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Analyzing Urbanization using Satellite Image Processing

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Abstract: Urbanization is directly proportional to the increase in population, which contributes to the increase in country's GDP but affects the environment and ecosystem. This paper introduces an analysis of the satellite imagery of Mumbai for past 5 years (2019-2023). Mumbai has witnessed significant changes in the geographic region. In order to control and prevent the effects of urbanization, it is necessary to analyze the geographical changes and effects of the same.

In this proposed analysis, we have analyzed urbanization with respect to changes in water, forest, urban land and barren land. Use of satellite imagery plays an important role in providing the opportunity for this analysis. Google Earth Engine (GEE) is used for the change detection for the selected area using the satellite imagery dataset provider COPERNICUS named Harmonized Sentinel-2 MSI as an input to this analysis. For this analysis we have used 3 classification methods i.e. supervised, unsurprised and NDVI.

Keywords: Satellite Imagery, Goggle earth engine, Environment, Urbanization, Smile Cart, supervised, unsurprised and NDVI.

I. INTRODUCTION

Urbanization plays a vital role in contributing in country's economy's GDP. In 1950 the occupants of Mumbai were 3,088,811, which grew up to 21,673,149 in the year 2024.Urbanization is directly proportional to population growth and urban expansion. This growth has led to changes in land use patterns, affecting natural resources such as water bodies, forests, and agricultural land.

Mumbai, as one of India's largest and most crowded cities, represents the dynamics of urbanization. Over the past decades, Mumbai has experienced unprecedented population growth, fueled by factors such as rural to urban migration, industrialization, and financial openings. This demographic shift has led to the expansion of urban infrastructure, increased demand for housing, and increased pressure on natural resources. Understanding these changes and their implications is crucial for sustainable development and environmental management.

The use of satellite imagery and remote sensing technologies has revolutionized our ability to monitor and analyze urbanization trends.

This research highlights the urbanization over the past 5 years using Google Earth Engine (GEE). To perform supervised and unsupervised classification for detecting changes in land cover types i.e. land, water, barren land, urban land and NDVI (Normalized Difference Vegetation Index) here by awakening the Government bodies to take necessary action upon the analysis.

II. LITERATURE SURVEY

The paper titled "Review on The Impact of Satellite Imagery in Urban Policy Planning" by Md. Rakin Sarder Arko1, Mohammed Raihanul Bashar1, Amin A Ali1, Moinul Zaber2, Md Abu Sayed. This paper reviews some of the works done in the field of satellite image sensing-based policy planning, and how they can be fitted into urban settings for faster and effective decision making. Rapid urbanization due to population growth and migration in the past decades had a consequence on the overall planning of the urban areas. Policy planning schemes are now more developing than the past. Satellite remote sensing data can provide enough evidence at a large scale to come to a policy interpretation. Impact analysis of how different researchers in this sector have created a positive impact on different policy planning has been conducted in this research.

The paper titled" Change Detection in Urban Areas using Satellite Data" by M.A. Al-Dail. Satellite data can be regarded as a powerful tool for providing information for urban monitoring that can be used by urban and regional planners in fraction of the cost and time compared to traditional methods (e.g. Aerial photos or field survey). However, most of the methods used in the literature to process such data will need a considerable time and experience. This has limited the application of such technology, since such experience is not always available in urban development sector of the community.

The study was conducted over the city of Riyadh, central Saudi Arabia, to test a simple Image Difference (ID) technique for urban change detection.

Landsat Thematic Mapper (LTM) data on 21 July, 1987 and 15 September, 1996 and SPOT Panchromatic Linear Array (PLA) data on 2 August, 1996 were acquired over the study area. The change detection using image difference procedure involves:
(i) Spatial registration of multi-temporal data sets collected by the different sensors,
(ii) Image difference was then used to detect changes in urban areas which enable the detection of changes in brightness values using Pixel by Pixel subtraction of the registered data sets.
Three small sub-scenes from the whole study area were generated to evaluate the method in more details. It was found that such technique emphasizes temporal changes and provides an excellent and easy to interpret first level indication of change in urban areas.

III. STUDY AREA

The population of Mumbai, which is one of the foremost crowded cities in India, is 21.6 million agreeing to 2024 information, and the population development rate is 1.77‰ [4]. Mumbai, moreover called Bombay, is the capital city of the state of Maharashtra in India, and it's the foremost crowded city in India. Mumbai is 4th most crowded city within the world and one of the crowded urban districts within the world.

Fig. 1 Map of India

Fig. 2 Map of Mumbai

Fig. 3 Satellite Image of Mumbai

IV. METHODOLOGY

In this Research, Harmonized Sentinel-2 MSI: Multispectral Instrument, Level-2A dataset is used for Analysing Urbanization using Satellite Image Processing.

A. Satellite Imagery Data Acquisition

For this project, high-resolution satellite imagery dataset of Mumbai were acquired from the dataset "Harmonized Sentinel-2 MSI" of the satellite provider Copernicus. These images provide detailed spatial information across multiple spectral bands, enabling precise land cover analysis.

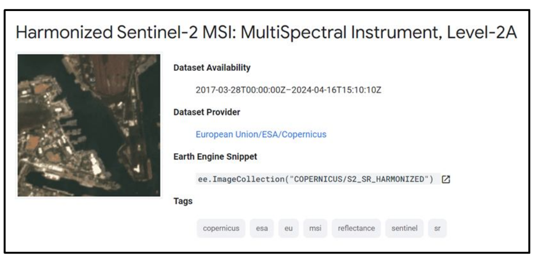

Fig. 4 Earth Engine Dataset

Name	Pixel Size	Wave-length	Description
B2	0.0001	10 m	Blue
B3	0.0001	10 m	Green
B4	0.0001	10 m	Red
B8	0.0001	10 m	NIR
B11	0.0001	20 m	SWIR 1

Fig. 5 bands

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These different spectral bands can be combined in different ways to enhance the contrast between different categories of interest. The most common is to use the red, green, and blue bands to create a natural color image, like what would be seen with the naked eye.

B. Google Earth Engine (GEE) for Change Detection.

Google Earth Engine (GEE) was utilized for change detection analysis. GEE is a cloud-based platform that offers a vast archive of satellite imagery and powerful processing capabilities, making it ideal for large-scale geospatial analysis.

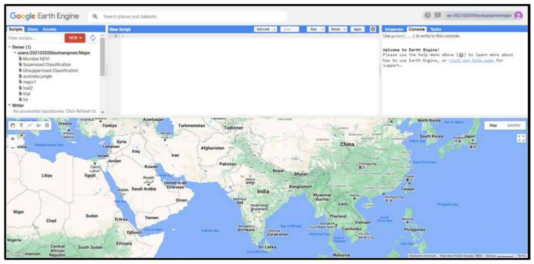


Fig. 6 Google Earth Engine Code editor

C. Classification Methods

1) *Supervised Classification using smileCart Classifier:* The supervised classification approach involved training the smileCart classifier using labeled data to classify land cover types such as water bodies, forests, urban areas, and barren land. The classifier's algorithm leverages spectral signatures to differentiate between different land cover classes.
2) *Unsupervised Classification using wekaKMeans Classifier:* In the unsupervised classification method, the wekaKMeans classifier was applied to cluster pixels based on spectral similarity, without prior training. This approach helps identify patterns and clusters within the satellite imagery data, providing insights into land cover distribution.
3) ***NDVI Calculation:*** Normalized Difference Vegetation Index (NDVI) was computed using bands B8 (Near-Infrared), B4 (Red), B3 (Green), and B2 (Blue) from the satellite imagery. NDVI is a widely used index for assessing vegetation health and density, with higher values indicating healthier vegetation.

The Normalized Difference Build-up Index (NDBI) highlights urban areas with higher reflectance in the shortwave-infrared spectral range (SWIR). Therefore, the NDBI was computed as follows:

In case of Harmonized Sentinel-2 MSI imagery, the SWIR band is 20 m resolution, so before the calculation, it was need to resample data to lower resolution. Therefore, the final result will be also obtained with a resolution of 20 m.

Index	Description	Formulation
NDVI	Normalized difference Vegetation index	$\frac{NIR-RED}{NIR+RED}$
NDBI	Normalized difference build-up index	$\frac{SWIR1-NIR}{SWIR1+NIR}$

Fig. 7 NDVI and NDBI formula

D. Evaluation Metrics

Various evaluation metrics were used to assess the accuracy of the classification results, including the confusion matrix parameters such as

1) *Overall Accuracy*- Tells us out of all of the reference sites what proportion were mapped correctly.
2) *Consumer's Accuracy*- The user’s accuracy for a given class tells us the proportion of the pixels identified on the map as being in that class that are actually in that class on the ground.
3) *Producer's Accuracy*- It refers to the probability that a certain feature of an area on the ground is classified as such. It results from dividing the numbers of pixels correctly classified in each category by the numbers of sample pixels taken for this category (column total).

4) ***Kappa coefficient*** –These metrics help evaluate the performance of the classification algorithms in accurately identifying land cover classes.

Accuracy	Formulae
Overall accuracy	$\frac{\text{Number of correct classified pixels}}{\text{Total reference points}}$
Producer accuracy	$\frac{\text{Correct impervious surface pixels}}{\text{Tota impervious pixels}}$
Consumer accuracy	$\frac{\text{Correct impervious surface pixel}}{\text{Correct + misclassified pixel}}$
Kappa coefficient [53]	$\frac{\sum_{i=1}^{K} nii - \sum_{i=1}^{K} nii(GiCi)}{n2 - \sum_{i=1}^{K} nii(GiCi)}$ where i = class number; n = total number of classified pixels; n_{ii} = number of correctly classified pixels in class i; C_i = total number of classified pixels belonging to class i; Gi = total number of actual data pixels of class i.

Fig. 8 Evaluation Metrics formula

V. SOFTWARE DESCRIPTION

Google Earth Engine is a cloud-based platform developed by Google for highly scalable remote sensing data analysis (Zhao et al., 2021). The platform provides access to a wide range of satellite imagery datasets and remote sensing data from various sources, including Landsat, Sentinel, MODIS, and more.[5] GEE allows to access multiple satellite imagery data as mentioned above and allows to perform multiple operations on it.

Google Earth Engine

Fig. 9 GEE

VI. OUTPUT

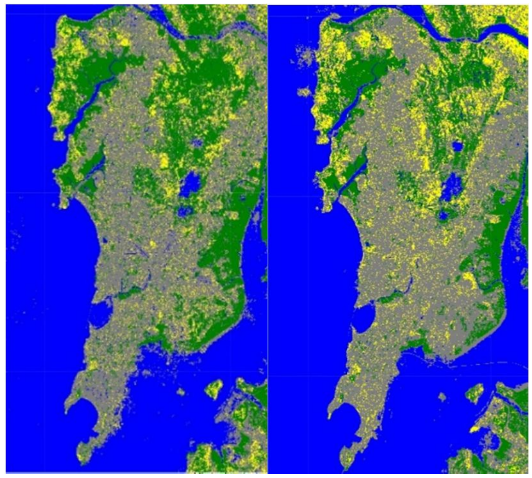
A. Supervised classification-

1) Satellite image:

2019 2023

Fig 10. Satellite image

Above two are "Harmonized Sentinel-2 MSI" satellite imagery of Mumbai for year 2019 and 2023 respectively.



2019 2023

Fig 11. smileCart Classification

Legend For above Classification

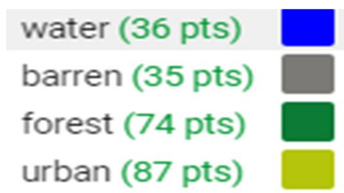


Fig.12 Classification Legend

Above two are the supervised classification images using smileCart classifier on the sentintel satellite images of year 2019 and 2023 respectively, the classification shows decrease in the forest area which leads to more barren land, resulting in deforestation and increase in urban land leading to urbanization.

Confusion matrix

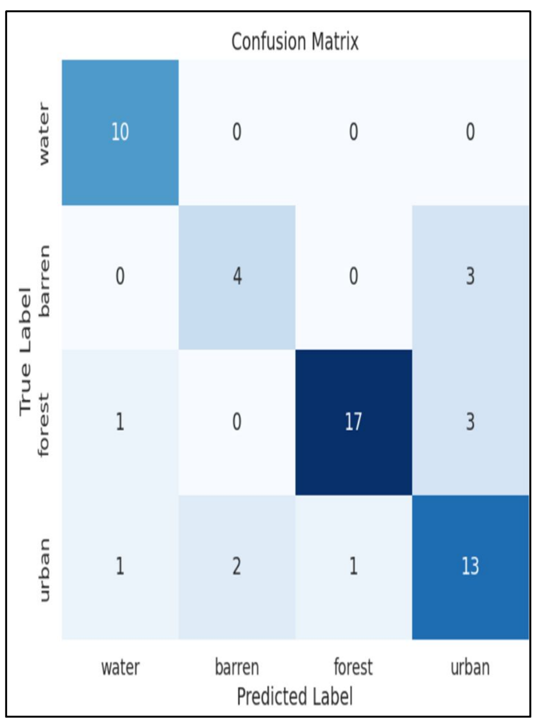


Fig 13. Confusion matrix year 2019

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Confusion Matrix 2019:
[[1,0,0,1],[0,3,0,3],[0,0,17,0],[1,4,2,7]]

Overall Accuracy 2019:
0.717948717948718

Consumer's accuracy 2019:
List (1 element)
  0: List (4 elements)
    0: 0.5
    1: 0.42857142857142855
    2: 0.8947368421052632
    3: 0.6363636363636364

Producer's accuracy 2019:
[[0.5],[0.5],[1],[0.5]]

Kappa 2019:
0.5701402805611222
```

Fig 14. Confusion matrix year 2019 parameters Result

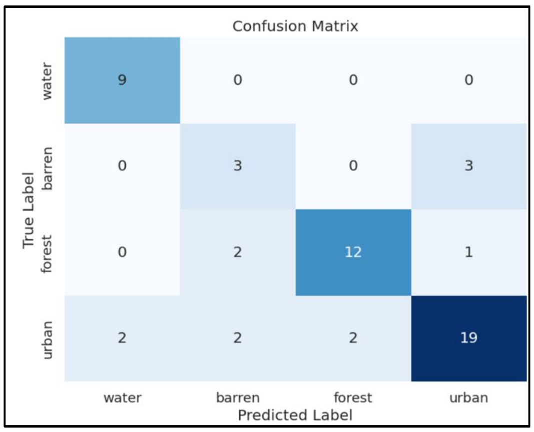

Fig 15. Confusion matrix year 2019

```
Confusion Matrix 2023:
[[9,0,0,0],[0,3,0,3],[0,2,12,1],[2,2,2,19]]
  0: [9,0,0,0]
  1: [0,3,0,3]
  2: [0,2,12,1]
  3: [2,2,2,19]

Overall Accuracy 2023:
0.7818181818181819

Consumer's accuracy 2023
List (1 element)
  0: List (4 elements)
    0: 0.8181818181818182
    1: 0.42857142857142855
    2: 0.8571428571428571
    3: 0.8260869565217391

Producer's accuracy 2023
[[1],[0.5],[0.8],[0.76]]
  0: [1]
  1: [0.5]
  2: [0.8]
  3: [0.76]

Kappa 2023
0.6855645545497857
```

Fig 14. Confusion matrix year 2019 parameters Result

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Area chart for above 2 Supervised classification satellite images

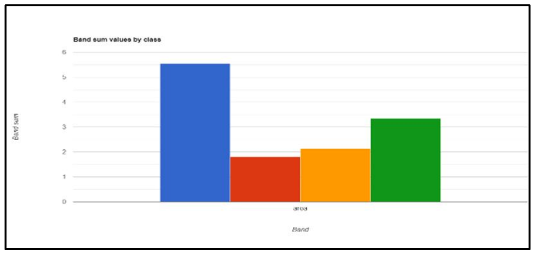


Fig 15. Supervised class chart for year 2019

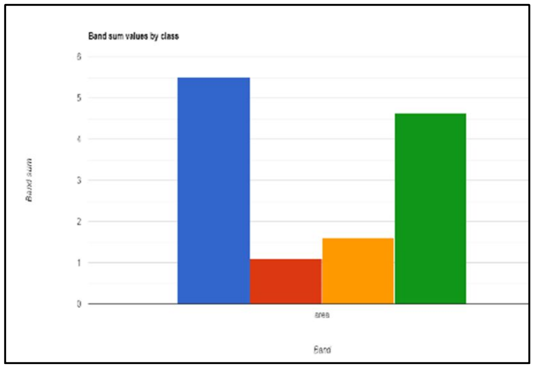
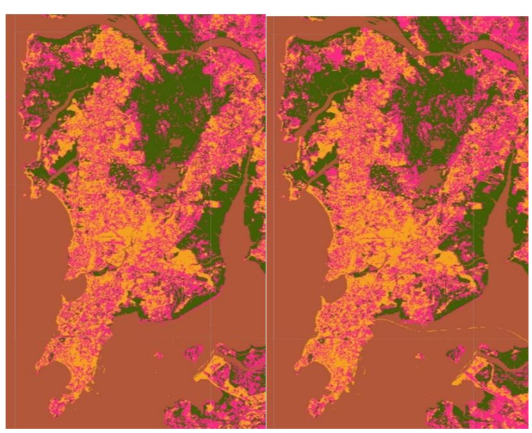


Fig 16. Supervised Classification area chart for year 2023

Fig 17. Legend for Supervised Classification area chart

Above chart shows decrease in the forest area which leads to more barren land, resulting in deforestation and increase in urban land leading to urbanization.

B. Unsupervised Classification



2019 2023

Fig 18. Unsupervised wekaKMeans classifier

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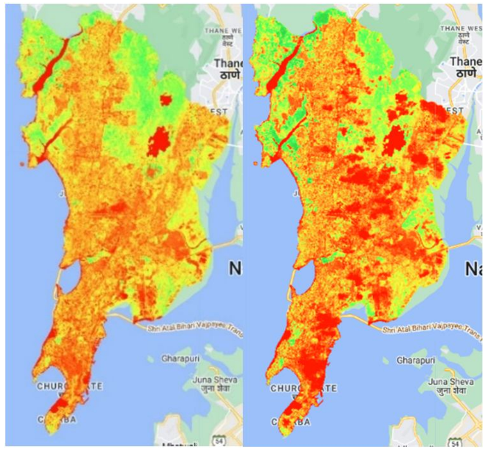
Above two are the unsupervised classification images using wekaKMeans classifier images on the sentintel satellite images of year 2019 and 2023 respectively, the classification shows decrease in the forest area leading to more barren land, resulting in deforestation and increase in urban land leading to urbanization.

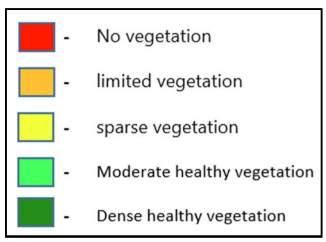
C. NDVI

1) NDVI

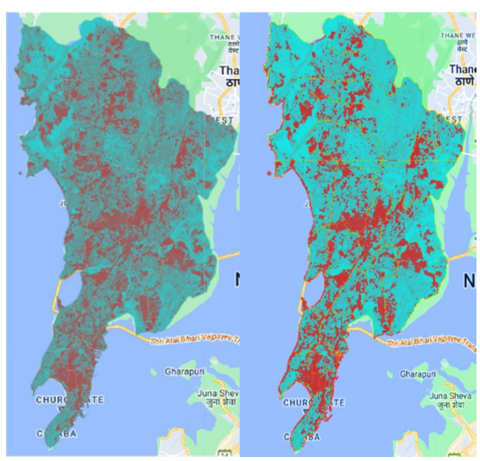


2019 2023

Fig 19. NDVI



2) NDBI



2019 2023

- Urban

- Non-Urban

Fig 20. NDBI

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Mumbai City Area in sq km
313252

Mumbai City Area in sq km
363798

Mumbai City Area in sq km
623389

Mumbai City Area in sq km
641032

Mumbai City Area in sq km
695902
```

Fig 21. Mumbai area in km^2

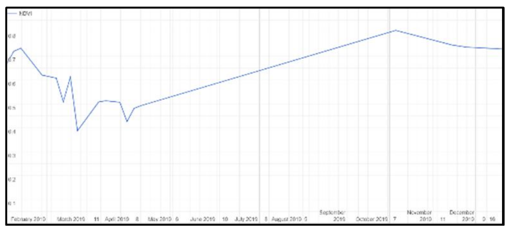

Fig 22. NDVI time series 2019

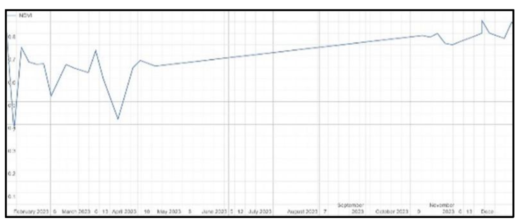

Fig 23. NDVI time series 2023

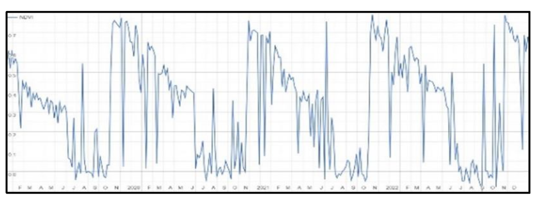

Fig 24. Mean NDVI time series 2019 -2023

VII. DISCUSSION

The results of the Research based project highlight significant changes in land cover types over the study period, particularly in urban areas. The supervised classification maps provide detailed insights into urban expansion patterns, while the unsupervised classification helps identify clusters of land cover types. The NDVI analysis reveals trends in vegetation health, reflecting the impact of urbanization on green spaces in Mumbai.

VIII. CONCLUSION

This research demonstrates the utility of satellite imagery and remote sensing techniques in analyzing urbanization effects. The research shows how Mumbai Urbanized from the year 2019 to 2023 using satellite images. The smileCart classifier showed that cities grew a lot, replacing forests and barren land with buildings. This is clear in our maps and charts. It's important to think about how this affects the environment, aiding decision-makers in sustainable urban development planning and conservation efforts.

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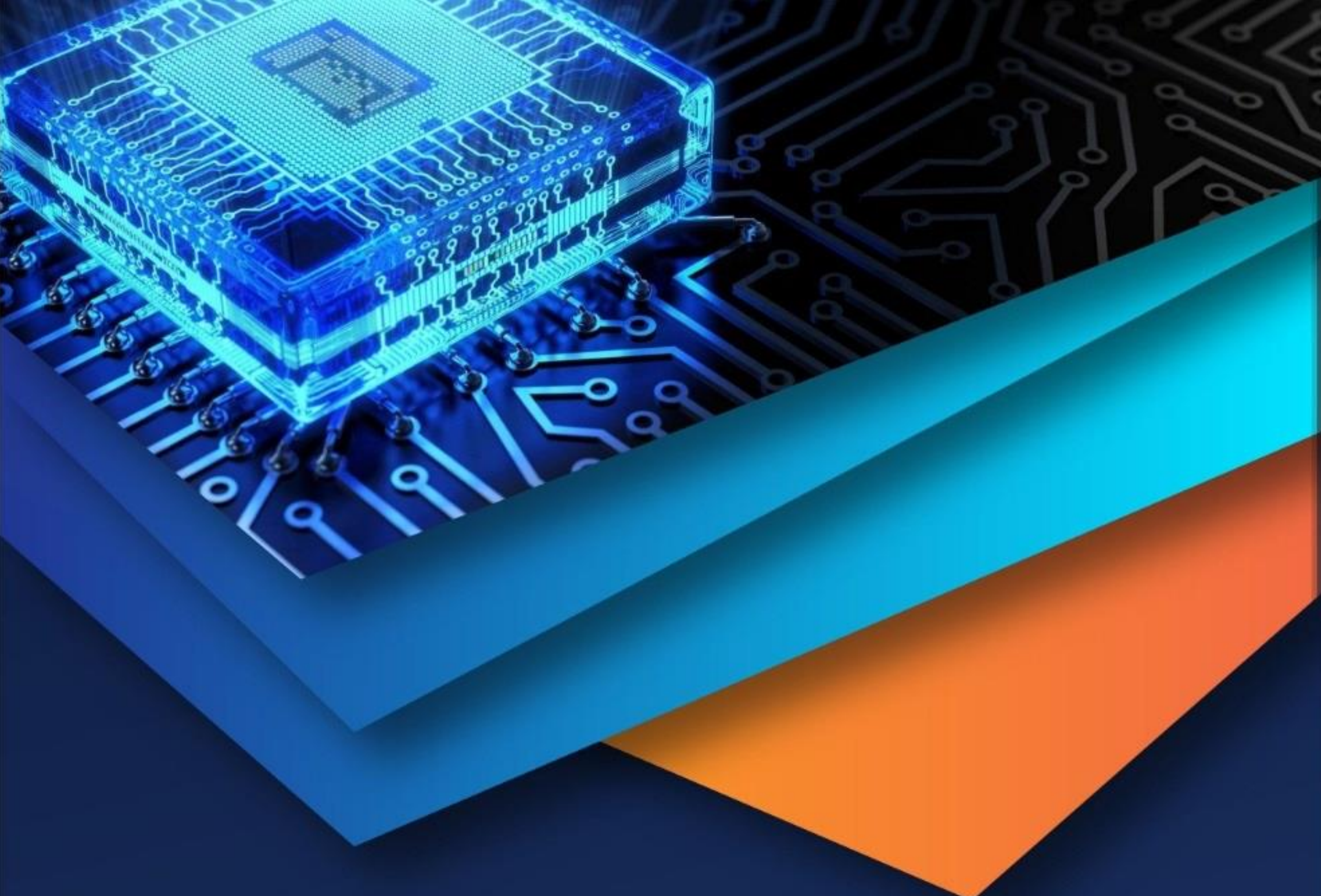

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