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ORIGINAL ARTICLE

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Groundwater suitability assessment for drinking and irrigation purposes in Aligarh, Uttar Pradesh, India

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ABSTRACT

As the global population is soaring their demand for freshwater has reached critical levels, especially in regions like Aligarh, India, where groundwater is a vital resource for drinking and irrigation. Drinking water is important for the present life, while irrigation water is important for the future livelihood. Therefore, this study addresses the pressing need to understand its suitability for potable and irrigation purposes. Water samples were collected from various locations to ensure the representative coverage of the study area from 2016 to 2019. Parameters including pH, Electrical Conductivity (EC), Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^-), Sulfate (SO_4^-), Nitrate (NO_3^-), Carbonate (CO_3^-), Bicarbonate (HCO_3^-), and Total Dissolved Solids (TDS) were rigorously examined. The results revealed deviations from permissible limits for several parameters, posing potential health risks associated with both types of water consumption. Higher concentrations of sodium, chloride, sulphate, and nitrate, with high electrical conductivity, raise significant concerns regarding water quality for drinking and irrigation purposes. The analysis of irrigation water quality showed different levels of salinity in the samples, indicating the need for tailored management strategies to mitigate salinity-related risks and optimize agricultural productivity. This study uniquely shifts the focus from surface water quality to a comprehensive analysis of groundwater suitability for drinking and irrigation. It addresses the overlooked correlations between salinity and other parameters. Therefore, these findings underscore the urgency of implementing remedial actions to improve water quality and ensure sustainable water use practices in the study area. This will help protect public health and support farming, especially as global water challenges continue to grow.

HIGHLIGHTS

- Groundwater is vital for drinking and irrigation in Aligarh, but elevated salinity and sodium levels pose significant challenges.
- A 2016-2019 study reveals contaminants like sodium, chloride, and sulfate exceed the safe limits.
- Over 80% of water samples are suitable, but southern blocks face higher contamination risks.
- Study suggests interventions like reverse osmosis, gypsum to ensure sustainable water use.

1 | INTRODUCTION

The qualitative suitability assessment of water resources underscores the necessity for self-sufficiency in meeting various needs such as potable, irrigational, and industrial uses (Merkel *et al.*, 2005). It is paramount due to the distinct yet interconnected needs and challenges of each use.

Groundwater emerges as a primary freshwater source in the present scenario, heavily relied upon for potable and irrigation purposes, with over 85% of the study area's total water demand being met through groundwater, predominantly for irrigation (Healy, 2010). However, concerns linger regarding water quality, especially in regions marked by high salinity levels, adversely affecting human health, crop production, and soil health (Singh *et al.,* 2020).

Groundwater must meet stringent quality standards to ensure public health and safety for drinking purposes (Singh *et al.,* 2020; Das *et al.,* 2023). Contaminants such as heavy metals, pathogens, and pollutants from industrial and agricultural activities can pose serious risks to human health if present in drinking water sources (Akubuenyi *et al.,* 2013). Therefore, conducting groundwater suitability assessments is essential to identify potential contaminants and ensure that groundwater meets regulatory standards for drinking water quality.

On the other hand, groundwater suitability for irrigation purposes is crucial for agricultural productivity and sustainability. The quality of irrigation water directly impacts crop yields, soil health, and the long-term viability of farming systems. High levels of salinity, alkalinity, or toxic substances in groundwater impair soil structure, hinder nutrient uptake by plants, and lead to reduced crop yields (Bagdi *et al.,* 2022). As by assessing groundwater suitability for irrigation, farmers and agricultural policymakers can implement appropriate irrigation practices, select tolerant crop varieties, and manage soil and water resources more effectively to optimize agricultural productivity while minimizing environmental degradation.

Therefore, this study marks a significant departure from previous research, shifting the focus from surface water quality to groundwater suitability, particularly emphasizing the correlation between drinking and irrigation water quality (Singh and Mishra, 2021). While past studies identified high salinity concentrations, they predominantly centered on salinity contamination alone, overlooking its sources and connections with other parameters. In contrast, our study offers a comprehensive analysis of all facets of this contamination within the groundwater context. By exploring the relationships between salinity and other factors, we bridge this research gap, offering crucial insights for effective water resource management.

2 | MATERIALS AND METHODS

2.1 | Study Area

The study area encompasses the westernmost region of Uttar Pradesh, comprising District Aligarh, spanning from 27° 29′ to 28° 11′ North and 77° 29′ to 78° 38′ East (Fig.1). Survey of India Topo sheet numbers 53H, L, 54E, and I comprehensively cover the entirety of the study area (Singh and Mishra, 2021).

Situated between the Ganga and Yamuna rivers, Aligarh resides within the Ganga Yamuna doab that formed the world's largest aquifers system which is Alluvial Aquifer System. The total population of the study area is recorded at 36,73,889, with a notable decadal growth rate of 22.78% as per the Census 2011 data. With this growth rate, the projected

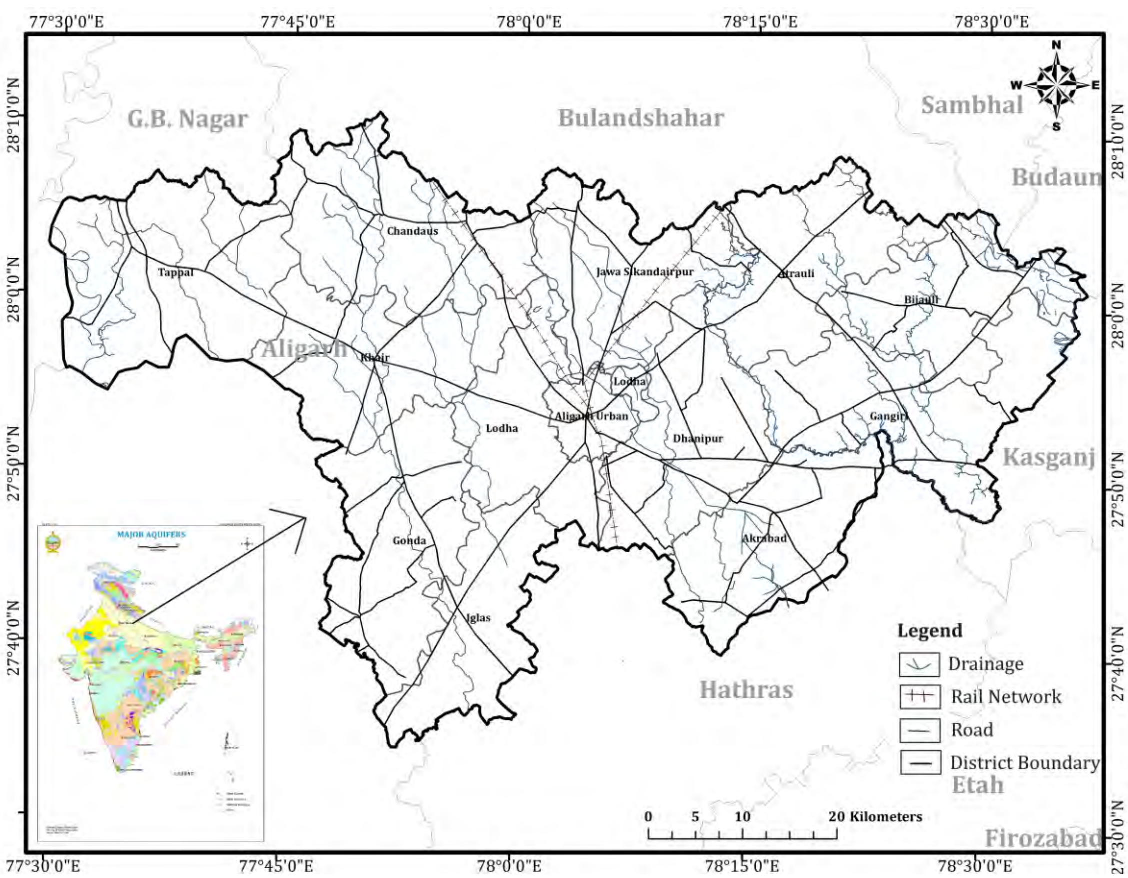

FIGURE 1 Location map of the study area

population in 2021 is estimated to be 8 lakhs, indicating a substantial increase and further exacerbating stress on underground water resources. The average annual rainfall of the study area is 652 mm.

The study area is situated at the doab of River Ganga and River Yamuna which is flowing at the eastern and western boundaries. The maximum depth of water level is at the centre part of the study area; 25 m.bgl. It is also the district headquarter and urban centre. While the population growth rate is more than 22% and groundwater exploration is more than 85% for the drinking and irrigation purposes with the 25 cm/year decline trend in water level. So, the groundwater suitability assessment is of paramount importance (Gupta *et al.,* 2018).

For the suitability assessment of drinking and irrigation water, groundwater samples were collected using clean high-density polyethylene (HDPE) cans with a capacity of 500 ml, gathered in June of the years 2016, 2017, 2018, and 2019. Samples were collected from various locations across the study area to ensure representative coverage as depicted in Fig. 2.

Certain parameters such as pH and Electrical Conductivity (EC) were measured on-site in the field, while Sodium (Na^+) and Potassium (K^+) concentrations were determined using a Flame Photometer (Systronics T-128). Parameters including Calcium (Ca^{2+}), Manganese (Mg^{2+}), Chloride (Cl^-), Carbonate (CO_3^-), and Bicarbonate (HCO_3^-) levels were assessed through volumetric titration methods, while Total Dissolved Solids (TDS) were derived as by-products of analyzed parameters. Additionally, Sulfate (SO_4^-) and Nitrate (NO_3^-) concentrations were measured using Shimadzu UV-VIS-1800 spectrophotometer. These parameters collectively contribute to classifying the water's suitability for drinking purposes, incorporating ion balance principles as outlined by Todd and Mays (1980).

Along with the initial water quality checks, we also calculated key parameters to assess if the water is suitable for irrigation as Sodium Percentage (Na %), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Permeability Index (PI), Magnesium Adsorption Ratio (MAR), and Electrical Conductivity (EC). These calculations help determine the impact of water on soil and plant health, assessing factors such as sodium levels and the potential for soil dispersion. The analysis was further enriched by using diagrams like the US Salinity diagram, Gibbs diagram, Piper diagram, and Wilcox diagram. Gibbs and Piper diagrams were plotted to identify contamination

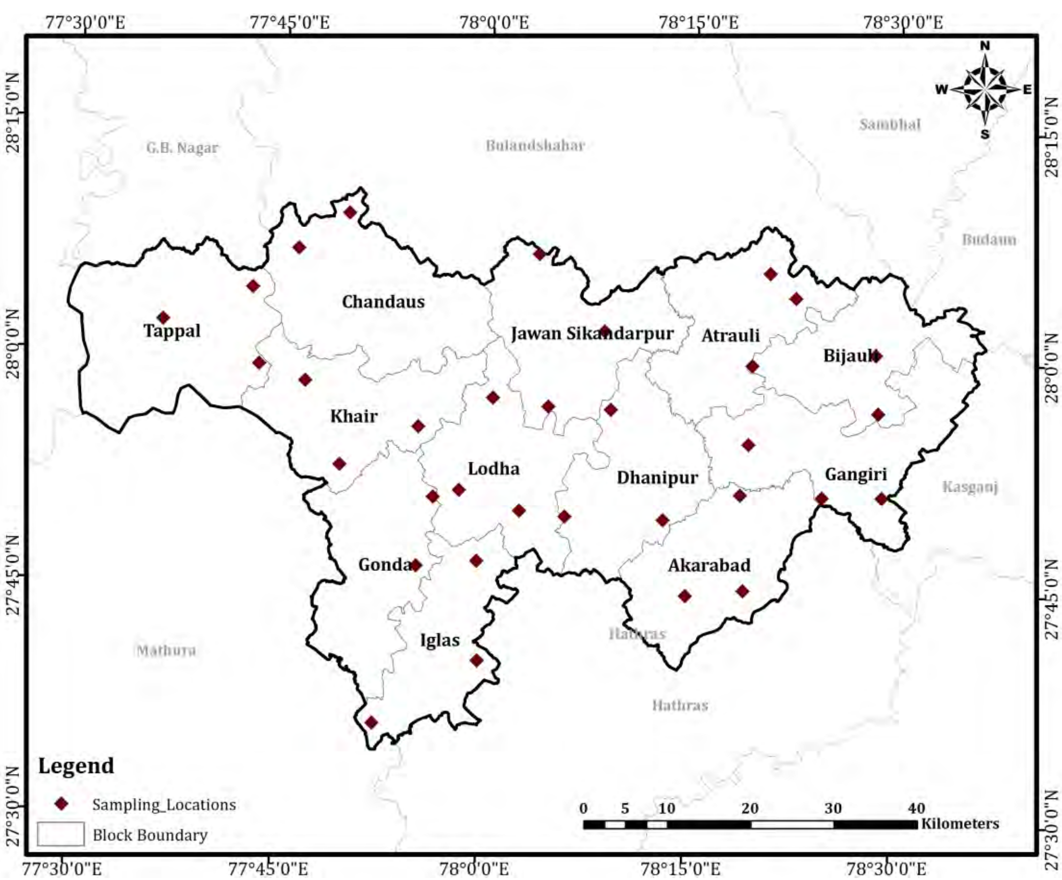

FIGURE 2 Ground Water sampling locations

sources, specifically focusing on cations including Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^-), Carbonate (CO_3^-), Sulphate (SO^-_4), and Bicarbonate (HCO_3^-). This detailed approach provided a complete evaluation of the water resources' sustainability for irrigation water, as described by Teng *et al.* (2016).

Subsequently, to explain the water suitability representation (both drinking and irrigation) of successive years, yearly average values were computed block-wise for each parameter and illustrated by the spider diagram (Fig's. 3 and 4a). A spider diagram is a graphical method of displaying multivariate data in the form of a two-dimensional chart with several axes. Each axis represents a variable (Block), and data points (Concentration of parameters) are plotted on each axis, with lines connecting the points to form a polygon; where the blue line indicates the average values (average concentration of respective parameter) of each block for the year of 2016 and in the same way brown line, green line, purple line are showing the average values of each block for the year of 2017, 2018, 2019 respectively. When these lines are at the centre of the spider diagram they show low concentration while reversing on another side.

Further for the overall or natural suitability of the study area, the calculations of minimum, maximum and average values have been done parameter-wise for all the years, these results were also compared against standards set by the World Health Organization (WHO, 2017) and the Bureau of Indian Standards (BIS, 2012) to verify suitability for drinking and irrigation water quality.

3 | RESULTS AND DISCUSSION

Qualitative suitability assessment of water resources for both potable and irrigation purposes involve evaluating various factors to determine the overall sustainability of water use.

3.1 | Potable Water

The sustainability assessment of potable water in Aligarh District, based on data collected from 2016 to 2019, has been analyzed using various parameters are detailed in Table 1. The suitability of drinking water for each year has been compared for all parameters, as illustrated in Fig. 3.

As shown in Fig. 3, the pH values were consistently above permissible limits, indicating a basic nature throughout the study area; more than 7.69. Calcium levels remained within acceptable ranges, with higher concentrations observed in the southernmost Gonda Block; 100 mg/l. Sodium concentrations exceeded (maximum limits upto 518 mg/l), particularly in Gonda, Khair, and Chandaus Blocks. Potassium levels were within permissible limits, primarily sourced from the central Lodha Block. Magnesium concentrations range from 10 to 213.84 mg/l and surpassed permissible limits in certain samples from Gonda and Khair Blocks. Chloride levels range from 7.10 to 560.11 mg/l and exceeded permissible limits, notably in Gonda and Khair Blocks, potentially attributed to salt dissolution or air pollution. Sulfate concentrations were elevated, especially in Gonda Blocks, possibly due to waterlogging or gypsum fertilizers (Dahiphale *et al.,* 2019; Singh and Mishra, 2021) and it range from 8 to 510 mg/l. Nitrate levels surpassed limits, primarily in central blocks, possibly stemming from urban sewage leakage which range up to 131 mg/l of concentration. Carbonate and Bicarbonate concentrations remained within limits, influenced by carbonate rock weathering. Electrical Conductivity levels exceeded permissible limits with the maximum value of 3200 µS/cm, particularly in central-western blocks, indicative of water quality concerns for both drinking and irrigation. Total Dissolved Solids was within acceptable ranges, yet still rendering most samples unsuitable for drinking, with maximum concentrations noted in Gonda and Khair Blocks.

TABLE 1 Water quality ranges with standards

S.No.	Parameter	Water Sample Result			WHO guidelines, 2017	BIS Guidelines (IS 10500: 2012)
		Min.	Max.	Mean	Maximum Permissible limit	Maximum Permissible limit
1	pH	7.69	8.70	8.15	6.5-9.2	6.5-8.5
2	EC (µS/cm)	439.0	3200.00	1162.7	2250	-
3	Ca^{2+} (mg/l)	4.00	100.00	37.23	100	200
4	Na^+ (mg/l)	18.05	518.00	142.33	200	-
5	K^+ (mg/l)	3.90	52.00	12.21	200	-
6	Mg^{+2} (mg/l)	10.00	213.84	55.11	150	100
7	Cl^- (mg/l)	7.10	560.11	111.60	250	1000
8	SO^{-2}_4 (mg/l)	8.00	510.00	73.78	250	400
9	NO^-_3 (mg/l)	0.00	131.00	26.38	50	45
10	HCO^-_3 (mg/l)	113.4	587.73	373.64	600	600
11	CO^-_3 (mg/l)	0.00	84.00	15.21	200	200
12	TDS (mg/l)	294.1	2144.00	779.02	600	2000
13	TH (mg/l)	87.00	950.00	291.72	300	600

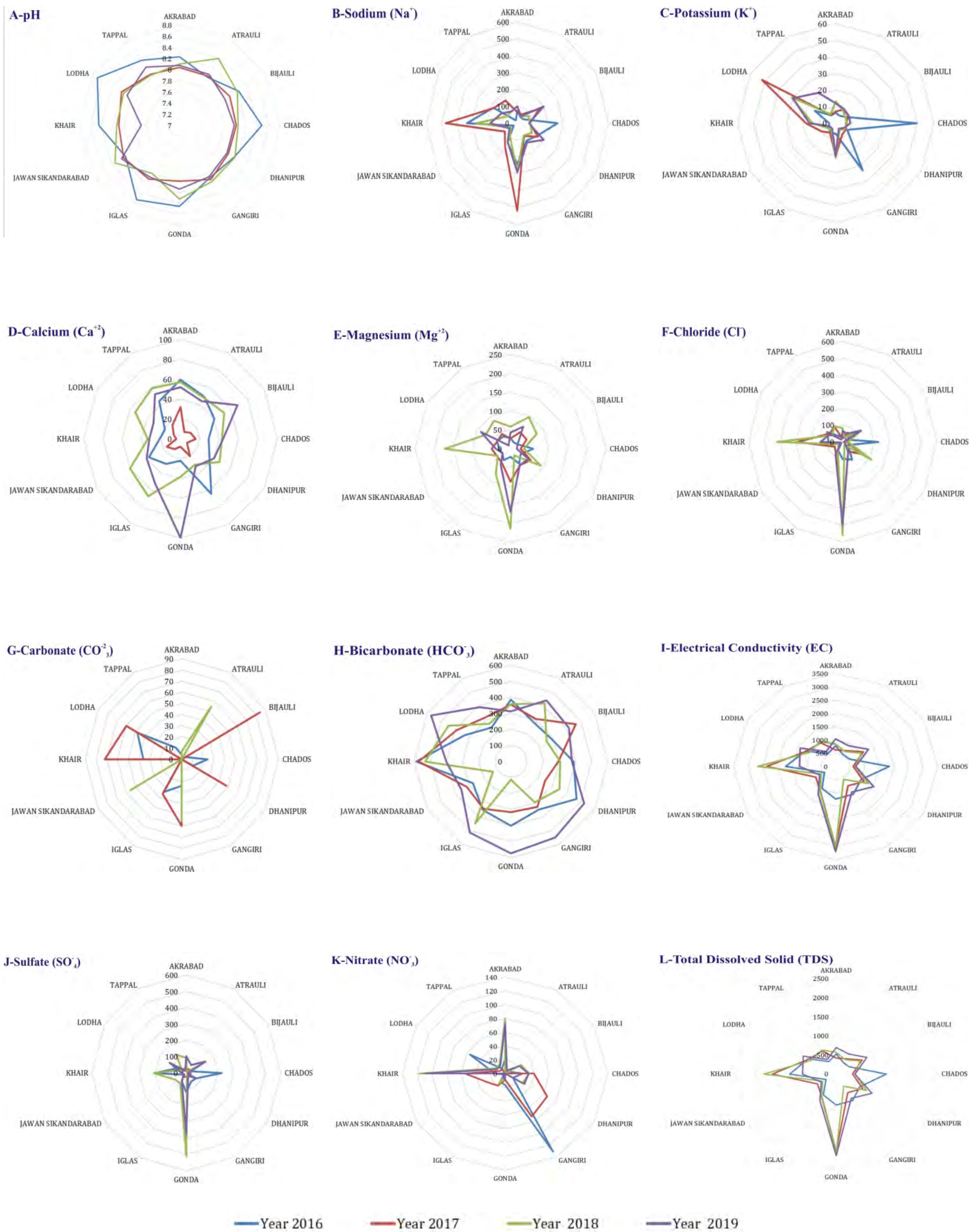

FIGURE 3 Groundwater suitability for the drinking purpose using Spider plot method

3.2 | Irrigation Water

In the same way, the sustainability assessment of irrigation water in Aligarh district, based on data collected from 2016 to 2019, has been analyzed using various parameters detailed in Table 2. The suitability of irrigation water for each year has been compared across all parameters, as illustrated in Fig. 4a and 4b.

In the same way the assessment for the irrigation water has also been done. The key parameters in the irrigation water assessment include the Sodium Absorption Ratio (SAR) and Electrical Conductivity (EC) (Kelley, 1940). It indicates the potential for irrigation water to disrupt soil structure and affect plant growth, showed values consistently within "Excellent" and "Good" categories, suggesting favourable conditions in some areas. EC, which measures salinity risk, varied from low to severe, with some regions showing high levels up to 3200 µS/cm, highlighting potential salinity challenges. The Sodium Percentage and Residual Sodium Carbonate (RSC) values ranged from "Good" to "Unsuitable," with averages of 49% and -0.02 meq/L, respectively. However, the Magnesium Adsorption Ratio (MAR) exceeded safe limits, potentially affecting soil pH and nutrient availability, while the Permeability Index (PI) indicated possible decreases in soil permeability due to high ion concentrations, ranging from 37.43 to 97.98 meq/L. These findings point to the need for careful management to address salinity and soil health issues in irrigation practices.

Furthermore, the US Salinity diagram and Wilcox diagram provide a clear visualization of irrigation water quality (Richards *et al.,* 1954; Wilcox, 1955), revealing that nearly 80% of the water samples fall within the "Good" or "Good to Permissible" categories as shown in Fig. 4b. Additionally, the Gibbs diagram highlights that rock dominance plays a significant role in determining water quality, underscoring the geological influence on the water's composition. Hydro-geochemical facies, illustrated through

TABLE 2 Irrigation water quality standards (Kelley, 1940; Todd and Mays, 1980)

Index	Range	Class/Category
Sodium Absorption Ratio (SAR)	<10	Excellent
	10-18	Good
	18-26	Doubtful
	>26	Unsuitable
Residual Sodium Carbonate (RSC)	<1.25	Safe
	1.25-2.5	Suitable
	>2.5	Unsuitable
Sodium Percentage (%)	>20	Excellent
	20-40	Good
	40-60	Permissible
	60-80	Doubtful
	>80	Unsuitable
Permeability Index (PI)	>75%	Suitable
	25-75%	Good
	<25%	Unsuitable
Magnesium Absorption Ratio (MAR)	<50	Suitable
	>50	Unsuitable

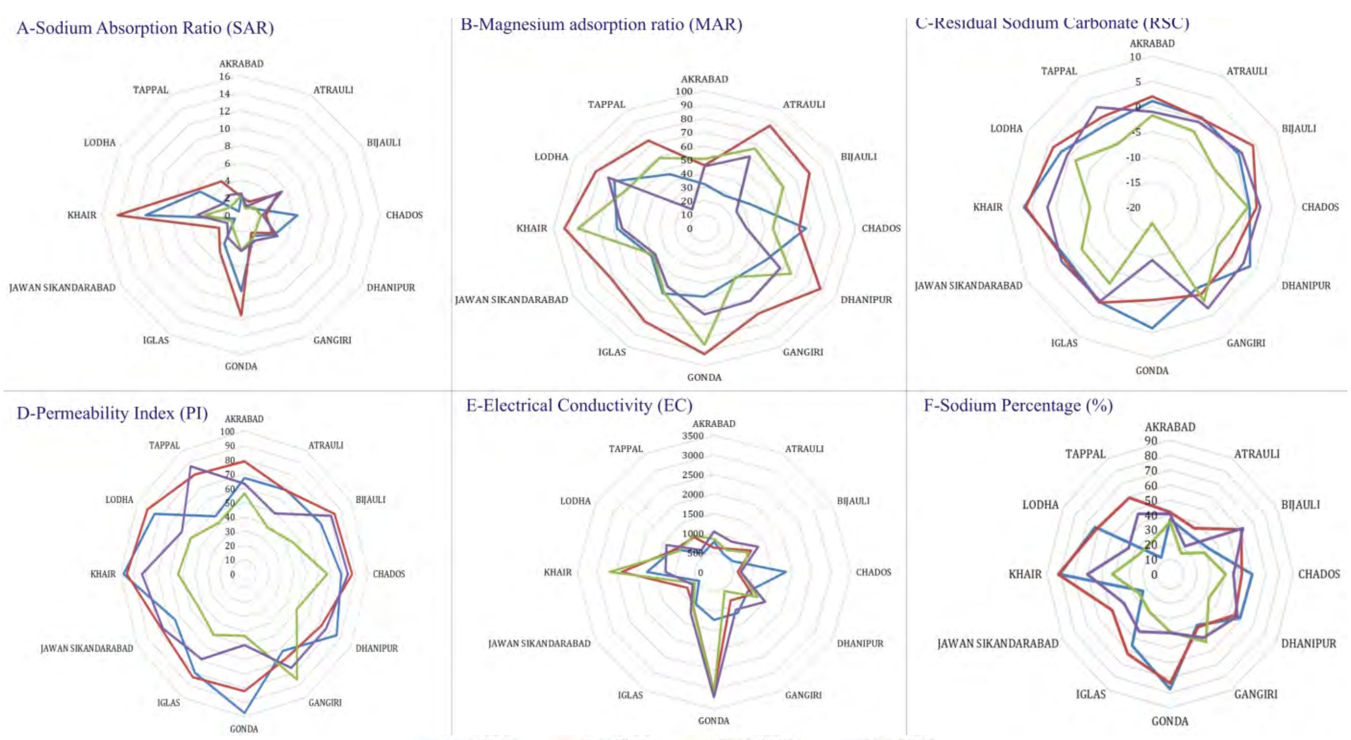

FIGURE 4a Groundwater suitability for the irrigation purpose using Spider plot method

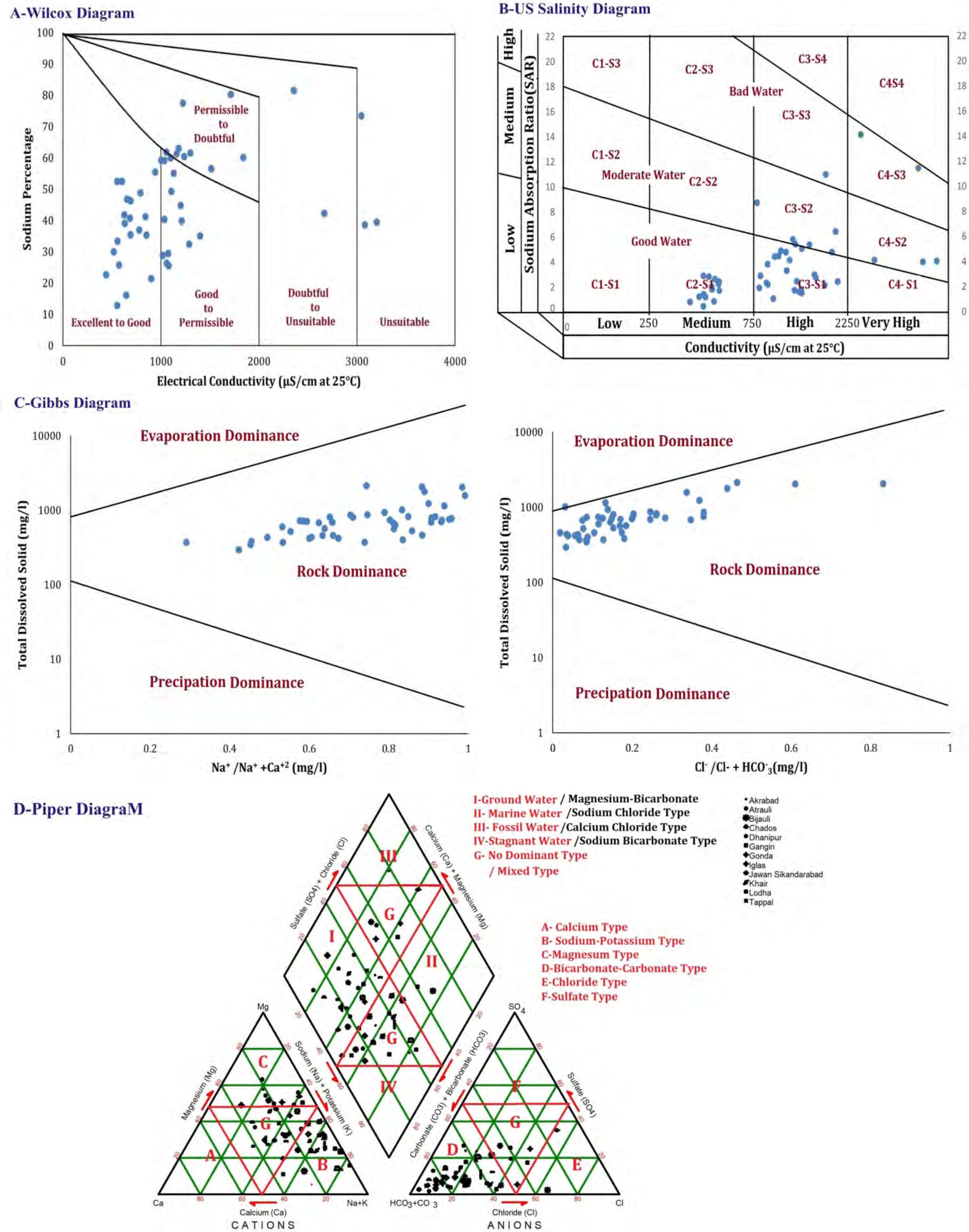

FIGURE 4b Groundwater suitability for the irrigation purpose using multi-parameters diagram

Piper diagrams, provide deeper insights into the composition and origin of water samples (Teng *et al.,* 2016; Bandyopadhyay *et al.,* 2021). The diagrams reveal a dominance of sodium and potassium ions, along with a classification of the water as bicarbonate type, highlighting the complex interaction between geological factors and water quality characteristics. These findings emphasize the critical role of understanding hydrogeochemical processes in developing effective water management strategies that are well-suited to local geological conditions.

The overall water quality for both drinking and irrigation purposes is generally favourable in most areas, which is more than 80% of the collected samples. However, higher concentrations of contaminants are found in specific areas, notably the Khair, Gonda, and Lodha blocks, as shown in Fig. 3 and 4a. These elevated concentrations negatively impact plant and crop growth by weakening plant stems and clogging soil pores (Kelley, 1940).

This study fills a critical gap in existing research by providing an in-depth analysis of groundwater contamination, particularly focusing on the sources of high salinity and its relationship with other water quality parameters (Shukla *et al.,* 2021; Singh and Mishra, 2021). While earlier studies have identified salinity issues, they often did not thoroughly examine the origins and effects of this contamination on both drinking and irrigation water. Our research addresses this gap, offering a more comprehensive understanding of groundwater quality and emphasizing the need for an integrated approach to managing water resources for both drinking and agricultural purposes. This holistic perspective is essential for developing effective strategies to ensure the sustainable use of groundwater (Bagdi *et al.,* 2022).

4 | CONCLUSIONS

This study offers an in-depth evaluation of water resource sustainability in Aligarh District, focusing on potable and irrigation water quality from 2016 to 2019. In this study pH levels remained basic, calcium, sodium, chloride, sulphate, and nitrate levels surpassed permissible limits in some areas, posing health risks. Elevated electrical conductivity levels indicate potential contaminants, challenging both drinking and irrigation use. The findings reveal that over 80% of the water samples are suitable for both drinking and agricultural use. However, specific areas particularly the southern-central blocks of Khair, Gonda, Iglas, and Lodha, exhibit higher concentrations of contaminants, including elevated levels of salinity, sodium, and chloride. It may be because of rock dominance as depicted in Gibbs diagram. These contaminants pose significant risks to human health and agricultural productivity.

The study emphasizes a holistic approach to water resource management in regions reliant on groundwater for drinking and irrigation. It identifies key factors like high salinity and sodium levels contributing to groundwater degradation, recommending targeted interventions such as reverse osmosis for drinking water and gypsum treatment for soil salinity. By providing a comprehensive analysis of groundwater contamination in Aligarh District, the research offers valuable insights for developing effective strategies that ensure sustainable groundwater use, protect public health, and support agricultural livelihoods.

RECOMMENDATION

Moving forward, canal-based irrigation should be implemented to dilute groundwater salinity. This addition will enhance sustainable groundwater management, alongside Integrated Water Resource Management, aquifer recharge, water conservation practices, monitoring, and stakeholder engagement. These measures are essential for addressing depletion and contamination challenges, and ensuring the long-term viability of water resources for both agricultural and potable purposes.

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DATA AVAILABILITY STATEMENT

Data will be available on the request.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR'S CONTRIBUTION

DSS and AJM conceived the idea, designed the study, and wrote the manuscript. AG helped the analysis, collection and tabulation of water quality data. All the authors discussed the results and contributed to the final form of the manuscript.

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