JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.95, June 2020, pp.616-625

# Hydrochemical Characteristics, Groundwater Quality and Sources of Solute in the Ramganga Aquifer, Central Ganga Plain, Bareilly District, Uttar Pradesh

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## ABSTRACT

**The quality of groundwater is determined in parts of Ramganga basin, Bareilly, UP, India. Spatial variation of all the major ions shows south-eastern increasing trend except chloride and sulphate. Groundwater in the area belongs to the $Mg^{2+}$-$Ca^{2+}$-$HCO_3^-$ cation facies. The monsoonal rainfall changes the ionic abundance order from $HCO_3^->Cl^->NO_3^->SO_4^{-2}> F^-$ and $Mg^{2+}> Ca^{2+}> K^+>Na^+$ of pre-monsoon to $HCO_3^->Cl^-> SO_4^{-2}>NO_3^->F^-$ and $Na^+> Mg^{2+}> Ca^{2+}> K^+$ of post-monsoon. Solute acquisition processes indicated that the rock weathering is the major mechanism of ions sources in groundwater. A coupled carbonate and silicate weathering type along with ion exchange processes are responsible for particular groundwater chemistry.**

**Groundwater quality parameters were tested for drinking, irrigation and corrosion purposes. It is found that 8.5%, 26%, 49%, 14% and 3% of the samples fall under the excellent, good, poor, very poor and unsuitable category respectively. SAR, Na%, RSC and Kelly index suggests that groundwater is safe for irrigation purposes. But high TDS of few samples suggested the salinity hazard while using it for irrigation purposes. Low CR values indicated a lower degree of corrosion hazard to the underground metal pipelines in the area.**

## INTRODUCTION

The quality of groundwater in a region is a function of physical, chemical and biological parameters. Groundwater quality is important as well as quantity. Poor quality of water adversely affects plant growth and human health (Todd, 1980; WHO, 1984; Hem, 1991). Groundwater may also be contaminated due to weathering of rock and agro-chemicals used for irrigation. Groundwater is usually used directly in rural water supply without proper treatment and for agricultural practice and human consumption in most parts of India. The industrial wastewater, sewage, sludge, and solid waste are also discharged into the drains. These contaminants enter aquifers and make drinking water polluted (Forstner and Wittman, 1981; Jerome and Anitha Pius, 2010). Hazardous substances, fertilizers, organic compounds, heavy metal, and sewage discharge can seep into groundwater from municipal sanitary landfills as well as from hazardous landfills, mining and agricultural operations, hotels, hospitals, etc. Such substances, if disposed improperly, can eventually contaminate groundwater (Akanpo and Igboekwe, 2011). Groundwater quality variation is a function of physicochemical patterns in an area influenced bygeological and anthropogenic activities (Subramanium et al., 2005). During last few decades, it is observed that groundwater gets polluted drastically because of rapid industrialization, improper solid and toxic waste management (Satish Kumar and Ravichandran, 2011; Ramesh and Soorya, 2012).

Several regions in India have encountered degradation in groundwater quality due to the increase of population growth and rapid urbanization (Ramesh and Elango, 2005; Brindha and Elango, 2010). In such conditions the protection of groundwater quality in needed for future and sustainable water supply. It can be achieved through the proper understanding of the hydrochemical processes in the regions. Hence, there is a need to understand the interaction of geochemical processes associated with a contaminant that determine the suitability of groundwater for public uses. In recent years, a number of detailed studies on groundwater quality deterioration and geochemical evolution of groundwater have been done in different parts of India as well as all over the globe (Jalali, 2006, 2007; Gupta et al., 2008; Irfan and Said, 2008; Kumar et al., 2009; Srinivasamoorthy et al., 2010; Zhang et al., 2011; Vasanthavigar et al., 2012).

## STUDY AREA

The study area is situated in lat. 28°01' N and 28°54' N and longitude 78°58' E and 79°47' E. It covers approximately 4120 km$^2$ of the area. Bareilly district occupies a part of Ramganga sub-basin of Ganga basin is close to the complex watershed of the main Himalayas (Fig.1). In the last few decades, with the rapid urbanization, expanding industrialization and increase in agricultural activities in the district, the demand for water has increased manifold. Since the groundwater is the most dynamic natural resource for a dependable urban/rural water supply and assured irrigation, it has been extensively exploited in the recent past in the entire district. In some parts of the district i.e. Aonla tehsil and in Baheri tehsil, it has been extensively exploited due to non-availability of surface water resources, and the whole groundwater regime in the area has been affected resulting in continuous depletion of ground water levels (CGWB, 2007).

## HYDROGEOLOGY

The area is underlain by the alluvial sediments of Quaternary age having a thickness of around 1000m comprising clay, silt, and various grades of sands. Depth to water level is less than 5.00mbgl during pre-monsoon in the northeast parts of the district, whereas it ranges from 3.00 to 5.00 mbgl in the post-monsoon season. Hence these areas are characterized by the shallow water table depth. In the south-western parts of the study area, the depth to water level varies from the 5.00 to 7.00 mbgl in the pre-monsoon and as well in the post-monsoon. Whereas in the central parts of the district, the water table depth is up to 15 mbgl (Fig.2). The alluvium occurring in the district is of different types, the older alluvium (khadar) and the newer alluvium (Bangar). The older has a predominance of clay and is generally rich in arenaceous concretion and nodules of impure calcium carbonate known as kankar. The newer alluvium is confined to the flood plains of the river Ramganga. These deposits comprise fine to coarse sand and are rich in detrital minerals like garnet and biotite (Fig.3).

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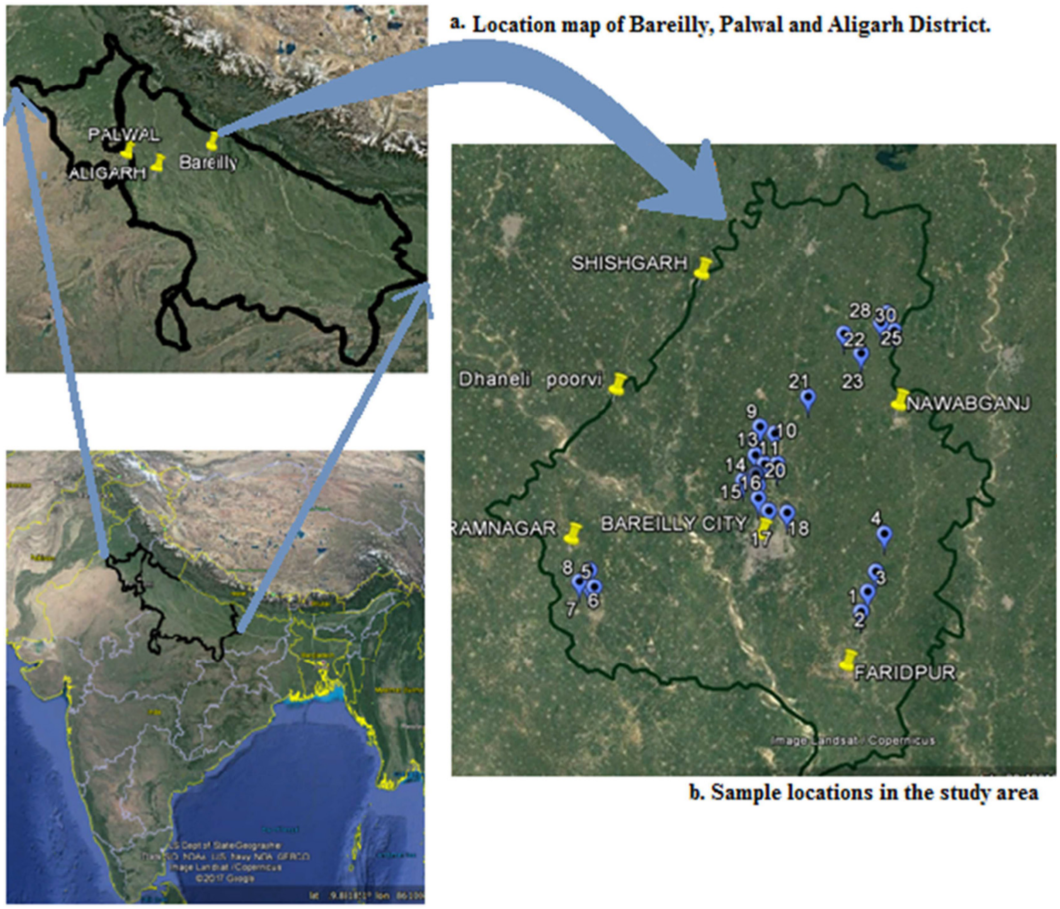


**Fig.1.** Location map of the study area along with the sample locations.

## MATERIALS AND METHODS

35 Groundwater samples were collected from hand pumps fitted bore holes during the pre-monsoon (June 2014) and post-monsoon (November 2014) season from the different locations of the Bareilly district, for chemical analysis. Samples were collected in plastic bottles and were analyzed as per the standard methods given by the APHA (1992). EC and pH were determined by the portable digital water analysis kit on the spot, at the time of collection of the water sample. The major anions and cations analysis was carried out by using the standard methods given by the APHA (1998).

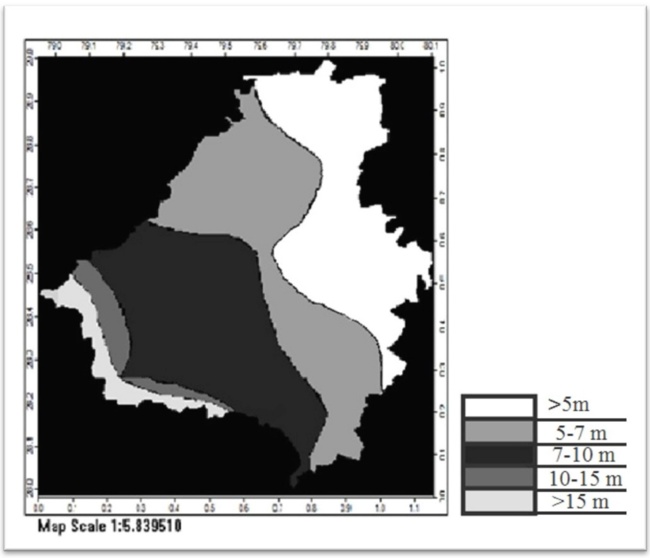


**Fig.2.** Groundwater depth in parts of Ramganga aquifer, Bareilly district

The groundwater depth data has been downloaded from India-WRIS web GIS and linear regression method is used for determining

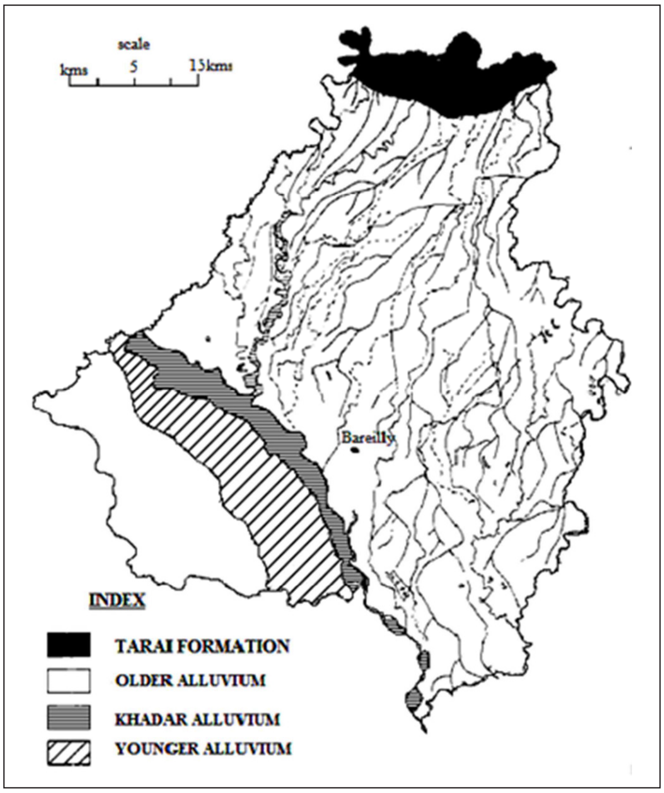


**Fig.3.** Geological Map of Bareilly district

the trends of groundwater. Spatial and temporal coverage of settlement area has been downloaded from Bhuvan ISRO'S Geoportal for the Bareilly city. The growth of the settlement area has been determined using PCI Geo-matica 9.1. Population statistics of Bareilly district has been taken from Census India 1991 and 2011. The comparative analysis has been conducted using the hydrochemical data of Trans-Yamuna aquifer Singh (2017) and Aligarh Doab region (Wasim et al. 2014).

## RESULTS AND DISCUSSION

In the present study, the hydrochemical characteristics of groundwater were assessed in parts of Ramganga. The water quality has been assessed for drinking and irrigation purposes. The detailed observations are as follows: pH value ranges from 6 to 8 with an average of 7, Hardness values ranges from 86 – 374 ppm with an average value of 184 ppm. $HCO_3^-$ having a range of 276-1191 mg/l with an average of 572. The concentration of $SO_4^{2-}$ shows minimum value of 193upto771 mg/l with an average of 385 mg/l. $Cl^-$ is having 11 to 241 mg/l with average value of 68 mg/l. $Ca^{2+}$ concentration is 22.44 to 192.38 mg/l with average of 48 mg/l whereas, $Mg^{2+}$ concentration ranges from 10to144 mg/l with average of 71 mg/l. $Na^+$ concentration ranges from 6.00 mg/l to 171.50 mg/l have an average value of is 53 mg/l. Whereas, $K^+$ concentration ranges from 9.50 to 111.50 mg/l and average values is 27.00 mg/l. $F^-$ Concentration ranges from 1.0-0.00 mg/l, average value is 1.00 mg/l. And TDS concentration is 254.22-1749.93 mg/l having average value of 679.89. The suitability of the groundwater has been assessed for its use for various purposes (ISI, 2000). It is found that most of the groundwater quality parameters are under permissible limit. The (S. No. 1, 11, 12, 26) are associated with low pH which is associated with acid washing of ceramic tiles industries in Faridpur industrial hub/battery work in the central city area. Acidified groundwater medium can lead to mobilization by dissolving the minerals from aquifer media.

The low gradient in southeast direction results in more residence time with aquifer media and leads to an increase in solute in this direction. To assess the relative contribution of water quality parameters with seasons the seasonal fluctuation has been studied. The results show that most of the groundwater becomes enriched during monsoonal recharge due to dissolution activity. Spatio-temporal distribution of nitrate and chloride show a higher concentration near the urban sites due to leaching of sewage during monsoonal recharge. The higher concentration of $NO_3^-$ is observed near the biggest congregation (Bareilly city) represented by S. No. 17 and 18 and decreases towards south of the district due to rapid flow of groundwater in southward direction. However, chloride concentrations were found to be the highest near industrial areas such as sugar mills, paper mills in north of the study area (S. No. 27). The higher concentration at this location is showing not much variation in chloride concentration in

**Table 1.** Hydrochemical characteristics of the groundwater in Ramganga basin during pre-monsoon (June 2014)

| S.No. | Long. | Lat. | TH | pH | EC | $HCO_3^-$ | $SO_4^{2-}$ | $NO_3^-$ | $Cl^-$ | $F^-$ | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 78.06 | 27.91 | 124 | 5 | 257 | 250 | 5 | 0.45 | 16 | 0.6 | 13 | 10 | 55 | 12 | 361 |
| 2 | 79.43 | 28.33 | 328 | 6 | 615 | 500 | 65 | 0.8 | 51.3 | 0.5 | 22 | 22 | 18 | 187 | 867 |
| 3 | 79.42 | 28.35 | 288 | 6.5 | 478 | 350 | 71 | 0.64 | 43.3 | 0.5 | 20 | 15 | 27 | 145 | 673 |
| 4 | 79.42 | 28.36 | 432 | 5.5 | 785 | 570 | 94 | 0.75 | 106 | 0.8 | 36 | 26 | 19 | 253 | 1106 |
| 5 | 79.42 | 28.36 | 360 | 6.5 | 680 | 490 | 87 | 0.2 | 85 | 0.5 | 40 | 26 | 14 | 214 | 956 |
| 6 | 79.4 | 28.37 | 468 | 6.5 | 854 | 570 | 90 | 0.8 | 123 | 0.5 | 39 | 88 | 27 | 264 | 1203 |
| 7 | 79.42 | 28.38 | 320 | 5.5 | 594 | 400 | 71 | 5.56 | 89.8 | 0.3 | 36 | 36 | 21 | 177 | 836 |
| 8 | 79.42 | 28.4 | 152 | 5.5 | 304 | 290 | 8 | 0.33 | 27.3 | 0.6 | 8 | 14 | 32 | 48 | 428 |
| 9 | 79.43 | 28.42 | 264 | 6.5 | 510 | 410 | 56 | 4.2 | 48.1 | 0.4 | 17 | 20 | 18 | 145 | 718 |
| 10 | 79.45 | 28.41 | 224 | 6 | 435 | 400 | 20 | 4.53 | 28.9 | 0.7 | 6 | 16 | 18 | 119 | 612 |
| 11 | 79.43 | 28.37 | 352 | 5 | 452 | 250 | 24 | 0.1 | 133 | 0.1 | 20 | 20 | 66 | 124 | 637 |
| 12 | 79.45 | 28.38 | 300 | 5 | 380 | 240 | 45 | 19.06 | 44.9 | 0.5 | 13 | 12 | 58 | 103 | 535 |
| 13 | 79.5 | 28.78 | 232 | 5.5 | 446 | 390 | 49 | 0.14 | 33.7 | 0.4 | 20 | 12 | 47 | 77 | 628 |
| 14 | 79.51 | 28.79 | 196 | 7.5 | 381 | 360 | 14 | 0.08 | 19.2 | 0.8 | 16 | 10 | 19 | 98 | 537 |
| 15 | 79.51 | 28.79 | 112 | 7.5 | 1313 | 940 | 82 | 5.1 | 128 | 0.8 | 44 | 84 | 364 | 201 | 1849 |
| 16 | 79.59 | 28.49 | 192 | 5.5 | 332 | 300 | 18 | 5.1 | 27.3 | 0.5 | 10 | 12 | 50 | 45 | 468 |
| 17 | 79.57 | 28.52 | 296 | 6.5 | 771 | 680 | 65 | 0.27 | 77 | 0.7 | 30 | 68 | 47 | 119 | 1086 |
| 18 | 79.57 | 28.52 | 152 | 5.5 | 347 | 360 | 4 | 3.2 | 19.2 | 1.0 | 18 | 12 | 45 | 26 | 489 |
| 19 | 79.63 | 28.54 | 192 | 5.5 | 334 | 320 | 1 | 3.2 | 14.4 | 0.8 | 15 | 12 | 35 | 69 | 470 |
| 20 | 79.64 | 28.52 | 124 | 8 | 341 | 370 | 1 | 0.64 | 30.5 | 1.0 | 12 | 12 | 45 | 8 | 480 |
| 21 | 79.62 | 28.53 | 232 | 6 | 374 | 370 | 1 | 1.2 | 8 | 0.4 | 12 | 12 | 48 | 74 | 526 |
| 22 | 79.51 | 28.46 | 260 | 7.5 | 449 | 440 | 2 | 1.5 | 20.8 | 0.5 | 6 | 12 | 34 | 116 | 633 |
| 23 | 79.51 | 28.46 | 152 | 6.5 | 264 | 230 | 1 | 0.15 | 27.3 | 0.1 | 4 | 10 | 88 | 12 | 373 |
| 24 | 79.59 | 28.29 | 288 | 7.5 | 563 | 320 | 47 | 44.83 | 72.1 | 0.8 | 22 | 132 | 55 | 100 | 794 |
| 25 | 79.57 | 28.24 | 240 | 8 | 419 | 410 | 5 | 2.05 | 16 | 0.3 | 5 | 14 | 31 | 108 | 591 |
| 26 | 79.56 | 28.23 | 120 | 5 | 286 | 230 | 34 | 7.78 | 22.4 | 0.4 | 12 | 8 | 74 | 15 | 403 |
| 27 | 79.54 | 28.21 | 568 | 6 | 1004 | 740 | 54 | 0.86 | 237 | 0.5 | 74 | 30 | 149 | 129 | 1415 |
| 28 | 79.46 | 28.33 | 200 | 6 | 398 | 410 | 12 | 0.6 | 16 | 0.6 | 10 | 12 | 51 | 48 | 560 |
| 29 | 79.17 | 28.28 | 256 | 6 | 543 | 540 | 24 | 0.55 | 25.7 | 0.5 | 20 | 18 | 51 | 84 | 765 |
| 30 | 79.16 | 28.28 | 296 | 5.5 | 491 | 432 | 27 | 3.05 | 36.9 | 0.5 | 10 | 18 | 48 | 116 | 691 |
| 31 | 79.15 | 28.27 | 292 | 6 | 834 | 840 | 33 | 5 | 75.4 | 0.3 | 42 | 28 | 64 | 87 | 1175 |
| 32 | 79.17 | 28.27 | 308 | 6 | 757 | 720 | 41 | 5.36 | 78.6 | 0.4 | 43 | 27 | 80 | 71 | 1066 |
| 33 | 79.17 | 28.27 | 292 | 6 | 875 | 900 | 40 | 6.64 | 77 | 0.5 | 42 | 28 | 83 | 55 | 1233 |
| 34 | 79.17 | 28.29 | 148 | 5.5 | 288 | 250 | 42 | 0 | 19.2 | 0.5 | 15 | 10 | 45 | 24 | 405 |
| 35 | 79.43 | 28.42 | 124 | 5.5 | 249 | 230 | 7 | 0.7 | 20.8 | 0.4 | 12 | 8 | 56 | 15 | 350 |
| MAXIMUM | | | 568 | 8 | 1313 | 940 | 94 | 45 | 237 | 1 | 74 | 132 | 364 | 264 | 1849 |
| MINIMUM | | | 112 | 5 | 249 | 230 | 1 | 0.08 | 8 | 0.3 | 4 | 8 | 14 | 8 | 350 |
| AVERAGE | | | 254 | 6 | 526 | 443 | 35 | 4 | 54 | 1 | 22 | 26 | 57 | 100 | 768 |

All the values in ppm except EC and pH, EC (µS/cm.): TH = Total Hardness,TDS=Total Dissolved Solids

**Table 2.** Hydrochemical characteristics of the groundwater in Ramganga basin during post-monsoon (November 2014)

| S.no. | Long. | Latit. | TH | Ph | EC | $HCO_3^-$ | $SO_4^{2-}$ | $NO_{3-}$ | $Cl^-$ | $F^-$ | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 78.06 | 27.91 | 48 | 6.5 | 388 | 260 | 4.2 | 0.3 | 28.4 | 0.7 | 5 | 12 | 68.9 | 8 | 387 |
| 2 | 79.43 | 28.33 | 112 | 7.5 | 534 | 390 | 4.3 | 0.57 | 28.4 | 0.8 | 20 | 8 | 27.3 | 54 | 533 |
| 3 | 79.42 | 28.35 | 136 | 7.7 | 435 | 208 | 4.8 | 0.75 | 51.1 | 0.2 | 65 | 16 | 40.1 | 48.7 | 435 |
| 4 | 79.42 | 28.36 | 164 | 7.2 | 821 | 403 | 5.1 | 0.45 | 139 | 0.4 | 155 | 23 | 59.3 | 35.5 | 821 |
| 5 | 79.42 | 28.36 | 140 | 7.8 | 867 | 364 | 6.1 | 0.85 | 162 | 0.3 | 200 | 40 | 36.9 | 56.6 | 867 |
| 6 | 79.4 | 28.37 | 108 | 6.2 | 856 | 468 | 9.46 | 0.67 | 96.6 | 0.3 | 110 | 98 | 48.1 | 25 | 856 |
| 7 | 79.42 | 28.38 | 120 | 7.8 | 916 | 487 | 5.2 | 0.8 | 134 | 0.5 | 175 | 34 | 36.9 | 43.5 | 916 |
| 8 | 79.42 | 28.4 | 124 | 6.9 | 637 | 286 | 6.1 | 0.75 | 111 | 0.4 | 120 | 23 | 25.7 | 64.6 | 637 |
| 9 | 79.43 | 28.42 | 148 | 7.2 | 582 | 273 | 6.1 | 5.04 | 85.2 | 0.4 | 105 | 14 | 44.9 | 48.7 | 582 |
| 10 | 79.45 | 28.41 | 100 | 7.8 | 316 | 221 | 5.2 | 0.8 | 41 | 0.4 | 9 | 11 | 35.3 | 32.9 | 357 |
| 11 | 79.43 | 28.37 | 160 | 8 | 580 | 182 | 5.5 | 0.8 | 230 | 0.4 | 50 | 21 | 65.7 | 25 | 580 |
| 12 | 79.45 | 28.38 | 112 | 7.9 | 454 | 230 | 6.1 | 28 | 65.3 | 1.0 | 20 | 10 | 68.9 | 25 | 454 |
| 13 | 79.5 | 28.78 | 184 | 7.2 | 1225 | 546 | 5.1 | 48 | 196 | 0.7 | 210 | 96 | 35.3 | 88.3 | 1225 |
| 14 | 79.51 | 28.79 | 84 | 8 | 499 | 325 | 5.4 | 0.8 | 17 | 1.3 | 75 | 11 | 25.7 | 38.2 | 499 |
| 15 | 79.51 | 28.79 | 140 | 7.2 | 643 | 325 | 4.4 | 0.8 | 93.7 | 0.1 | 90 | 25 | 20.8 | 83 | 643 |
| 16 | 79.59 | 28.49 | 100 | 8.3 | 379 | 247 | 4.1 | 0.8 | 25.6 | 1.1 | 20 | 11 | 33.7 | 35.5 | 379 |
| 17 | 79.59 | 28.52 | 160 | 6.1 | 931 | 308.4 | 4.1 | 108.6 | 131 | 0.8 | 170 | 96 | 27.3 | 85.7 | 931 |
| 18 | 79.57 | 28.52 | 84 | 8 | 576 | 301.6 | 4.1 | 88.8 | 28.4 | 0.1 | 60 | 10 | 57.7 | 25 | 576 |
| 19 | 79.63 | 28.54 | 76 | 8.1 | 433 | 301.6 | 6.1 | 0.8 | 11.4 | 0.8 | 35 | 12 | 40.1 | 25 | 433 |
| 20 | 79.64 | 28.52 | 84 | 8.7 | 423 | 301.6 | 3.1 | 0.8 | 19.9 | 0.6 | 20 | 12 | 24 | 40.8 | 423 |
| 21 | 79.62 | 28.53 | 96 | 8 | 404 | 268.7 | 3.4 | 0.8 | 22.7 | 0.9 | 25 | 14 | 43.3 | 25 | 404 |
| 22 | 79.51 | 28.46 | 80 | 8.3 | 313 | 195 | 7.1 | 4.31 | 14.2 | 0.5 | 15 | 9 | 16 | 51.4 | 313 |
| 23 | 79.51 | 28.46 | 88 | 8.7 | 288 | 156 | 6.1 | 0.8 | 34.1 | 0.3 | 14 | 12 | 28.9 | 35.5 | 288 |
| 24 | 79.59 | 28.29 | 132 | 7.7 | 644 | 267 | 10.1 | 6.04 | 108 | 0.4 | 70 | 91 | 32.1 | 59.3 | 644 |
| 25 | 79.57 | 28.24 | 72 | 8.8 | 338 | 234 | 6.2 | 6.8 | 14.2 | 0.1 | 10 | 12 | 27.3 | 27.6 | 338 |
| 26 | 79.56 | 28.23 | 88 | 7.9 | 272 | 176 | 6 | 2 | 11.4 | 0.6 | 5 | 11 | 27.3 | 38.2 | 277 |
| 27 | 79.54 | 28.21 | 180 | 7 | 1377 | 715 | 5.1 | 1.95 | 244 | 0.8 | 225 | 86 | 68.9 | 30.3 | 1377 |
| 28 | 79.46 | 28.33 | 100 | 8.2 | 325 | 221 | 3 | 6.33 | 5.68 | 0.3 | 8 | 10 | 32.1 | 38.2 | 325 |
| 29 | 79.17 | 28.28 | 128 | 7.2 | 613 | 340 | 7.3 | 0.8 | 68.2 | 0.4 | 90 | 25 | 43.3 | 38.2 | 613 |
| 30 | 79.16 | 28.28 | 132 | 8.2 | 427 | 208 | 6.1 | 1.22 | 76.7 | 0.6 | 25 | 26 | 44.9 | 38.2 | 427 |
| 31 | 79.15 | 28.27 | 164 | 7.8 | 1096 | 702 | 5.1 | 15.6 | 99.4 | 1.0 | 130 | 46 | 56.1 | 40.8 | 1096 |
| 32 | 79.17 | 28.27 | 136 | 6.9 | 1215 | 455 | 7.1 | 25.6 | 312 | 1.1 | 300 | 30 | 48.1 | 35.5 | 1215 |
| 33 | 79.17 | 28.27 | 80 | 6.8 | 614 | 416 | 2.5 | 0.49 | 39.8 | 1.0 | 78 | 16 | 27.3 | 32.9 | 614 |
| 34 | 79.17 | 28.29 | 56 | 8.4 | 639 | 325 | 83.9 | 0.57 | 59.6 | 0.6 | 105 | 12 | 14.4 | 38.2 | 639 |
| 35 | 79.43 | 28.42 | 76 | 6.1 | 576 | 338 | 5.2 | 3.65 | 48.3 | 0.7 | 108 | 13 | 24 | 35.5 | 576 |
| MAXIMUM | | | 184 | 9 | 1377 | 715 | 84 | 109 | 312 | 1 | 300 | 98 | 69 | 88 | 1377 |
| MINIMUM | | | 48 | 6 | 272 | 156 | 3 | 0.35 | 6 | 0.25 | 5 | 8 | 14 | 8 | 277 |
| AVERAGE | | | 114 | 8 | 618 | 327 | 8 | 10 | 82 | 1 | 83 | 28 | 39 | 42 | 640 |

All the values in ppm except EC and pH, EC (µS/cm.): TH = Total Hardness,TDS=Total Dissolved Solids

pre and post monsoon time. Absence of dilution at this location is due to continuous infiltration of chloride rich industrial effluent in nearby groundwater. While, the sample no. 32 and 31 in extreme north show the highest degree of variations in chloride concentration due to post monsoon groundwater recharge. The high permeability of aquifer in north is a result of tarai formation that allows the quick dilution of chloride in groundwater due to monsoonal recharge.

The order of abundance in the post-monsoon is $HCO_3^-$>$Cl^-$> $SO_4^{2-}$ >$NO_3^-$>$F^-$ and $Na^+$ > $Mg^{2+}$>$Ca^{2+}$> $K^+$ and for the pre-monsoon it is $HCO_3^-$>$Cl^-$>$NO_3^-$>$SO_4^{2-}$> $F^-$ and $Mg^{2+}$>$Ca^{2+}$>$K^+$>$Na^+$. Total dissolved solids (TDS) show 16% dilution in post monsoon time. This is due to dilution of $K^+$ and $Na^+$; $Cl^-$, and $HCO_3^-$ which are the main components of TDS. $K^+$ shows 90% dilution and $Na^+$ 27% dilution. The $Ca^{2+}$ and $Mg^{2+}$ show 84% and 68% dilution respectively while, $Ca^+$ and $HCO_3^-$ are diluted by 32% and 25%, respectively. It is observed that $SO_4^{2-}$ concentration decreases tremendously during post monsoon season. On the basis of degree of dilution the ions along with TDS, hardness and pH can be grouped into; Highly diluted species ($K^+$, $F^-$ and $Na^+$), Moderately diluted species ($Cl^-$ and $HCO_3^-$); Enriched parameters include $HCO_3^-$, $Mg^{2+}$, $Ca^+$.

The term hydrochemical facies is used to distinguish groundwater in an aquifer on the basis of their different chemical composition by plotting on Piper diagram. The piper diagram is a graphical representation of the chemistry of water samples. The diagram is a matrix transformation of graphs of anions and cations. It can be concluded from the figure that the average concentration of the water samples falls in Ca-Mg cation type and $HCO_3$-$SO_4$ anion type facies. The plot of chemical data on diamond shaped trilinear diagram reveals that the majority of groundwater samples fall in the fields of 1, and 3 i.e., Ca-Mg-$HCO_3$ suggesting that alkalies exceeds in most of the water samples. However, few groundwater samples fall in non-dominant type (Fig.4).

A comparative analysis of water samples from different part of the Ganga-Yamuna aquifer suggests that the groundwater facies of the Ramganga aquifer changes with seasons dramatically. But, the groundwater facies from Ganga-Yamuna Doab aquifer and Trans-Yamuna aquifer do not show any significant change with the season (Fig.5). It suggests that high permeability of aquifer material and slope facilitate the flushing of old groundwater from the Ramganga aquifer, causes a significant change in groundwater chemistry during pre-post monsoon season. An assessment of relative importance of different hydrochemical processes was determined in Ramganga-Ganga-Yamuna aquifer area using DUROV diagram (Fig.6). It indicates that there is a systematic change in different hydrochemical processes from NE to SW. The ion exchange processes was dominant in Ramganga region; dissolution action was prominent in Ganga-Yamuna Doab and reverse ion exchange processes govern the hydrochemical characteristics in Trans–Yamuna aquifer.

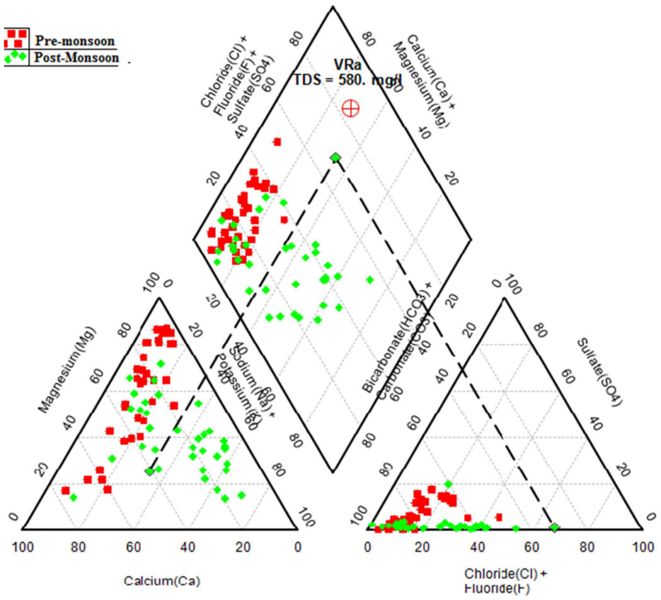


**Fig.4.** Piper's diagram for pre-monsoon (June 2014) and post-monsoon (November 2014) groundwater in Bareilly district.

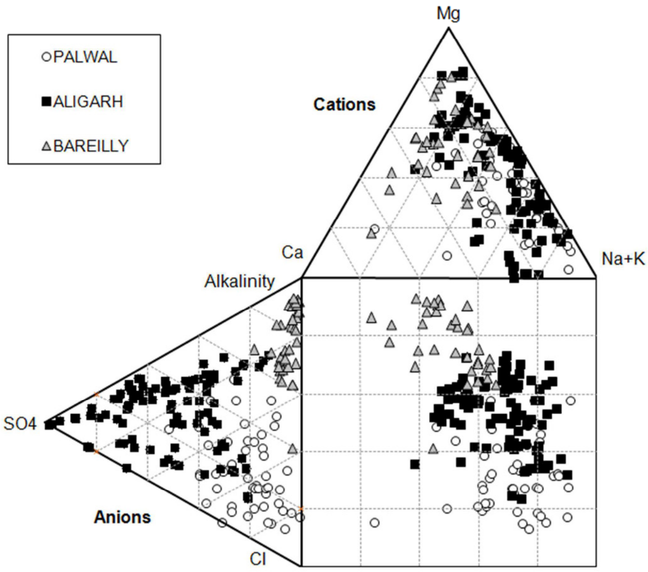


**Fig.6.** Durov diagram for average groundwater in Bareilly, Palwal and Aligarh districts.

## Sources of Solute in Groundwater

Gibbs (1970) proposed the boomerang envelope model to describe the dynamics of chemical compositions of surface water and classified the controlling factors to three types, namely atmospheric precipitation, rock weathering, and precipitation. The weight ratio $Na^+/(Na^++Ca^{+2})$ as a function of TDS has been plotted. It has been observed that all samples belong to rock weathering dominated processes that controls hydro-geochemistry of the groundwater (Fig.7).

The sources and mechanism controlling groundwater chemical composition can also be evaluated by applying the mass balance approach through scatter diagrams (Stallard and Edmond, 1983). Analysis based on stoichiometric relationships demonstrates that in the present groundwater $(Ca^{+2}+Mg^{+2})$ together accounts for 75% of the total cations and the plot of $(Ca^{+2}+Mg^{+2})$ Vs. $HCO_3^-$ illustrates that in most of the groundwater samples, the $Ca^{+2}+Mg^{+2}$ content is in quite excess of $HCO_3^-$, indicating the part of the charge is balanced by $SO_4^{2-}$, $NO_3^-$ and $Cl^-$. It implies that the part of $Ca^{+2}$ and $Mg^{2+}$ could be through silicate mineral weathering. Furthermore, the high contribution of $(Ca^{2+} + Mg^{2+})$ to the total cations, high $(Ca^{+2}+Mg^{+2})/(Na^++K^+)$, 2.9, and low $(Na^++K^+)/Tz^+$ equivalent ratio indicate that the carbonate weathering could be a major source of dissolved ions in the groundwater. The excess of $(Na^++K^+)$ over chloride $(Na^++K^+)/Cl^-$, 1.65; indicate that in the present study area, the chemical weathering contribution is much important and most of the $Na^+$ and $K^+$ could be derived from silicate weathering can also be evaluated by plotting $(Na^++K^+)$ Vs. $TZ^+$. The ratio of $(Na^++K^+)/TZ^+$, 0.25, for groundwater is indicative of intermediate contribution via silicate weathering and major contribution by carbonate weathering assisted by dissolved underground $CO_2$ (Fig.8).

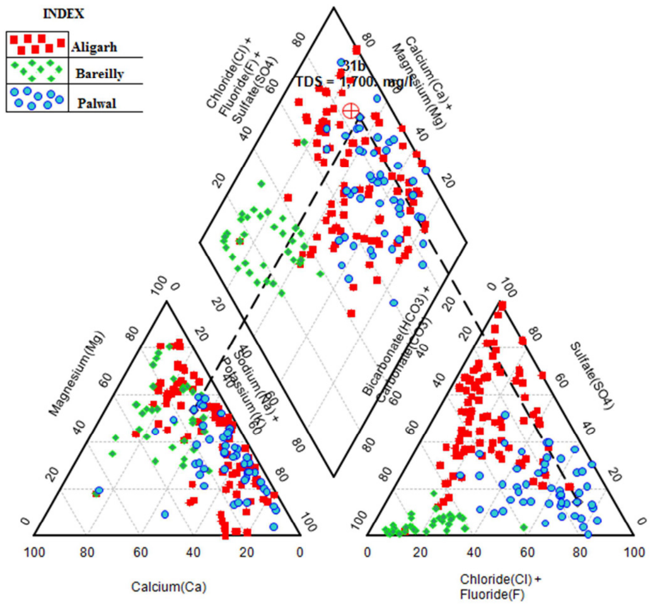


**Fig.5.** Piper's diagram for average of groundwater in Bareilly, Palwal and Aligarh districts.

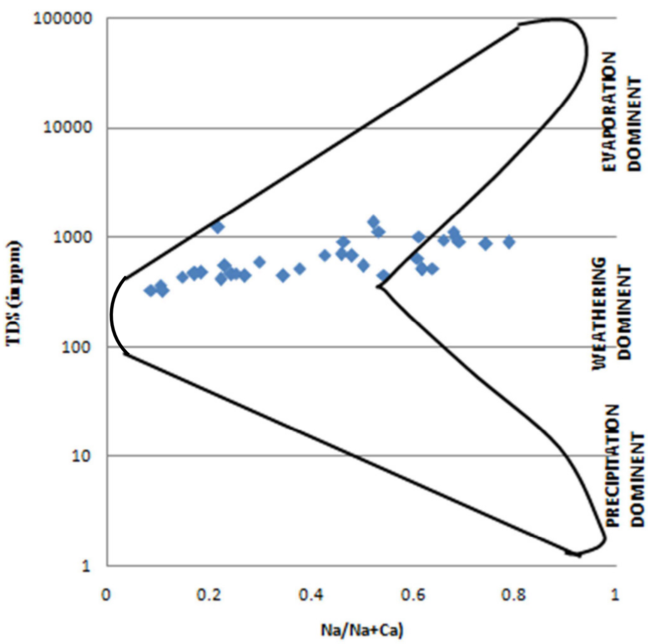


**Fig.7.** Variation of weight ratio of Na/(Na+Ca) as a function of TDS(after Gibbs 1970)

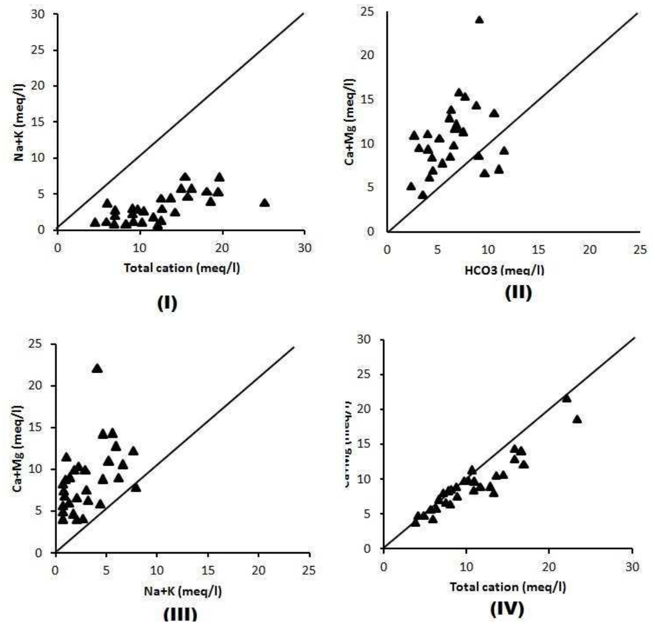


**Fig.8.** Scatter diagram showing (I) ($Na^{+}$+$K^{+}$) vs. Total Cation. (II) ($Ca^{+2}$+$Mg^{+2}$) vs. $HCO_3^-$. (III) ($Ca^{+2}$+$Mg^{+2}$) vs ($Na^{+}$+$K^{+}$). (IV) ($Ca^{+2}$+$Mg^{+2}$) vs Total Cation.

**Correlation Matrix**

The statistical analysis has been carried out by correlation coefficient between different pairs of water quality parameters of groundwater to develop and assess the mechanism of solute acquisition processes in the area. The data analysis yielded an R-value, which is a correlation representing the linear relationship between the data parameters. A linear association indicates that as one variable increases, the other increases or decreases linearly. For the ideal relationship, the correlation coefficient is close to1 (positive correlation) imply that as one variable increases, the other increases nearly linearly. However, a correlation coefficient close to -1 indicates that as one variable increases, the other decreases nearly linearly If the values close to 0 suggest no or linear correlation between the variables (Mudgal et al., 2009). When the correlation coefficient is zero, it implies independent behaviour of the variable. The values of the coefficient of correlation were determined using SPSS software version13 in both PRM and POM seasons. Relationships during PRM (Pre-monsoon) and POM (Post-monsoon) seasons showed strong positive and negative relationships among the parameters as shown in Table 3 and 4.

The strong positive correlation of $Mg^{2+}$ with $SO_4^{2-}$ in PRM (r = 0.81) and during POM this relationship is lost (r = -0.03). Hardness showed strong positive correlations in PRM and less significant in POM with alkalinity (r = 0.92 and 0.48). Hardness shows strong positive correlation with $Ca^{2+}$ (r = 0.922) and results showed that there was great dependence of hardness on calcium, TDS, and alkalinity. During PRM the alkalinity shows a positive correlation with TDS (r = 0.92). TDS has strong positive correlation with $Ca^{2+}$ (r = 0.59) during PRM season. The positive and negative correlation among the parameters could be taken as representing the major sources of seasonal changes in water quality (see Table 3 and 4).

**Principal Component Analysis (PCA)**

The PCA technique has been used to recognize the important parameters that determine the water quality in many studies (Akbal et al., 2011 and Jalali, 2010). Investigation of water quality data using PCA, an attempt is made to find the presence of factors governing the quality of water by taking important principal components (PCs) that helps us to identify the mechanism. These components explain 84% of the total variance in PRM and 75% of the total variance in POM for the complete data sets.

During the pre-monsoon, the first PC accounting for 52% of the total variance and it has a high correlation with pH, $HCO_3^-$, $Cl^-$, $Ca^{+2}$, TDS. The II$^{nd}$ component is associated with pH, $SO_4$, $Na^+$, $Mg^{+2,}$ and TDS probably contributed by the dissolution of $MgSO_4$ and subsequent change in pH. The III$^{rd}$ component is associated with $K^+$ and $NO_3^-$ that is related to biological processes/ leaching of artificial fertilizers. The fourth component explains about 8% of the total variance that is associated with only $Ca^{+2}$.

The first four PCs components during POM has less total variance than PRM. During POM the I$^{st}$ component has 41% of the total variance, associated with $NO_3^-$, $Cl^-$, $K^+$, $Mg^{+2,}$ and TDS. The II$^{nd}$ component is associated with pH and hardness. The III$^{rd}$ and IV$^{th}$ component is related to $F^-$ and $Ca^{+2}$ respectively (Table 5 and 6).

**Drinking Water Quality Analysis**

Water quality index provides an inclusive interpretation of the quality of surface and groundwater and its suitability for drinking purpose. The weighted arithmetic index method is used in present case for calculation of WQI using 11 water quality characteristics namely, turbidity, pH, total hardness, alkalinity, chloride, total dissolved solids, calcium, magnesium, sulphate, nitrate and fluoride, which showed maximum variations in seasons and also varied significantly at different sampling sites, using the following equation:

$$WQI = (\Sigma SIi) / (\Sigma wi) \quad (1)$$

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

$$SIi = Wi \times qi \quad (2)$$

The unit weight (Wi) for each water quality parameter is calculated using the following equation:

$$w_i = k / S_i \quad (3)$$

where, k is appropriately constant and $S_i$ is the standard permissible value of the $i_{th}$parameter. The quality rating ($q_i$) of Eq. (2) is calculated as under.

$$q_i = (C_i/S_i)*100 \quad (4)$$

where, $C_i$ is the estimated concentration of i$^{th}$ parameter in the analyzed water. The standard rating of water quality according to WQI is given below in Table 7. The calculated WQI for water samples of the groundwater of the Bareilly district for determining their suitability for drinking purpose is given in Table 8. The WQI suggest that 8.5% sample falls in the excellent category, 26% fall in the good category, 49% were of poor water quality standard; 14% fall under the very poor category and 3% samples are unsuitable.

**Irrigation Water Quality Analysis**

The suitability of water for irrigation purposes has been evaluated through three parameters namely, SAR, sodium percent (Na%) and RSC.

**Sodium Adsorption Ratio**

Sodium adsorption ratio is used to evaluate the excess of sodium with calcium and magnesium (Richards, 1954). In general, the permeability of water reduces excessive sodium content in water. Use of water having high SAR level continuously can lead to an increase in $Na^+$ level over time, which in turn can adversely affect soil infiltration

Table 3. Matrix of Correlation among parameters during Pre-monsoon (June 2014)

| | *TH.* | *pH* | *EC* | *$HCO_3^-$* | *$SO_4^{2-}$* | *$NO_3^-$* | *$Cl^-$* | *$F^-$* | *$Na^+$* | *$K^+$* | *$Ca^{+2}$* | *$Mg^{+2}$* | *TDS* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *TH.* | 1.00 | | | | | | | | | | | | |
| *pH* | -0.04 | 1.00 | | | | | | | | | | | |
| *EC* | **0.56** | 0.25 | 1.00 | | | | | | | | | | |
| *$HCO_3^-$* | 0.41 | 0.27 | **0.92** | 1.00 | | | | | | | | | |
| *$SO_4^{2-}$* | 0.60 | 0.01 | **0.70** | 0.47 | 1.00 | | | | | | | | |
| *$NO_3^-$* | 0.04 | 0.14 | 0.05 | -0.08 | 0.10 | 1.00 | | | | | | | |
| *$Cl^-$* | **0.75** | 0.02 | **0.78** | **0.58** | **0.62** | 0.04 | 1.00 | | | | | | |
| *$F^-$* | -0.20 | 0.29 | 0.08 | 0.09 | 0.02 | 0.23 | -0.11 | 1.00 | | | | | |
| *$Na^+$* | **0.67** | 0.01 | **0.85** | **0.77** | 0.65 | 0.00 | **0.87** | 0.00 | 1.00 | | | | |
| *$K^+$* | 0.31 | 0.37 | **0.59** | 0.39 | 0.52 | 0.61 | 0.48 | 0.27 | 0.43 | 1.00 | | | |
| *$Ca^{+2}$* | -0.14 | 0.17 | **0.59** | 0.50 | 0.17 | 0.06 | 0.44 | 0.07 | 0.41 | 0.34 | 1.00 | | |
| *$Mg^{+2}$* | **0.70** | 0.19 | **0.65** | 0.42 | **0.81** | -0.01 | 0.57 | 0.02 | 0.49 | 0.46 | 0.06 | 1.00 | |
| *TDS* | 0.56 | 0.25 | **0.64** | **0.92** | **0.70** | 0.05 | **0.78** | 0.08 | **0.85** | **0.59** | **0.59** | **0.65** | 1.00 |

TH= Total hardness, TDS = Total Dissolved Solids

**Table 4.** Matrix of Correlation among parameters during Post monsoon (November 2014)

| | *TH.* | *pH* | *EC* | *$HCO_3^-$* | *$SO_4^{2-}$* | *$NO_3^-$* | *$Cl^-$* | *$F^-$* | *$Na^+$* | *$K^+$* | *$Ca^{+2}$* | *$Mg^{+2}$* | *TDS* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *TH.* | 1.00 | | | | | | | | | | | | |
| *pH* | -0.29 | 1.00 | | | | | | | | | | | |
| *EC* | **0.70** | -0.50 | 1.00 | | | | | | | | | | |
| *$HCO_3^-$* | 0.48 | -0.40 | **0.87** | 1.00 | | | | | | | | | |
| *$SO_4^{2-}$* | -0.27 | 0.18 | 0.03 | 0.00 | 1.00 | | | | | | | | |
| *$NO_3^-$* | 0.23 | -0.24 | 0.30 | 0.09 | -0.09 | 1.00 | | | | | | | |
| *$Cl^-$* | **0.74** | -0.38 | **0.83** | 0.53 | -0.02 | 0.17 | 1.00 | | | | | | |
| *$F^-$* | -0.02 | -0.14 | 0.21 | 0.31 | -0.04 | 0.03 | 0.09 | 1.00 | | | | | |
| *$Na^+$* | **0.62** | -0.51 | **0.93** | **0.71** | 0.07 | 0.27 | **0.84** | 0.16 | 1.00 | | | | |
| *$K^+$* | **0.60** | -0.48 | **0.71** | 0.55 | -0.05 | 0.37 | **0.56** | 0.02 | 0.57 | 1.00 | | | |
| *$Ca^{+2}$* | 0.36 | -0.19 | 0.31 | 0.28 | -0.27 | 0.11 | 0.40 | 0.10 | 0.16 | 0.15 | 1.00 | | |
| *$Mg^{+2}$* | 0.51 | -0.21 | 0.33 | 0.13 | -0.03 | 0.34 | 0.25 | -0.13 | 0.37 | 0.44 | -0.50 | 1.00 | |
| *TDS* | **0.70** | -0.50 | **1.00** | **0.87** | 0.03 | 0.30 | **0.83** | 0.21 | **0.93** | **0.71** | 0.31 | 0.33 | 1.00 |

TH= Total hardness, TDS = Total Dissolved Solids

and percolation rates. In addition to this, excessive SAR levels can also cause soil crusting, poor seedling and poor aeration (Lesch and Suarez, 2009).The following equation is used for the calculation of SAR values.

$$SAR = Na / \sqrt{[(Ca + Mg)/2]}$$

(where all the concentrations of ions in meq/l)

The SAR for all the samples is calculated using the above equation and the results of SAR were found within the range 0.14–2.9. Based on classification (Richards 1954) represented in Table 9, it is observed that the groundwater of the study area was excellent for irrigation purposes.

**Table 5.** Principal Component Analysis (PCA) of the Groundwater quality parameters

| | Rotation Sums of Squared Loadings | | | | | |
|---|---|---|---|---|---|---|
| | pre-monsoon | | | post-monsoon | | |
| Components | Eigen-Values | % of Variance | % of Cumulative | Eigen-values | % of Variance | % of Cumulative |
| 1 | 3.972 | 50.323 | 50.323 | 4.689 | 40.703 | 40.703 |
| 2 | 3.083 | 14.789 | 65.112 | 1.853 | 16.176 | 56.880 |
| 3 | 1.535 | 10.510 | 75.621 | 1.315 | 9.427 | 66.307 |
| 4 | 1.493 | 8.403 | 84.024 | 1.196 | 9.130 | 75.436 |

Salt concentration in water is a prime parameter of water quality for irrigation purpose (Wilcox, 1955). In the present study, the Wilcox diagram based on salt content in the water has been prepared to determine the suitability of the groundwater for irrigation purpose. It indicates that all samples fall under the good quality

**Table 6.** Rotated Component Matrix and Factors

| Parameters | Rotated Component Matrix[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pre-monsoon | | | | Post-monsoon | | | |
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Hardness | 0.15 | 0.05 | 0.02 | **0.84** | 0.02 | **0.89** | -0.03 | -0.15 |
| pH | **0.82** | **0.54** | 0.06 | 0.15 | 0.02 | **0.86** | -0.14 | 0.13 |
| $HCO_3^-$ | **0.82** | 0.34 | -0.13 | 0.22 | 0.77 | 0.20 | -0.26 | -0.19 |
| $SO_4^{-2}$ | 0.28 | **0.87** | 0.16 | -0.06 | **-0.49** | 0.42 | 0.49 | -0.16 |
| $NO_3^-$ | -0.05 | -0.02 | **0.95** | 0.11 | **0.97** | -0.02 | -0.02 | 0.18 |
| $Cl^-$ | **0.67** | 0.55 | 0.14 | -0.21 | **0.77** | -0.08 | 0.04 | 0.37 |
| $F^-$ | -0.02 | -0.01 | 0.21 | 0.71 | 0.07 | -0.07 | **0.86** | 0.01 |
| $Na^+$ | **0.74** | **0.53** | 0.05 | -0.13 | 0.29 | 0.28 | -0.43 | 0.03 |
| $K^+$ | 0.35 | 0.41 | **0.70** | 0.31 | **0.88** | -0.06 | -0.01 | -0.06 |
| $Ca^{+2}$ | **0.85** | -0.20 | 0.15 | 0.07 | 0.07 | -0.01 | -0.03 | **0.94** |
| $Mg^{+2}$ | 0.15 | **0.92** | -0.01 | 0.13 | **0.92** | 0.00 | 0.02 | 0.14 |
| TDS | **0.82** | **0.54** | 0.06 | 0.15 | **0.76** | 0.07 | -0.24 | -0.07 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

**Table 7.** Relative weight of the groundwater quality parameters

| Parameters | Indian Standards | Weight (wi) | Relative weight (Wi) |
|---|---|---|---|
| Ph | 7.5 | 4 | 0.1081 |
| Total Hardness | 300 | 2 | 0.0540 |
| Alkalinity | 200 | 3 | 0.0810 |
| Chloride | 250 | 3 | 0.0810 |
| Fluoride | 1 | 4 | 0.1081 |
| Calcium | 75 | 2 | 0.0540 |
| Magnesium | 30 | 2 | 0.0540 |
| Sodium | 20 | 2 | 0.0540 |
| Potassium | 10 | 3 | 0.0810 |
| Nitrate | 45 | 4 | 0.1081 |
| Sulphate | 200 | 4 | 0.1081 |
| TDS | 500 | 4 | 0.1081 |

**Table 8.** Standard rating of water quality as per WQI

| WQI scale | Water quality rating (WQR) | Grading |
|---|---|---|
| 0–25 | Excellent water quality | 8.5% A |
| 26–50 | Good water quality | 26% B |
| 51–75 | Poor water quality | 49% C |
| 76–100 | Very poor water quality | 14% D |
| >100 | Unsuitable water quality | 3% E |

**Table 9.** Classification of river water for irrigation purposes based on SAR

| SAR scale | Water class | % of the samples |
|---|---|---|
| 0–10 | Excellent | 100 |
| 10–18 | Good | - |
| 18–26 | Fair | - |
| >26 | Poor | - |

of water with respect to alkali hazard. But a good number of samples are falling under salinity hazards. Therefore, the techniques of drip irrigation that can lessen the salinity hazard has to be implemented (Fig.9).

**Sodium Percentage**

Sodium percentage is a parameter to evaluate water quality for irrigation purposes. Excess of sodium in water reacts with soil, reduces soil permeability and supports little or no plant growth (Wilcox 1955). The $Na^+$ % in water sample was calculated by the following equation:

$$Na\% = [(Na^+ + K^+) / (Ca^{2+} + Mg^{2+} + K^+ + Na^+)] * 100$$

Where all the concentrations of ions are in meq/l. $Na^+$% in water ranged from 0.98 to 13.9 %. The calculated $Na^+$% showed that all water samples fall within the excellent for irrigation needs (Table 10).

**Residual Sodium Carbonate (RSC)**

The sodium hazard also increases, if the water contains a higher concentration of bicarbonate ions. As the soil solution becomes more

**Table 10.** Classification of river water for irrigation purposes based on Na%

| SAR/TDS | Water class | % of the samples |
|---|---|---|
| >20 | Excellent | 100 |
| 20–40 | Good | 0 |
| 40–60 | Permissible | 0 |
| 60–80 | Doubtful | - |
| <80 | Unsuitable | - |

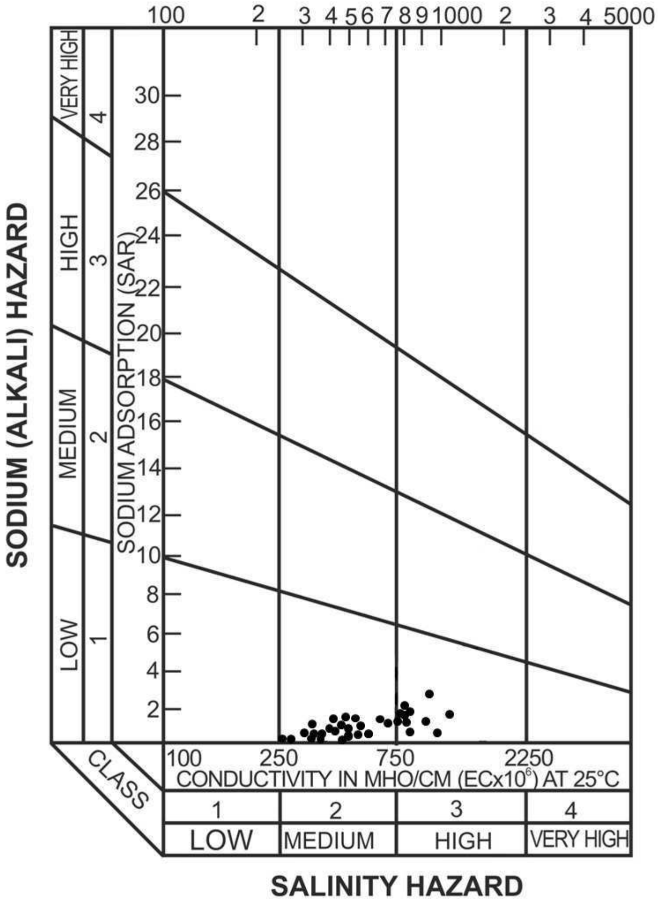


**Fig.9.** Wilcox diagram representing the Groundwater quality for irrigation purposes (Average)

concentrated, there is a tendency for calcium and magnesium to precipitate as carbonates, increasing thereby the relative proportion of sodium as a consequence. In the present case, RSC was used to quantify the effect of the carbonate and bicarbonate (Eaton, 1950). RSC has been calculated by using the following equation:

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

Where, all ionic concentrations are measured in terms of meq/l. The calculated RSC values of all the water samples ranged from -118 to -7 meq/l. The classification of all the samples according to RSC value indicates that obtained results of RSC fall under the excellent category, safe and unsuitable category of water quality for irrigation purposes (Table 11).

**Table 11:** Classification of groundwater samples for irrigation purposes based on RSC

| RSC scale | Water class | % of the samples |
|---|---|---|
| >0 | Excellent | 85 |
| <1.25 | Safe/good | 8.5 |
| 1.25–2.50 | Marginal/doubtful | 00 |
| >2.50 | Unsuitable | 5.7 |

**Kelly's Ratio**

Based on Kelly's ratio waters are classified for irrigation. Sodium measured against Calcium and Magnesium was considered by Kelly (1957) to calculate this parameter. Kelly's ratio of more than one indicates an excess level of sodium in waters. Therefore, water with Kelly's ratio less than one is suitable for irrigation, while those with a ratio of more than three are unsuitable for irrigation. Kelly's ratio of groundwater of the study area varies from 0.03 to 0.89with an average of 0.25. Therefore according to the Kelly' ratio, all the water samples are suitable for irrigation.

### Permeability Index

The permeability index (PI) of the water derived by Doneen (1984) using cation and bicarbonate concentration adopting the following expression:

$$PI = [\{Na^+ + \sqrt{HCO_3^-}\} / \sqrt{(Ca + Mg + Na)}] * 100$$

PI is a factor, which greatly influences the quality of irrigational water, in relation to soil development in agriculture. Permeability index of the water classes in the study area was calculated as part of the assessment of the irrigation quality of the groundwater. PI values were plotted together with total ions concentration in meq/l values of the groundwater samples. It is found that most of the samples fall under suitable conditions for groundwater uses (Table 12). Based on PI and total dissolved ions concentrations in meq/l, A plot has been designed and most of the samples falling in class 1 (Fig.10). It suggests that most of the water samples are good for irrigation purposes.

### Corrosion Water Quality Analysis

Corrosion is an electrolytic process that takes place on the surface of the metal, which severely attacks and corrodes away the metal surfaces. Stream water in the study area is transported through metallic pipes to various places that may or may not be suitable for transport. This fact is shown by using the Corrosivity ratio (CR) proposed by Ryzner (1994). Corrosivity ratio of all the samples study area is <1 except at Kushlok hospital (S. No. 11) where it is >1 and is unsafe.

$$CR = [\{(Cl/35.5) + (SO_4/96)\}/2(HCO_3^-)] * 100$$

**Table 12.** PI (Permeability Index) of the groundwater in study area.

| Types | PI value | Water class | % of the samples | |
|---|---|---|---|---|
| Class I | 0-40 | excellent | 100 | suitable |
| Class II | 40-80 | good | 0 | acceptable |
| Class III | 80-120 | poor | 0 | not suitable |

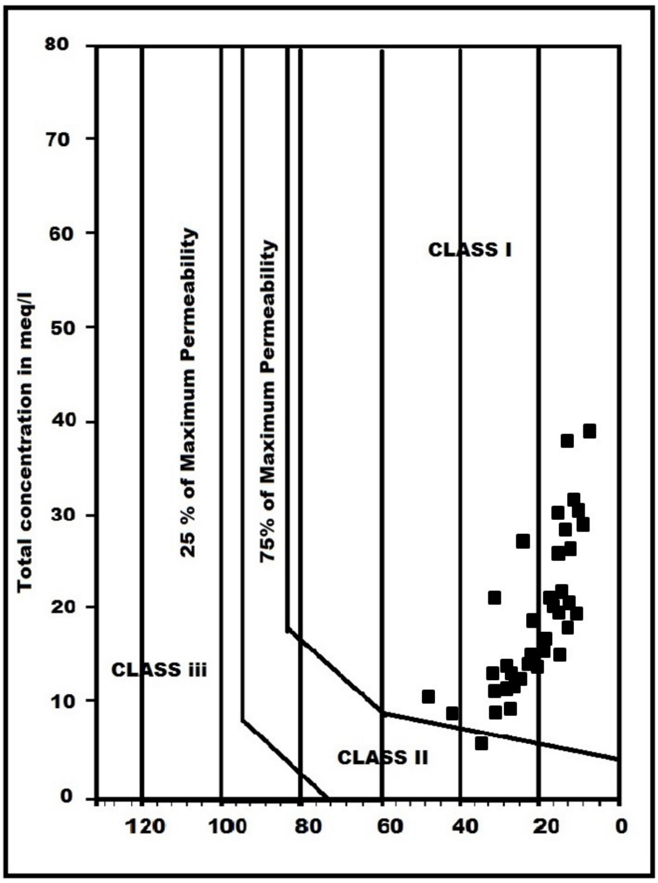


**Fig.10.** Permeability Index relation with groundwater quality in study area (Average)

## CONCLUSION

The results suggest that most of the groundwater quality parameters are under limits, except $NO_3^-$ at few locations. All the major ions show south-eastern increasing trend due to sluggish movement of groundwater in the direction. The groundwater in part of Ramganga basin belongs to the Ca-$HCO_3^-$ ionic facies. Spatio- temporal fluctuation of $NO_3^-$ and $Cl^-$ show plume behaviour due to leaching at the biggest habitat of the district and industrial area. The acid washing of ceramic tile in Faridpur industrial hub/battery work in the central city area is responsible for lower pH of groundwater at a local scale. This acidified medium can lead to mobilization of the other metal from the mineral/metals in groundwater.

Groundwater Quality Index suggested that a fair percentage of water samples fall under the category of very poor and unsuitable for drinking purposes. Numbers of the parameters indicated that most of the samples are suitable for irrigation purposes. But high TDS with low Na% suggests that using continuously this type of water may result in the development of salinity in soil without sodium hazard.

A change in landuse/landcover pattern lis resulting in overexploitation of water resources. It is reflected in deepening of the water table particularly in southern Ramganga plain. In the future, only the deeper groundwater will be available for irrigation that is characterized by high SAR and TDS values.

*Acknowledgements:* The authors would like to express their sincere thanks to Chairman, Department of Geology, Aligarh Muslim University for providing the laboratory and library facilities. The authors would like to appreciate the financial assistance provided by UGC, Ministry of HRD, Govt. of India to conduct the present research work under DRS II (SAP- 1) programme.

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*(Received: 5 February 2019; Revised form accepted: 24 December 2019)*