATION

Environmental Considerations These findings indicate that the environmental stability of Henry Island is highly compromised. The increased LST fluctuations along with NDVI patterns are bound to change the distribution and availability of different flora and fauna in the region altering its composition and functional capabilities.

Recommendations In relation to the study, we suggest a number of conservation policies. – Detecting Changes in LST Patterns: The thermal behaviour of Henry Island is time dependent, therefore there is need to have modern technology to continuously monitor the changes in LST. – Protection of Existing Ecological Systems: Preventive approaches should focus on safeguarding those existing ecological systems from any changes including LST fluctuations. – Management of Land Use: Adoption of practices like shifting cultivation and permaculture minimises the change in LST. – Ecosystem Management: Interventions that facilitate the regrowth of lost ecosystem functions through planting of trees are said to be beneficial to ecosystem recovery and resilience however should not be used as the sole strategy.

VIII. FUTURE RESEARCH DIRECTIONS

Integration of Multiple Source Data Future research will be able to focus on the integration of MODIS LST data together with other satellite and ground-based datasets, in order to improve thermal mapping in its accuracy and of spatial detail associated with it.

Development of Predictive Strategies In fact, the development of predictive models based on machine-learning and statistical models is projected considerably to facilitate prediction of LST variations due to meteorological or land cover effects.

Ecological Impact Analysis Definitely, understanding at depth the ecological implications of thermal dynamics will be possible through studying the impacts of values of LST on local ecosystems, which include mangroves, habitat for wildlife species, and coastal erosion. 11. Conclusion This study demonstrates how MODIS LST data together with Google Earth Engine (GEE) have been useful to monitor thermal dynamics in Henry Island, providing beneficial insights for ecosystem conservation and suitable land use practices. The discovery of this present study has large implications for studying the impacts caused by climate changes on the region of Sundarbans and could inform strategies developed to mitigate some of these adverse effects.

IX. LIMITATIONS AND CHALLENGE

Data quality: MODIS LST data are prone to contamination due to cloudy conditions, sensor calibration biases, and other challenges; all these may cause product quality failure. – Spatial resolution is inadequate: One-kilometre spatial resolution may not entirely capture local-scale thermal variations in MODIS LST data. – The temperature changes or short-term fluctuations are not clearly detected in 8-day MODIS data.

X. CONCLUSION

The study demonstrated how GGEs can use satellite-derived LST and NDVI data to generate important information on the thermal and ecological conditions of Henry Island in the Sundarbans. The study revealed annual and decadal trends in LST, with some seasonal variability and the formation of heat cells in areas that are less vegetated and built up. NDVI analyses further reflected marked changes in vegetation all through the year, emphasizing the sensitivity of the region's ecosystems to climatic changes.

Conversion of surface temperature and versatility of vegetation health status emphasize climate change within this fragile coastal zone. Therefore, it is imperative to institute permanent monitoring, adopt sustainable land-use practices, and umbrella conservation strategies aimed toward sustaining the biodiversity of the area plus the ecosystems that support livelihood.

Furthermore, the study also serves as a guide for further studies and policy development in fostering climate resilience in the Sundarbans and other similar coastal ecosystems.

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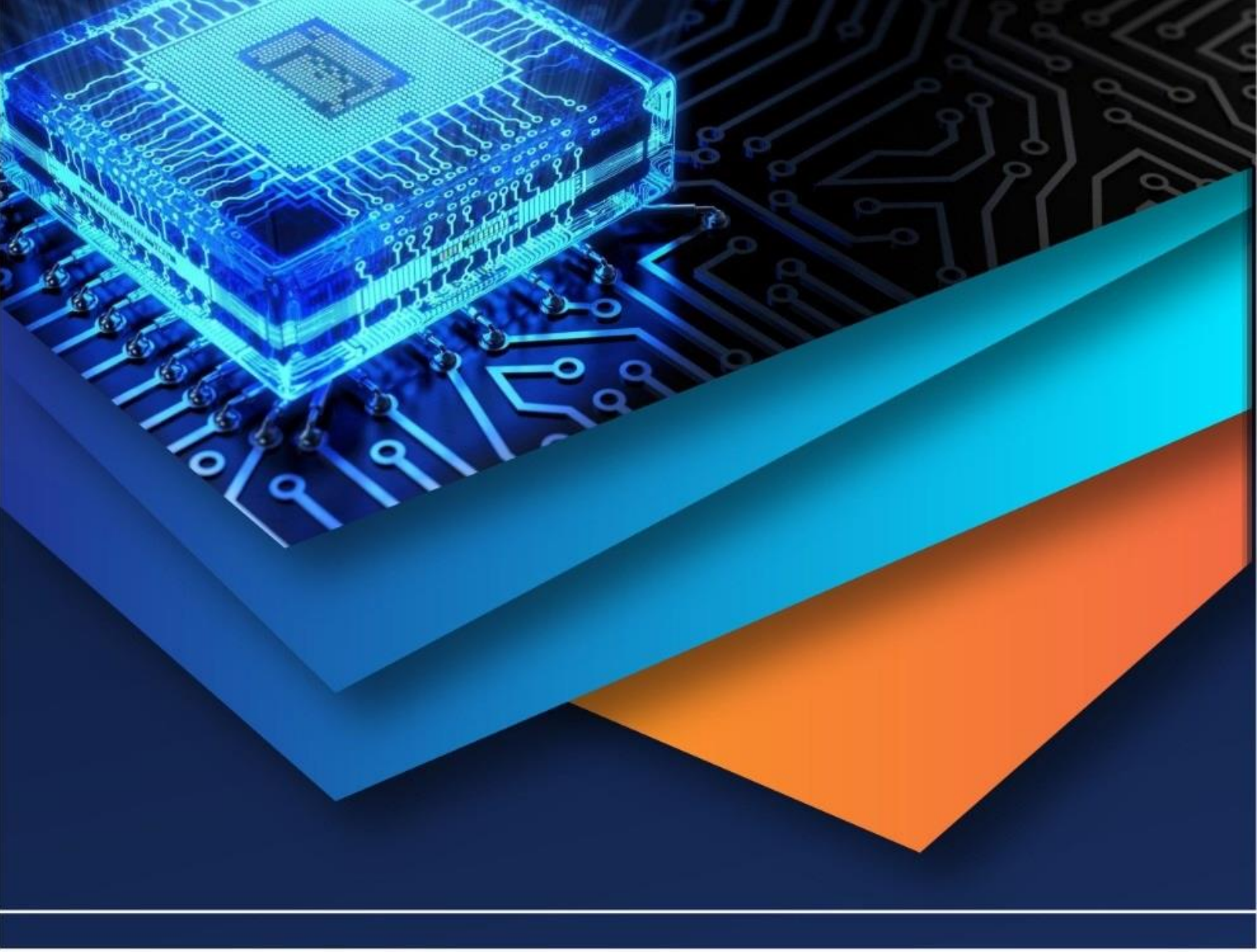

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