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Study of Spatial Variation of Groundwater Quality Parameters and its Contamination in Ropar District of Punjab

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Abstract: Groundwater forms an indispensable portion of hydrological cycle. The availability of groundwater relies upon the recharge conditions and precipitation. Excessive use of groundwater, change in cropping pattern, production of good quality rice and discharge from industries has led to its exploitation which is one of the important environmental hazards and needs immediate attention. The regular check on the quality and level of groundwater should be done in order to ensure continuous supply. The present study was carried out in Ropar district of Punjab and it revealed that parameters of groundwater quality like nitrate exceeded the permissible limit at Ahmedpur, Bhallan and Dumewal region. The water quality index (WQI) was very poor at Ahmedpur and its surrounding areas. GIS technique was adopted to prepare the maps showing the spatial variation of groundwater quality parameters. Inverse Distance Weighted (IDW) method of interpolation in Spatial Analysist tool in ArcMap software was used. For soil texture analysis Lithological 3D model was prepared using Rockworks15 software. In order to group the areas having similar extent of pollution Cluster analysis (CA) technique was implemented. From this study it has been concluded that fluorine content is less than the desired value at every sampling location and also immediate chlorination of water supply sources is required in order to avoid bacterial infection as chlorine level is also less than the desirable level.
Keywords: Water Quality Index (WQI), GIS, Inverse Distance Weighted (IDW), Lithological 3D Model, Cluster Analysis

I. INTRODUCTION

Water is a privilege to the planet earth making life possible here. For the areas where surface water resources are inadequate to fulfil the demand, groundwater is a significant source of water supply to the household, agricultural and industrial purposes [1]. The importance of groundwater is enhanced by its intrinsic qualities like uninterrupted accessibility, lesser cost of development and reliability in drought conditions for usage in our country [2]. Ropar district of Punjab is rich in agriculture and industrial units, so the water dependency of the area is satisfied by groundwater. Due to the excessive use of fertilizers and pesticides, discharge from the thermal power plants and unhygienic sanitary conditions have deteriorated the groundwater quality leading to its unsuitability for drinking and other purposes [2]. There is an alarming increase in number of cases reported by the residents of the area regarding the health issues like cancer, gastroenteritis and kidney related problems due to poor quality water. The spatial variation in the groundwater quality parameters (pH, total hardness, nitrate, chloride) is influenced by strata of the soil above, percolating rain water and material of the aquifer Therefore, a systematic analysis of groundwater quality has become vital for its optimum utilization in an appropriate manner. But the water quality data is multidimensional in nature and it is cumbersome to make any useful interpretation from it. Hence multivariate techniques like cluster analysis (CA) and principal component analysis (PCA) can be used to make a comprehensive result for the assessment of groundwater overall quality [3]. Remote sensing and GIS (Geographic Information System) are also widely used nowadays for examination and integration of water quality data to obtain useful visual outputs [4]. So in this present study, the water quality index of the Ropar district was calculated mathematically considering the parameters like pH, electrical conductivity, bicarbonate, chlorine, sulphate, nitrate, fluorine, magnesium, calcium, sodium, potassium, total hardness, sodium absorption ratio (SAR), phosphate, silica ions and residual sodium carbonate (RSC). Secondly, lithological modelling of the Ropar block was done with the help of Rockworks15 software to study the soil strata. The thematic maps of water quality parameters and water quality index were also prepared using ArcGIS software [5].

II. OBJECTIVES

A. To determine the various parameters which affect the groundwater quality of Ropar district of Punjab for estimating the Water Quality Index of groundwater of sampling locations.
B. To map the spatial variation of the groundwater quality parameter on the study area using GIS.
C. To prepare the 3D Lithological model of Ropar block of Punjab with the help of algorithm provided in RockWorks15 software.

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III. STUDY AREA

Ropar district falls in the Shivalik region of Punjab and lies between 30°-32′ and 31°-24′N latitudes and 76°-18′ and 76°-55′ E longitudes having a total area of 1440 km^2. This district has mixed composition of agricultural and industrial land. The soil strata of Rupnagar consists of clay, sand and gravel conglomerates. The Satluj is main river of Punjab and passes in the vicinity of many towns of Ropar district. This river takes care of the power supply and irrigation water needs of the district. The highest gravity dam of India Bhakra dam is situated near Nangal town of Ropar. There are many small and large scale canal networks within the district to support the agriculture. The temperature of the area is generally dry but it is very cold in winters and too hot in summers. The temperature falls down to 4 in the coldest month of the year which is January and rises up to 45 in the month of June. The district receives on an average a rainfall of 775.6mm on annual basis mostly in the months of July to September. In this area locations which were taken under consideration are Hardoh Namoh, Ahmedpur, Dhair, Brahampor, Bhallan, Dumewal, Noorpur Bedi, Bada Chaunta, Roorkee Heeran, Chatamali. The study area map *is* shown in Fig. 1.

Fig. 1 Study area map

IV. METHODOLOGY

A. Estimation of Water Quality Index

The water quality parameters data for the groundwater is obtained from Central Ground Water Board (CGWB), Chandigarh. The data includes mean annual values for 17 water quality parameters including pH, Electrical Conductivity (EC) at 25 degrees Celsius, Carbonate ($C0_3^{2-}$), bicarbonate (HCO_3^-), Chlorine (Cl), Sulphate (SO_4^{2-}), Phosphate (PO_4) Nitrate (NO_3^-), Fluorine (F), Calcium (Ca), Sodium (Na), Magnesium (Mg), Potassium (K), Total hardness (TH), Silica Ions (SiO_2), Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC). The data for the years 2014, 2015 and 2016 is averaged and then analyzed [6-8]. The water quality index is then calculated mathematically. First of all, each parameter is assigned a weight ranging from 2 to 5 with respect to its contribution in increasing the groundwater pollution [9]. The relative weight and quality rating scale is then calculated for each parameter using the formula [2].

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

$$q_i = \frac{c_i}{s_i} \times 100 \quad (2)$$

Here W_i = Relative Weight w_i = Assigned Weight   n = Number of parameters

q_i = Quality rating scale c_i = concentration of parameter in water sample

s_i = Indian standard limit for parameter

Finally, the water quality index (WQI) is given by

$$WQI = \sum_{i=0}^{n} SI \qquad (SI_i = W_i \times q_i) \quad (3)$$

SI = Sub Index of each parameter

For studying the soil type of the study area, the data of the soil strata is obtained from Punjab Water Resource Management and Development Corporation (PWRMDC), Chandigarh. The lithological model of the Ropar block is prepared using Rockwrks15 software as shown in Figure 19.

B. Maps preparation using GIS software

The data of quality parameters collected from the CGWB for the years 2013-14, 2014-15, 2015-16 is averaged and then analysed. The data was in the non-spatial format which is not accepted by ArcGIS. It is first of all stored in excel and then imported to the ArcMap. For preparing the spatial distribution maps in the Spatial Analyst module in ArcGIS out of kriging, spline, Inverse Distance Weighted (IDW) and Cokriging, IDW method has been adopted in this study [10]. In IDW method a weight is assigned to the unknown point. This assigned weight depends inversely with the distance between the known and unknown points. The basic formula used in IDW is:

$$v = \frac{\sum_{i=1}^{n} \frac{1}{di} vi}{\sum_{i=1}^{n} \frac{1}{di}} \qquad (4)$$

v = estimated value.

vi= known value.

di…dn = distances from the n data points to the estimated n point.

C. Cluster Analysis

Analysis of a multivariate dataset is done with the help of Cluster Analysis (CA). Cluster analysis tool in SPSS software applies some algorithms to group the quantities having similar characteristics into same category. CA organises the raw dataset into relevent clusters by combining the variables. To group the locations having similar extent of water pollution cluster analysis is applied on the raw data. Ward's mean method with Euclidian distance linkage in Hierarchical clustering has been used to produce the dendogram [3].

V. RESULTS AND DISCUSSION

Each parameter is analyzed separately and then its spatial distribution map is prepared using ArcGIS 10.5 software. With the help of these maps it is evident that which parameter is within permissible range. The spatial variation map of overall WQI estimated is also plotted and with its help the groundwater quality of any location within Ropar district can be seen.

A. pH

In Ropar, pH of groundwater is alkaline in nature as shown in Fig. 2. As per BIS, pH range for drinking water should be within 6.5-8.5. The pH of the sampling locations ranged from 7.9 to 8.8. The pH of Bhallan and Chatamali was found above the permissible limits and hence it is not suitable for drinking.

B. Electrical Conductivity

The EC for the Ropar district ranged between 350-1550 µS/cm and all the points have EC within the permissible range as shown in Fig. 3.

C. Bicarbonate

Water having bicarbonates above 200 mg/l has taste issues. Most of the sampling locations have quantity above 200 mg/l thus the water has taste issues in Ropar district as shown in Fig. 4.

D. Chlorine

BIS range for chlorine in drinking water is 250-1000 mg/L. The study area points have chlorine content ranging between 7-174 mg/L. So the level of chlorine is less than the desired level at each sampling location as shown in Fig. 5.

E. Sulphate

Sulphate ions enter groundwater by excessive use of fertilizers and by leaking sewage wastewater pipes. BIS range for sulphate is 200-400 mg/L. The sampling points have the sulphate value from 5-135 mg/L as shown in Fig. 6. Hence no sulphate contamination is there.

F. Nitrate
BIS guidelines state that the nitrate concentration above 45mg/L is highly condemned. In the study area at points Ahmedpur, Bhallan and Dumewal high concentration of nitrate is found as shown in Fig. 7. So water at these places is unfit for drinking as it can lead to "Blue baby disease" or " Methemoglobinemia".

G. Fluorine
The BIS requirement of fluorine in water is 1 mg/l. All the sites have the fluorine less than desired limit which can lead to osteoporosis in children as shown in Fig. 8.

H. Magnesium
The BIS permissible limit is 30 mg/l for magnesium. Four sampling locations have magnesium value above permissible limit as shown in Fig. 9. Higher concentrations of magnesium cause diarrhea, encrustation of pipes, hypermagnesemia and abnormal kidney functions.

I. Calcium
Calcium is one of the essential mineral which is required in drinking water as it makes the bones of the body strong. The BIS desirable limit for calcium is 75mg/l. All the sampling locations have calcium lower than the required value which can lead to osteoporosis, low insulin resistance and nephrolithiasis as shown in Fig. 10.

J. Sodium
Sodium reaches groundwater by percolation of surface water contaminated by road salt and infiltration of leachate from landfills. The permissible limit of calcium by WHO is 220 mg/l and all the sampling locations have value less than this as shown in Fig. 11.

K. Potassium
Excessive use of fertilizers results in the presence of potassium in groundwater. Two sampling locations Hardoh Namoh and Dhair have potassium value above permissible limit which is 12mg/l as shown in Fig. 12.

L. Total Hardness
BIS range for hardness in the groundwater is 200-600 mg/l. But the water having hardness above 180 mg/l is termed as very hard water. Except for the two sampling locations Noorpur Bedi and Chatamali, all other locations have very hard water as shown in Fig. 13. So, this water is not recommended for household purposes as it will cause scaling.

M. Sodium Absorption Ratio (SAR)
The SAR is an important parameter in deciding the suitability of water for irrigation purpose. The water having SAR below 10 is termed as good for irrigation purpose. All the sampling locations have SAR within permissible limits so water quality of Ropar is good for irrigation as per SAR value.

N. Phosphate
The permissible limit for phosphate is 0.1 mg/l. All the sampling locations have phosphate value within permissible limits. The range of phosphate in sampling locations was 0.01 to 0.06 mg/l as shown in Fig. 15.

O. Silica Ions (SiO_2)
The SiO_2 concentrations in drinking water range from 5-25 mg/l and all the sampling locations in Ropar region found to be within the permissible limits as shown in Fig. 16.

P. Residual Sodium Carbonate (RCS)
This quality parameter is used to analyze whether the water is good for irrigation or not. The water having RSC value below 1.5 is termed as good for irrigation purpose. While the value above 2.5 is objectionable. The RSC value at Chatamali is above 2.5 and hence unsuitable for irrigation while at other locations the quality of water is moderate as shown in Fig. 17.

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Q. Water Quality Index (WQI)

The WQI values ranged from 35.92- 115.21. The water quality of Ahmedpur and its surroundings is very poor while other sampling locations have good quality water as shown in Fig. 18.

Table 1. Water Quality Index

S. No.	Sample Area	WQI	Water Quality
1	Ahmedpur	115.21	Poor
2	Hardoh Namoh	47.45	Excellent
3	Dhair	87.61	Good
4	Brahampor	42.97	Excellent
5	Bhallan	65.69	Good
6	Dumewal	58.96	Good
7	Noorpur Bedi	35.92	Excellent
8	Bada Chaunta	82.80	Good
9	Roorkee Heeran	62.90	Good
10	Chatamali	64.76	Good

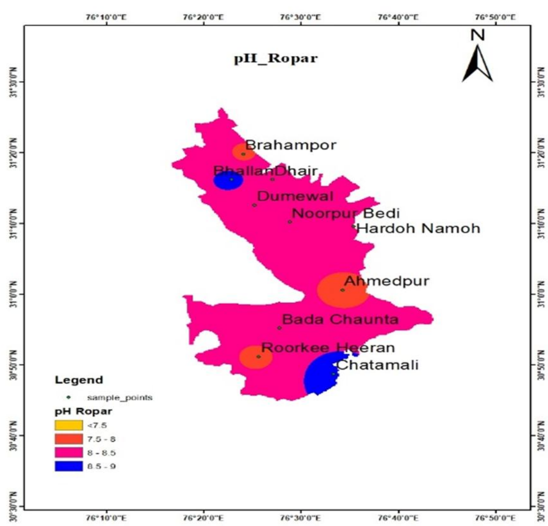

Fig. 2. Spatial variation of pH

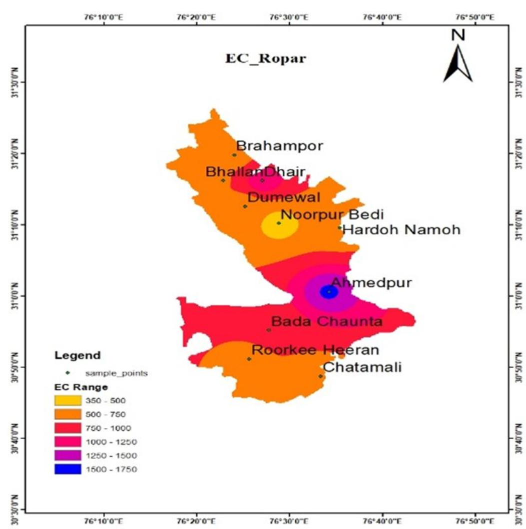

Fig. 3. Spatial variation of EC

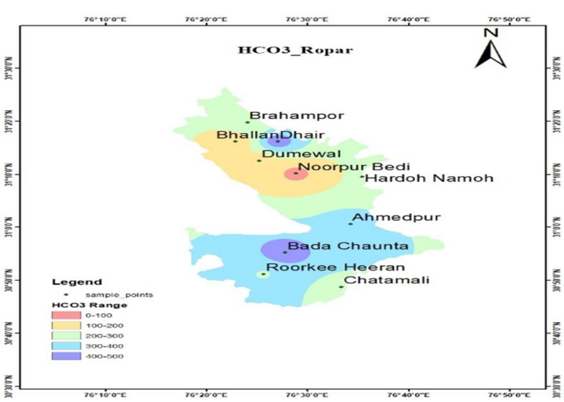

Fig. 4 Spatial variation of Bicarbonate

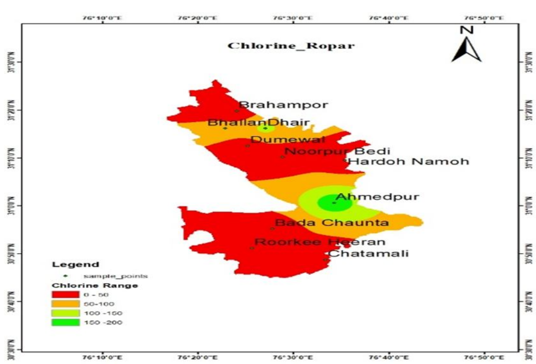

Fig. 5 Spatial variation of Chlorine

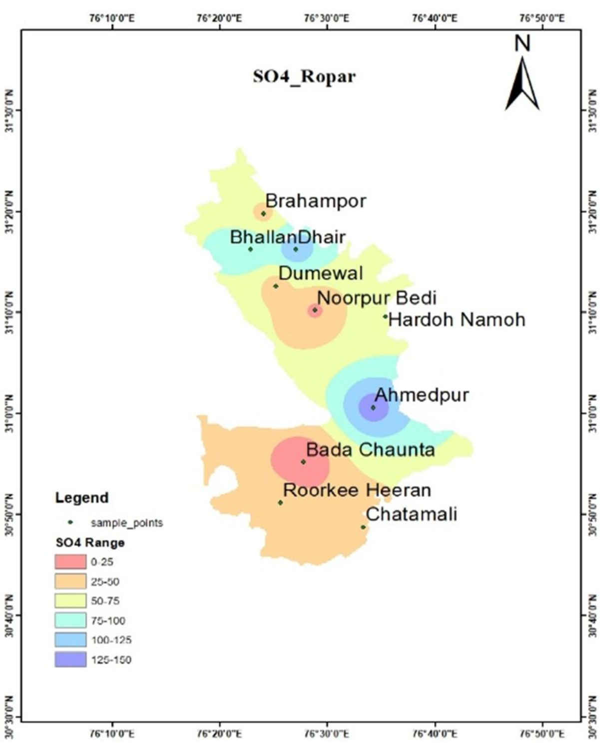

Fig. 6 Spatial variation of Sulphate

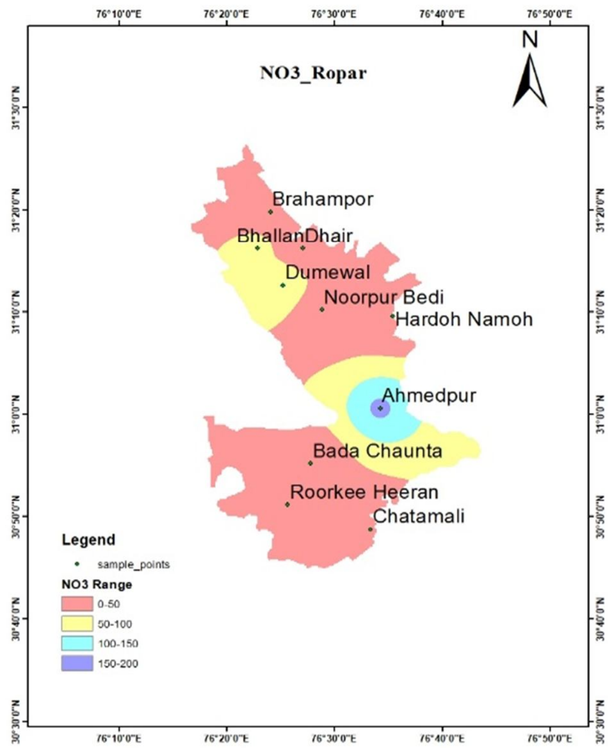

Fig. 7 Spatial variation of Nitrate

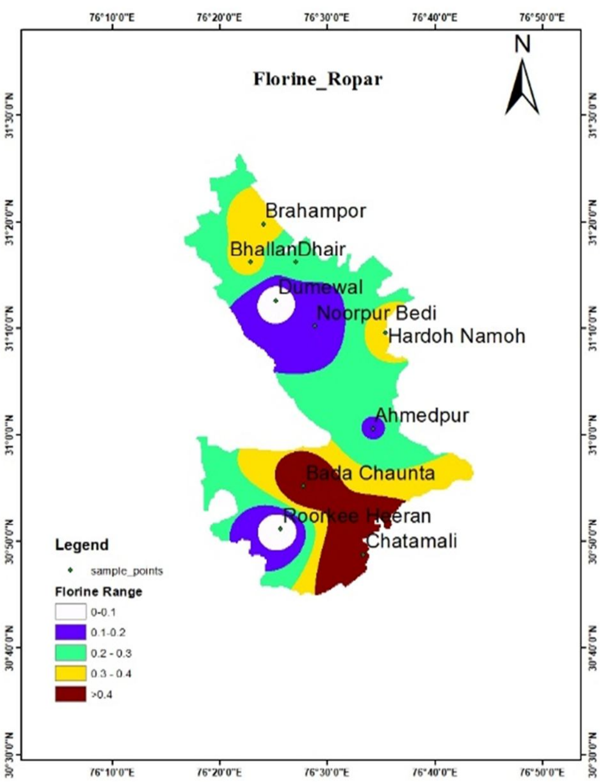

Fig. 8. Spatial variation of Fluorine

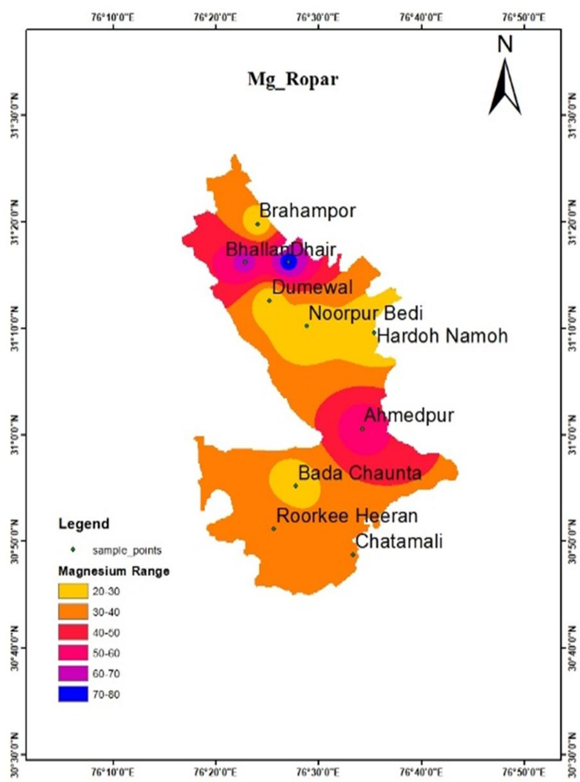

Fig. 9. Spatial variation of Magnesium

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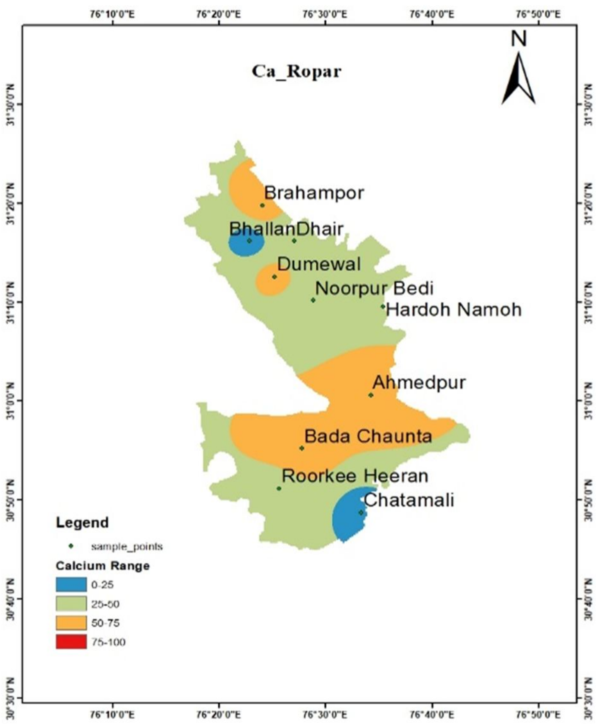

Fig. 10 Spatial variation of Calcium

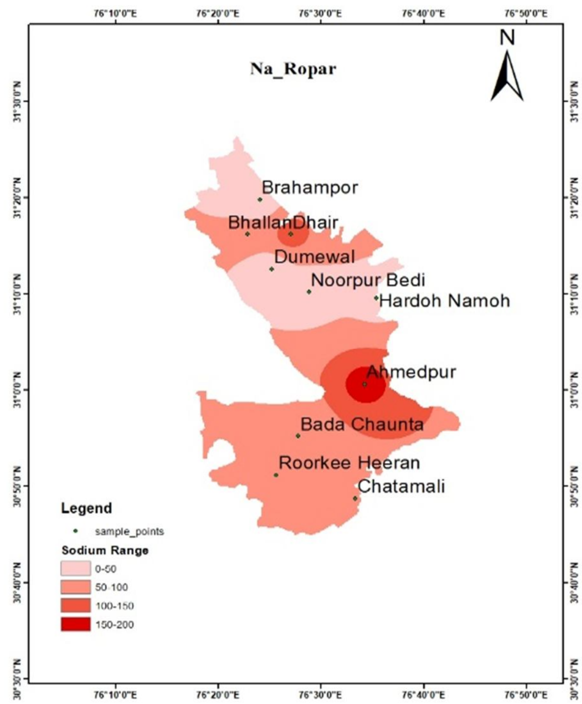

Fig. 11 Spatial variation of Sodium

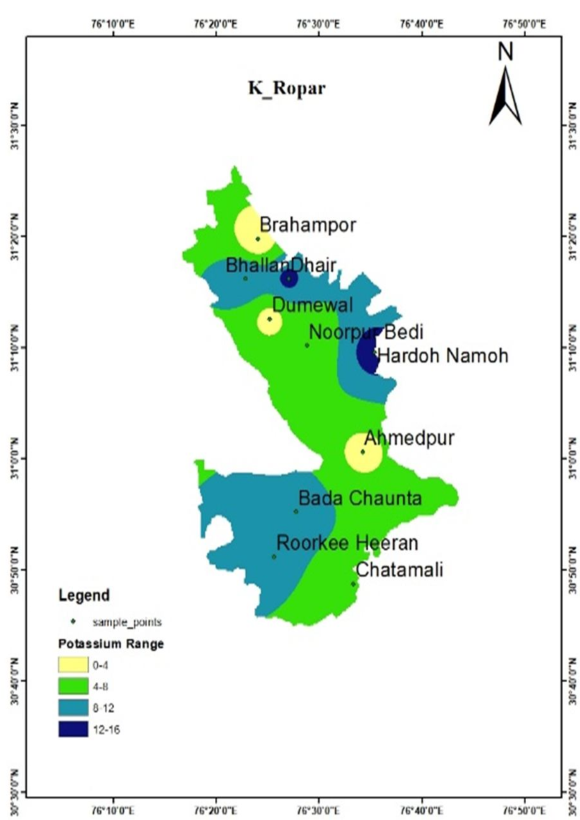

Fig. 12 Spatial variation of Potassium

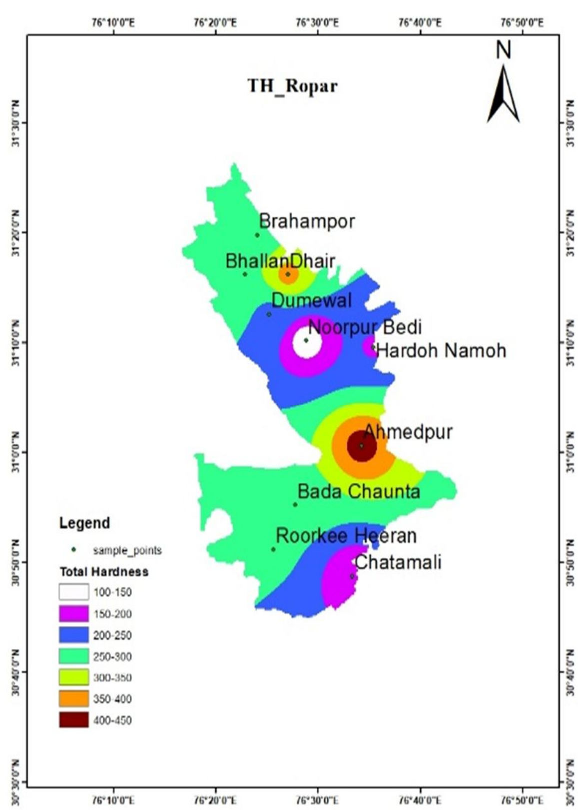

Fig. 13 Spatial variation of Total Hardness

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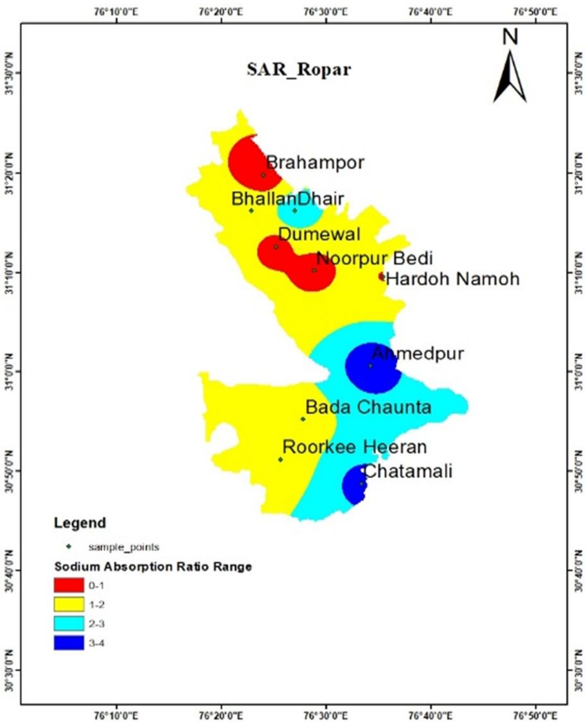

Fig. 14 Spatial variation of SAR

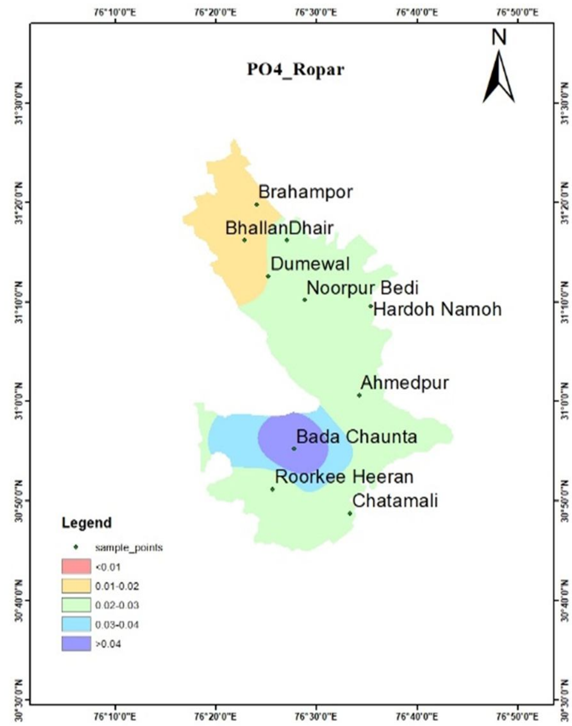

Fig. 15 Spatial variation of Phosphate

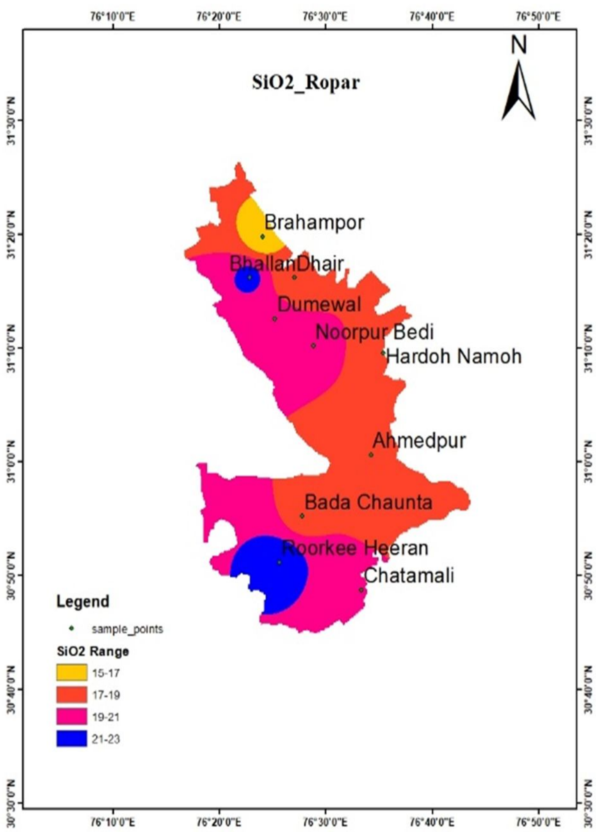

Fig. 16 Spatial variation of Silica Ions

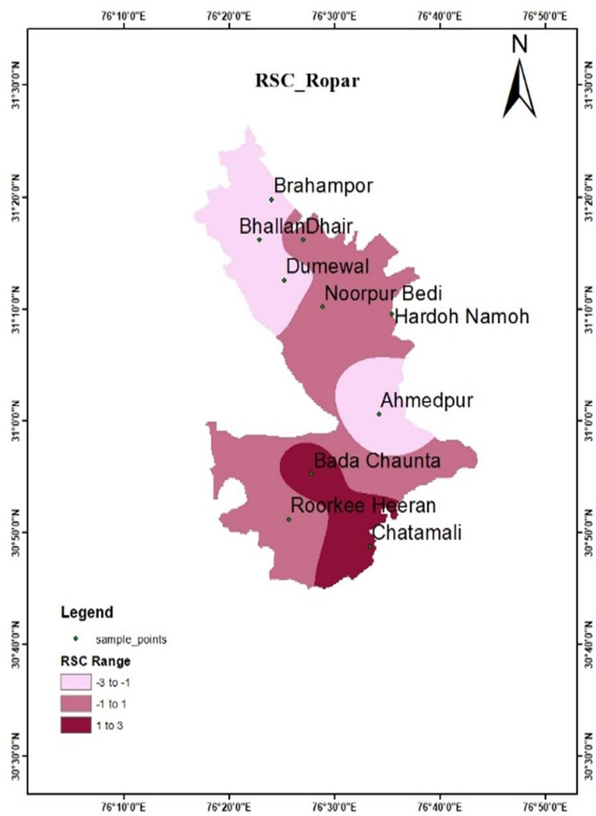

Fig. 17 Spatial variation of RCS

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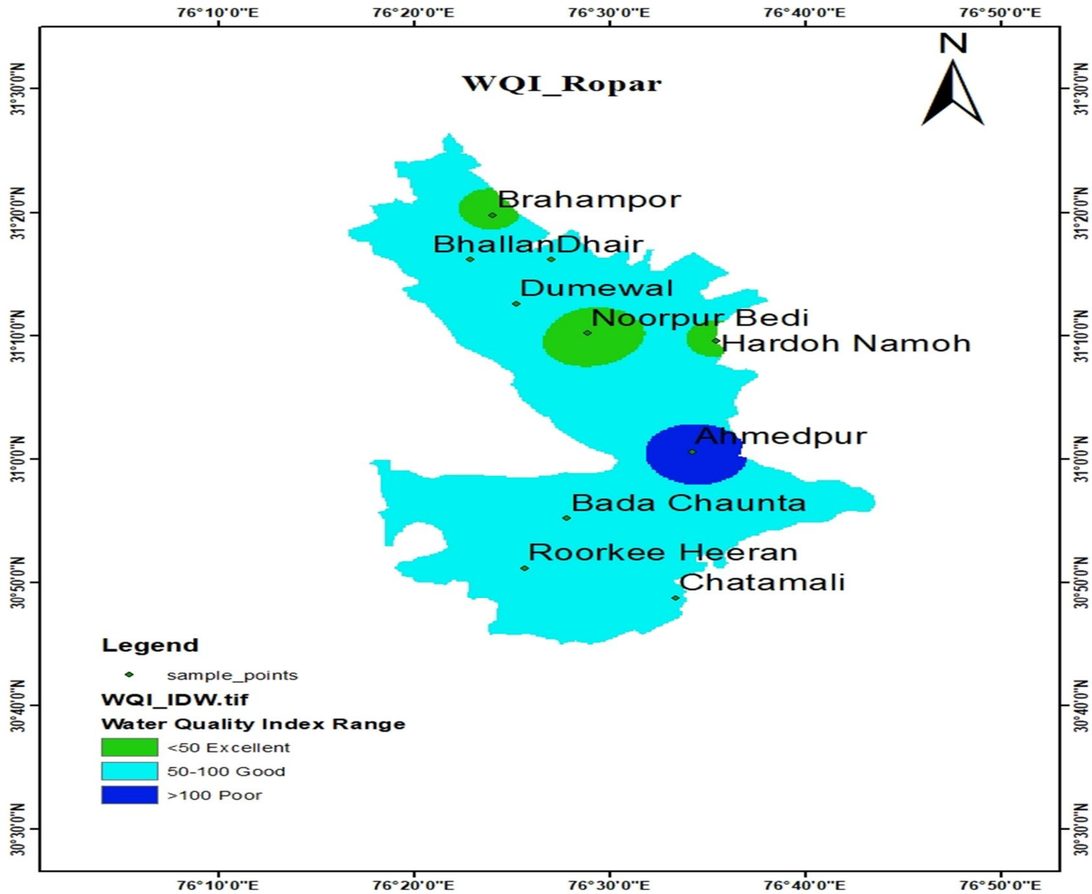

Fig. 18 Spatial variation of Water Quality Index

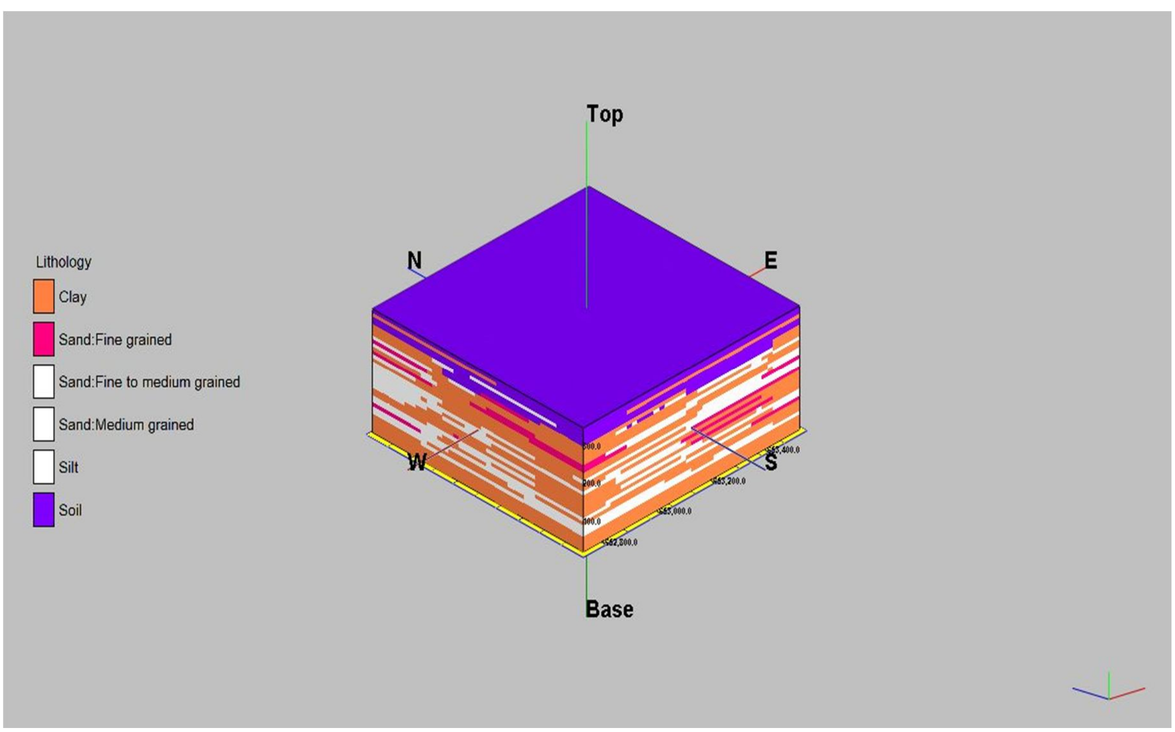

Fig. 19. 3D Lithological plot of Ropar Block

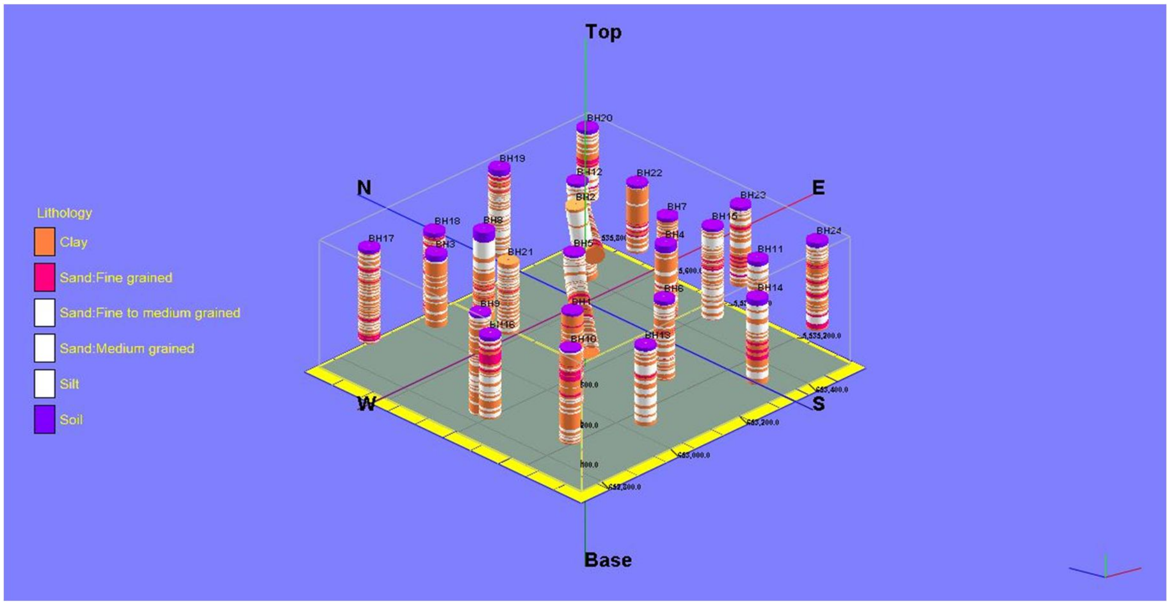

Fig. 20. 3D Multilog plot of Wells in Ropar Block

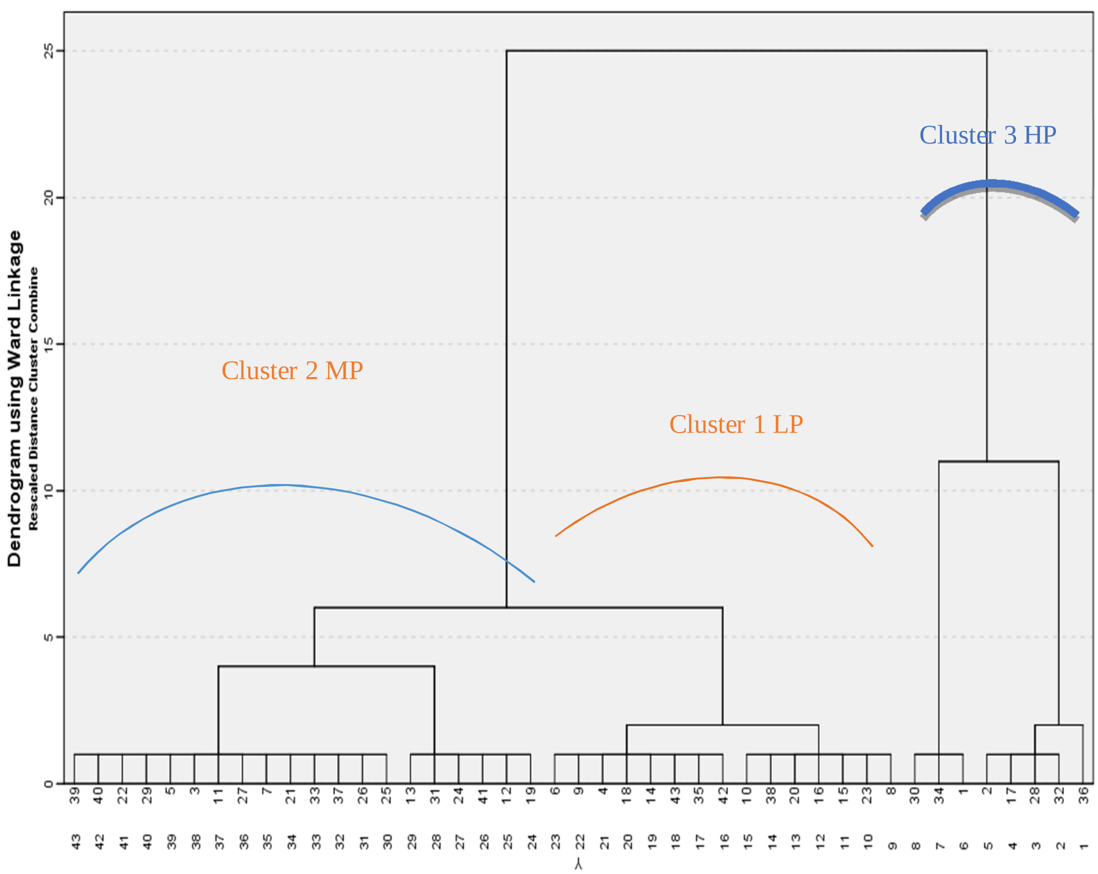

Fig. 21 Cluster Analysis Result

Table 2. Classification of 43 monitoring stations in Ropar Block for Cluster Analysis

Station No.	Less polluted (LP)	S.No.	Moderately polluted (MP)	S.No.	Highly polluted (HP)
4	Roorkee Heeran	3	Goga	1	Soara
6	Dumewal	5	Bara Chaunta	2	Landan
8	Brahmpur	7	Bhalan	17	Kishanpura
9	Dhair	11	Ahmedpur	28	Sabour
10	Hardo Namoh	12	Channalon	30	Balewal
14	Kakrali	13	Chatamali	32	Katta
15	Ropar	19	Haripur	34	Kalheri
16	Chakdera	21	Rampur	36	Amloh
18	Madhpur	22	Rormajra		
20	Panjoli	24	Babani Khurad		
23	Ramgarh Taprian	25	Azampur		
35	Fatehgarh Sahib	26	Boor Majra		
38	Bhatria	27	Baloli		
42	Pawala	29	Ganura		
43	Nalini	31	Gopalpur		
		33	Nangran		
		37	Badliala Singh		
		39	Chunni Kalan		
		40	Bir Bhramarsi		
		41	Bhgrana		

VI. CONCLUSIONS

The lithological model shows that most of the soil is clay and sand in Ropar. These soil types facilitate the ion exchange process and hence increase the flow of contaminants through strata. From this current study it has been found that the water quality index value for the sampling locations ranged between 35.92 to 115.21. The overall groundwater quality of the study area is good except for the Ahmedpur and its surrounding where the WQI value is 115.21 which is poor. The concentration of chlorine at all the places ranged between 0-200 mg/l which is less than the desirable limit. So immediate chlorination of water is mandatory. Also the fluorine value in the study area is found to be less than 0.4 mg/l whereas it should be between 0.5- 1.5 mg/l. Due to this the inhabitants of Ropar district are facing many health issues so to mitigate this pollution the effluents from industries near Ropar should be treated before disposal.

VII. ACKNOWLEDGMENT

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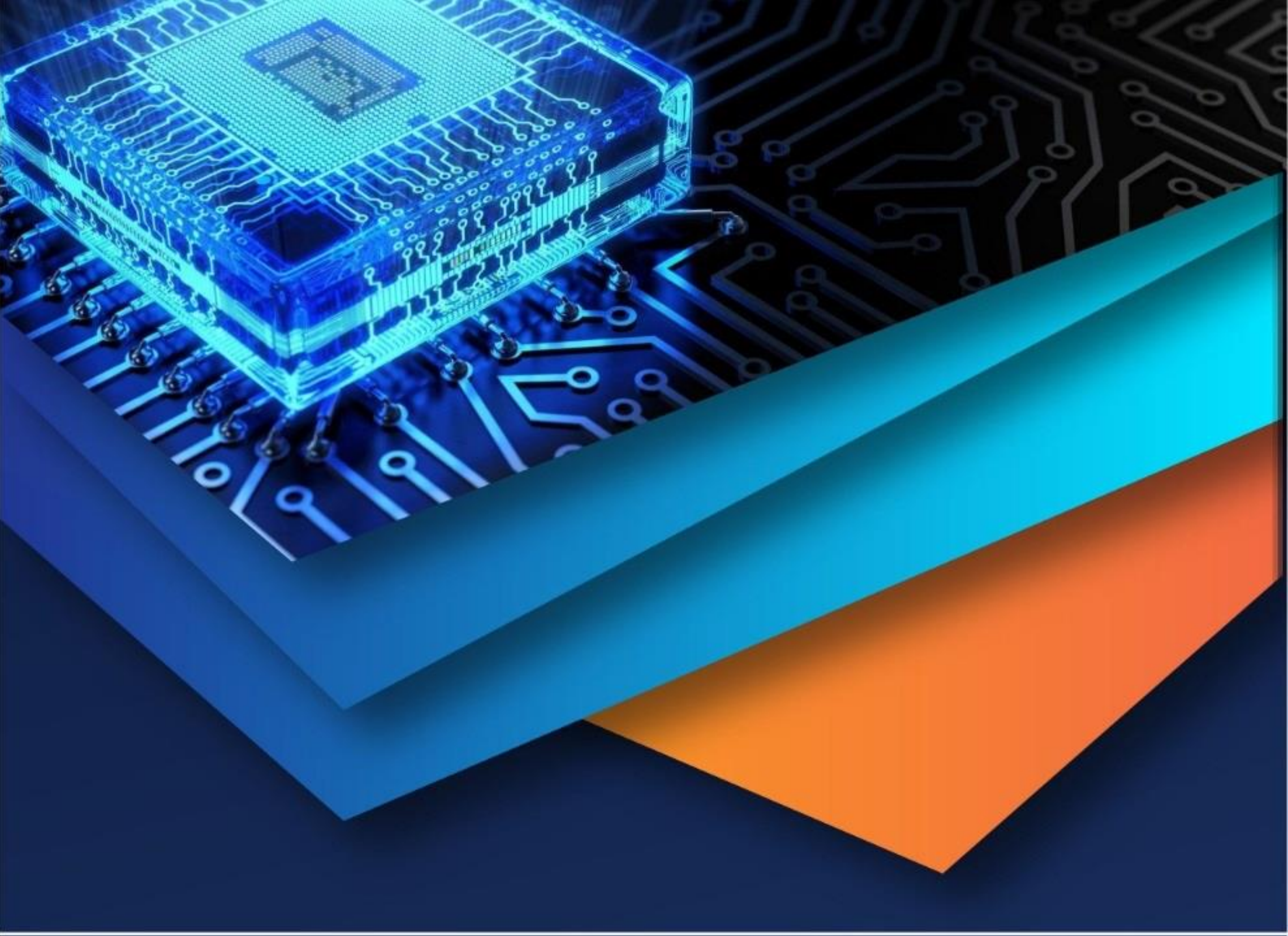

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