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Study of Bedrock River Profile of Upper Catchment of Kosi River Using Integral Method Called as Chi Analysis

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Abstract: Bedrock Rivers are generally interpreted with help of slope –area analysis, but noisy data makes such interpretation difficult. An integration of steady state form of stream power equation is applied. This integral method has the potential to provide precise quantity information about erosion rates and their temporal and spatial variations over areas of which topographic data are available. The chi (χ) value is dependent upon area upstream of channel, so an increase or decrease in the drainage area of river can be used to find the equilibrium across a drainage divide. Such that the rivers with same base level and uniform uplift and erosion tends to remain in steady state across the divide but any change in the base level because of tectonics or climate can force the river systems to move towards a unsteady state condition across the divide. We illustrate these applications with analyses of Kosi river profile extracted from digital topographic datasets.
Keywords: Bedrock River, integration, stream power, topographic data, chi (χ) value, Channel, Drainage divide, drainage area, base level, Kosi river.

I. INTRODUCTION

Rivers are the backbone for landscape evolution on the earth. Fluvial processes are the fundamental geomorphic processes for shaping earth's surface. Fluvial incision is one of the primary processes that modified landscape. Bedrock rivers record information about a landscape's bedrock lithology, tectonic context, environmental and climate history (Perron et.al,2012). It has become common practice to use bedrock river profiles to test for steady state topography, infer deformation history, and calibrate erosion models .Bedrock river profiles has been widely interpreted with the help of slope-area analysis but, having various drawbacks, one of them is noisy topographic data which make such interpretation challenging. Because slope is the spatial derivative of topography, slope data contain yet more noise, so analysis of channel slopes requires a degree of smoothing and data binning that may reveal broad patterns of landscapes (Wobus et al, 2006). So I have applied a statistical technique for analyzing longitudinal channel profiles, this technique is based on integration of the steady-state form of stream power equation. Stream power depends on the flux of water, which is function of drainage area and channel gradient (Mudd et al., 2014).Integral transformation of the river's longitudinal profile produces a horizontal coordinate χ (chi), which has units of distance but accounts for longitudinal variations in the drainage area. Plots of channel elevations against this transformed length variable (χ) are called as "chi plots". It can be used to reveal the steepness of the river reaches without any requirement to calculate channel slopes (Perron et.al, 2012;Mudd et.al, 2014). As integral method does not involve differentiation, there is a significant reduction in noise related to slope-area analysis. This can be used to gain insight into the spatial and temporal variations in the controlling external forces, namely tectonic and climate. The procedure is well suited to analyzing both steady state and transient river profiles.

II. STUDY AREA

The Kosi River is an international river which flows through Nepal, India and along a small region of China. It is one of the largest tributaries of the Ganga River. The upper catchment of Kosi falls in the eastern part of Nepal and Tibet Himalayan region. Based on the analysis from digital elevation data the entire catchment was sub-divided into 3 sub-catchments viz. Arun, Sunkosi and Tamur. The upper Kosi basin covers an area of ~52,731 km^2 up to Chatara with elevation varying from 8642m to 164m , and slope ranging from 0° to 84°. The area under sub-catchment of Arun is the largest (32396 km^2) followed by Sunkosi (17623 km^2) and Tamur (5849 km^2). The outlet point is located at the confluence of Sunkosi, Arun and Tamur are bounded by 26°48‟34"N to 29°07‟48"N latitude and 85°22‟19"E to 88°55‟44"E longitude covering total area of 55868 km^2.

The lithology of Kosi river upper catchment Arun and Sunkosi passes through three different Himalayan region namely Tethyan Himalayan sequence (THS) ,Great Himalayan crystalline sequence (GHC) and Lesser Himalayan sequence (LHS), while small basin Tamur passes through GHC and LHS. THS and GHC separated by normal fault called as Sothern Tibetan Detachment (STD). GHC and LHS are separated by a major reverse fault known as Main Central thrust (MCT)

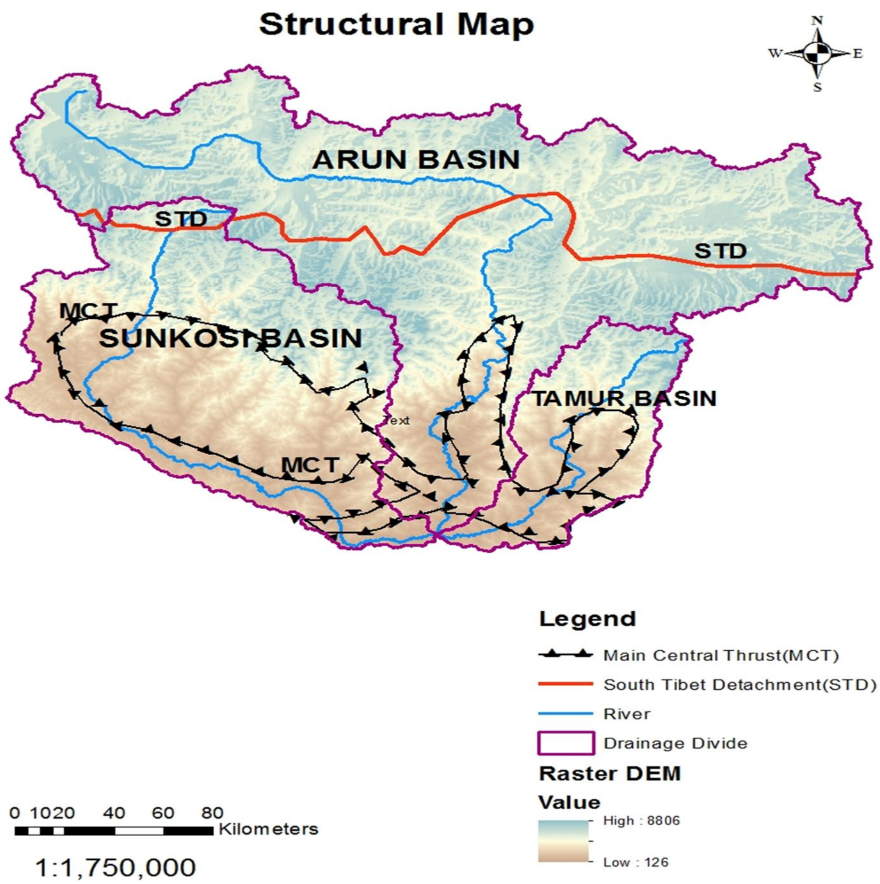

Figure 1: Simplified geological map shows major faults which are present in the study area. DEM is shown in the background. Retracing Using ArcGIS

III. METHODOLOGY

This geomorphic study is based on the visual interpretation from various satellite data. SRTM (Shuttle Radar Topography Mission) 90 m Digital Elevation Model (DEM) is used to carry out the Chi analysis and the geomorphologic features were mapped using Google Earth imagery. Geological map is prepared from the maps published in literature. The maps from various sources are georeferenced and converted into GIS format and combined to prepare a composite map. Preparation of different maps has been done using ArcGIS and Qgis. Watershed required for the study is extracted using ArcGIS. The derivation of chi coordinate and other formula taken from (Perron et al., 2012),(Mudd et al., 2014) and Mudd et al., (2018).while software and commands to generate data, are taken from Mudd et al., (2014) and (Mudd et al., 2018).

We used LSDTopoTools software for performing chi analysis. It is a collection of programs written in C++ that analyses topographic data, and performs some modelling tasks such as fluvial incision, hill slope evolution and flood inundation. The chi analysis, and a host of other analyses, is run using the "chi_mapping_tool.exe" program, present in LSDTopoTools. We use Python software for both automation and visualization of data produced by the LSDTopoTools.

Following observations made by early workers such as Gilbert (1877), later workers proposed models to explain erosion rates in channels. Many of these models suggests that erosion rate is proportional to both topographic slope and to discharge. The relationship to discharge is related to a number of factors, including how likely the river is to pluck material from the bed, and how much sediment it can carry. Bedload can damage the bed and thus bedload particles can act as "tools" to erode the bed. A number of formulations to capture this behaviour have been proposed (e.g. Howard and Kerby, 1983; Howard, 1994; Whipple and Tucker 1999; Gasparini and Brandon, 2011) and these formulations can be generalized into the stream power incision model (SPIM):

$$E=KA^mS^n$$

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Where E is the long-term fluvial incision rate, A is the upstream drainage area, S is the channel gradient, K is an erodibility coefficient, which is a measure of the efficiency of the incision process, and m and n are constant exponents. In order to model landscape evolution, the SPIM is often combined with detachment-limited mass balance, where:

$$\frac{dz}{dt} = U - E = KA^m \left(\frac{dz}{dx}\right)^n$$

where z is the elevation of the channel bed, t is time, x is the distance downstream, and U is the rock uplift rate, equivalent to the rate of base level lowering if the base level elevation is fixed.In order to examine fluvial response to climatic and tectonic forcing, this differential equation is often rearranged for channel slope, assuming uniform incision rate:

$$S = K_s\, A^{-\theta}$$

where $\theta = m/n$, and represents the concavity of the channel profile, and $K_s=(E/K)^{1/n}$, and represents the steepness of the profile. θ and K_S are referred to as the concavity and steepness indices respectively. This relationship therefore predicts a power-law relationship between slope and drainage area, which is often represented on a logarithmic scale. The concavity and steepness indices can be extracted from plots of slope against drainage area along a channel, where θ is the gradient of a best-fit line through the data, and K_s is the y-intercept. These slope-area plots have been used by many studies to examine fluvial response to climate, lithology and tectonics.

IV. RESULT

The Chi analysis was carried out for the upper Kosi river catchment .The results of the analysis are discussed below. In this analysis for estimation of concavity index two methods are used, first is commonly used method slope- area analysis and second is collinearity methods based on integral analysis

Chi bootstrap analysis shows best-fit θ for Arun and Sunkosi is 0.1 and for Tamur it is 0.2. While Chi disorder analysis shows 0.5 best-fit θ for Arun and Sunkosi and 0.3 for Tamur. Slope area analysis shows best-fit θ for Arun is 0.42 , Sunkosi is 0.49 and for Tamur it is 0.49. When all the three basin run as single catchment by changing parameter of basin size then Chi disorder analysis shows best-fit θ for single catchment is 0.4 , Slope area analysis shows best-fit θ is 0.45

The resultant chi plots and chi coordinate maps are generated and interpreted to find the bedrock river profile and concavity of the catchment. The chi plots give insight about the river profile and concavity. Steepness index is also calculated for these basins, using the m/n value as 0.5 and A0 value as 1. The resultant steepness index values are plotted and used as a proxy to identify zones of higher stream power and gradient which can tell about the erosional power of the streams.

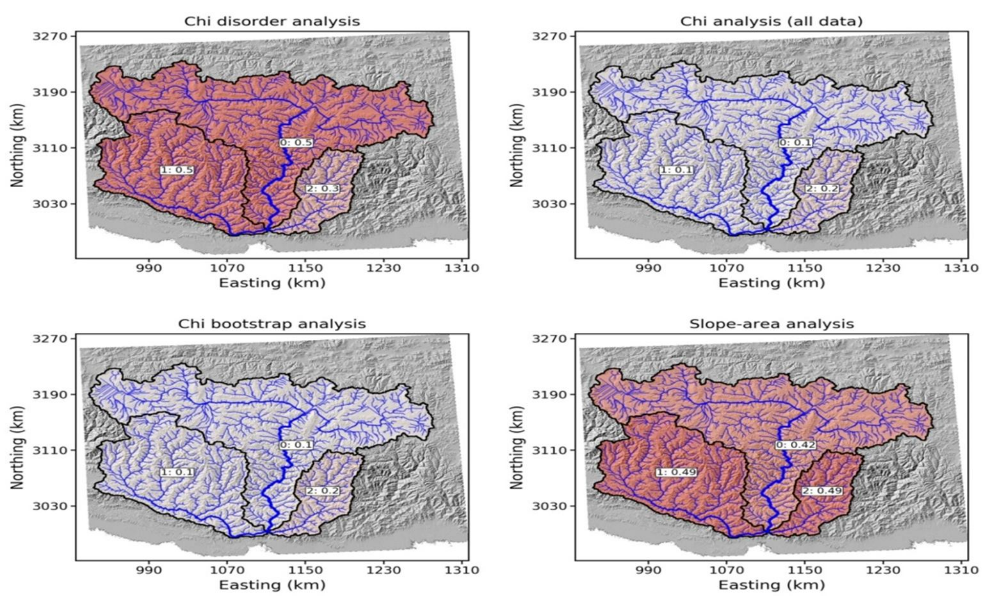

Figure : Exploration of most likely concavity indices in Kosi River upper catchment, Universal Transverse Mercator (UTM) zone 45N.Figure shows chi disorder analysis and slope-area analysis respectively with the basin number is followed by the most likely concavity index in the basin labels.Chi bootstrap analysis and chi analysis (all data) with the basin number is followed by the most likely concavity index in the basin labels.

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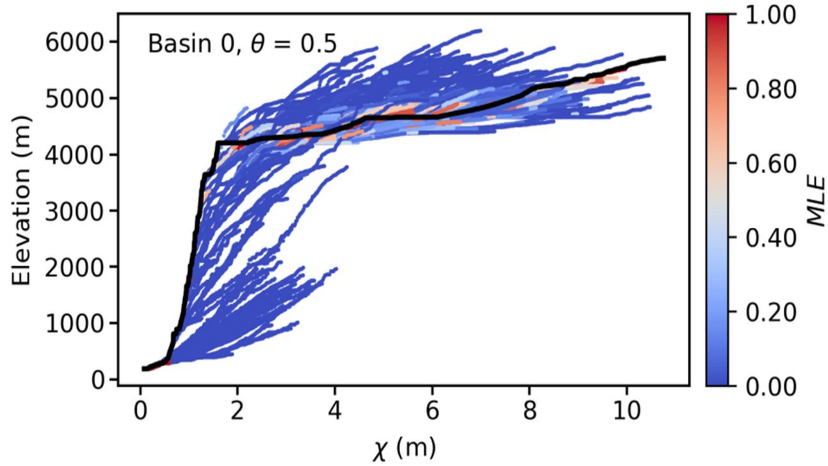

Figure: shows χ- elevation graph for Arun Basin .Main Channel is shown by black line and all the tributaries by sky blue lines.

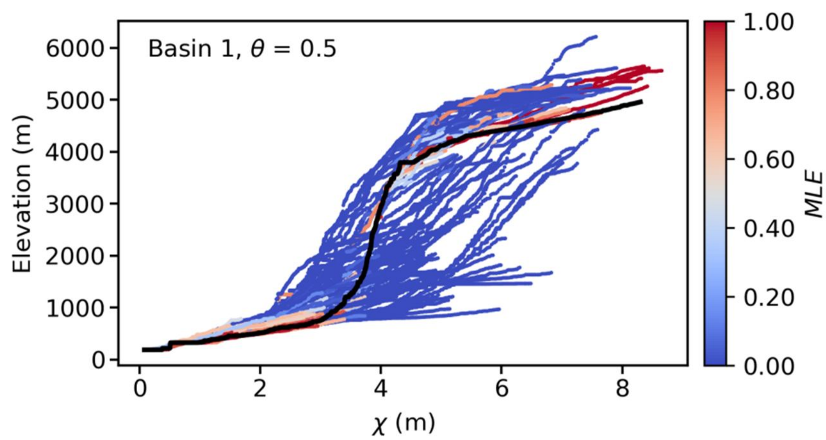

Figure: shows χ- elevation graph for Sunkosi Basin.

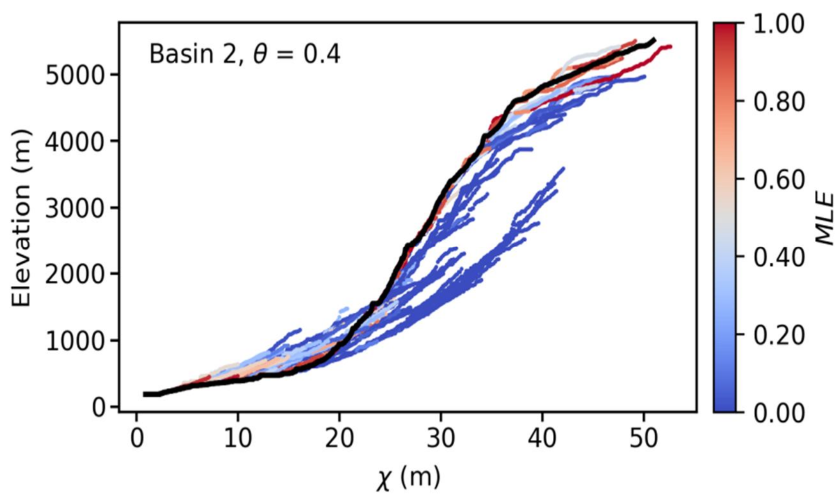

Figure: shows χ- elevation graph for Tamur Basin.

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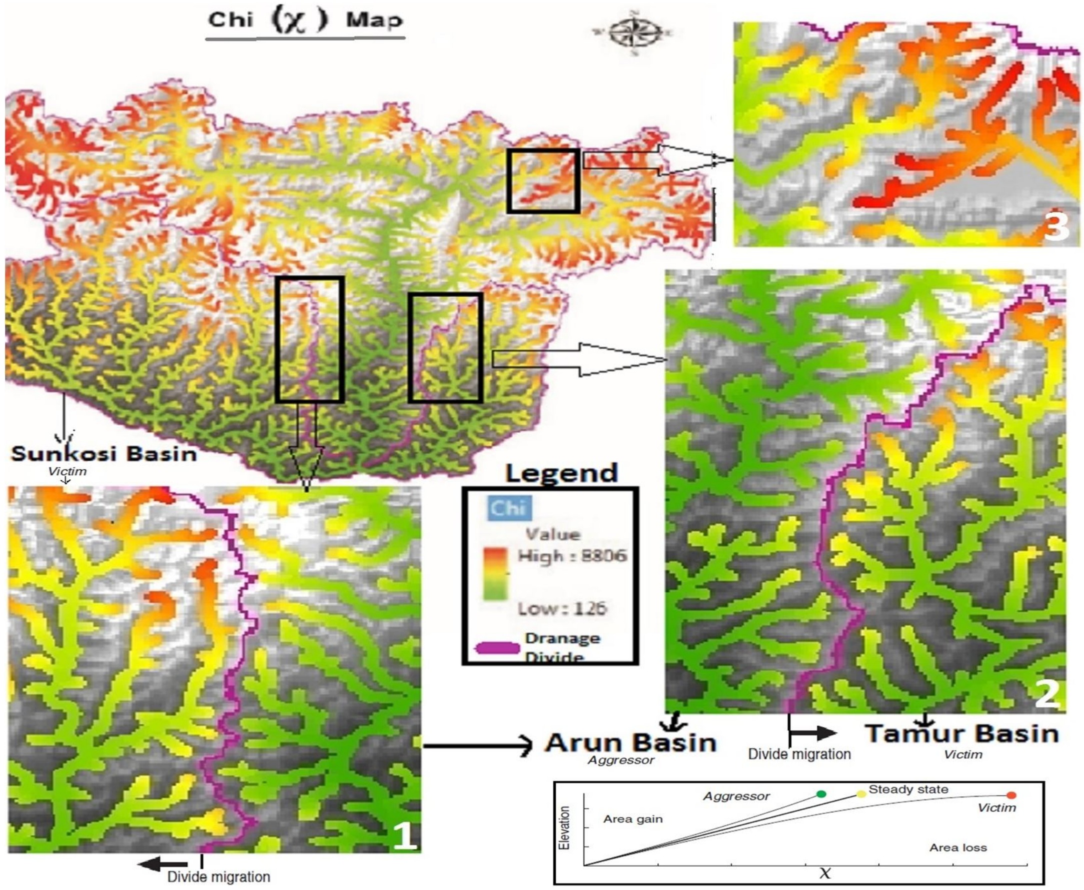

Figure - Raster plot showing chi coordinate value of every tributary as well as main channel. Chi value is higher for small tributary having steep slope and gradually decreases as it coming from higher elevation to lower elevation as river discharge area increases and slope decreases downward.

Measure of River Basin Disequilibrium shown in above figure. River basin on drainage divide migrate from high chi value to low chi value (Willett et al., 2014). Wedge shape of Arun Basin surrounded by Sunkosi and Tamur on right side and left side respectively shows that it is expending from both side , drainage divide migration of Arun and Sunkosi contact from Arun to Sunkosi can be seen(figure-1), thus Arun basin is gaining area and called Aggressor and Sunkosi loosing basin area called as Victim. Similarly drainage divide migration of Arun and Tamur contact from Arun to Tamur figure (2), thus Arun basin is gaining area and called Aggressor and Tamur is losing basin area called as Victim.

χ- elevation graph shown in figure shows that the parameter provides a prediction of the steady-state elevation for a given point on a channel. The basin on the left (aggressor) has lower steady-state elevation at channel heads and therefore drives the drainage divide toward the basin on the right (victim).

Mapping χ throughout a channel network and comparing χ values across drainage divides yield a snapshot of the dynamic reshaping of drainage basins. As a divide moves, either by continuous migration or through discrete river capture, drainage area is removed from one basin and added to the other. The channel length of each affected tributary also changes, leading to a change in the steady state elevation of each channel head bounding the moving divide, presumably moving the channels toward equilibrium. It is recognised that transient landscapes are likely settings for drainage network reorganisation (Willett et al., 2014). In the absence of lithologic variability, climate gradients and tectonic transience, gradients in χ in the channel network between adjacent drainage basins are predicted to indicate locations where drainage divides are migrating toward the catchment with higher χ and drainage network reorganization is ongoing. On the other hand, numerical simulations suggest that spatial variability in uplift is more important than temporal gradients in uplift rates (Whipple et al., 2016). Rivers draining across normal fault systems are often routed through the relay zones between fault tips, where uplift rates are lowest, capturing and rerouting much of the drainage area above the footwall (e.g. Paton, 1992).

V. CONCLUSION

Analysis of the topography in the Kosi upper catchment, highlights that river profiles and the resulting concavities (and/or steepness index K_S) derived from topography are not alone sufficient to interpret the history of landscape evolution but must be considered alongside other observational data and in the context of a process-based understanding of landscape evolution and tectonics.

The parameter χ characterizes the river network topology and geometry, which determine how Tectonic forcing generates variable topography throughout a river basin. Thus, with constant tectonic forcing and homogeneous physical properties, a difference in χ across a divide implies disequilibrium and, presumably, motion of the divide in the direction of larger χ to achieve equilibrium.

In the present study various methods has been used to quantify the most likely concavity index of Kosi upper catchment using both slope–area analysis and the integral method. In addition to concavity index it can be linked to variations in these landscape properties.

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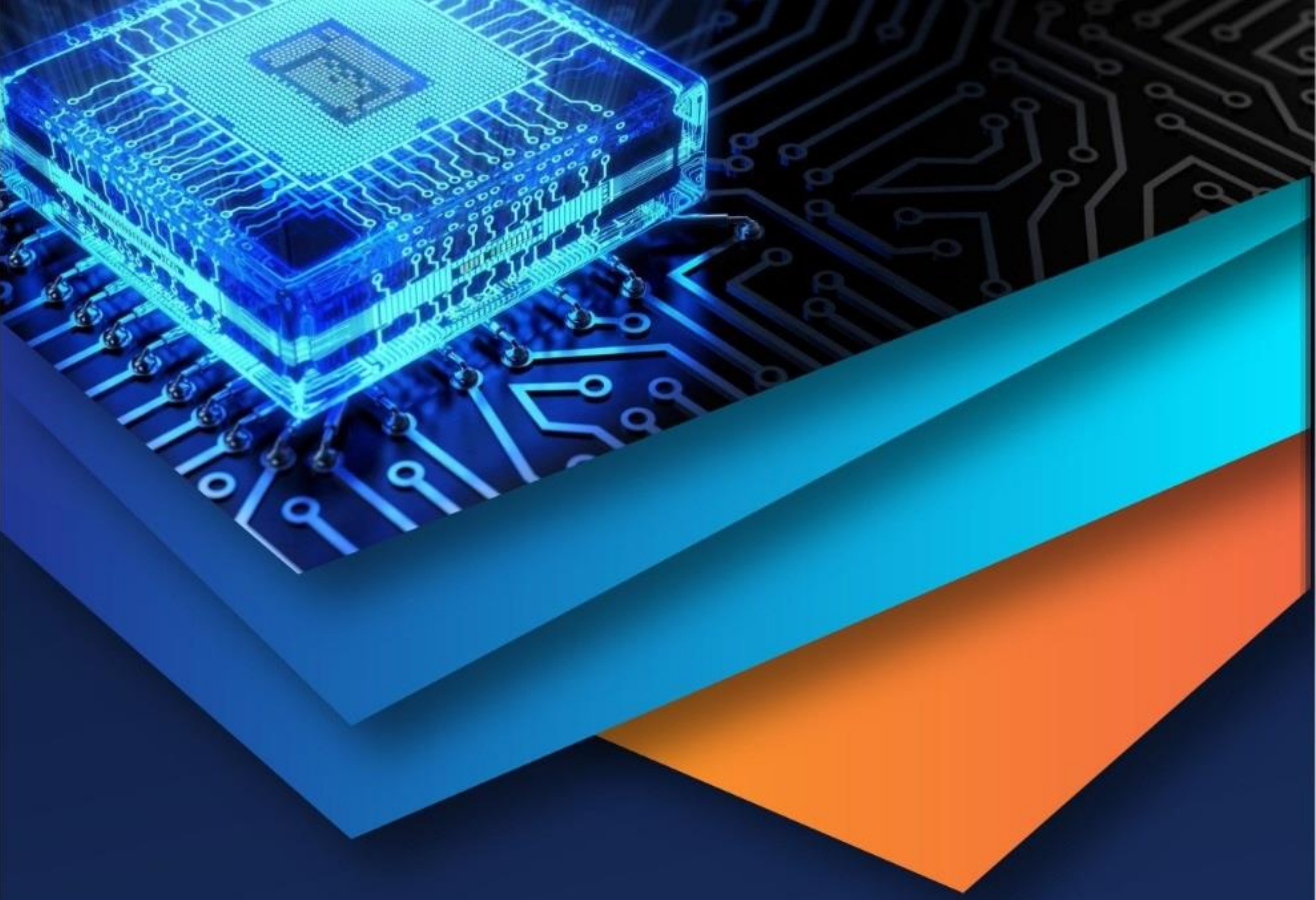

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