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Demarcation of Landslide Susceptibility Zones using Frequency Ratio Method in Coonoor Macro-Watershed, Nilgiris District, Tamil Nadu, India

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Abstract: Present study attempted in Coonoor macro-watershed, Nilgiris District, Tamil Nadu, India where severely affected by landslide during 1978 and 1979. Frequency Ratio (FR) method coupled with geomatic technology is a statistical model to replication environmental conditions. It also uses to take the parameters associated with dependant variables. FR method used for prepare the landslide susceptibility map. Pixel land sliding and non-land sliding calculated in ten factors associated to landslide. Landslide susceptibility map has been categorized into five classes based on natural breaks (Jenks) method. In particular, the method can be used for predicting the landslide occurrence area in future.
Key words: Coonoor macro-watershed, Landslide, Frequency Ratio, Nilgiris District.

I. INTRODUCTION

A landslide is a geological factor which includes a wide range of ground movement, such as rock falls, shallow debris flows, deep seated, shallow landslides, etc. Landslides are a complex natural phenomenon that constitutes a serious natural hazard in many countries (Brabb and Harrod, 1989). Landslides also play a vital role in the changes of landforms. The term 'landslide' includes a wide variety of slope movements, such as soil slips, deep-seated slides, mud flows, debris flows and rock falls (Varnes, 1978; Pierson and Costa, 1987; Hutchinson, 1988; Cruden and Varnes, 1996; Hungr et al., 2001). The materials may move by falling, topping, sliding, spreading (USGS 1981). Landslides cause vulnerable threats to human settlements and to infrastructure, including developmental programmers, highways, railways, waterways and pipelines.

Landslide or failures of slope are one of the major natural hazards in India, which causes human death, property damage and adversely affect variety of resources such as water supplies, agriculture, forest, water resource structures and road networks. Rock falls in mountainous terrains play a major role to landscape shaping factors. Landslide and other slope failure are occurred in mountainous regions due to combined effect of geological factors and human activities such as deforestation and urban development. In mountainous terrain the causes of slope failure due to under the influence of various factors and triggered by natural events such as heavy rainfall. The extreme rain events triggered the major landslides by disturbing the existing stability of slope and other geological and geomorphological factors in nature. Landslides are like lyto occur along the road sides of mountainous region.

India has about 25% of its geographical area under mountainous terrain. The southern, central and western mountains namely the Western Ghats, Sapura and Vindhyan ranges and Aravalis are geologically very old and stable formations as compared to the Himalayas and the Sivalik range in the north. These recent formations are geologically unstable, are in seismic zone and are still in the upheaval stage (Valdiya, 1975). Recently, a very rapid increase in the developmental activities in whole Himalaya which comprises of large scale construction of mountain roads, mining activity, overgrazing, deforestation and opening up of steep land for agriculture. The most affected areas are Jammu and Kashmir, Garhwal Himalayas, North East Himalayas, Western Ghats and Nilgiri Hills.

For the landslide-hazard assessment, the important steps are collection of data, extraction of relevant parameters from spatial database followed by evaluation of the landslide susceptibility using the relation between the landslide events and landslide causing parameters and validation and results. The key approach of this study is to predict future with the current and past scenarios. In other words, the possibility of occurrence of landslides could be comparable with historic frequency of landslides (Pradhan and Lee, 2010). The objective of this study is to prepare the landslide susceptibility by recognizing the implications of landslide using Frequency Ratio method coupled with geomatic techniques.

II. STUDY AREA

The study area Coonoor macro-watershed (Fig.1) falls in the north-eastern part of Bhavani River Sub-Basin of Tamil Nadu. It lies between Latitudes 11°18'27.42" N - 11°24' 35.426" N and Longitudes 76°41'19" E – 76°53'20" E and falls in the Survey of India Toposheet (SOI) Nos. 58 A/11/SE, 58 A/15/NW, 58 A/15/SE, & 58 A/15/SW. It covers an area of about 134.9 sq. kms with a maximum length of 22 kms in East – West direction and 12 kms in NE – SW direction. The minimum and maximum altitudes of the watersheds are 340 m and 2600 m respectively above MSL. The macro-watersheds can be divided into four sub-watersheds viz., Upper Coonoor, Upper Katteri, Lower Coonoor and Lower Katteri.

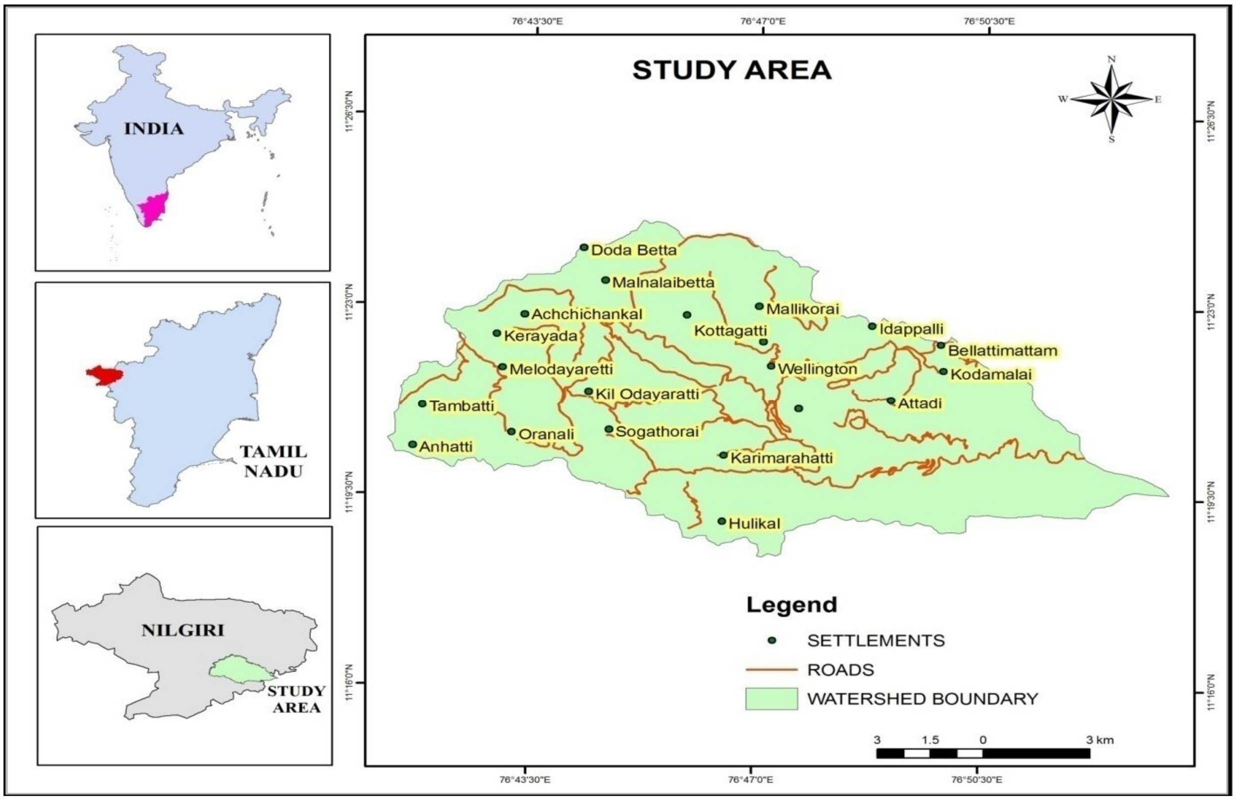

Fig.1 Location map of Coonoor macro-watershed

III. MATERIALS AND METHODS

The landslide inventory layers of the area prepared by the interpretation of aerial photos were scanned and geo-referenced. The landslide locations were demarcated by using of point data in Arc GIS software by validating it with the field visits and surveys. Nilgiris is highly prone to shallow debris which is difficult to recognize due to vegetation cover and deep earth landslides which is recognized by the paleo scars that is preserved as evidence. One hundred and two landslides had taken place in the Coonoor macro watershed of area 134.9 km^2 during the period of 1978 and 1979. This study integrates various factors such as slope, aspect, drainage density, and distance from drainage, lineament density, distance from lineament, geomorphology, land use, soil and distance from road for generating the landslide susceptibility map.

IV. RESULTS AND DISCUSSION

A. Slope

Landslides in mountainous terrain often occur during or after heavy rainfall, resulting in the loss of life and damage to the natural and/or built environment. A variety of approaches has been used in slope instability mapping and can be classified into qualitative factor overlay, statistical models, and geotechnical process models. In the qualitative approach, several maps representing the spatial distribution of those physical parameters which may have influence on the occurrence of landslides are combined into a hazard map using subjective decision rules, based on the experience of geoscientists involved (Anbalagan, 1992; Pachauri and Pant, 1992; Sarkar et al., 1995). The elevation layer of the macro-watershed was obtained by digitising the contours in10 m interval in the

Survey of India (SOI) toposheets. The DEM of the area was created in ArcGIS using spatial analyst. The slope and aspect layers were generated from the DEM and the pixel size was kept as 30 x 30 m. The slope of the study area was categorised in to six classes such as 0 to10°, 10 to 15°, 15 to 25°, 25 to 35°, 35° to 45° and 45° to 60°.

B. Aspect

The aspect of the study area was generated from the DEM using spatial analyst tool in ArcGIS. The aspect map is classified in to nine viz., north, northeast, and east, southeast, south, southwest, west, northwest and flat. Among these nine classes the eight classes were representing the slope angle and ninth class flat denotes the area where slope angle is minor or absent.

C. Drainage Density

The geomorphic character of drainage basins, following techniques first suggested by Horton (1945) may be measured or described in a variety of ways. In a general way these properties may be divided into four classes: (1) length or geometric properties of the drainage net, (2) shape or area of the drainage basin, (3) relation of the drainage net to the basin area, and (4) relief aspects of the basin. It has been assumed by hydrologists and geomorphologists that certain relations must exist between runoff characteristics and topographic or geomorphic characteristics of stream basins. The digitization of stream and river in the area by using ArcGIS software with georeferenced toposheets obtain from Survey of India. According to Sarkar and Kanungo, (2004) Drainage density plays a vital role to trigger landslide and provides an indirect measure of groundwater conditions. The drainage density of study area was classified in to five categories and it ranges from 0 to 10 Km/Sq. Km.

D. Distances from Drainage

The distance from drainage was generated from drainage layer by using multiple ring buffer tool of spatial analyst in ArcGIS. It was categorized in to five classes namely, 0 – 50 m, 50 – 100 m, 100 – 150 m, 150 – 200 m and 200 – 250 m.

E. Soil

Sethumadhava Rao, (1961) delineate that, Nilgiris is comprised with many types of soil and its thickness may reach some places up to 45 m in depth. Lateritic soil covered major part of the area followed by clayey loam with humus rich black soils are seen along the river courses. The study area covered with clay, clayloam, habitation, loam, loamysand, sandyclay, sandyclayloam and sandyloam. The soil layer was procured from soil Atlas, Tamilnadu Agriculture University, Coimbatore and field check was carried out to confirm the characteristic of the map.

F. Geomorphology

The geomorphology layer was generated from the GSI map (Seshagiri et al., 1982). The layer was vectorised in ArcGIS using Landsat ETM+ FCC image with 30 m resolution which was improved by resolution merge with PAN data in ENVI image analysis software. The features of the area were classified in to four categories viz, deflection slope, highly dissected plateau, moderately dissected plateau and valley fills and the features were verified in the field.

G. Lineament Density And Distance From Lineament

The lineament layer was vectorised in ArcGIS from satellite imagery using Landsat ETM+ FCC image. The lineament density of study aea was generated by using density tool in extension Spatial Analyst of ArcGIS. The search radius used for the generation of the lineament density map was 1 km and the cell size was selected as 30 m. The lineament density layer was classified into five classes such as very low, low, moderate, high and very high. The very high lineament density has been observed center and western part of the study area.The distance from lineament contributes to landslide and the layer was generated using multiple ring buffer tool in ArcGIS and was also classified into seven classes as 0 to 100 m, 100 to 200 m, 200 to 300 m, 300 to 400 m, 400 to 500 m and > 600 m.

H. Land Use

The land use/ land cover of study area was vectorised from satellite imagery using Landsat ETM+ FCC image and the features were verified in the field. The Google Earth image and toposheet information is also used while preparing the training site signature file. The land use recognised in area are Built-up, crop land, forest, forest plantation, land with scrub, tea plantations, tank bed cultivation, tank bed vegetation and reservoir.

I. Distance From Road

Distance from road is similar to the effect of the distance from drainage, occurrence of landslide along road and on the side of the slopes affected by roads (Pachauri and Pant 1992; Pachauri et al. 1998; Ayalew and Yamagishi 2005; Yalcin 2005). A road constructed along slopes causes reduce in the load on both the landscape and on the toe of slope may develop some cracks. Although a slope is balanced before the road construction, some instability may be observed because of negative effects of excavation. Some landslides were recorded whose origin can be attributed to road construction (H. R. Pourghasemi et al, 2012). Distance from Road was prepared by using multiple ring buffer techniques in ArcGIS spatial analyst tool and is classified 6 classes with 100 m interval and most of the landslides occurred very near to the road i.e., less than 100 m.

Table: 1 Frequency ratio values calculated for generation of LSM

Factor	classes	Landslide occurrence	Landslide occurrence in %	Pixels domain	Pixels domain %	Frequency Ratio
Slope	0 – 10°	20	19.61	21458	17.20	1.14
	10 – 15°	37	36.27	22727	18.22	1.99
	15 – 25°	30	29.41	21875	17.54	1.68
	25 – 35°	12	11.76	20466	16.41	0.72
	35 – 45°	3	2.94	19644	15.75	0.19
	45 – 60°	0	0.00	18578	14.89	0.00
Aspect	Flat	0	0	13901	11.14	0.00
	North	7	6.86	16872	13.53	0.51
	Northeast	9	8.82	13273	10.64	0.83
	East	12	11.76	15060	12.07	0.97
	Southeast	21	20.59	18253	14.63	1.41
	South	17	16.67	16195	12.98	1.28
	Southwest	19	18.63	12046	9.66	1.93
	West	15	14.71	10032	8.04	1.83
	Northwest	2	1.96	9112	7.30	0.27
Drainage Density	0 to 2	10	9.80	19044	15.27	0.64
	2 to4	23	22.55	28116	22.54	1.00
	4 to 6	28	27.45	31413	25.18	1.09
	6 to8	24	23.53	26722	21.42	1.10
	8 to 10 Sqkm	17	16.67	19454	15.59	1.07
Distance from Drainage	0 - 50 m	36	35.29	37023	29.68	1.19
	50 - 100 m	29	28.43	31312	25.10	1.13
	100 - 150 m	25	24.51	23589	18.91	1.30
	150 - 200 m	7	6.86	17253	13.83	0.50
	200 - 250 m	5	4.90	15571	12.48	0.39
Lineament Density	very low	33	32.35	66023	52.93	0.61
	low	11	10.78	31671	25.39	0.42
	moderate	28	27.45	10102	8.10	3.39
	high	26	25.49	10968	8.79	2.90

	very high	4	3.92	5983	4.80	0.82
Distance from Lineament	0 - 100 m	27	26.47	23781	19.06	1.39
	100-200 m	16	15.69	21281	17.06	0.92
	200 - 300 m	16	15.69	19059	15.28	1.03
	300 - 400 m	11	10.78	17306	13.87	0.78
	400 - 500 m	14	13.73	15770	12.64	1.09
	500 - 600 m	13	12.75	14419	11.56	1.10
	>600 m	5	4.90	13129	10.52	0.47
Geomorpology	Deflection Slope	8	7.84	29287	23.48	0.33
	Highly Dissected plateau	69	67.65	49721	39.86	1.70
	Moderately Disssected plateau	19	18.63	29872	23.95	0.78
	Valley Fill	6	5.88	15869	12.72	0.46
Land Use	Built-up	8	7.84	11230	9	0.87
	Crop land	6	5.88	10471	8	0.70
	Forest	1	0.98	15557	12	0.08
	Forest Plantations	1	0.98	12749	10	0.10
	Land with scrub	3	2.94	9270	7	0.40
	Tea Plantations	83	81.37	44984	36	2.26
	Tank bed cultivation	0	0.00	6825	5	0.00
	Tank bed vegetation	0	0.00	6811	5	0.00
	Reservoir	0	0.00	6854	5	0.00
Distance from Road	0 - 100 m	25	24.51	19451	15.59	1.57
	100 - 200 m	20	19.61	19111	15.32	1.28
	200 - 300 m	23	22.55	23901	19.16	1.18
	300 - 400 m	14	13.73	19742	15.83	0.87
	400 - 500 m	8	7.84	17865	14.32	0.55
	500 - 600 m	12	11.76	24679	19.78	0.59
Soil	Clay	0	0.00	7936	6.36	0.00
	Clayloam	0	0.00	6559	5.26	0.00
	Habitation	4	3.92	12774	10.24	0.38
	Loam	1	0.98	10477	8.40	0.12
	Loamysand	46	45.10	21879	17.54	2.57
	Rockout crop	15	14.71	12488	10.01	1.47

	Sandyclay	16	15.69	21748	17.43	0.90
	Sandy clay loam	17	16.67	19932	15.98	1.04
	Sandy loam	3	2.94	10951	8.78	0.34

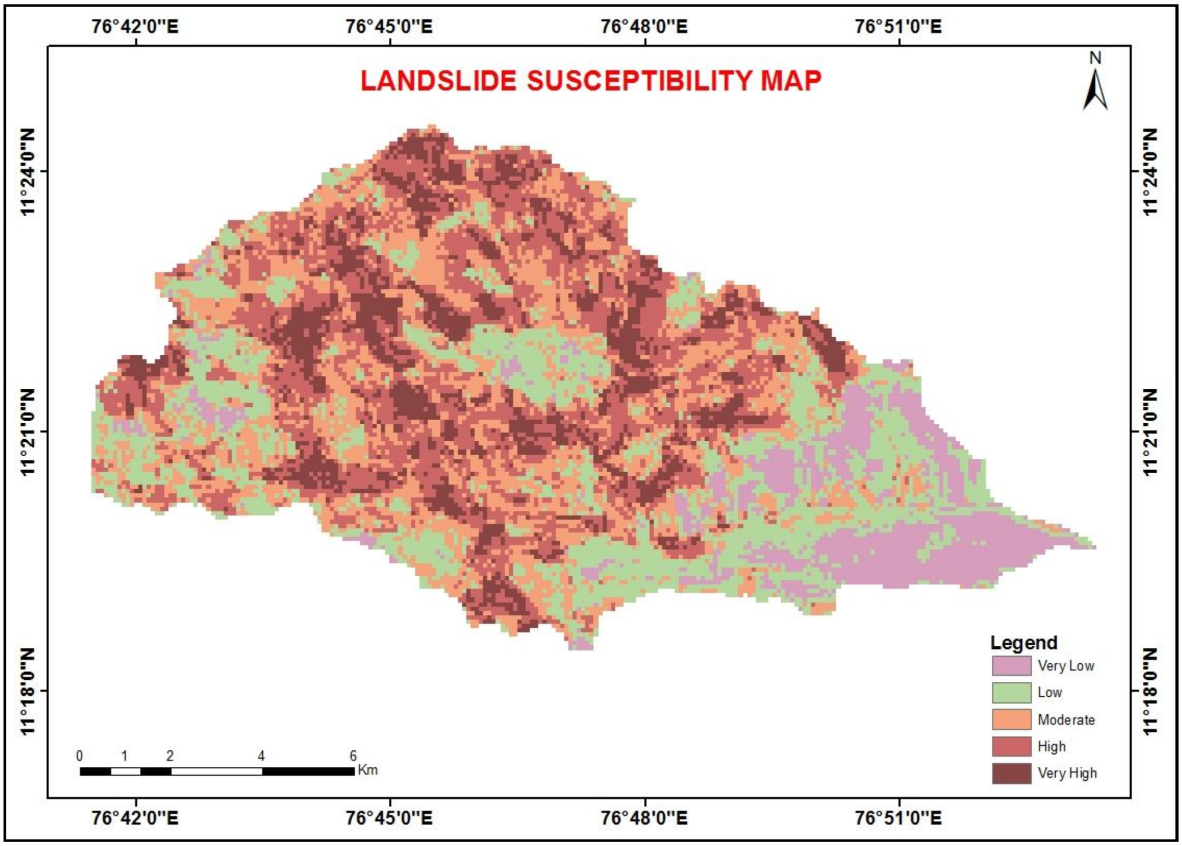

Fig.2 Landslide susceptibility map generated from frequency ratio method

The frequency ratio value 1 indicates that the probability of landslide event is higher than normal landslide occurrence in the area. Slope classes the FR values also show that landslides have not occurred in slopes of greater than 45° indicating such slopes do not have soil cover. In aspect the frequency ratio ranges from 0 to 1.88 with ratios more than 1 for the classes are east, southeast, south, southwest and west. The FR values also show that landslides have not occurred in flat, since the class indicating horizontal surface.

The drainage density class, the relationship between landslide occurrences and drainage density shows that the FR value is less in very low drainage density class and it attain the maximum value of 1.27 in high drainage density class indicating that the drainage density class increasing the FR values also increasing. The frequency ratio value of distance from drainage is ranges from 0.62 to 1.24 with ratios more than 1 for the class is 50 – 150 m. The total 64 landslides out of 77 falls within 150 m and remaining 13 landslides occurred above 150 m to 250 m. These indicate that head ward and toe erosion action of the stream is influencing the landslides and this pattern resultant with drainage density and areas with more streams have more landslides. The relationship between landslide occurrences and lineament density shows that the FR value is less in very low and low lineament density 0.64 and 0.36 respectively and it attain the maximum value of 3.40 in moderate high density class indicating that the lineament density class increasing the FR values also increasing. In distance from lineament class, the frequency ratio values ranges from 0.37 to 1.43 with ratios more than 1 for the class is 0 – 300 m, 100 – 200 m and 200 – 300m and the landslides are almost equally distributed in 300 to 600m classes. The variation in frequency ratio is mainly due to the variation in the percentage of the class in the area.

The frequency ratio of geomorphology indicates that highly dissected has a high frequency ratio of 1.66 followed by moderately dissected plateau had frequency ratio of 1.08 and deflection slope landform has very low probability 0.33. Land use, the frequency ratios values calculated for various sub-variables show that areas where tea plantation are have the highest probability of slope instability followed by built-up land, and crop land. In distance from road, the frequency ratio of 0 to 100 m distance from road class shows high frequency ratio (1.83) followed by 100 to 200 m class. These two classes constitute 41 landslides which is 53.25% of the total slides used for calculation of frequency ratio. The frequency ratio values of variable factor are shown in table .1

IV. CONCLUSION

In this study, results from the susceptibility map have been validated which represent 79.22% of landslide occurred in high and very high susceptibility class. The density increases in high and very high landslide susceptibility classes which show that the Landslide Susceptibility Map (LSM) (Fig: 2) is reliable.

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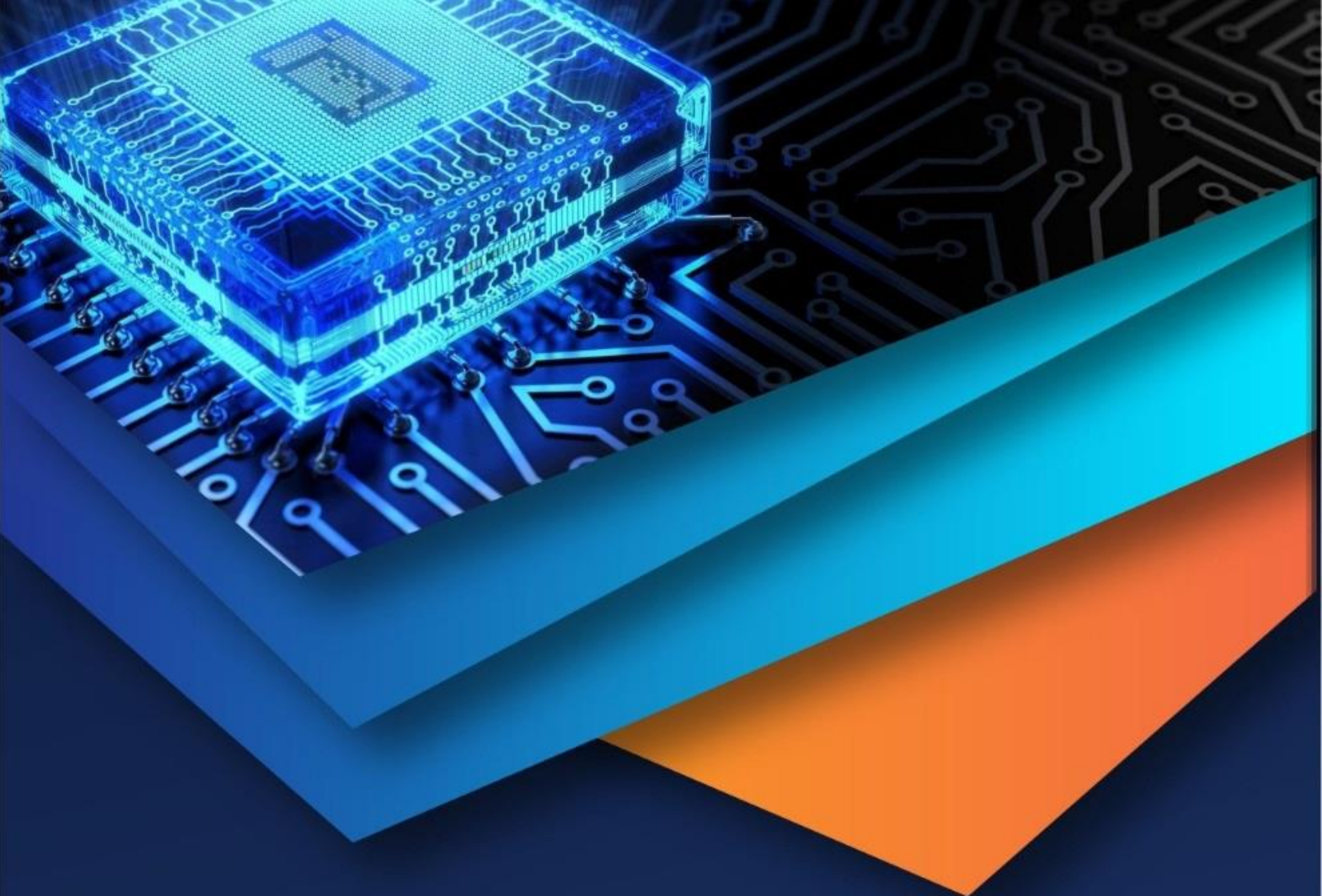

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