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Spatial Distribution of Ambient Air Pollution Using Air Quality Index in Himachal Pradesh- A Case Study

Suneha Dhiman[1], Har Amrit Singh Sandhu[2]
[1,2] *PEC University of Technology, Chandigarh*

Abstract: The concentration of any pollutant is desirable in the atmosphere but if it increases a certain limit of safety, air pollution occurs. The monitoring of Ambient Air Quality (AAQ) is an important task at the present times. Moreover, to develop an understanding about the air quality parameters is as important as the monitoring program. Indian - Air Quality Index (IND-AQI) is used to understand air quality parameters through a single number in India. Further, AQI may be spatially distributed throughout the study area to analyze and visualize its trend in a specific area. This distribution may be done using Inverse Distance weighting (IDW) or Kriging method in GIS environment. Here, an attempt has been made to understand the AQI of Himachal Pradesh using IDW method. In this study, AAQ data for 17 sites has been procured from the state agency and segregated in Residential, commercial and Industrial zones to understand the variation of AQI during 2010-2015. Further, these zones are analyzed and it is observed that industrial area of Baddi, Kala Amb and Paonta sahib are most polluted among all the studied sites. Overall, it has been found that 60% of the residential, 37% of the industrial and 50% of the commercial monitoring stations showed AQI category as Satisfactory. Similarly, 20 % of the residential, 57% of the industrial and 16% of the commercial monitoring stations showed the study area to be moderately polluted.
Keywords: Air Pollution, Air Quality Index, Ambient air quality, Geographic Information System, Inverse Distance Weighting, Spatial Distribution

I. INTRODUCTION

Air is present in abundance on the surface of the earth. But increasing urbanization, industrial development have led to the pollution of the air. Lack of awareness, poor maintenance of motor vehicles and poor road conditions also contribute to this fact of deteriorating air quality. This resulted in availability or presence of more polluted air in the atmosphere than the clean air [1]. All these facts made air pollution as one of the major concern nowadays and great topic of debate at all levels in India and the world. The pollution levels are increasing at a rate faster than expected in various parts of the world and thus require serious attention not only in India but also all over the world. Thus, the monitoring of environmental parameters has become one of the highest priorities to know the status of air quality and further to develop environmental protection policies [2]. The air quality is mainly affected due to emission and accumulation of RSPM, SO_2, and NO_x. The large cities in India through various air pollution related studies depict that pollutant concentration levels can cause serious health impacts as all of these are main reason for cardiovascular and respiratory diseases [3].

Since the most of the studies are focused on the large cities, considering them to be the center for the pollution problem; the small cities are not very far behind in the race. A time will come when these small cities will breathe out more pollution than the large ones. The study is hence been focused in an area where there is very less growth in terms of industries but it contributes to the pollution problems because of the presence industrial areas majorly in Baddi, district Solan, Gondpur and Kala Amb, district Sirmaur. The above stated reasons thus implies to check these parameters on regular basis at such places. The Central Pollution Control Board (CPCB) in India do the work to provide standard limits in the form of National Ambient Air Quality Standards (NAAQSs) for emissions of a number of pollutants from a number of sources which have been classified into two categories: industrial or residential and sensitive areas. Since the concentrations of almost all the pollutants are generally expressed as $\mu g/m^3$ or mg/m^3 (micro/milli-grams per cubic meters), the monitoring and checking the pollutants' limit alone are not sufficient until these complex values are understood by the general public. Thus, there comes an index give by CPCB, called Air Quality Index (AQI) [4], which not only categorize the distribution of concentrations air pollutants but also provides a color coding (see Table 1) to understand the air quality.

The study is hence been focused on developing AQI using the pollutant concentrations collected from the Himachal Pradesh State Pollution Control Board's website (www.hppcb.ac.in) and further using GIS to develop spatial-maps of the study area. The present study also includes comparing these spatial maps during the study period (from 2010 to 2015).

II. STUDY AREA

The study area Himachal Pradesh, came into being on 25 January, 1971. Himachal Pradesh located in the northern region of India, is famous for its natural beauty, hill stations and temples. The state has a number of perennial rivers like Chenab, Beas, Yamuna, Sutlej, Rabi are flowing through it and thus hydro-electric power plants plays a big role in the economy of the state along with tourism and agriculture. Himachal Pradesh is situated between latitudinal extensions ranges from 30^0 22' 40" to 33^0 12' 20" N and longitudinal extension from 75^0 45' 55"E to 79^0 04' 20" E (See Figure 1). The altitude in the Pradesh, a wholly mountainous region lying mostly on the foothills of Dhauladhar range and Himalayas, ranges from 350 meters to 6975 meters above MSL. It is surrounded by the state boundaries of Jammu and Kashmir to the North, Uttaranchal in the South-East; Haryana in the South and Punjab in South-West. On the North-East, it shares its boundary with Tibet, forming India's border.

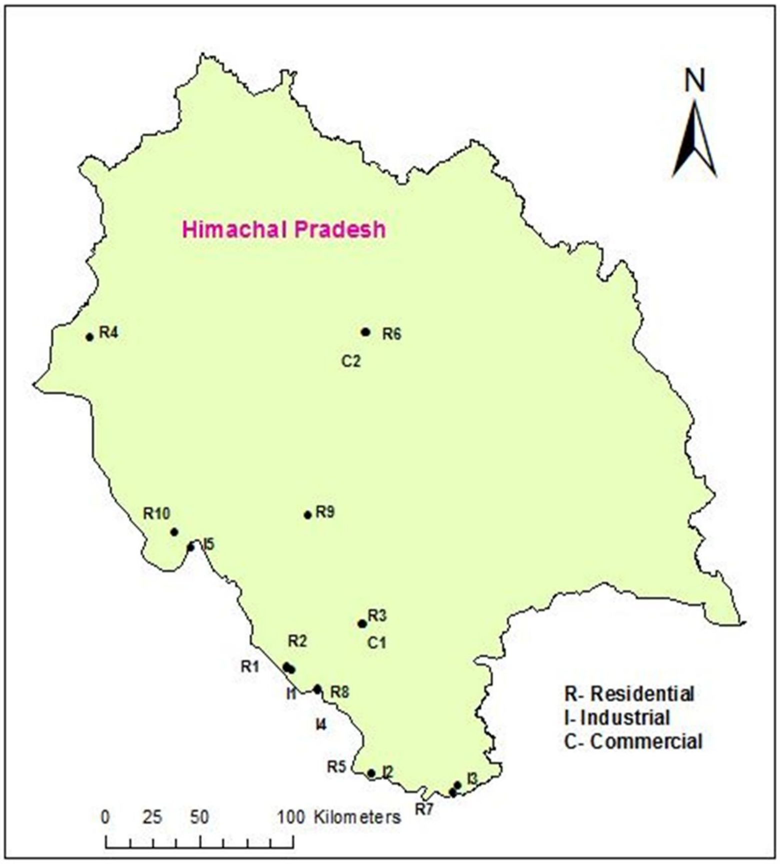

Figure 1: Map showing the study area

Himachal Pradesh has an area coverage of 55,673 square kilometers (21,495 square miles) with a population of 6,864,602 (Census of India 2011). 90 % of which lives in rural areas. The state is divided into 12 districts having Shimla as the summer capital and Dharamshala as the winter capital. The climatic conditions vary from the semi- tropical to semi-artic having an average temperature range of 28^0C to 32^0C.

III. METHODOLOGY

Figure 2 shows the methodology adopted for the present study. This methodology is discussed briefly in the coming sections. In this study, AAQ data for 17 sites has been procured from the state agency and segregated in Residential, commercial and Industrial zones to understand the variation of AQI during 2010-2015. For the convenience to calculate the AQI at different monitoring

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stations in the study area, a code has been assigned to each particular monitoring station in which R stands for residential, I for industrial and C for commercial. The AQI at these monitoring stations is then calculated accordingly (Table 1).

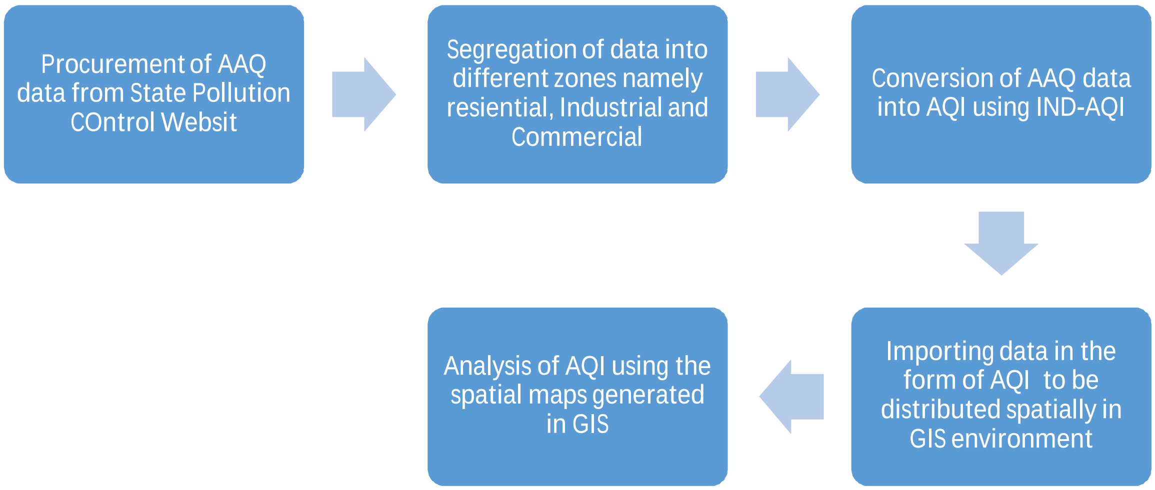

Figure 2: Flow chart for the adopted methodology

Table 1: Locational details of monitoring sites in the study area

Local Name of Site	Site Label	Lat./Long	Local Name of Site	Site Label	Lat./Long
HB Baddi	R1	30.94023N, 76.80708E	R.O. , Una, R	R10	31.46840N. 76.27028E
DIC, Baddi	R2	30.93234N, 76.80431E	Barotiwala, Baddi	I1	30.92255N. 76.83173E
Tekka Bench, Shimla	R3	31.10481N, 77.17467E	Johron, Kala Amb, I	I2	30.51730N. 77.20890E
Ro, Damtal	R4	32.22575N, 75.86008E	Gondpur, Paonta, I	I3	30.46717N. 77.62258E
Trilokpur, Kala Amb, R	R5	30.51730N, 77.20890E	Sector-1, Parwanoo, I	I4	30.84780N. 76.95420E
Hadimba Road, Manali, R	R6	32.24602N, 77.18251E	Mehatpur, Una, I	I5	31.43400N. 76.33100E
Paonta, R	R7	30.44528N, 77.60206E	Bus Stand, Shimla	C1	31.10279N .77.16018E
Sector-4, Parwanoo, R	R8	30.84926N, 76.95346E	Nehru Park, Manali, C	C2	32.24589N. 77.18994E
Mc Office, Sundernagar	R9	31.53360N, 76.90490E			

IV. FORMULATION OF AIR QUALITY INDEX (AQI)

The ambient air quality requires systematic as well as scientific investigations so as to find a proper spatial expansion of pollutants or pollution [5]. For the spatial distribution of the pollutants, AQI was calculated for the reason that air pollution measured in the form of Air Quality Index can be used to provide a meaningful assessment of air pollution in the common man's perception [6]. The related health impacts corresponding with the category of AQI is shown in Table 2. The calculation of AQI involves sub-index calculation (1). Sub-index function depicts the relationship between the concentration of pollutant (C_P) and the corresponding sub-

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index (Ii) The sub index I_p for a given pollutant concentration is calculated as per *Linear segmented principle* in *equation (1)* as follows [4]:

$$I_P = [\{(I_{HI} - I_{LO})/ (B_{HI} - B_{LO})\} * (C_P - B_{LO})] + I_{LO} \quad (1)$$

Where,
B_{HI} = Breakpoint concentration greater or equal to given concentration (See Table 3)
B_{LO} = Breakpoint concentration smaller or equal to given concentration (See Table 3)
I_{HI} = AQI value corresponding to B_{HI} (See Table 3)

I_{LO} = AQI value corresponding to B_{LO}; subtract one from I_{LO}, if I_{LO} is greater than 50 (See Table 3)
C_P = Pollutant concentration.
A large number of methods are available for the aggregation of Sub-indices such as Green Index (GI), Ontario Air Quality Index (OAQI), Oak Ridge Air Quality index (ORAQI). The method (linear regression) selected for the aggregation of sub-indices is maximum operator system because of the reason that it is free from Ambiguity (over estimation of AQI) and Eclipsing (under estimation of AQI).The AQI as per maximum operator system is calculated in equation (2) as [4]:

$$AQI = \text{Max. of } (I_1, I_2, I_3 \ldots\ldots I_n) \quad (2)$$

Where,
$I_1, I_2, I_3 \ldots$In are the sub-indices for the pollutants calculated using equation (1).

Table 2: Categories of IND-AQI (National Air Quality index), Range and associated Health Impacts as approved by CPCB (Central Pollution Control Board), 2014 [7].

AQI Category	AQI Range
GOOD	0-50
SATISFACTORY	51-100
MODERATE	101-200
POOR	201-300
VERY POOR	301-400
SEVERE	>401

Table 3: Breakpoints for AQI Scale 0-500 (units: $\mu g/m^3$ unless mentioned otherwise), National Air Quality Index, CPCB, October 2009 [8].

AQI Category (Range)	PM10 (24 hour)	SO_2 (24 hour)	NO_2 (24 hour)
Good (0-50)	0-50	0-40	0-40
Satisfactory (51-100)	51-100	41-80	41-80
Moderate (101-200)	101-250	81-380	81-180
Poor (201-300)	251-350	381-800	181-280
Very Poor (301-400)	350-430	801-1600	281-400
Severe (>401)	430+	1600+	400+

It is to be noted that all the six pollutants concentrations are not necessary to calculate the AQI, although it is desirable. The index is so designed that a minimum of three pollutants RSPM, SO_2, and NO_2 are sufficient for the purpose [4].

V. SPATIAL DISTRIBUTION OF AQI USING GIS

Geographic information systems (GIS) can be used to track the emissions by delineating the effects of them on plant and animal life, so that they can be monitored to ensure no further increase in pollution levels. It helps to locate the sources of air so that these sources can be monitored to improve the emissions and thus environment [9]. Further, it is not possible to monitor the ambient air at each and every point and thus it becomes very important to have a process which can be used to calculate or predict the data for unknown points in the area under study [10]. GIS have been used to make valuable contributions to this purpose [11]. GIS is a computer based tool for collecting, storing, transforming, retrieving and displaying spatial data from the real GIS world. It provides tools for managing, compiling, distributing and analyzing the data. The spatial analyst tool extension in ArcGIS provides a number of tools for this. Even a few number of sample points representing change in data such as landscape, population or environment and environmental factors can be used to visualize its continuity and variability through the use of interpolation tools [5]

GIS provides a special tool called interpolation, which can precisely calculate the values of un-sampled points using sampled data i.e. collected or observed data. Interpolation is a technique based on the principle of spatial autocorrelation or spatial interdependence, and measures the relationship between near and distant points. Spatial interpolation is used for predicting the changes in a particular feature, to examine the trends in the available data and to fill the missing values [12]. Inverse Distance Weighing method under spatial interpolation tool in GIS does the work for us and predicts the pollutants concentrations at unmonitored stations and thus, we can get information about the distribution pattern of the air pollutions at un-sampled locations also. This method uses linear function of extent or distance between the un-sampled and the sampled points to assign higher value to the close by points and lower to the far away ones. Thus, the measured values (known values) will have more influence on the predicted value (unknown value) than those farther away as defined above. More specifically, it can be said that IDW assumes a local influence created by each measured point which goes on decreasing with increase in distance. Thus, the points in the near neighborhood of the observed point are given higher weights, whereas points at a far distance are given small weights [13]. Whenever there are less known observed data, IDW is preferred over any other method of interpolation [14]. Thus for spatial distribution of AQI in the present study, IDW is used.

VI. RESULTS AND DISCUSSIONS

The calculated AQI using equation (1) is imported to GIS software, to be distributed spatially. For this purpose, Inverse Distance Weighing method is used as stated above. This method uses the fact of inverse distance to distribute the weights. According to this, the points of observation i.e. the monitoring stations are given highest values. The points near to the monitoring stations are given more weight than the points which are far from the monitoring stations. The AQI distribution was carried out in the form of spatial maps in GIS (See figure 3 - 8).

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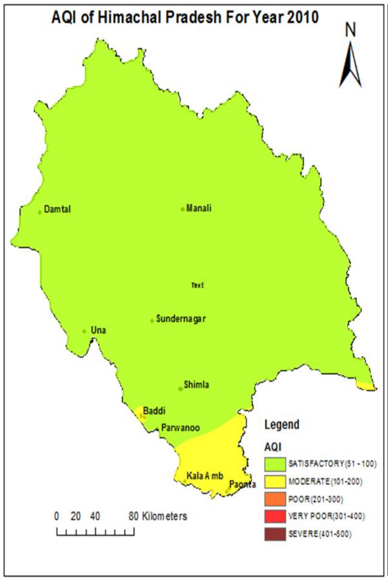

Fig. 3: Spatial distribution in 2010

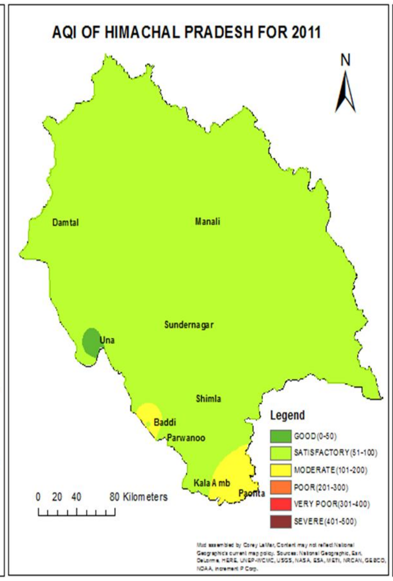

Fig. 4: Spatial distribution in 2011

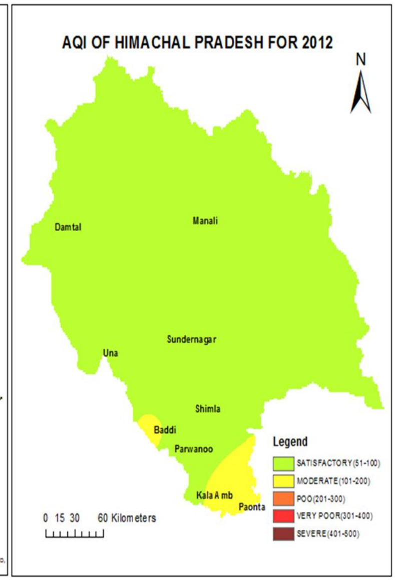

Fig. 5: Spatial distribution in 2012

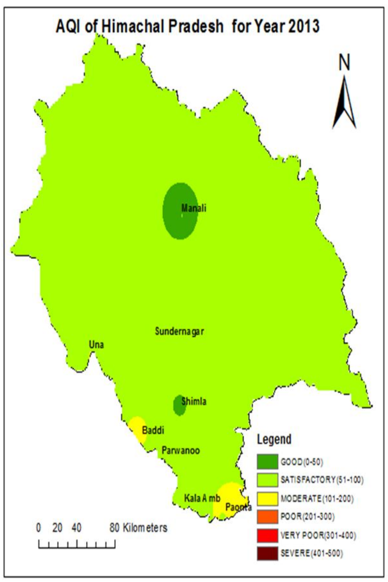

Fig. 6: Spatial distribution in 2013

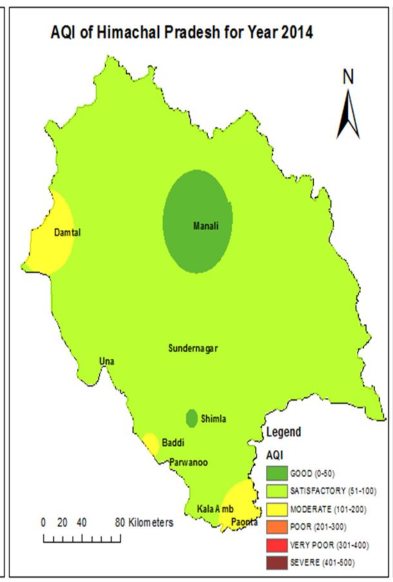

Fig. 7: Spatial distribution in 2014

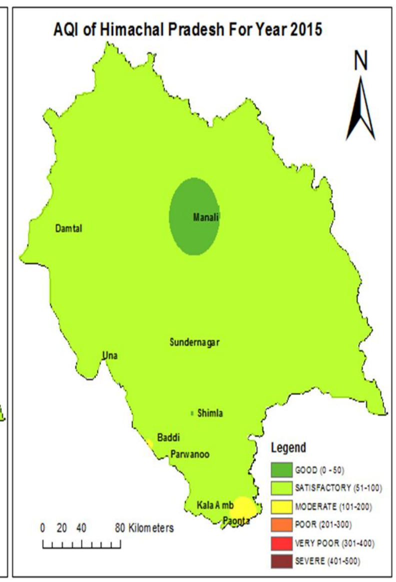

Fig. 8: Spatial distribution in 2015

The distribution of the AQI showed most of the area (nearly 70%) dominating the Satisfactory category of AQI distribution. But with the passage of time, the quality of air is being improved resulting in a minimization of the moderately polluted area as depicted by the spatial maps. These parts of the study area, earlier showing the area as moderately polluted shifted to satisfactory category. These spatial maps can be easily interpreted and understood. The study also showed that some of the residential sites also crossed the satisfactory limit of AQI distribution in the study area during the study period. The distribution showed almost 70% of the time during the study period the area lying in the satisfactory category of the AQI distribution.

Moreover, if seen individually during the study period, 60% of the residential, 37% of the industrial and 50% of the commercial monitoring stations showed AQI category as Satisfactory. Similarly, 20 % of the residential, 57% of the industrial and 16% of the commercial monitoring stations showed the study area to be moderately polluted. During the study period, the AQI at R1 has been improved from moderate to satisfactory category, R3 from satisfactory to good, R8 from satisfactory to very close to good. The AQI at R5, R6, R8 and R9 have improved well within their already existing category of IND-AQI. The remaining three residential sited showed decrement in the air quality during 2010-2015.Among the industrial monitoring stations, I1 showed the maximum improvement in the AQI and changed from moderately polluted to satisfactory category of AQI distribution. Two of the industrial stations showed quite well improvement in AQI being within the same category of AQI. The AQI at these stations is expected to improve further in future. Similarly, the commercial sites also showed improvement in the AQI shifting from moderately polluted to satisfactory category of IND-AQI.

VII. CONCLUSION

The overall AQI gives a clear view about ambient air and the critical pollutant mainly responsible to access the air quality. The AQIs were calculated to assess the ambient air quality at three different zones namely the industrial, commercial and residential sites in Himachal Pradesh during the year 2010-2015. The AQIs were calculated according to Indian Air quality Index (IND-AQI). The conclusions from this study are (a) the concentrations of two pollutants namely SO_2 and NO_2 are well within the prescribed standards as per CPCB (b) Particulate Matter is the key pollutant behind the pollution in major polluting sites as it has been found that it's concentration is 51% higher than the prescribed limits (c) The spatial distribution of AQI showed that maximum area (60%) is covered in Satisfactory category (51-100), followed by 30% in Moderately polluted category (101-200) and approx. 10 % in Good category (0-50) (d) Moreover, Baddi, Paonta Sahib, Kala Amb are found to be the most polluted sites.

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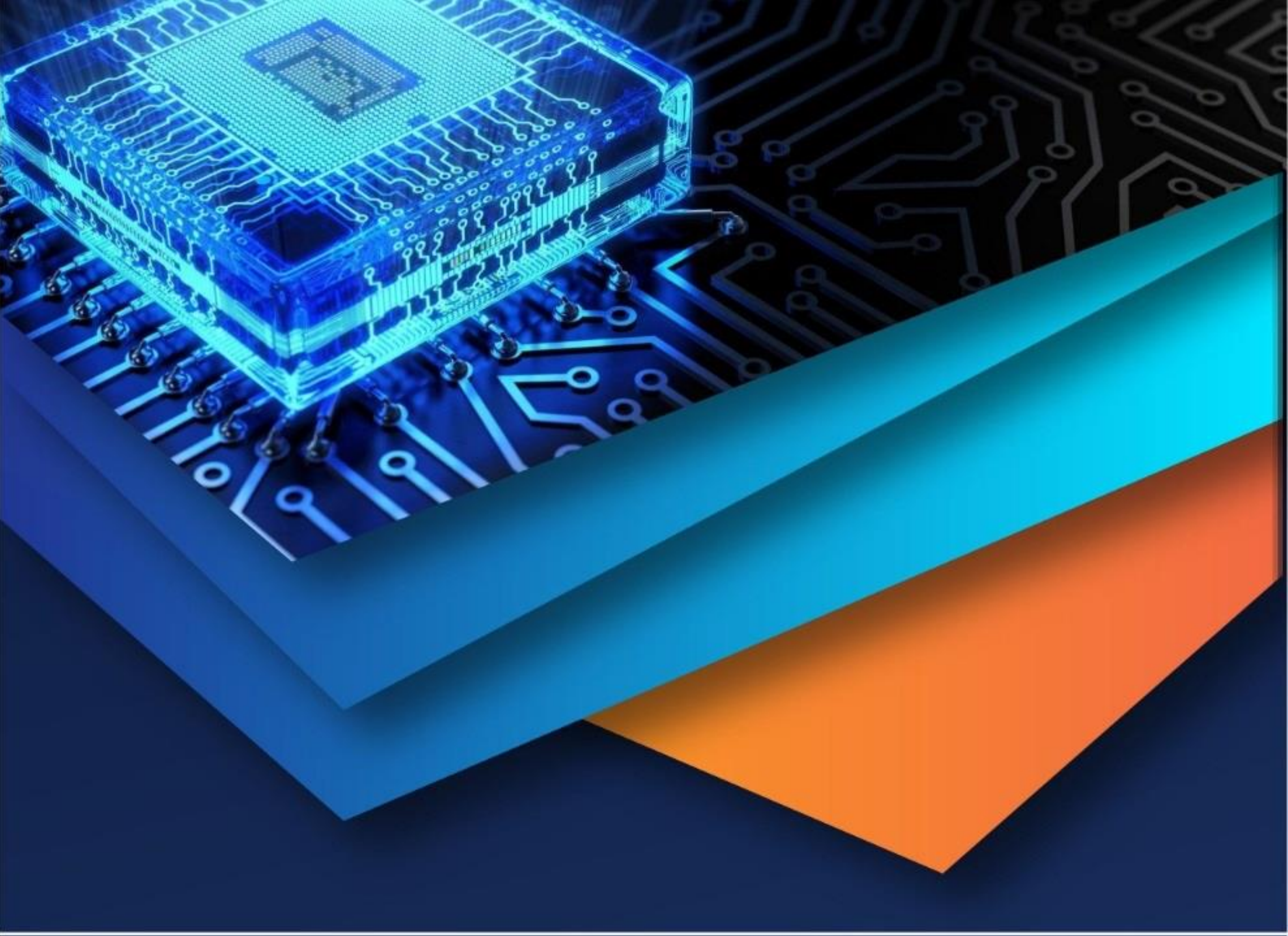

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