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# Hydrogeological assessment of high salinity in groundwater in parts of Bharatpur district, Rajasthan, India

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**ABSTRACT**

Hydrochemical analysis of groundwater characteristics and statistical interpretation assist to evaluate the development of high salinity in groundwater. The present study comprises of a watershed catchment boundary covering parts of Deeg, Kaman, Nagar, Pahari and Kumher tehsils of Bharatpur district in Rajasthan, India. Groundwater plays a key role to meet the water demand for various purposes in the study area having no perennial river-system. Therefore, groundwater samples were collected during Pre- and Post-monsoon seasons for a comprehensive understanding of hydrochemistry within the region. The hydrochemical results of groundwater samples for both the season revealed the dominance order of major anions as $Cl^- > HCO_3^- > SO_4^{-2} > NO_3^- > CO_3^{-2} > F^- > PO_4^{-3}$ and the major cations as $Na^+ > Ca^{+2} > Mg^{+2} > K^+$. The hydrochemical analysis results indicated the Na-Cl water-type as governing character of groundwater with higher salinity during Post-monsoon season as compared to Pre-monsoon season. The seasonal variation of salinity level in groundwater within the tehsils are confirmed by the spatiotemporal distribution maps based on (Inverse Distance Weighted) interpolation method using ArcGIS 10.2. The scatter plots between different hydrochemical attributes suggested the direct-ion exchange, mineral dissolution, rock dominant weathering and crystallization contributing high salinity in groundwater. The weathering of aquifer materials and mineral (halite) dissolution with the infiltration of recharge water augmented the total dissolved solids in the groundwater. The prevalence of shallow aquifers, overdraft of groundwater and semi-arid climatic conditions also supported the hydrogeochemical processes associated with the development of salinity in the groundwater.

***Key words :*** *Hydrochemical analysis, Watershed boundary, Spatiotemporal distribution, Weathering, Hydrogeochemical processes*

## Introduction

Since time immemorial water resources have played a crucial role for the human existence on the planet and making nature functional (Priscoli, 2000). With time being the rapid pace of urbanization and growing population have placed enormous pressure on surface water and deteriorated the groundwater quality (Carpenter *et al.,* 1998). Semi-arid climatic conditions and limited surface water resources in Rajasthan favoured the groundwater as a major source to meet the water-demands for domestic, agricultural and industrial puposes (Rajput *et al.,* 2020). Shallow groundwater table in the aquifers and the associated geochemical processes develop high salinity in the groundwater. Salinization of the groundwater is one of the most widespread process that degrades the water quality and challenges water resource management (Petalas and Diamantis, 1999). Earlier studies have focused in the chemical characteristics of groundwater in Gambhir river basin (Umar and Absar, 2003) and physic-chemical and bectriological and biogenic groundwater contamination of town Deeg (Bharatpur), Rajasthan (Singh and Gupta, 2016). Several studies have suggested the various approaches for water resource management following the groundwater potential zone mapping of Kakund watershed (Javed and Wani, 2009; Pareta, 2004) and the estimation of groundwater resource in and around Keoladev Ghana National Park, Bharatpur, (Shekhawat and Chundawat, 2010). Evaporation, crystallization, leaching of aquifer sediments through weathering and rock-water interaction are the vital hydrogeochemical processes controlling hydrochemical characteristics of groundwater (Mohapatra *et al.,* 2011; Singh *et al.,* 2018). Overburden on groundwater resources, extensive use of fertilizers, change in land use-land cover, and wastewater disposal are the other significant factors which control groundwater chemistry (Zaidi *et al.,* 2015). However, the quality assessment of groundwater in the northern part of Bharatpur district comprising of Ruparail and Banganga basins need more focus to solve the salinity problem of groundwater. Therefore, the main objective of the present study is to identify the hydrochemical characteristics and to examine the associated hydrogeochemical processes contributing to the increase in salinity of the groundwater.

## Materials and Methods

### Study Area

The present study is focused in a watershed catchment boundary covering five blocks of Bharatpur district of Rajasthan in India as seen in Figure 1. Administratively, the entire Bharatpur district is divided into three subdivisions, i.e. Deeg, Bharatpur and Bayana and ten blocks (CGWB, 2017). The study area covers a major part of Deeg subdivision within the five blocks viz. Deeg, Kaman, Nagar, Pahari and Kumher. The study area is situated in the east of Aravali hill range on the eastern plains of Rajasthan. There are three hydrogeology basins i.e. Ruparail, Banganga and Gambhiri across the district (Vyas *et al.,* 2016; Yadav *et al.,* 2019). The present study area is a part of Ruparail and Banganga basins as a part of Yamuna middle sub basin. The study area lies between 77° 02' 40.536" E to 77° 24' 37.097" E longitude and 27°19' 39.359" N to 27°45' 15.482" N latitude covering an area of 944.40 km$^2$. All the major rivers (Ruparail, Banganga and Gambhiri) of the district, originate from outside the district and are ephemeral in nature. Since the area has no perennial river, groundwater plays as a key source of water supply in the locality (Chadha, 2006).

The district has an arid climate with a hot and dry summer and cold winter while monsoon stays for a very shorter period (July to September). More than 90% of rainfall is contributed by South-West monsoon in the study area. The soil type is Muddy sand and very coarse silty to very fine sand is most prevalent in the study area. The soil type of the study area is vertisols which are having more clay fraction. Thus, the soil of the study area is compact and less permeable which also develop wide cracks when dry and become sticky when wet. Soil salinity and alkalinity are the major soil quality problems which can also be credited to groundwater salinity and shallow water table in the region (CGWB, 2017). Agricultural activity in the area is mainly of Kharif crops depending upon monsoon and Rabi crops dependent upon irrigation facility available.

### Study Method

The present research work is focused on the evaluation of hydro-geochemical processes contributing higher salinity in the groundwater. The study area was delineated with the help of watershed hydrological transport model SWAT (Soil and Water Assessment Tool) by using SRTM (Shuttle Radar Topography Mission- 30 m resolution) dataset. The seventy-five sampling locations for groundwater were identified based on the varied spectral responses of various features using remotely sensed data, detailed literature study and field based experience (Mukherjee, 2008). The groundwater samples were collected for two seasons, i.e. Pre-monsoon and Post-monsoon during 2016, for a comprehensive assessment of seasonal change in the hydrochemistry. The geo-coordinates for the sampling locations were marked by using Garmin Global Positioning System (GPS). The groundwater samples were collected from dug-well, tube-well and hand-pumps. To avoid iron pipe contamination 10 to 20 strokes of hand-pump were spilled out without collecting the sample. Further, the groundwater sampling was carried out in acid-washed high-density polypropylene plastic bottles

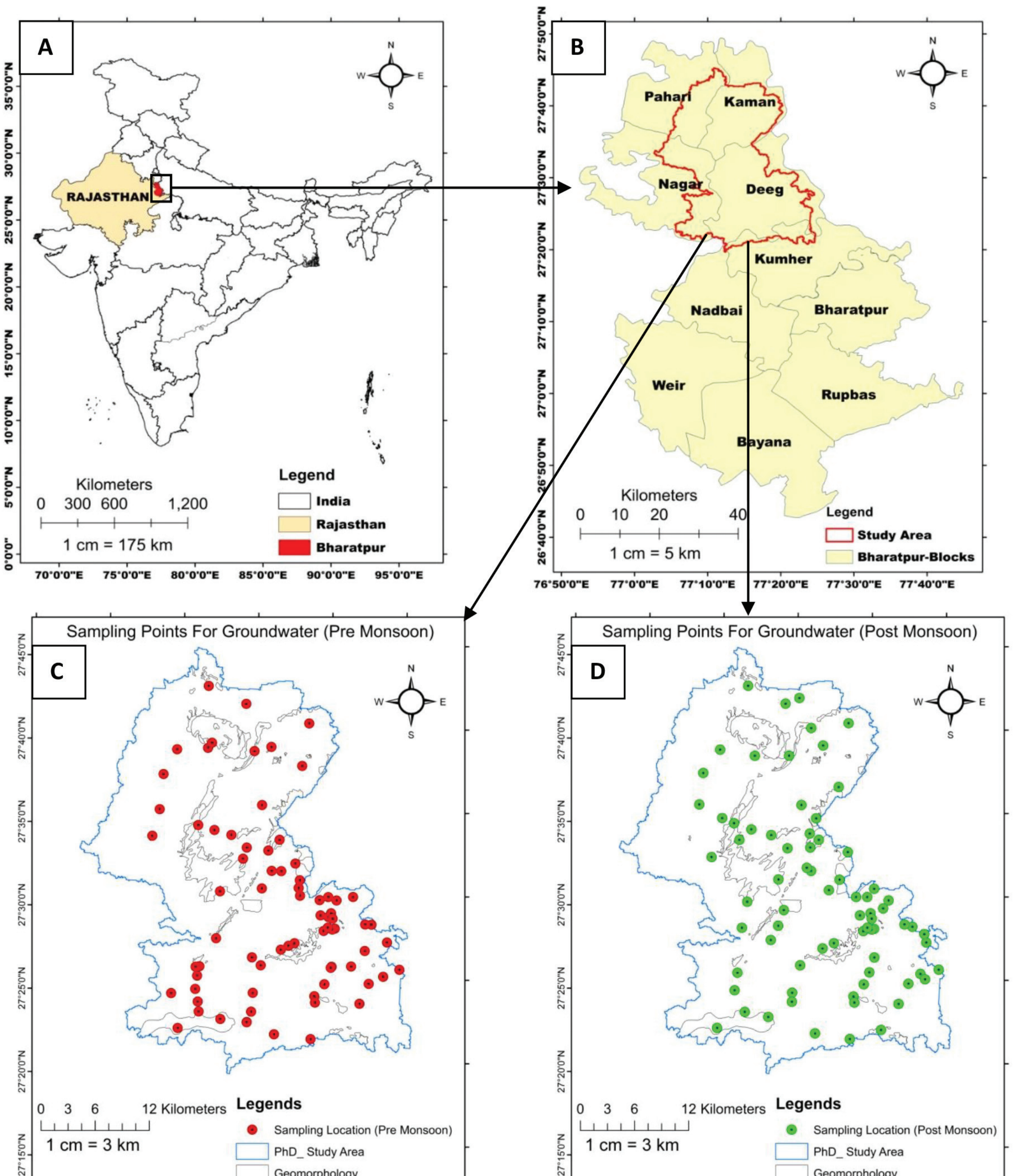


**Fig. 1.** Study area map showing its' location within (A) India (B) Bharatpur district administrative boundary, and groundwater sampling locations during (C) Pre-monsoon and (D) Post-monsoon season.

(TARSON) of two sizes, 125 ml and 250 ml. During groundwater sampling, the bottles were rinsed properly with the sample, and the groundwater was filled up to brim with utmost care to avoid any contamination and oxidization of the water sample (American Public Health Association, 1995; Singh *et al.,* 2014; Singh *et al.,* 2018). Some of the physico-chemical parameters were analyzed on the site with handheld instruments. Temperature, pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS) and salinity were analyzed by using Thermo Fischer multi-parameter TESTR 35 series. Alkalinity was also analyzed using Aquamerck Kit for alkalinity test. Further, major cations and anions were analyzed in the laboartory by using laboratory-based experiments. The anions such as $CO_3^{-2}$, $HCO_3^-$ and $Cl^-$ were analyzed by using the titrimetric method,(American Public Health Association, 1995). $NO_3^-$(TRI method), $PO_4^{-3}$(Malachite green method), $SO_4^{-2}$ (Barium sulphate method) and $F^-$ (SPANDS method) anions were analyzed based on spectro-photometric analysis by using UV/VIS Spectrometer (Perkin Elmer-Lambda 35) (American Public Health Association, 1995; Diatloff and Rengel, 2001). Among major cations, $Na^+$, $K^+$, $Ca^{+2}$ were analyzed by a flame photometer (ELICO-CL378) and Mg was analyzed by using Atomic absorption spectrophotometer (Thermo Fischer Scientific) (American Public Health Association, 1995). In general, the ion balance error of the samples was found in a range of ± 0.05. The spatial distribution of salinity in groundwater of the study area was prepared by IDW (Inverse Distance Weighted) method of interpolation by using spatial analyst tool of ArcGIS 10.2. Ionic relations based on scatter plots to understand the hydrochemical facies and the process were developed by using Microsoft Excel 2010.

## Results and Discussion

### General hydrochemistry

The hydrochemical results show that groundwater is found slightly alkaline based on pH parameter during pre- and postmonsoon seasons. Greater electrical conductivity during premonsoon (257 to 5620 with an average of 2069 μS/cm²) and postmonsoon (534 to 15430 with an average of 4142 μS/cm²) strongly suggests the more serious salinity problem is prevalent in the study area. High average EC during postmonsoon is a clear indication that runoff water leaches out the minerals like $Na^+$ and $K^+$ and dissolves them in the groundwater (Handa, 1975; Singh *et al.,* 2018). During both the seasons, chloride, bicarbonate, sulfate and nitrate are the dominant anions following the order of $Cl^- > HCO_3^- > SO_4^{-2} > NO_3^- > CO_3^{-2} > F^- > PO_4^{-3}$ in groundwater chemistry. On the other hand, for both the seasons' sodium, calcium, magnesium and potassium cations have shown their dominance in the order of $Na^+ > Ca^{+2} > Mg^{+2} > K^+$ which is indicative of silicate weathering and direct-ion exchange process in the region (Singh *et al.,* 2011; Singh *et al.*, 2018). Higher dissolved solids and electrical conductivity also signifies to salinity hazard within the study area. The salinity level of groundwater of the study area is found in the range of 120.30 to 2930.91 mg/l (average 982.82 mg/l) during Pre-monsoon and 250 to 9200 mg/l (average 2114.64 mg/l) during Post-monsoon season.

### Spatiotemporal distribution of salinity in groundwater

Spatial and temporal variation of groundwater quality parameters have been evaluated by using interpolation method in GIS environment. Interpolation creates a continuous dataset by predicting the values of un-sampled locations from the values of sampled locations (Zandi *et al.,* 2011). IDW as a deterministic method and Kriging as geostatistical method, were performed in spatial and geospatial analyst tool of Arc GIS 10.2, respectively. IDW method showing least Root Mean Square Error (RMSE) is adopted for mapping of the groundwater quality parameters. The variability in the salinity of groundwater is explained at block level within the study area during Pre-monsoon as shown in figure 2-A and Post-monsoon as shown in Figure 2-B.

The evaluation has suggested the numerous factors controlling the distribution of the hydrochemical parameters such as land use patterns, geology, geomorphology and seismotectonic features within the study area (Mukherjee, 2007; Mukherjee *et al.,* 2007). Erratic rainfall, evapotranspiration due to arid environment, leaching of aquifer sediments by infiltration of precipitation and overdraft of groundwater are mainly attributed to higher salinity problem of groundwater commonly observed in the study area (CGWB, 2017; Chadha, 2006).

### Suitability assessment for drinking and irrigation puposes based on EC, TDS and Salinity of groundwater

Electrical Conductivity (EC) is one of the most critical hydrochemical parameter to evaluate salinity hazard, suitability of water for drinking and irrigation purposes and the degree of mineralization in hydro-geologic environment (Sawid and Issa, 2015). According to Rhoades (1992) the water may be divided into 6 types based on EC, Type-I is non-saline

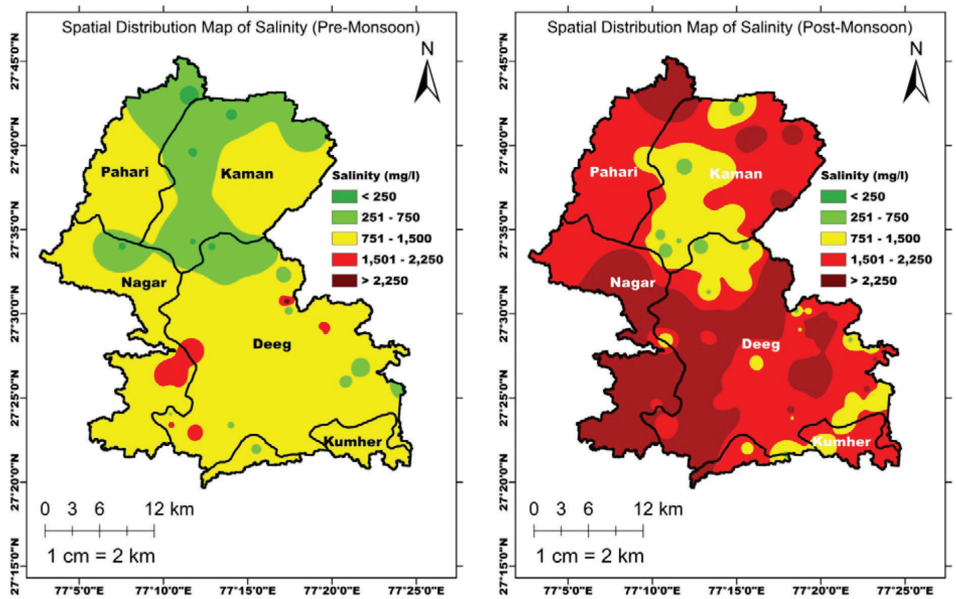


**Fig. 2.** Spatial distribution maps of Salinity in groundwater of the study area during (A) Pre-monsoon and (B) Post-monsoon seasons.

(EC < 700 µS/cm), Type-II is slightly saline with EC (700-2000 µS/cm), Type- III moderately saline with EC (2,000-10,000 µS/cm), Type-IV is highly saline with EC (10,000-25,000 µS/cm), Type- V is very highly saline with EC (25,000-45,000 µS/cm) and Type-VI is Brine water with EC exceeding 45,000 µS/cm (Rhoades *et al.,* 1992). Four categories of water-types were prevalent across the study area in both the seasons (Table 1). The groundwater samples from *Tankoli* village (15430 µS/cm), *Kandola* village (12,800 µS/cm), *Bedham* village (10,270 µS/cm) and *Parmadra* village (14,350 µS/cm) of the study area had EC higher than 10,000 µS/cm and were classified as type-IV, highly saline groundwater zones.

The results from Table 2 show that 77.63% and 72.98% of groundwater samples during Pre-monsoon and Post-monsoon season, respectively were brackish type. The results from the Table 2 showed that 22.37% and 24.32% of groundwater samples were freshwater during pre- and post-monsoon season, respectively. Saline water (10,700 mg/L) was observed in two samples of collected from *Tankoli* and *Parmadara* villages of Deeg block during the post-monsoon season. High TDS values during the post-monsoon season are suggestive of leaching of dissolved solids through aquifer sediments by infiltration of recharge water or rainfall (Kumar *et al.,* 2014).

The EC and $Na^+$ are considered as important parameter in examining the water suitability for irrigation purpose (Raju *et al.,* 2009). Based on Electrical Conductivity the water can be classified into four different categories for irrigation purpose (Richards, 1954). As per Richards, 1954 classification Table 3 reveals the more water samples showing poor/bad water type during Post-monsoon (33.78%) season as compared to Pre-monsoon season (2.63%). The re-

**Table 1.** Seasonal variation of percentage of groundwater samples for different water-classes based on Electrical Conductivity (EC) of groundwater during Pre- and Post-monsoon seasons (Rhoades *et al.,* 1992)

| Water-Type | Salinity Level | EC (µS/cm) | Pre-Monsoon (76) | Post-Monsoon (74) |
|---|---|---|---|---|
| Type-I | Non-Saline | < 700 | 9.21 | 2.70 |
| Type-II | Slightly Saline | 700-2000 | 40.79 | 22.97 |
| Type-III | Moderately Saline | 2000-10,000 | 50.00 | 68.92 |
| Type-IV | Highly Saline | 10,000-25,000 | 0.00 | 5.41 |

• The seasonal status of groundwater samples is expressed as percentage of groundwater samples.

**Table 2.** Seasonal variation of percentage of groundwater samples for different water-classes based on TDS of groundwater during Pre- and Post-monsoon seasons (Todd and Mays, 2004).

| Water-Type | Water-Class | TDS (mg/L) | Pre-Monsoon (76) | Post-Monsoon (74) |
|---|---|---|---|---|
| Type-I | Freshwater | <1000 | 22.37 | 24.32 |
| Type-II | Brackish Water | 1,000-10,000 | 77.63 | 72.98 |
| Type-III | Saline Water | 10,000-100,000 | 0 | 2.70 |
| Type-IV | Brine Water | >100,000 | 0 | 0 |

• The seasonal status of groundwater samples is expressed as percentage of groundwater samples.

**Table 3.** Seasonal variation of percentage of groundwater samples for irrigation water-classification based on salinity during Pre-monsoon and Post-monsoon seasons (Richards, 1954)

| Water Quality | EC (µS/cm) | Pre-monsoon (76) | Post-monsoon (74) |
|---|---|---|---|
| Excellent | < 250 | 9.21 | 1.35 |
| Good | 250-750 | 21.05 | 14.86 |
| Fair/Medium | 750-2250 | 67.11 | 50.00 |
| Poor / Bad | >2250 | 2.63 | 33.78 |

•The seasonal status of groundwater samples is expressed as percentage of groundwater samples.

sults also explain the moderate salinity problem occurring within most of the water samples. There are only 9.21% and 1.35% water samples falling as excellent water for irrigation during Pre- and Post-monsoon season, respectively. High salinity of irrigation water interferes with the osmotic activity of the plant restricting the absorption of mineral nutrients along with water (Saleh *et al.,* 1999).

In general higher SAR leads to the replacement of $Ca^{2+}$ and $Mg^{2+}$ from the soil which in turn decreases the soil aggregate making it less suitable for irrigation purpose. The irrigation water with high SAR also declines the soil permeability and infiltration rate. The groundwater samples showing SAR value less than 3 are suitable for irrigation purpose and conserve soil structure when used as irrigation water. The percentage of groundwater samples with SAR value greater than 9 indicate that groundwater from those area is unsuitable for irrigation purpose. The percentage of groundwater samples exceeding SAR value 9 were found 51.31% during Pre-monsoon and 36.48% during Post-monsoon season as shown in Table 4.

**Table 4.** Seasonal variation of percentage of groundwater samples for different SAR categories during during Pre-monsoon and Post-monsoon season

| SAR- Value | Pre-monsoon (76) | Post-monsoon (74) |
|---|---|---|
| 0-3 | 21.05 | 27.03 |
| 03 to 9 | 27.63 | 36.49 |
| 9 to 15 | 36.84 | 24.32 |
| >15 | 14.47 | 12.16 |

• The seasonal status of groundwater samples is expressed as percentage of groundwater samples.

## Interpretation of geochemical processes associated with high salinity in groundwater

The seasonal variation in groundwater quality parameters plotted on different scatter plots has revealed the dominant geochemical processes controlling groundwater chemistry. The processes are here evaluated for the assessment of controlling factors of salinity enrichment in groundwater. The scatter plot between $Na^+$ (meq/l) and $Cl^-$ (meq/l) parameters has shown a quite close trendline to equiline with a higher R-squared ($R^2$) value. Higher $R^2$ value explains smaller sum of squared residuals with a smaller difference between the observed data and the fitted value. The higher $R^2$ value of 0.87 during Pre-monsoon (Figure 3-A) and 0.82 during Post-monsoon (Figure 3-B) season suggested the equivalent concentrations of $Na^+$ and $Cl^-$ resulted from the dissolution of halite minerals (Belkhiri *et al.,* 2011). The semi-arid environment of the study area favors evaporation attributed to elevated concentrations of $Na^+$ and $Cl^-$ in groundwater developing higher salinity (Fisher and Mullican III, 1997). So, Presence of halite minerals, weathering process and evaporation induced higher ion concentration in groundwater accounted for higher salinity (Rao, 2006). Moreover, the semi-arid climate, long sunshine hours, hot sum-

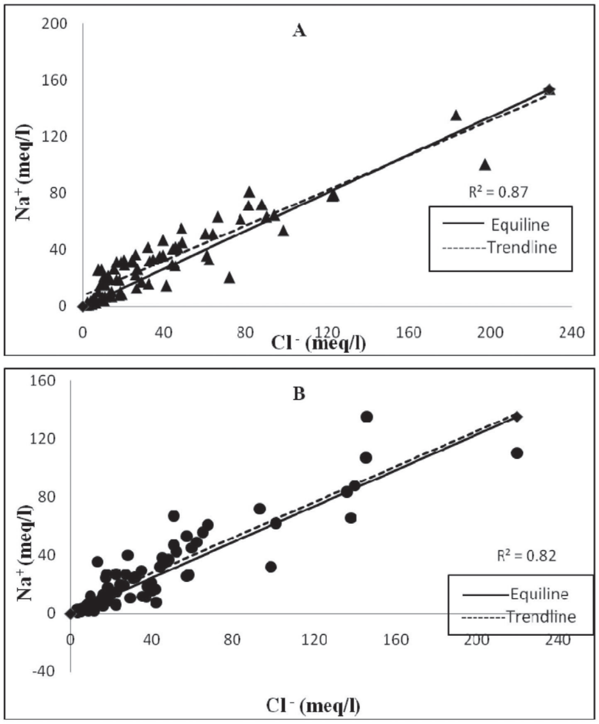


**Fig. 3.** Scatter plot between $Na^+$ and $Cl^-$ (meq/l) during (A) Pre-monsoon and (B) Post-monsoon seasons.

mers and erratic rainfall plays a vital role in major groundwater character of the study area.

The scatter plot for seasonal variation in between $Na^+/Cl^-$ and EC during Pre-monsoon (Figure 4-A) and Post-monsoon (Figure 4-B) have shown a horizontal trendline. The horizontal trend-line for both the scatter plots explains the constant $Na^+/Cl^-$ ratio with the EC. The elevated values of EC confirms the higher salinity and the influence of evaporation on hydrochemistry of the region (Fisher and Mullican III, 1997). The elevated EC across the study area during Post-monsoon season is suggestive of, the leaching of minerals from aquifer sediments through weathering process caused by the infiltration of surface run-off water (Handa, 1975; Singh *et al.,* 2014).

In 1970 Gibbs has suggested a new diagram between $Na^+/(Na^++Ca^{2+})$ and log TDS (mg/L) and $Cl^-/(Cl^-+HCO_3^-)$ and log TDS (mg/L) as a suitable method to identify hydrogeochemical process (Gibbs, 1970). The Gibbs plot explains the water samples falling above the 1000 line, bellow 1000 line and bellow 100 line of log TDS are suggestive of salinization induced by evaporation, rock dominant weathering process and precipitation dominance,

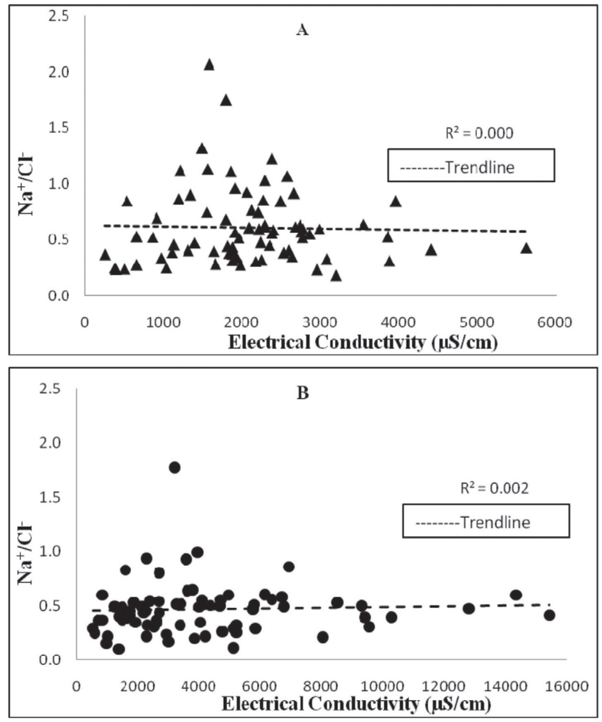


**Fig. 4.** Scatter plot between $Na^+/Cl^-$ versus Electrical Conductivity during (A) Pre-monsoon and (B) Post-monsoon seasons

respectively (Madhav *et al.,* 2018). The figure $Na^+/(Na^++Ca^{2+})$ and log TDS (mg/L) during Pre-monsoon (Figure 5-A) and Post-monsoon (Figure 5-B) suggested the evaporation and crystallization processes are responsible for rock dominant weathering and salinization. The Figure $Cl^-/(Cl^-+HCO_3^-)$ and log TDS (mg/L) during Pre-monsoon (Figure 5-C) and Post-monsoon (Figure 5-D) recommended the evaporation induced silicate weathering and mineral (halite) dissolution as dominant process contributing the development of high salinity in the groundwater of the aquifers.

## Conclusion

High salinity development in groundwater of Deeg, Kaman, Nagar, Pahari and Kumher blocks of Bharatpur district has adversely impacted the groundwater quality for various purposes. The hydrochemical analysis has resulted in the dominant hydrochemical facies of Na-Cl type. The groundwater classification during both the seasons, based on EC, TDS and salinity has categorized the major groundwater samples as moderately saline,

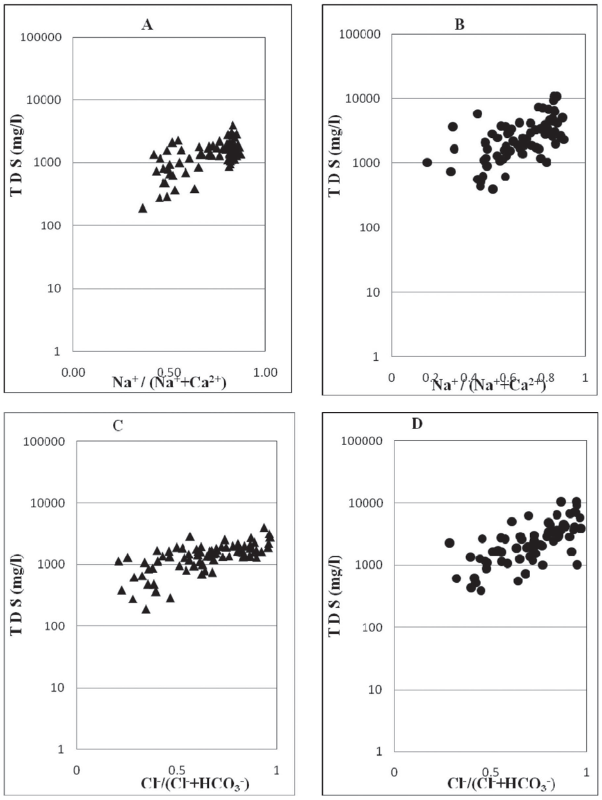


**Fig 5.** Scatter plot between $Na^+/(Na^++Ca^{2+})$ and log TDS (mg/L) during (A) Pre-monsoon and, (B) Post-monsoon seasons and Scatter plot between $Cl^-/(Cl^-+HCO_3^-)$ and log TDS (mg/L) during (C) Pre--monsoon and, (D) Post-monsoon seasons (Gibbs, 1970)

brackish water and medium water quality for irrigation purposes. The spatiotemporal distribution maps have suggested the restricted salinity in groundwater near the hillocks of Kaman and Pahari blocks. The groundwater samples with high salinity have shown the augmented $Na^+$ and $Cl^-$ ionic concentrations. The almost equivalent concentrations of both the ions have suggested the mineral (halite) dissolution as a key process in the hydrogeologic environment. The various compositional relations through scatter plots amongst $Na^+$, $Cl^-$, EC, TDS and $HCO_3^-$ are found suggestive of the direct ion exchange process, mineral dissolution, rock dominant weathering process and crystallization processes. The weathering of aquifer sediments and mineral dissolution with the infiltration of surface run-off water during monsoon period has supported the higher salinity of groundwater during Post-monsoon season. The investigation of dominant geochemical processes contributing salinity development in groundwater leads to a new dimension for the planning strategies in water resource management.

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