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Assessment of groundwater quality by using water quality index (WQI) in the Karchhana tehsil of Prayagraj district

Sachchida Nand Singh and Mohd. Aftab Alam

Abstract
The groundwater quality analysis revealed that all groundwater quality parameters such as pH, total dissolved solids (TDS), electrical conductivity (EC), Total hardness (TH), calcium (Ca^{2+})· magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), chloride (Cl^{-}), sulphate ($SO4^{2-}$) and nitrate (NO_3^{-}) were found to be within the maximum desirable limits in all groundwater samples when compared to both WHO and BIS standards. On the basis of this, it is possible to say that the groundwater of the study area is suitable for drinking and domestic purpose. Based on the result findings of the all irrigation quality parameters such as Electrical Conductivity (EC), Total Dissolved Solids (TDS), Sodium Adsorption Ratio (SAR), Percentage Sodium (Na%), Kelly's Ratio (KR), Magnesium Adsorption Ratio (MAR) and Permeability Index (PI), it is conclude that the groundwater of the study area is also suitable for irrigation. The values of water quality index (WQI) ranged from 16.82 to 51.68 with an average 37.05. According to the obtained WQI values, only 20.00% of the groundwater samples are fall in the "Excellent" category, 73.33% are in the "Good" category and remaining 6.67% are in "Poor" category. Based on this result, the groundwater of the study area is "Good" for drinking, irrigation and industrial purposes.

Keywords: Groundwater, WHO, BIS, water quality index, groundwater quality

Introduction
Water is one of the most valuable and basic requirements for human existence and survival, providing him with luxuries and comforts in addition to meeting his basic needs, as well as for industrial and agricultural production, making it an essential component of our eco-system. A man's daily drinking water demand is usually 7% of his body weight but this water can become a danger to life if it becomes polluted with hazardous or toxic substances (Khan and Rehman, 2017) [8]. Groundwater quality is a highly important issue that has a significant impact on human health and ecological systems. Anthropogenic factors such as urbanization, industrial, and agricultural activities, as well as natural processes such as deforestation and regional climatic conditions, all influence the quality of surface water. However, in India, including Prayagraj, water pollution is a serious issue. Most of the surface water bodies of Prayagraj are connected to drains. Furthermore, increased use of agrochemicals such as insecticides, pesticides, and chemical fertilizers to boost crop production is increasing water pollution in the study area. Surface water, such as rivers, canals, fresh water lakes and streams and ground water, such as well and borewell water are the two major sources of water (Khan and Rehman, 2017) [8]. Water is responsible for about 80% of all human diseases, according to the World Health Organization. Generally, groundwater is known to be less polluted than surface water due to less exposure to the external environment. The proper quality of the water used for drinking and irrigation purposes must be ensured. In developing countries like India, many people use untreated groundwater for different uses because they do not have access to good quality water. Various suspended, dissolved and biological constituents influence the drinking water quality. Maximum permissible limits for various dissolved ions in water used for human consumption have been defined by the Bureau of Indian Standards (BIS 2003) [16] and the World Health Organization (WHO 2006) [17]. These standards have been used by researchers all over the world to study the reliability of water. Keeping this in mind, the study have been undertaken to assessment groundwater quality in the study area by using Water Quality Index (WQI) and also to prepare the spatial distribution maps for the all water quality parameters by using QGIS software.

Methodology

General Description of the Study Area

The study area (Karchhana Tehsil) is located in Prayagraj district of Uttar Pradesh as shown in Figure 1. There are total three blocks comes under the study area namely Chaka, Karchhana, Kaundhiyara. Prayagraj district lies between 24˚47' and 25˚43' N latitude and 81˚31' and 82˚21' E longitude. The total geographical area and total Population of Prayagraj district is 5482.00 km^2 and 559088, respectively. The study area lies between 25˚09'15" and 25˚25'02" N latitude and 81˚48'25" and 82˚04'45" E longitude. The total geographical area and total Population of the study area is 546.03 km^2 and 583658, respectively.

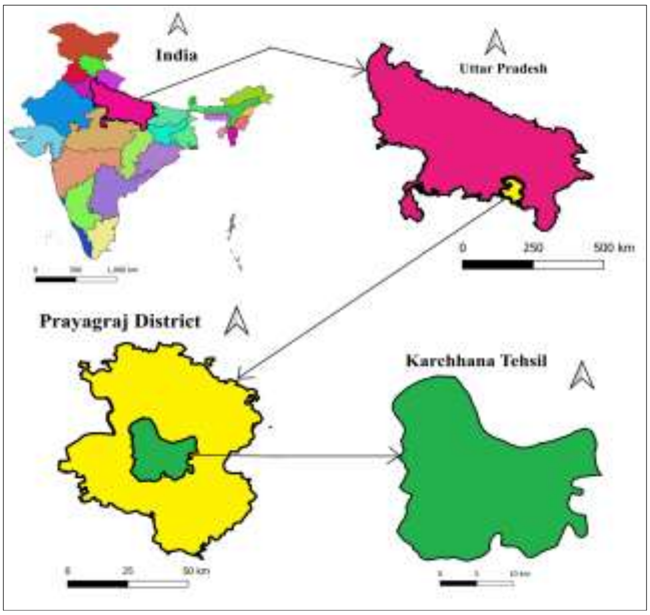

Fig 1: Index map of the study area

Collection of groundwater samples

For this study, 15 groundwater samples were collected from different locations such as five at head end, five at middle end and five at tail end of the study area. The latitude and longitude of the observations point were recorded by using GPS. Water samples were collected in plastic bottles of 1 L capacity for the analysis. Prior to collection of samples, bottles were washed with nitric acid (HNO_3) and rinsed two times with distilled water. Groundwater samples were collected after pumping the pump for 10-15 minutes to avoid debris. The location of the observation points of groundwater sample and spatial distribution map of water quality parameters were prepared by using QGIS V.3.30.0 software. The locations of the observation points are shown in Figure 2 and the names of observation points with latitude and longitude are given in Table 1.

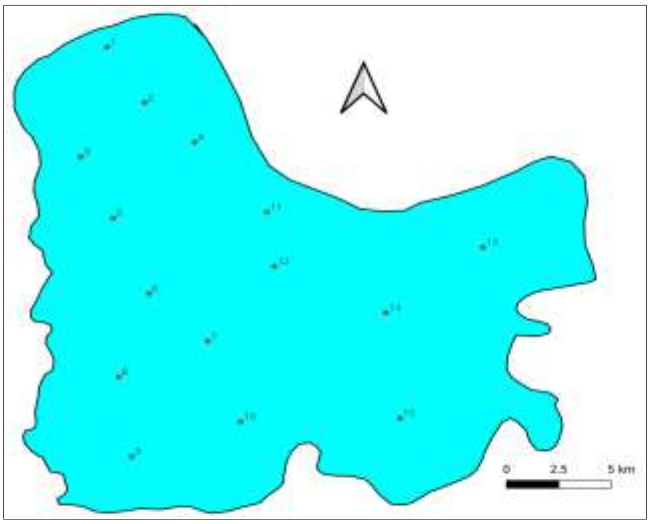

Fig 2: Location of observation points of groundwater sample in the study area

Table 1: Observation I.D. and its latitude and longitude.

Block	Observation I.D.	Observation point name	Latitude	Longitude
Chaka	1	Gangotri Nagar	25.4063	81.8469
	2	Chaka	25.3756	81.8646
	3	Palpur	25.3457	81.8343
	4	Bharauha	25.3537	81.8884
	5	Ubhari	25.3118	81.8497
Kaundhiyara	6	Bargohana Khurd	25.2702	81.8668
	7	Gidhaura	25.2439	81.8946
	8	Ikauni	25.2242	81.8524
	9	Dewara	25.1803	81.8586
	10	Benipur Arail	25.1994	81.9102
Karchhana	11	Bayohara	25.3151	81.9227
	12	Akodha	25.2851	81.9262
	13	Kolaahi	25.2957	82.0252
	14	Karchhana	25.2596	81.9792
	15	Bhandewara	25.2013	81.9858

Analysis of groundwater samples

The groundwater quality analysis was carried out for the parameters such as pH, total dissolved solids (TDS), electrical conductivity (EC), Total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate ($SO4^{2-}$) and nitrate (NO_3^-) by the following standard methods prescribed as per IS: 10500-2012 codes.

The characteristics of groundwater quality were compared to World Health Organization (WHO) and Bureau of Indian Standards (BIS) drinking water guidelines. Statistical summary of analytical results and comparison with WHO and BIS (IS: 10500) for drinking purpose is given in Table 2.

Comparison of groundwater quality with the BIS and WHO drinking water quality standard

Parameters of water quality were compared with the drinking water guidelines of WHO and Bureau of Indian standards as given in Table 2.

Table 2: Drinking water quality parameters of WHO and BIS

Water quality parameters	BIS (IS 10500)		WHO	
	Maximum desirable limit	Maximum permissible limit	Maximum Desirable limit	Maximum permissible limit
pH	6.5 - 8.5	-	7 - 8.5	-
TDS	500	-	500	1500
EC	500	2000	750	1500
TH	300	600	100	500
Ca^{2+}	75	200	75	200
Mg^{2+}	30	100	30	150
Na^{+}	-	200	50	200
K^{+}	-	-	100	200
HCO_3^-	200	600	300	600
Cl^-	250	1000	200	600
$SO4^{2-}$	200	400	200	400
NO_3^-	45	100	50	100

Irrigation Water Quality Parameters

To evaluate the overall irrigational water quality of the groundwater samples collected, seven computed water quality parameters were considered; namely-Electrical conductivity (EC), Total dissolved solids (TDS), Sodium Adsorption Ratio (SAR), Percentage Sodium (Na%), Magnesium Adsorption Ratio (MAR), Permeability index (PI) and Kelly's Ratio (KR) (Das and Nag, 2015) [5].

Electrical conductivity (EC)

Water salinity hazard as measured by electrical conductivity is the most important water quality guideline on crop productivity. The greater EC, the less crops have access to water, even though the soil may seem humid. Because crops can only transpire "pure" water, the soil solution's usable plant water dramatically reduces as EC rises. A saline soil is created by higher EC in water.

Total dissolved solids (TDS)

Total dissolved solids (TDS) indicate the salinity conduct of water. High TDS levels in water in field plants can lead to physiological drought. Under these conditions, a crop may appear stressed for water and even wilt despite the availability of sufficient soil moisture because the roots cannot absorb the water from a concentrated soil solution.

Sodium adsorption ratio (SAR)

SAR is an alkali/sodium hazard measure for crops. Sodium adsorption ratio (SAR) is expressed as:

$$\text{SAR (meq/l)} = \frac{Na^+}{[\,(Ca^{2+} + Mg^{2+})/2\,]^{0.5}}$$

Percent sodium (Na %)

Sodium percentage (Na %) is used to assess sodium risk. High concentration of sodium ions in soil can affect inner drainage patterns in soil as calcium release and magnesium ions are facilitated by sodium absorption by clay particles. Water with Na% of more than 60% can lead in accumulations of sodium that will cause a breakdown in the physical characteristics of the soil (Das and Nag, 2015) [5]. Soluble sodium percentage (Na %) or Na % is described as below:

$$\text{Na \%} = \frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100$$

Kelley's ratio (KR)

Groundwater quality classification for irrigation is also performed on the basis of Kelly's ratio (1963). Kelly's ratio is evaluated against levels of calcium and magnesium ions based on sodium ion. A Kelley's Ratio (KR) of more than one indicates an excess sodium concentration in waters. Hence, waters with a Kelley's Ratio less than one are appropriate for irrigation, while those with a ratio more than one are inappropriate for irrigation. Kelley's ratio (KR) is described as:

$$\text{KR} = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

Magnesium adsorption ratio (MAR)

Paliwal (1972) [18] developed a magnesium adsorption ratio (MAR) index to calculate the magnesium risk. MAR shows the magnesium risk that can be created if magnesium stays in groundwater balance. Magnesium adsorption ratio (MAR) also known as magnesium hazard (MH) and it is estimated by using following formula:

$$\text{MAR \%} = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$$

Permeability index (PI)

A modified criterion for estimating the quality of agricultural waters was developed based on salt solubility and the soil solution response from cation exchange. Due to ongoing irrigation methods, the soil permeability of an area ultimately reduces and is described based on the amount of bicarbonate, sodium, calcium and magnesium in water. The permeability index was calculated by using the following formula:

$$\text{PI \%} = \frac{\left(Na^+ + \sqrt{HCO_3^-}\right)}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$$

Limits of significant groundwater quality parameter indicators and their suitability for irrigation use were considered according to Das and Nag, 2015 [5] as given in Table 3.

Table 3: Limits of significant groundwater quality parameter indicators and their suitability for irrigation use

Parameter	Water class	Category
EC (µS/cm)	Excellent	< 250
	Good	250-750
	Permissible	750-2000
	Doubtful	2000-3000
	Unsafe	> 3000
TDS (mg/L)	Excellent	< 160
	Good	160-500
	Permissible	500-1500
	Doubtful	1500-2500
	Unsafe	>2500
SAR	Excellent	< 10
	Good	10 18
	Fair	18-26
	Poor	>26
Na %	Excellent	< 20
	Good	20-40
	Permissible	40-60
	Doubtful	60-80
	Unsafe	>80
PI %	Excellent	< 20
	Good	20-40
	Fair	40-80
	Poor	>80
MAR %	Suitable	< 50
	Unsuitable	>50
KR	Suitable	< 1
	Unsuitable	>1

Water quality index (WQI)

WQI is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. It was first proposed by Horton in 1965 [19]. Physicochemicals parameters of groundwater including pH, Total dissolved solids (TDS) and major cations [calcium (Ca), magnesium (Mg), sodium (Na), potassium (K)] and anions [bicarbonate (HCO_3), chloride (Cl), sulphate (SO^2) and nitrate (NO_3)] were used to calculate WQI for the study area. WQI was calculated using the "weighted arithmetic index" method with the help of following equation:

$$WQI = \frac{\sum Q_n W_n}{\sum W_n}$$

Where, Q_n = quality rating of nth water quality parameter, W_n = unit weight of nth water quality parameter.

The first step in calculating WQI using the "weighted arithmetic index" approach is to estimate the 'unit weight' allocated to each physicochemical parameter taken into account for the calculation. By assigning unit-weights, all of the relevant parameters of various units and dimensions are converted into a common scale.

The quality rating Q_n is calculated using the equation

$$Q_n = 100 \times \left[\frac{(V_n - V_i)}{(V_s - V_i)}\right]$$

Where,
V_n = actual amount of n^{th} parameter present,
V_i = ideal value of the parameter, V_i = 0, except for pH (V_i = 7)
V_s = standard permissible value for the n^{th} water quality parameter.

Unit weight (W_n)

It is calculated by using the following formula.

$$W_n = \frac{K}{V_n}$$

Where,
k = constant of proportionality and it is calculated using the following equation

$$K = \left[1 / \sum {}^{1}/_{V_s} = 1, 2, 3 \ \dots\dots, n\right]$$

The water quality standards and unit weights were assigned to every parameter which is given in Table 4. The WQI range, status and possible usage of the groundwater are given in Table 5.

Table 4: Standards for water and the unit weight of parameters

S. No.	Parameter	Standards WHO (V_s)	$1/V_n$	K	Unit weight (W_n)
1	pH	8.5	0.118	0.291	0.034
2	TDS	500	0.002	0.291	0.001
3	Ca^{2+}	75	0.013	0.291	0.004
4	Mg^{2+}	30	0.033	0.291	0.010
5	Na^+	200	0.005	0.291	0.001
6	K^+	12	0.083	0.291	0.024
7	HCO_3^-	200	0.005	0.291	0.001
8	Cl^-	250	0.004	0.291	0.001
9	$SO4^{2-}$	200	0.005	0.291	0.001
10	NO_3^-	45	0.022	0.291	0.006

Table 5: WQI range, status and possible usage of the water (Bora. 2016)

WQI	Water quality status (WQS)	Possible usage
0-25	Excellent	Drinking, irrigation and industrial
25-50	Good	Drinking, irrigation and industrial
50-75	Poor	Irrigation and industrial
75-100	Very poor	Irrigation
Above 100	Unsuitable for drinking and fish culture	Proper treatment required before use

Results and Discussion

Physico-chemical analysis of groundwater samples

The lowest value of p^H of groundwater was found to be 6.40 at Palpur observation point in Chaka block whereas the highest value of p^H was obtained as 7.84 at Bharauha observation point in Chaka block. Block wise average p^H value of groundwater was found to be 7.30, 7.17 and 7.45 in Chaka, Kaundhiyara and Karchhana blocks, respectively. The average p^H value of groundwater of the study area was found to be 6.82, which indicates the groundwater neutral in nature. The p^H values of each groundwater samples in the study area are shown in Fig. 3.

TDS is the concentrations of all dissolved minerals which present in water. Total dissolved solids indicate the nature of water salinity. The highest value of TDS was found to be 511.88 mg/L at Ikauni observation point in Kaundhiyara block whereas the lowest value was obtained as 311 mg/L at Bharauha observation point in Chaka block. Block wise average TDS value of groundwater was found to be 400.53, 401.87 and 395.17 mg/L in Chaka, Kaundhiyara and

Karchhana blocks, respectively. The average TDS value of the study area was obtained to be 399.19 mg/L. The TDS values of each groundwater samples in the study area are shown in Fig. 4.

Electrical conductivity measures the concentration of total dissolved solids present in water. At 25 °C, the values of EC were ranged between 465.00 to 764.00 µS/cm. The lowest value of EC was found at Bharauha observation point in Chaka block whereas the highest value was obtained at Ikauni observation point in Kaundhiyara block. Block wise average EC value of groundwater was found to be 597.80, 599.80 and 589.80 in Chaka, Kaundhiyara and Karchhana blocks, respectively. The average EC of the groundwater in the study area was determined to be 595.80. The EC values of each groundwater samples in the study area are shown in Fig. 5.

The acceptable limit of TH (as $CaCO_3$) is 300 mg/L, which can be increased to 600 mg/L if no other source of water is available. The values of TH ranged from 198.20 mg/L to 308.42 mg/L. The lowest TH value was obtained at Bharauha observation points in Chaka blocks, while the maximum value was discovered at Palpur observation points in Chaka blocks. The average TH average value of groundwater in Chaka, Kaundhiyara, and Karchhana blocks was found to be 234.96, 254.55 and 226.08 mg/L, respectively. The average TH of the groundwater in the study area was determined to be 238.53 mg/L. The TH values of each groundwater samples in the study area are shown in Fig. 6.

The lowest calcium value of groundwater was found to be 32.12 mg/L at Bharauha observation point in Chaka block, while the highest value was obtained as 54.52 mg/L at Palpur observation points in Chaka blocks. The average calcium value of groundwater was determined to be 43.08, 45.52 and 38.59 mg/L in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average calcium value of groundwater of the study area was found to be 42.39 mg/L. The calcium levels of each groundwater samples in the study area are shown in Fig. 7.

The values of magnesium ranged from 21.24 mg/L to 46.42 mg/L with an average 32.44 mg/L. The lowest value of magnesium was obtained at Bhandewara observation points in Karchhana blocks, while the maximum value was found at Benipur Arail observation points in Kaundhiyara blocks. The average magnesium value of groundwater in Chaka, Kaundhiyara, and Karchhana blocks was found to be 33.16, 37.90 and 26.26 mg/L, respectively. The magnesium values of each groundwater samples in the study area are shown in Fig. 8.

The sodium values of each groundwater samples in the study area are shown in Fig. 9. The sodium concentration in the groundwater ranged from the minimum value of 36.15 mg/L at Bayohara observation points in Kaundhiyara block to the maximum value of 62.44 mg/L at Palpur observation points in Chaka block. The average value of sodium concentration in groundwater of different blocks of the study area was obtained to be 55.65, 52.08 and 45.44 mg/L in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average value of sodium content in the groundwater of the entire study area was found to be 51.06 mg/L.

The potassium concentration in the groundwater varied from 1.52 mg/L at Bhandewara observation points in Karchhana block to 3.24 mg/L at Bharauha observation points in Chaka block. The average potassium concentration value in groundwater, in different blocks of the study area, was found to be 2.59, 2.27 and 2.28 mg/L in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average potassium content value in the groundwater of the entire study area was found to be 2.38 mg/L. The potassium values of each groundwater samples in the study area are shown in Fig. 10.

The bicarbonate levels of each groundwater samples in the study area are shown in Fig. 11. The bicarbonate content in the groundwater ranged from the minimum value of 190.42 mg/L at Palpur observation points in Chka block to the maximum value of 342.30 mg/L at Karchhana observation points in Karchhana block. Block wise average value of bicarbonate content in the groundwater of the study area was found to be 255.13, 241.54 and 305.40 mg/L in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average bicarbonate of the groundwater in the study area was determined to be 267.36 mg/L.

The chloride concentration in groundwater varied from the minimum value of 26.31 mg/L at Bharauha observation points in Chaka block to the maximum value of 67.25 mg/L at Palpur observation points in Chaka block. The chloride content in the groundwater in the study area is shown in Fig. 12. Block wise average value of chloride concentration, in the groundwater of the study area was found to be 52.85, 41.69 and 39.99 mg/L in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average bicarbonate of the groundwater in the study area was determined to be 44.85 mg/L.

The sulphate content in groundwater ranged from the minimum value of 11.15 mg/L at Bharauha observation points in Chaka block to the maximum value of 18.45 mg/L at Palpur observation points in Chaka block. Block wise average value of sulphate concentration in the groundwater of the study area was found to be 14.58, 13.86 and 14.53 mg/L in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average sulphate of the groundwater in the study area was obtained to be 14.32 mg/L. The chloride content in the groundwater in the study area is shown in Fig. 13.

The nitrate concentration level in groundwater in the study area is shown in Fig.14. In the study area, it ranged from the minimum value of 7.65 mg/L at Ubhari observation points in Chaka block to the maximum value of 47.23 mg/L at Ikauni observation points in Kaundhiyara block. The average values of nitrate concentration in groundwater of different blocks were found to be 22.71, 30.51 and 2483 mg/L in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average nitrate of the groundwater in the study area was obtained to be 26.02 mg/L.

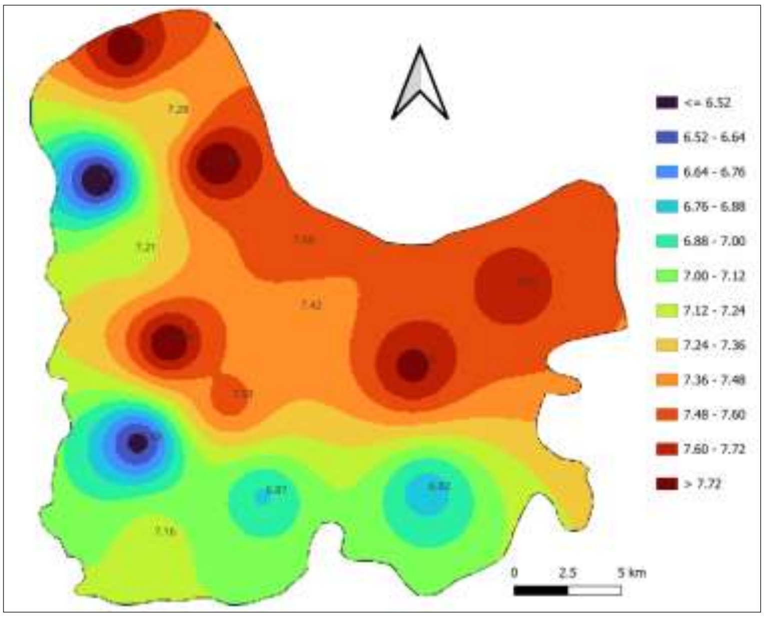

Fig 3: Spatial distribution map of p^H value in the Study Area

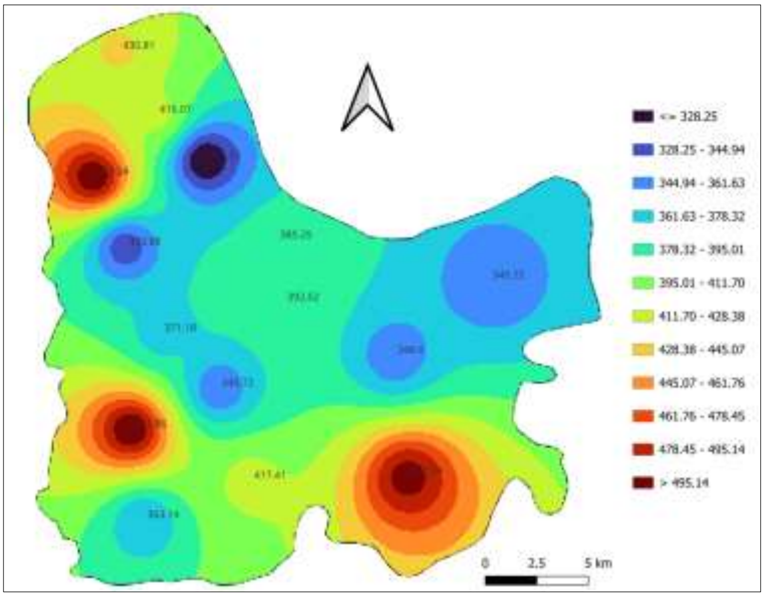

Fig 4: Spatial distribution map of TDS value in the Study Area

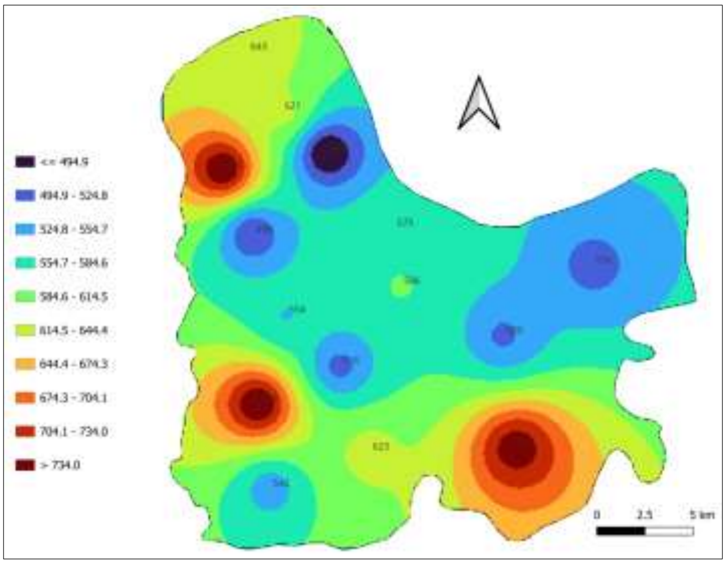

Fig 5: Spatial distribution map of EC value in the Study Area

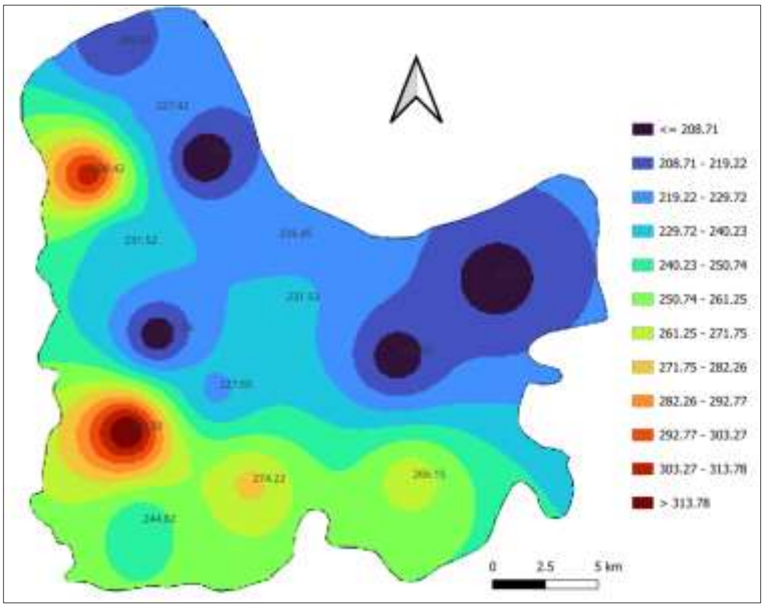

Fig 6: Spatial distribution map of TH value in the Study Area

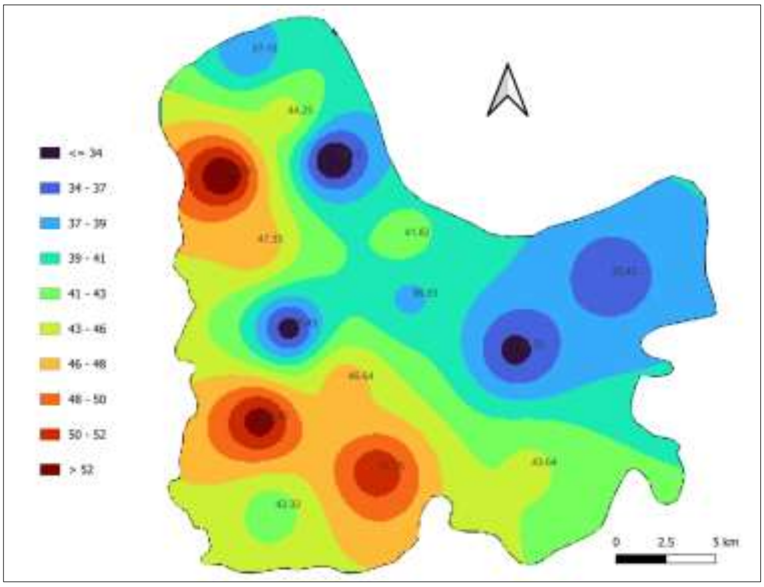

Fig 7: Spatial distribution map of calcium value in the Study Area

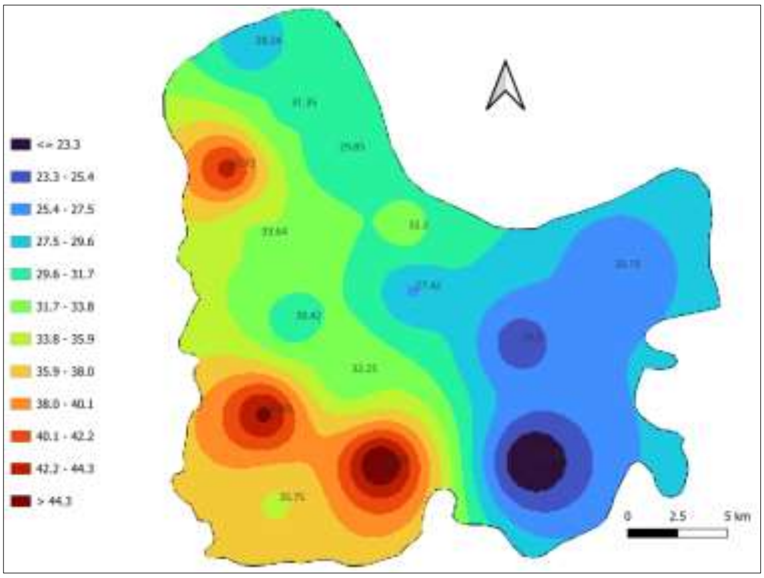

Fig 8: Spatial distribution map of magnesium value in the Study Area

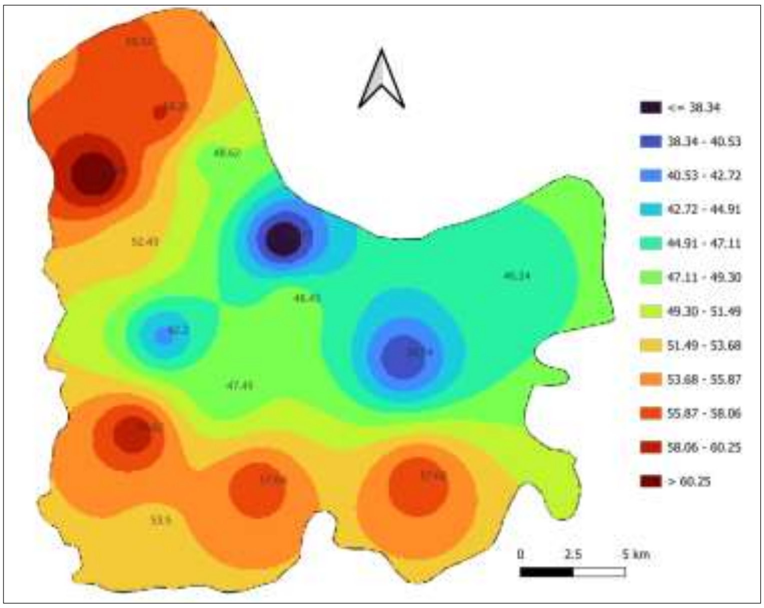

Fig 9: Spatial distribution map of Sodium value in the Study Area

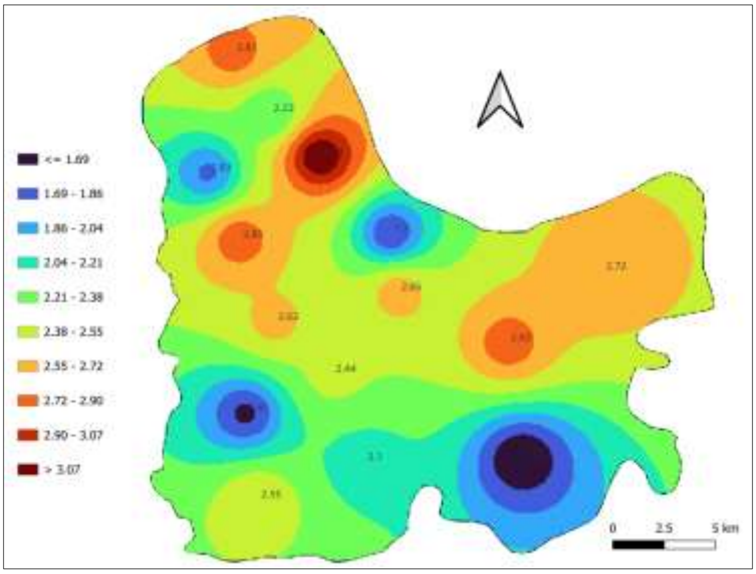

Fig 10: Spatial distribution map of potassium value in the Study Area

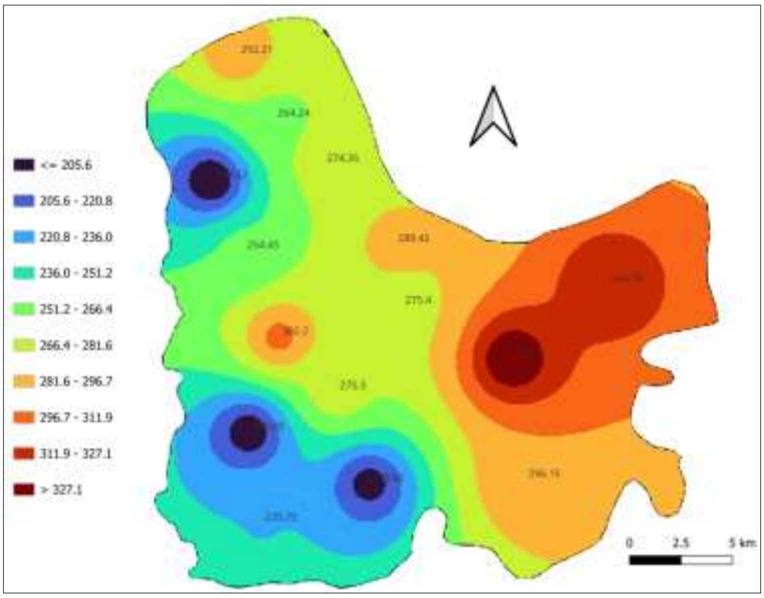

Fig 11: Spatial distribution map of bicarbonate value in the Study Area

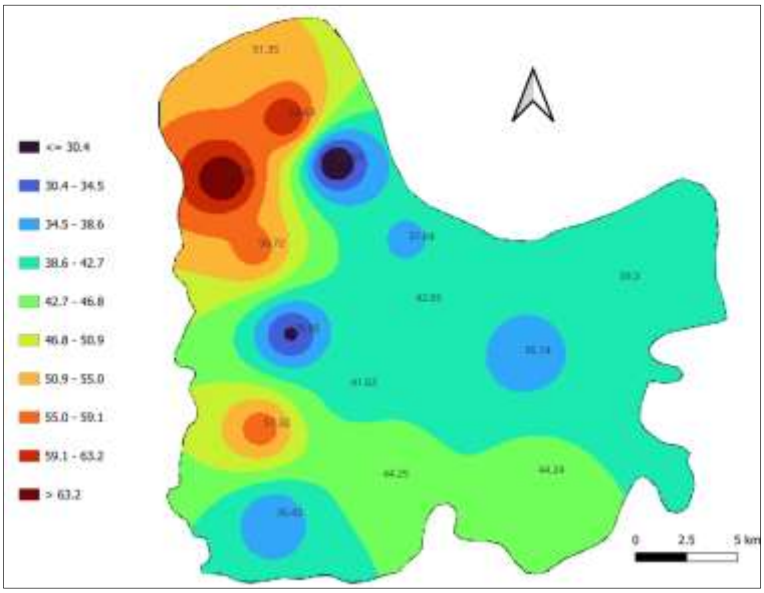

Fig 12: Spatial distribution map of Chloride value in the Study Area

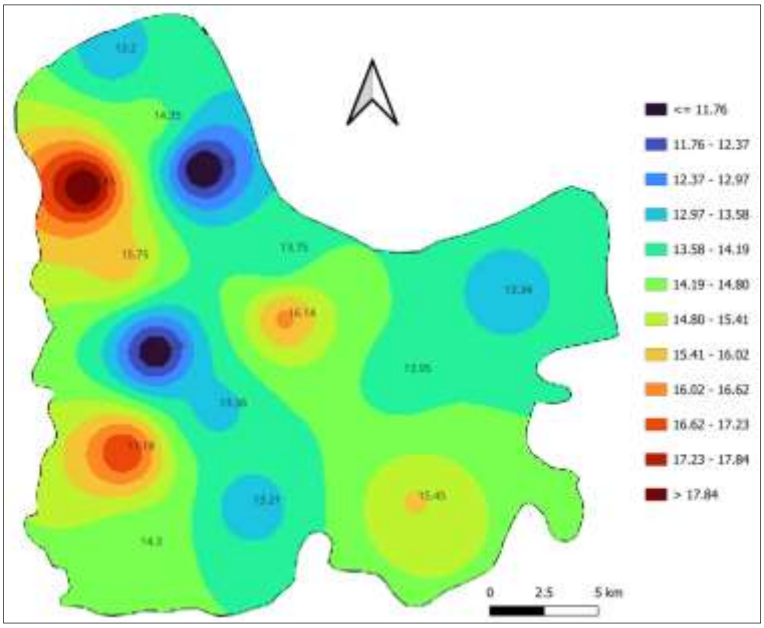

Fig 13: Spatial distribution map of sulphate value in the Study Area

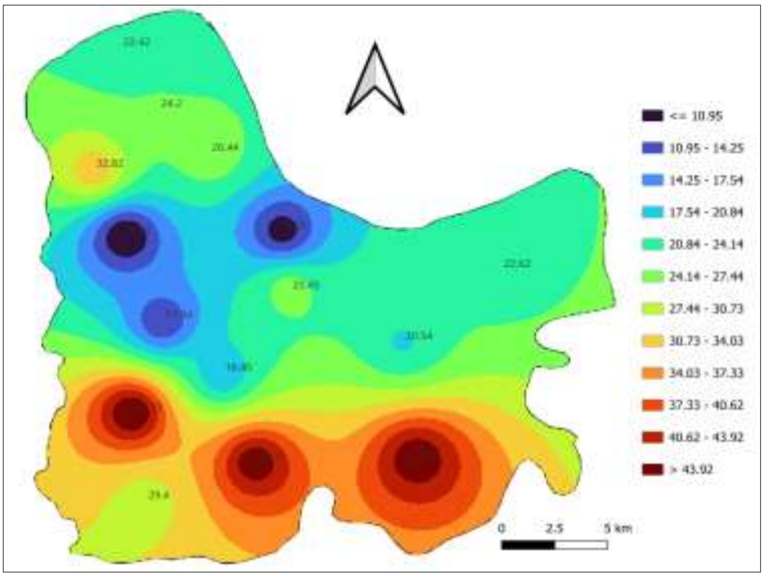

Fig 14: Spatial distribution map of nitrate value in the Study Area

Chemistry of major ions

Sodium was the leading ion among major cations, accounting for 39.80% of all cations on average. Calcium and magnesium ions were secondary in importance, accounting for 33.05% and 25.29% of total cations on average. Potassium was the least dominant cation, accounting for 1.86% of all cations on average. The order of cation concentration was $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. The percentage contribution of cations to the overall anionic balance in the groundwater of the study area is shown in Fig. 15.

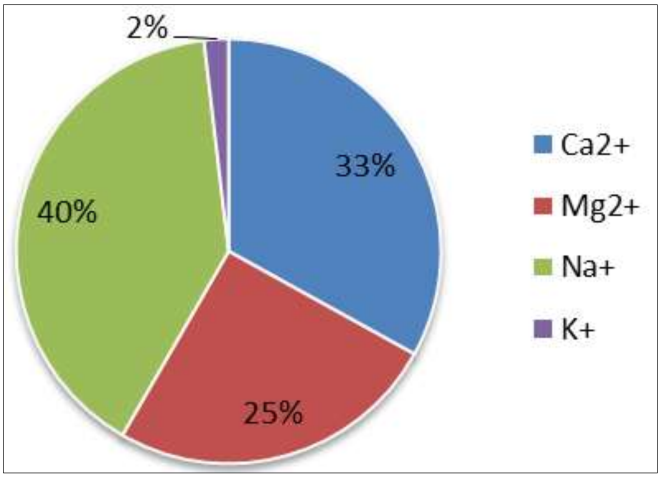

Fig 15: Percentage contribution of cations to the overall cationic balance

Bicarbonate was the most common major anion, accounting for 75.84% of all anions on average. Chloride is the second most abundant anion, accounting for 12.72% of all anions on average. Nitrate and sulphate were the least dominant ions, accounting for 14.5% and 4.5% of total anions on average, respectively. The order of anion concentration was $HCO_3^- > Cl^- > NO_3^- > SO4^2$. The percentage contribution of anions to the overall anionic balance in the groundwater of the study area is shown in Fig. 16.

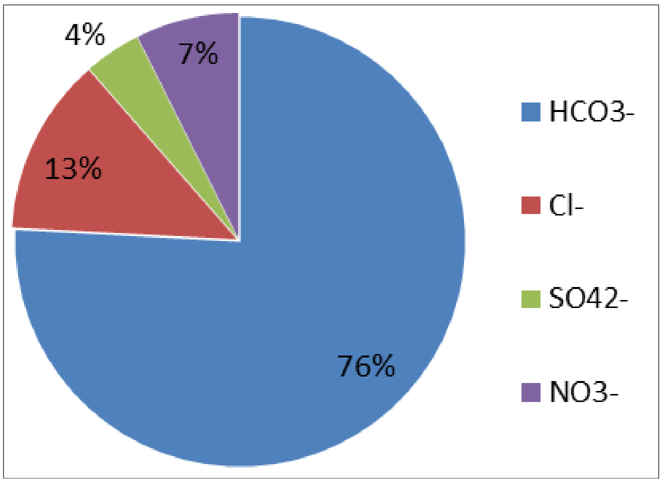

Fig 16: Percentage contribution of anion to the overall anionic balance

Comparison of groundwater quality with the BIS and WHO drinking water quality standard

The characteristics of groundwater quality were compared to World Health Organization (WHO) and Bureau of Indian Standards (BIS) drinking water guidelines. Statistical summary of analytical results and comparison with WHO and BIS (IS: 10500) for drinking purpose is given in Table- 6. The pH values of the all groundwater samples (6.40-7.84) are within the maximum desirable limit as per both WHO and BIS standard, accepted for drinking use. When compared to both standards, the EC values in 86.67% of groundwater samples exceeded the maximum desirable limit of 500 mg/L. TDS values exceed the maximum desirable limit of 500 mg/L in 13.34% of groundwater samples tested against the BIS standard. But, in compare to WHO standard, all groundwater samples are within the maximum desirable limit. The total hardness of water is the property of water that prevents soap lather production and raises the boiling point of water. Based on hardness, water may be divided into four categories: soft water (75 mg/L), moderately hard water (75-150 mg/L), hard water (150-300 mg/L) and very hard water (>300 mg/L) (Singh *et al.*, 2014) [14]. Groundwater in the study area has a total hardness that ranges from 198.20 to 308.42 mg/L, indicating that it is hard to very hard water. The analytical results show that 93.33% of groundwater samples are hard water and only 6.67% are very hard water.

Calcium and magnesium are critical nutrients for plant and animal growth as well as for the bone, nervous system and cells development. Calcium concentrations are found to be within the maximum desired limits in all groundwater samples as compared to both standards. Whereas, in 60% of the groundwater samples, magnesium concentrations surpass the maximum recommended limits of 30 mg/L as compared to both standards.

Table 6: Statistical summary of analytical results and comparison with WHO and BIS (IS: 10500) for drinking purpose

Water quality parameters	Range	Average	BIS (IS 10500)				WHO			
			Max desirable limit	Max permissible limit	Percent of samples above desirable limit	Percent of samples above permissible limit	Max Desirable limit	Max permissible limit	Percent of samples above desirable limit	Percent of samples above permissible limit
pH	6.40-7.84	7.31	6.5 - 8.5	-	00.00	00.00	7 - 8.5	-	00.00	00.00
EC	465.00-764.00	595.80	500	2000	86.67	00.00	500	1500	86.67	00.00
TDS	311.55-511.88	399.19	500	-	13.34	-	750	1500	00.00	00.00
TH	198.20-308.42	238.53	300	600	13.34	00.00	100	500	100.00	00.00
Ca^{2+}	32.72-54.52	42.39	75	200	00.00	00.00	75	200	00.00	00.00
Mg^{2+}	21.24-46.42	32.44	30	100	60.00	00.00	30	150	60.00	00.00
Na^{+}	36.15-62.44	51.06	-	200	-	00.00	50	200	53.34	00.00
K^{+}	1.52-3.24	2.38	-	-	-	-	100	200	00.00	00.00
HCO_3^-	190.42-342.30	267.36	200	600	80.00	00.00	300	600	20.00	00.00
Cl^-	26.31-67.25	44.85	250	1000	00.00	00.00	200	600	00.00	00.00
$SO4^{2-}$	11.15-18.45	14.32	200	400	00.00	00.00	200	400	00.00	00.00
NO_3^-	7.65-47.23	26.02	45	100	20.00	00.00	50	100	00.00	00.00

Sodium and potassium are the two most significant naturally occurring elements. In addition to sewage and industrial effluents, weathering of rocks may be a major source of both cations. In 53.34% of the groundwater samples, sodium concentrations surpass the maximum recommended limits of 50 mg/L and potassium concentrations are found to be within the maximum desired limits in all groundwater samples as compared to WHO standards.

In 80% of groundwater samples tested against the BIS standard, bicarbonate concentrations exceeded the maximum desirable limit of 200 mg/L. However, it exceeds the WHO standard in only 20% of groundwater samples. As per WHO and BIS standards, the chloride and sulphate values of all groundwater samples are within the maximum desirable limit. In 13.34% of groundwater samples tested against the BIS standard, Nitrate concentrations exceeded the maximum desirable limit of 45 mg/L. However, when compared to WHO standards, all groundwater samples fall within the desirable limit. As per both WHO and BIS standards, there were no any groundwater quality parameters of any groundwater samples within the maximum permissible limit. Based on the result findings, it is possible to say that the groundwater of the study area is suitable for drinking and domestic purpose.

Irrigation water quality parameters

Irrigated farming depends on an appropriate supply of usable quality of water. To evaluate the overall irrigational water quality of the groundwater there were seven parameters estimated; namely-Electrical conductivity (EC), Total dissolved solids (TDS), Sodium Adsorption Ratio (SAR), Percentage Sodium (Na%), Kelly's Ratio (KR), Magnesium Adsorption Ratio (MAR) and Permeability index (PI). The EC and TDS result were discussed in section 3.1.

The SAR values in the groundwater varied from 7.19 at Karchhana observation points in Karchhana block to 10.12 at Bhandewara observation points in Karchhana block. The average SAR values value in groundwater in different blocks of the study area was found to be 9.06, 8.07 and 8.01 in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average SAR value in the groundwater of the entire study area was found to be 8.38. The SAR values of each groundwater samples in the study area are shown in Fig. 17.

The values of N% ranged from 33.83% to 47.69% with an average 41.82%. The lowest value of N% was obtained at Bayohara observation points in Karchhana blocks, while the maximum value was found at Bhandewara observation points in Karchhana blocks. The average N% value of groundwater in Chaka, Kaundhiyara, and Karchhana blocks was found to be 43.59, 39.61 and 42.26%, respectively. The N% values of each groundwater samples in the study area are shown in Fig. 18.

The lowest value of Kelly's Ratio (KR) of groundwater was found to be 0.49 at Bayohara observation point in Karchhana block, while the highest value was obtained as 0.89 at Bhandewara observation points in Karchhana blocks. The average KR value of groundwater was determined to be 0.74, 0.63 and 0.71 in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average KR value of groundwater in the study area was found to be 0.69. The KR levels of each groundwater samples in the study area are shown in Fig. 19.

The MAR values of each groundwater samples in the study area are shown in Fig. 20. The MAR value in the groundwater ranged from 32.74 at Bhandewara observation points in Karchhana block to 48.17 at Bharauha observation points in Chaka block. The average value of MAR in groundwater of different blocks of the study area was obtained to be 43.66, 45.42 and 40.46 in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average value of MAR content of the groundwater in the entire study area was found to be 43.18.

The permeability index (PI) in groundwater vary from the minimum value of 46.68% at Ikauni observation points in Kaundhiyara block to the maximum value of 61.08% at Bhandewara observation points in Karchhana block. Block wise average value of permeability index concentration of the groundwater in the study area was found to be 54.80, 50.38 and 57.01% in the Chaka, Kaundhiyara, and Karchhana blocks, respectively. The average permeability index of the groundwater in the study area was obtained to be 54.06%. The permeability index in the groundwater in the study area is shown in Fig. 21.

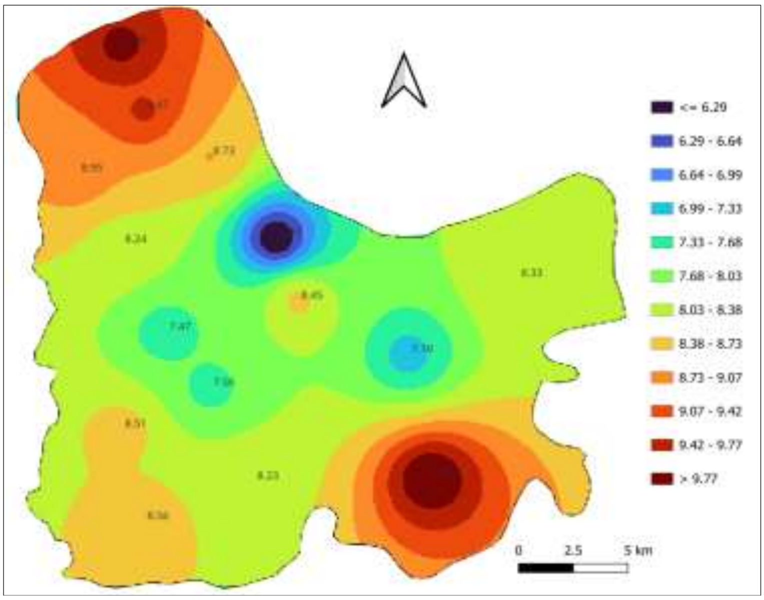

Fig 17: Spatial distribution map of SAR value in the Study Area

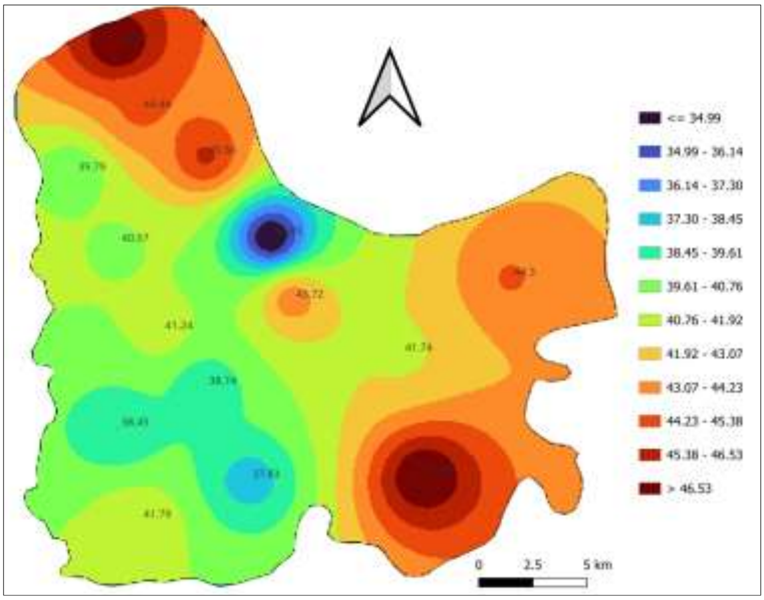

Fig 18: Spatial distribution map of Na% value in the Study Area

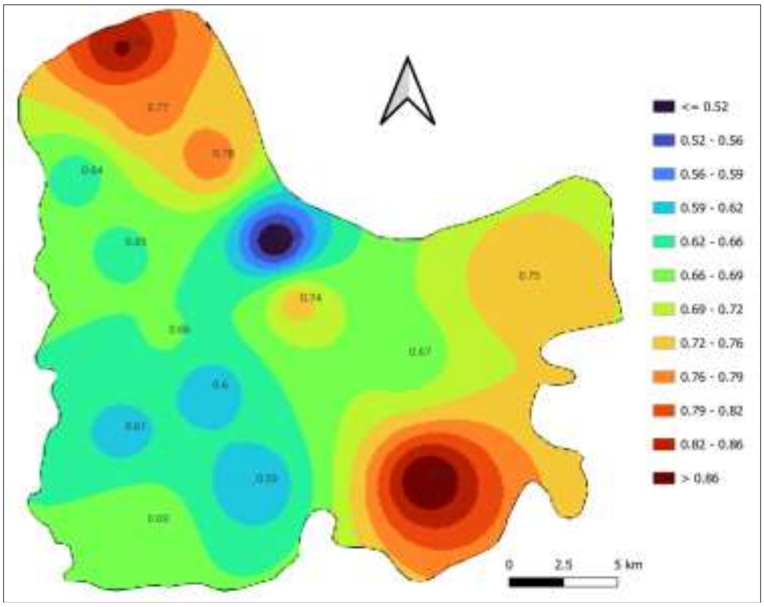

Fig 19: Spatial distribution map of KR value in the Study Area

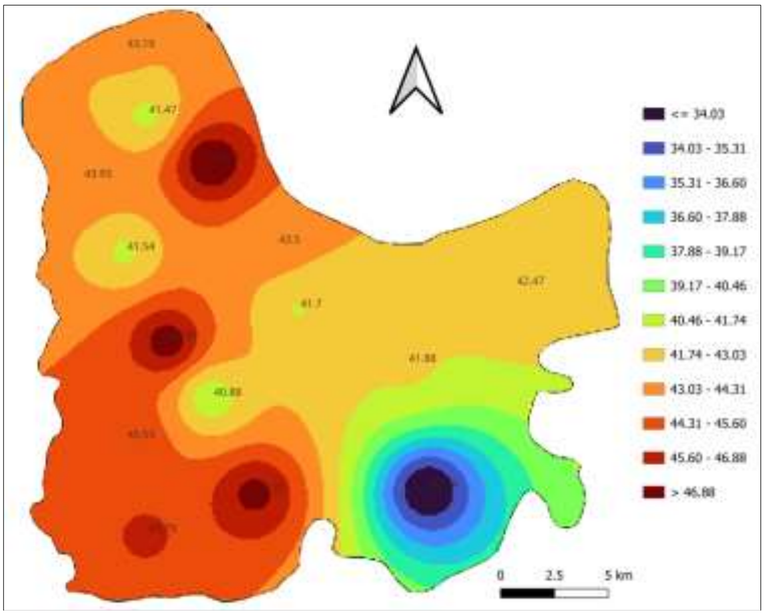

Fig 20: Spatial distribution map of MAR value in the Study Area

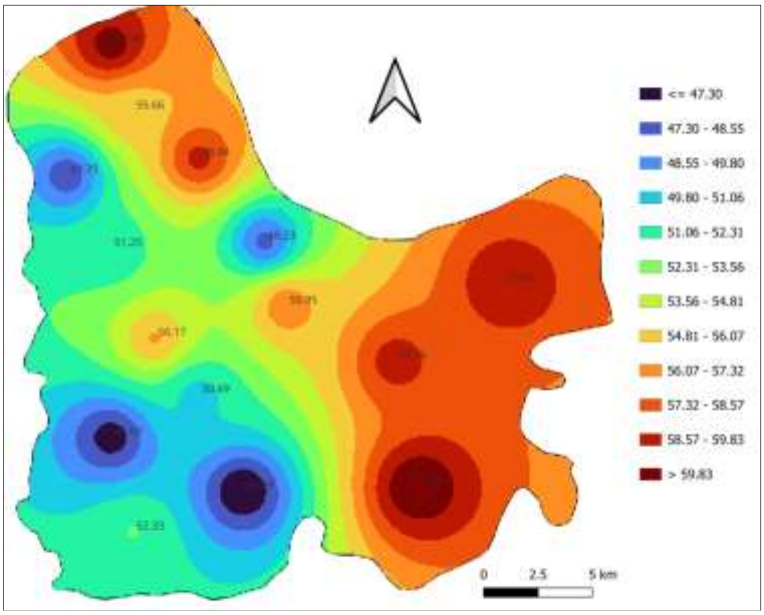

Fig 21: Spatial distribution map of PI value in the Study Area

Comparison of groundwater quality with different irrigation water quality parameters

Groundwater is regarded as a valuable resource that is essential for plant growth and crop production. Thus, the groundwater quality in the study area is evaluated to determine its suitability for agricultural uses. The characteristics of groundwater quality were compared to different irrigation water quality parameters. Statistical summary of analytical results and comparison with different irrigation water quality parameters is given Table 7.

According to the EC values obtained, 80.00% of the groundwater samples are in the "good" category and 20% are in the "permissible" category. There are no any samples found under “excellent” as well as “doubtful or unsafe” category. SAR is a common approach for evaluating irrigation water that is based on sodium concentration. As a result, extremely high salt concentrations in groundwater harm the soil and are unsuitable for crop growth. During the study, it discovered that 93.33% of the groundwater samples are found under the “excellent" category and 6.67% of the samples contain medium sodium water (good), making them suitable for any crops. There are no any samples are in “Fair” as well as “Poor” category.

Soil drainage permeability may reduce the higher sodium availability by irrigation water. Groundwater samples in the study area are classified as Good (33.33%) and Permissible (66.67%), indicated them suitable to irrigate any crops. There are no any samples found under “excellent” as well as “doubtful or unsafe” category. According to KR and MAR values, all (100%) groundwater samples are suitable for irrigation. The permeability index (PI) is one of the greatest important irrigation water quality indices for assessing long-term effects of soil permeability. According to PI values, 100% of groundwater samples fall into the "Fair" category. There are no any samples found under “excellent” as well as “Fair or Poor” category. Based on the aforesaid findings, it is possible to conclude that the groundwater of the study area is suitable for irrigation.

Table 7: Samples are classified according to the standards specified for various water quality parameters

Parameter	Water class	Category	Percent of samples
EC (µS/cm)	Excellent	< 250	00.00
	Good	250-750	80.00
	Permissible	750-2000	20.00
	Safe	2000-3000	00.00
	Unsafe	> 3000	00.00
TDS (mg/l)	Excellent	< 160	00.00
	Good	160-500	80.00
	Permissible	500-1500	20.00
	Safe	1500-2500	00.00
	Unsafe	>2500	00.00
SAR (meq/l)	Excellent	< 10	93.33
	Good	10 - 18	6.67
	Fair	18-26	00.00
	Poor	>26	00.00
Na %	Excellent	< 20	00.00
	Good	20-40	33.33
	Permissible	40-60	66.67
	Safe	60-80	00.00
	Unsafe	>80	00.00
KR	Suitable	< 1	100
	Unsuitable	>1	00.00
MAR	Suitable	< 50	100
	Unsuitable	>50	00.00
PI %	Excellent	< 20	00.00
	Good	20-40	00.00
	Fair	40-80	100
	Poor	>80	00.00

Water quality index (WQI)

The lowest value of WQI was found to be 16.82 at Ubhari observation point in Chaka block, while the highest value of WQI was obtained as 51.68 at Naini (I.T.I.) observation points in Chaka blocks. The average value of WQI was determined to be 37.12, 35.98 and 38.04 in the Chaka, Kaundhiyara and Karchhana blocks, respectively. The average value of WQI in the study area was found to be 37.05. The estimated values of WQI at various observation points in the study area are shown in Fig. 22. Based on WQI value, the classification of water quality in the study is given in Table 8.

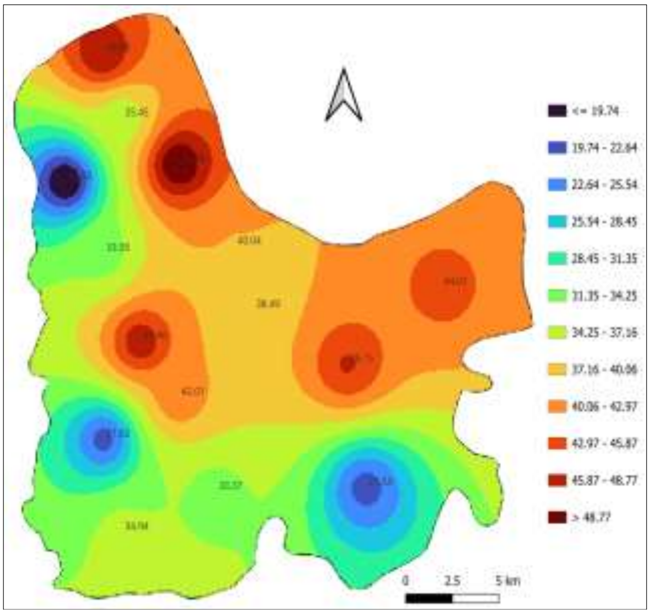

Fig 22: Spatial distribution map of WQI in the study area

Table 8: Water quality classification based on WQI value

WQI	Water quality status	Possible usage	Percent of samples
0-25	Excellent	Drinking, irrigation and industrial	20.00
25-50	Good	Drinking, irrigation and industrial	73.33
50-75	Poor	Irrigation and industrial	6.67
75-100	Very poor	Irrigation	00.00
Above 100	Unsuitable for drinking and fish culture	Proper treatment required before use	00.00

As per the results shown in Table 8 and the obtained WQI values, only 20.00% of the groundwater samples are in the “Excellent" category, 73.33% are in the “Good” category and remaining 6.67% are in “Poor” category. There are no any samples found in the "Very poor" or "Unsuitable for drinking and fish culture" categories. Based on the foregoing findings, it is possible to conclude that the groundwater in the study area is "Good" for drinking, irrigation and industrial purposes.

Conclusions

The analysis of the groundwater of the study area showed that the all groundwater quality parameters such as pH, total dissolved solids (TDS), electrical conductivity (EC), Total hardness (TH), calcium (Ca^{2+})' magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), chloride (Cl^{-}), sulphate ($SO4^{2-}$) and nitrate (NO_3^{-}) were found to be within the maximum desired limits as compared to both WHO and BIS standards. As per both WHO and BIS standards, there were no any groundwater quality parameters of any groundwater samples within the maximum permissible limit. Based on the result findings, it is possible to conclude that the groundwater of the study area is suitable for drinking and domestic purpose. Based on the result findings of irrigation quality parameters sach as Electrical conductivity (EC), Total dissolved solids (TDS), Sodium Adsorption Ratio (SAR), Percentage Sodium (Na%), Kelly’s Ratio (KR), Magnesium Adsorption Ratio (MAR) and Permeability index (PI), it is possible to conclude that the groundwater of the study area is suitable for irrigation. The values of water quality index (WQI) ranged from 16.82 to 51.68 with an average 37.05. According to the obtained WQI values, only 20.00% of the groundwater samples are in the “Excellent" category, 73.33% are in the “Good” category and remaining 6.67% are in “Poor” category. Based on this result it is possible to conclude that the groundwater of the study area is "Good" for drinking, irrigation and industrial purposes.

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