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Hydrological Modelling of Cooum River Basin using GIS and SWAT Model

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Abstract: In India the availability of accurate information on runoff is scarce. However in view of the quickening watershed management program for conservation and development of natural resources and its management, runoff information assumes great relevance. Soil and Water Assessment Tool (SWAT) is a physically based distributed parameter model which has been developed to predict runoff, erosion, sediment and nutrient transport from agricultural watersheds under different land management practices. The basic intent of the current study is to derive the parameters required for runoff modeling using the geospatial database and the runoff estimation. During the basic data preparation stage of the study, the land use map and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) digital elevation model covering the study area were derived with the help of remotely sensed information. Hydrological response units were created by defining the unique land use, soil and slope conditions. By providing topological and climatic data, the model was simulated successfully for the period of thirty six years (year 1969–2005). The runoff values obtained from the SWAT simulation were compared with monthly discharge values of the real time data.

Keywords: Hydrologic model; SWAT; Land use; Soil data; DEM; Runoff

I. INTRODUCTION

The water is the most important natural resource especially in the urban areas, which face high population growth, scarcity of freshwater, irregularity of rainfall and excessive land use change. Thus, the availability and sustainable use of this resource becomes the core of the local and national strategies in this region. Environmentally, socially and financially sound management of water resources requires long term, reliable hydrologic information. Managing water resources is mostly required at watershed scale [10] given that is the basic hydrologic unit where can be studied the heterogeneity and complexity of processes and interactions linking land surface, climatic factors and human activities. Many models were developed for watershed hydrology [8] but the availability of temporally and spatially data was the main constraint hindering the implementation of these models especially in developing countries. However the development of remote sensing techniques and Geographic Information System (GIS) capabilities has encouraged and improved the expansion use of these models worldwide. The big evolution in watershed modeling will be made as a result of advances in remote sensing data availability [9].

The river Cooum, located in Tamil Nadu state is once a fresh water source is today a drainage collecting surpluses of 75 small tanks of minor basin[4]. The length of the river is about 65 km, of which 18 km, fall within the Chennai city limits. This is once fishing river and boat racing ground has borne the brunt of the city's population explosion. The estimation of discharge plays an important role in planning and management of water resources in the catchment area. The estimation of flow values requires a model, which can realistically simulate the runoff values, this defines the resolution for a hydrologic modelling.

The soil and water assessment tool (SWAT) was chosen for this case study because it includes many useful components and functions for simulating the water balance and the other watershed processes such as water quality, climate change, crop growth, and land management practices. In addition, it's efficiency and reliability was confirmed in several areas around the world and it was the opportunity to test its performance in Indian basins also. SWAT model was already tested in few regions of India, especially in southern regions [13]. In Cooum river basin SWAT was never tested or used to estimate the runoff. Therefore, this study aims to test and evaluate the usefulness and performance of SWAT to model the hydrological parameters. It is indicated that SWAT is capable of simulating hydrological processes with reasonable accuracy.

II. STUDY AREA AND DATA USED

For the current study, Cooum river basin up to the Cooum delta has been selected as a study region. The Cooum River is origin at Cooum village, Thiruvallur district, Tamil Nadu state. Cooum River is one of the most polluted river of India which ends in the city of Chennai draining into the Bay of Bengal. Owing to intensive use of surface water upstream for agriculture, indiscriminate pumping of ground water leading to reduced base flow in the river, formation of sand bar at the mouth of the river, discharge of untreated sewage and industrial effluents and encroachment along the banks, the river, especially the downstream, has been highly polluted. Along with the ADYAR River trifurcates the city and separates northern Chennai from central Chennai. The total length of the cooum river is about 72 Km long. The geographical limits of the Cooum River is lie between Latitude 13.0678°N to Longitude 80.29°E. The total catchment area of the river is 400 Sq.km.

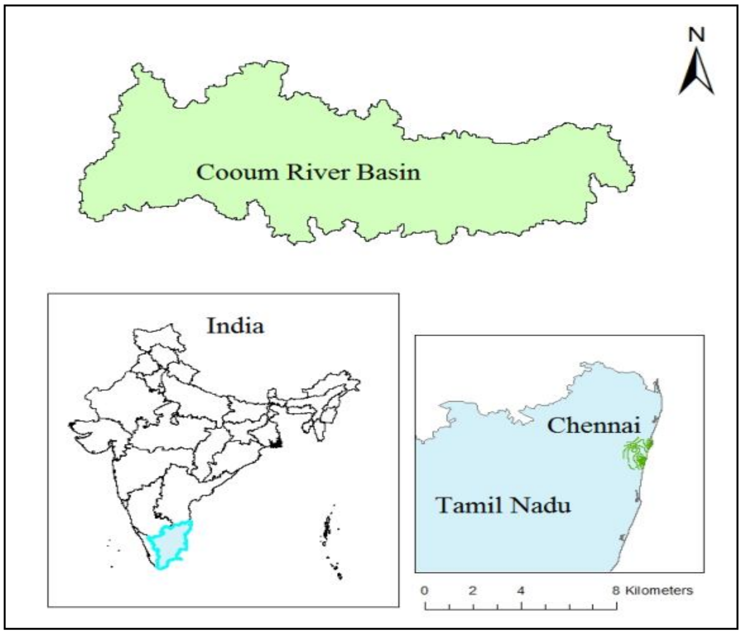

Fig. 1 Location of Cooum River Basin in TamilNadu (India)

A. The datasets used in the Current Study include The Following

1) ASTER *(Advance Space Borne Thermal Emission and Reflection Radiometer)* DEM *(Digital Elevation Model)* of 30m resolution
2) Land use data based on LANDSAT imagery [5].
3) Soils data obtained from the Tamil Nadu agricultural university [7].
4) High resolution (1° × 1°) daily gridded rainfall data (1971-2005) developed by India Meteorological Department (IMD) [6].
5) 1°X1° daily temperature data from IMD (1969 to 2007) [15]

III. METHODOLOGY

The Soil and Water Assessment Tool is a complex physically based distributed parameter hydrologic model developed by the United States Department of Agriculture (USDA), which operates on a daily time step [1] and [2]. In SWAT surface runoff is estimated using the SCS curve number procedures [12] from the daily rainfall data. SWAT can be used to simulate a single watershed or a system of multiple hydrologically connected watersheds. Each watershed is first divided into sub basins and then in hydrologic response units (HRUs) based on the land use and soil distributions. The hydrologic cycle is simulated by SWAT model based on the following water balance equation.

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (1)$$

Where, SW_t is the final soil moisture content (mm), SW_0 is the initial moisture content (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of percolation and bypass flow existing soil profile on day i (mm), and Q_{gw} is the amount of return flow in day i (mm).

SCS curve number procedures [11] to estimate the runoff is as follows. The SCS curve number equation is:

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$$Q_{Surf} = \frac{\left(R_{day} - I_{a}\right)^{2}}{\left(R_{day} - I_{a} + S\right)} \qquad (2)$$

Where, ‘Q_{surf}’ is the accumulated rainfall excess(mm), ‘R_{day}’ is the rainfall depth for the day (mm), ‘I_a’ is the initial obstructions which includes surface storage, interception and S is the retention parameter (mm). SWAT requires many sets of spatial and temporal in-put data. As semi-distributed model, SWAT has to process, combine and analyze spatially these data using GIS tools. Therefore, to facilitate the use of the model, it was coupled with two GIS software as free additional extensions: ArcSWAT for ArcGIS

IV. CREATION OF DATABASE

In this study, the ArcSWAT graphical user interface was used to manipulate and execute the major functions of SWAT model from the ArcGIS tool. The basic spatial data needed for the ArcSWAT interface are DEM, soil type and land use [3]. The temporal data required by the model to establish the water balance include weather and river discharge data. The main sets of data used are briefly explained below.

A. Digital Elevation Model (DEM)

The DEM (Figure 2) was extracted from the ASTER DEM) which has a spatial resolution of 30 m. This was used to delineate the watershed and subbasins as the drainage surfaces, stream network and longest reaches. The topographic parameters such as terrain slope, channel slope or reach length were also derived from the DEM.

B. Land Use

The land use map (Figure 3) was extracted through the processing of satellite Landsat image TM that has a spatial resolution of 30 m. The supervised classification technique was used to derive and distinguish the most present land use classes in the basin. Eight major classes are so identified. The dominant categories are urban (57.37%) and Agricultural land (generic) (11.75%).

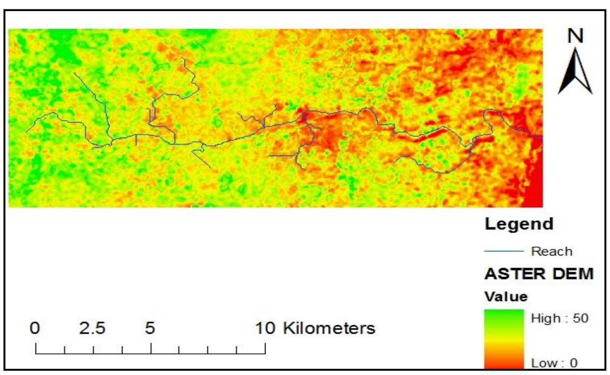

Fig.2. Digital Elevation Model

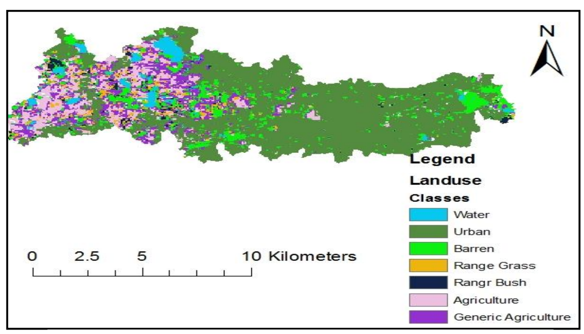

Fig. 3. Land use Classification

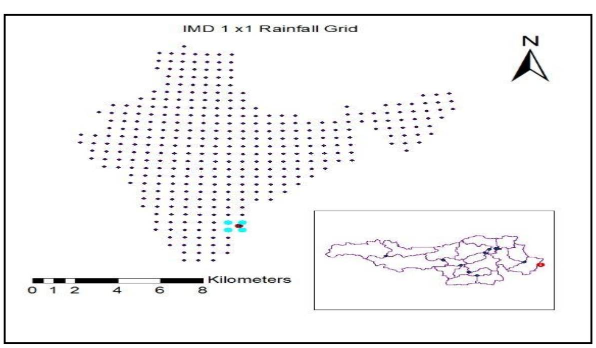

Fig. 4. Soil Classification

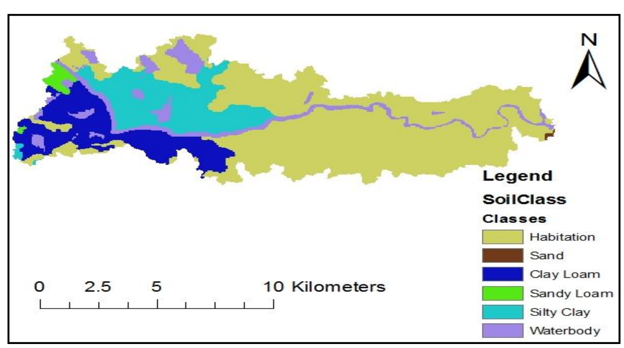

Fig. 5. IMD (1^0x1^0) Rainfall Grid

C. Soils Data
Based on the soils data, the study area has divided into six classes (Figure 4). Major portion covers in this area is habitation (60%).

D. Weather Data
SWAT needs daily rainfall, maximum and minimum temperature for hydrologic simulation. As the individual rain gauge data with long historical records were not readily available, 1º×1º high resolution gridded data developed by the Indian Meteorological Department (IMD) was used for model setup. The extent of the 1º×1º gridded rain gauge data is shown in Figure 5.

V. MODEL SETUP
Hydrologic modeling was carried out by using a distributed hydrological model SWAT. The data required to setup SWAT include topography, land use, soil, weather and land management practices.
Accordingly, the ArcGIS SWAT model setup involves five major processes: 1) Watershed delineation 2) Landuse and Soil setup 3) Hydrologic Response Unit (HRU) definition 4) Weather data and 5) Land management information.
Figure 6 gives a global view of SWAT model components including the spatial and GIS parts.

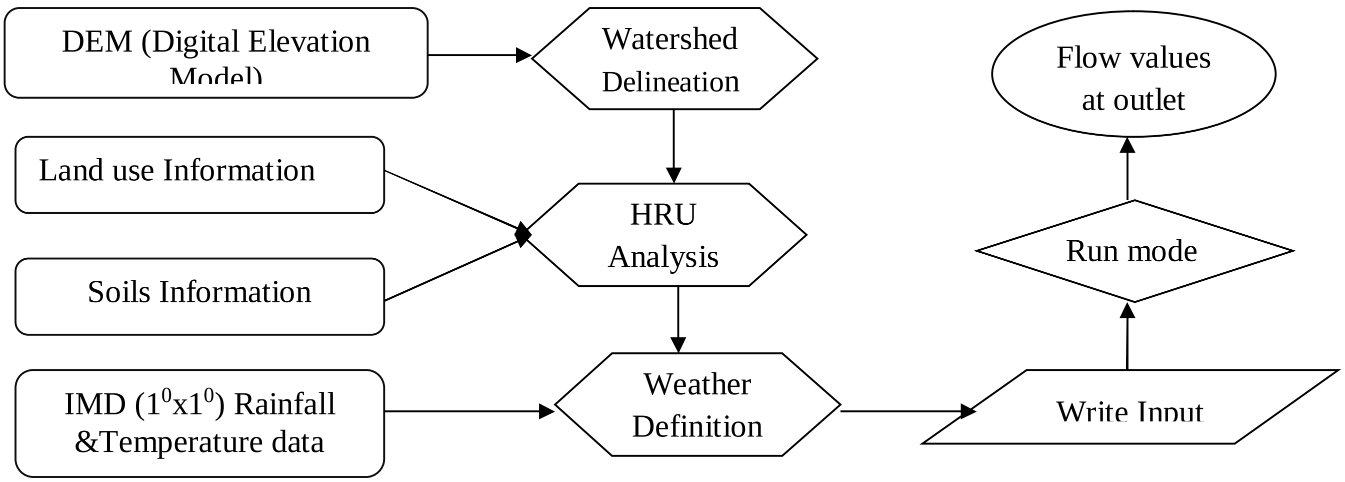

Fig. 6. Global view of SWAT model components

The first step in using SWAT model is to delineate the studied watershed and then divide it into multiple sub basins based on Digital Elevation Model (DEM) and the outlets generated by the intersection of reaches or those specified by the user. Thereafter, each sub basin is sub divided into homogeneous areas called hydrologic response units (HRUs) that GIS derives from the overlaying of slope, land use and soil layers.Watershed delineation is the process of identifying the natural drainage pattern in the river basin for delineating the streams, demarking the contributing watershed area and subdividing a large river basin into small subunits called sub basins. Based on these manually added outlets and the natural topography, the watershed was divided into 29 sub basins as shown in

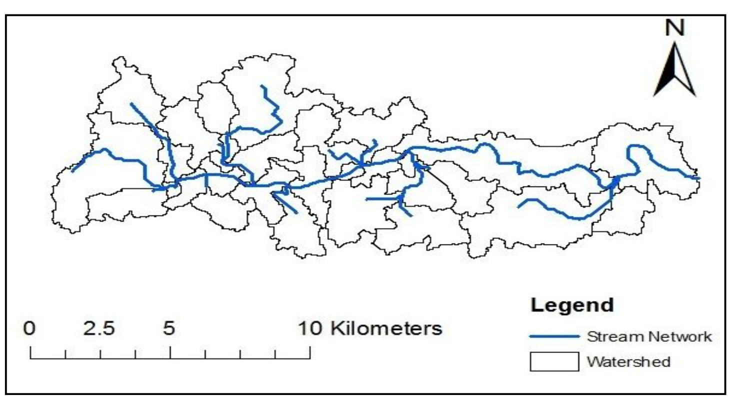

Fig. 7. Watershed delineation

Based on the unique land use and soil type combination, the sub basins were further subdivided into HRU's (Hydrologic Response Unit) for hydrologic simulation. HRU represent a patch of land within the sub basin with similar land use and soil. Hence, the individual land parcels included within an HRU are expected to possess similar hydrologic characteristics and can be simulated as a single unit. It is not feasible to include every small area representing a unique land use/soil combination in the model. Hence, a cut off criterion was therefore defined to reduce the number of HRU's. criteria for HRU is based on the Dominant landuse, soil, slope classification. The eliminated land use and soil area were redistributed proportionally among the land use and soil types included for simulation. Based on the above cut off criteria, a total of 387 HRUs were identified for simulation. Most model parameters are specified at the HRU level.

VI. RESULTS AND DISCUSSION

Outflow is the most important parameter estimated in the model. After the successful run of SWAT model, the hydrograph is plotted from 1969 to 2005 with annual peak discharge as shown in figure 8.

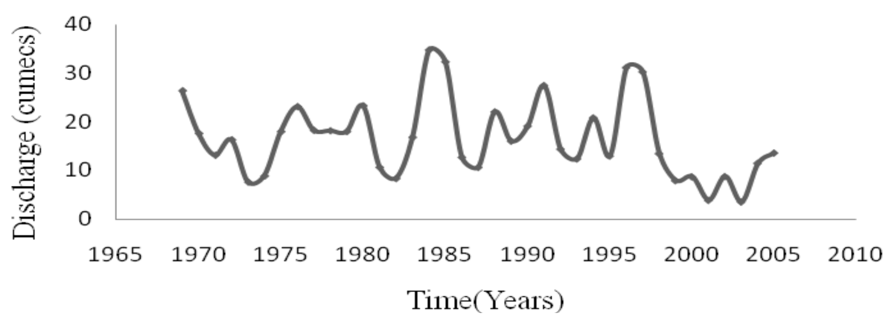

Fig. 8. Hydrograph from the simulation

The peak discharge from 1969 till 2005 is an ephemeral river, also due to lack of available daily discharge data, the calibration is done for the average values obtained from SWAT.

Unfortunately, Cooum river is not frequently monitored for it's outflow values at the outlet but is monitored frequently for the sedimentation load to calculate the pollution level. The referenced value of discharge is of the order of 266.45×10^6 to 709.34×10^6 litres/day which is 3.083 Cumecs to 8.209 Cumecs [14].

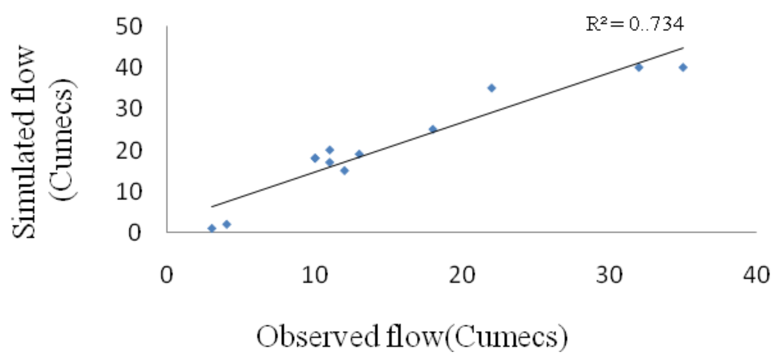

Fig. 9. Comparison of monthly observed and simulated flow values

average discharge value obtained from SWAT simulation was 3.597 cumecs, which lies in between the desirable limits. The monthly average values obtained from the SWAT simulation were compared with the monthly observed flow values obtained from the ground observation data as shown in the figure 9. The root mean square error for the above plot is 0.734. It clearly depicts that there is a good correlation between the real time data and the simulated values.

VII. CONCLUSION

With the increasing availability of GIS data, the combination of SWAT model provides a method for modelling and visualizing the spatial distribution of the catchment response for a given storm event. The hydrologic analysis from this study shows that SWAT model could be used to get a reasonable estimate of the hydrology with minimal calibration. The results of the model could be further improved if dense network of weather stations are available along with a good network of stream gauge data. This study had demonstrated the utility of the remote sensing and GIS to create combine and generate the necessary data to set up and run the hydrological models especially for those distributed and continuous. This study has demonstrated that SWAT model may be used with reasonable confidence to simulate the water quantity discharge from a river basin understudy.

VIII. ACKNOWLEDGEMENTS

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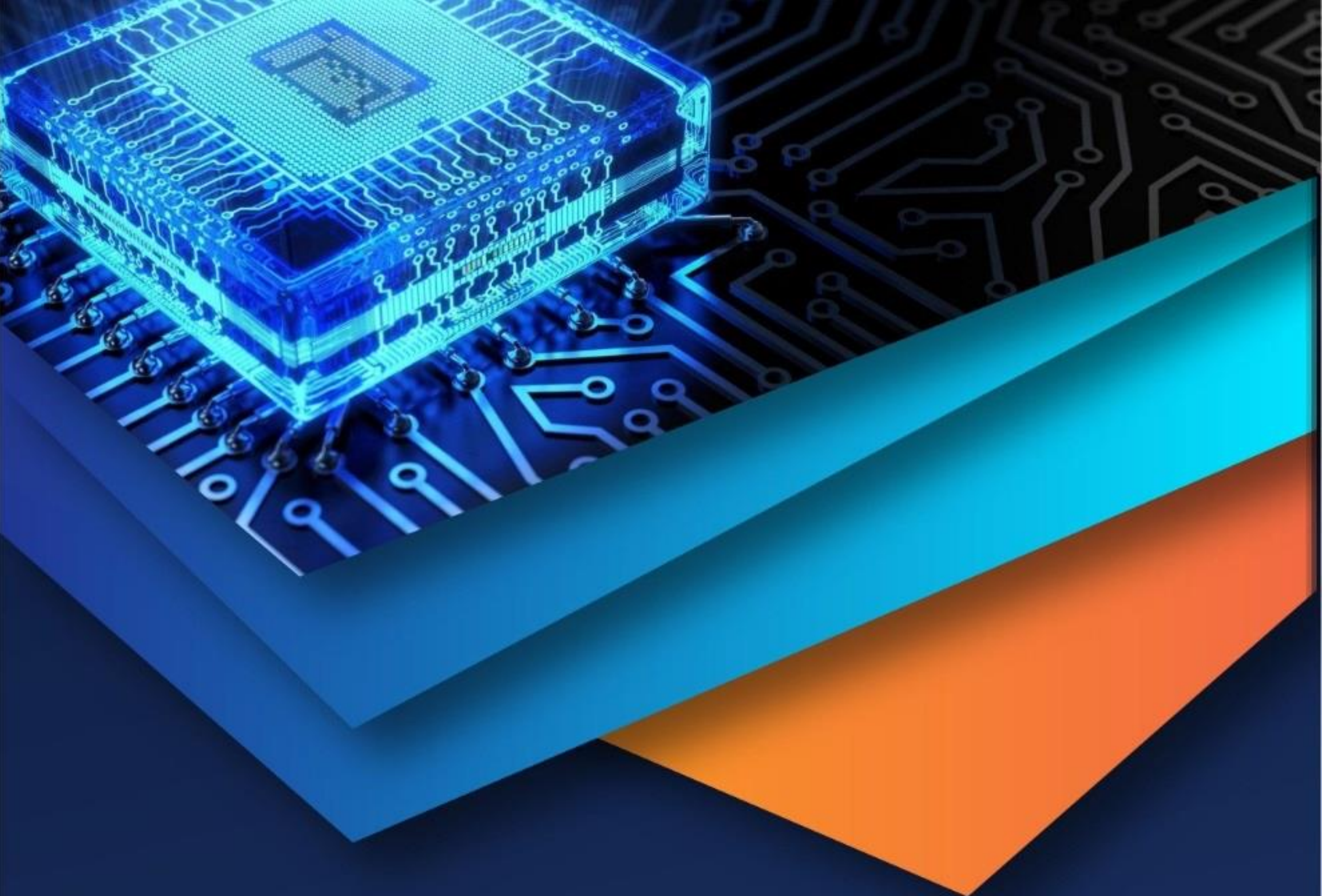

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