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Chemical characterization and assessment of groundwater quality for irrigation purpose in Muzaffarnagar district, Uttar Pradesh, India

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Abstract
The chemical characteristics of seventy seven groundwater samples collected from totally different locations of Muzaffarnagar district, Uttar Pradesh, India, were analysed to review numerous quality parameters for their suitability to irrigation purpose. The groundwater samples were analysed for chemical properties viz. pH, electrical conductivity, K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, NO_3^-, Cl^-, SO_4^{2-}, F^- and B^-. The range of pH and EC were 7.1 to 8.0 and 0.23 to 1.49 dsm^{-1}, respectively. The concentration of K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, NO_3^-, Cl^-, SO_4^{2-}, F^- and B^- were within the recommended limits prescribed for irrigation water in most of the locations. The Ca^{2+}, Mg^{2+} and Na^+ were the dominant cations, whereas HCO_3^-, NO_3^- and Cl^- were the dominant anions within the groundwater. Calculated total dissolved solids, total alkalinity, total hardness, carbonate hardness, non-carbonate hardness and excess alkalinity in groundwater samples were within the suggested limits for irrigation water. The suitability of groundwater for irrigation purpose was assessed by various criteria like magnesium ratio (MR), sodium percentage (Na %), residual sodium carbonate (RSC), sodium adsorption ratio (SAR), permeability index (PI) and Kelly's index (KI). The values of MR, Na%, RSC, SAR, PI and KI showed that the groundwater was good and appropriate for irrigation purposes in the study area.

Keywords: Groundwater, chemical characteristics, irrigation water quality, Muzaffarnagar

1. Introduction
Water is a very important natural resources. It's essential for forever. Water on earth is present in different forms. Among the different forms of water, groundwater is a very important type. Due to inadequate supply of surface water demand for groundwater resource has increased many folds in recent time for drinking, irrigation and industrial functions within the world. It is calculated that approximately one third of the world's population use groundwater for drinking (Nickson *et al*., 2005) [13]. In a country like India, majority of the population (85%) lives in villages and depends mainly on groundwater resources. Approximately 65% (50 to 80%) of the irrigated land is under groundwater consumption (Raju, 1998) [16]. Groundwater is a very important water supply source worldwide. It is the main source of water in both urban and rural area in India. Due to the over-exploitation of groundwater, it's harmfully affected its amount and quality additionally. The chemical quality of groundwater influence the chemical composition of soils and rocks through mineral solubility, ion exchange, oxidation, reduction etc.; additionally to the sources of anthropogenic activities like population explosion, poor hygienic conditions, application of fertilizers and pesticides for higher crop yield without understanding the chemical characteristics of soils, and industrial development without following any appropriate remedial measures (Subba Rao, 2002, Naik *et al*., 2009) [21, 12].
Water quality analysis is one amongst the foremost vital aspects in groundwater studies. The hydro-chemical study reveals quality of water that is appropiate for drinking, agriculture and industrial purposes. Chemical analysis forms the idea of interpretation of the quality of water in relation to source, geology, climate and use. Water being a superb solvent, it is vital to know the geochemistry of dissolved constituents and strategies of reporting analytical data. The normal groundwater have generally neutral to slightly alkaline pH dominated by base

cations (Ca^{2+}, Mg^{2+}, Na^{+}) and bicarbonate (Frengstad and Banks, 2000) [7].

Groundwater is the main source for irrigation in the present study. Besides, the groundwater can become a significant supply for industrial development very shortly due to liberalization governmental policies. Groundwater is an important part of the environment and therefore cannot be looked upon in isolation. Therefore, the elemental information of chemical constituents of water could be a necessity for rational management and quality of water resources. Keeping this in view, the present study is concentrated on chemical characteristics of groundwater and their suitability for irrigation purpose.

2. Materials and Methods

2.1 The study area

The study was carried out in Muzaffarnagar district, that lies within the northwest of Uttar Pradesh. It is delimited on the north by Saharanpur district, Haridwar district of Uttarakhand in the northeast, Bijnor district in the east, Meerut district in the south and Shamli district in west. The eastern boundary of the district with Bijnor is split by river Ganga. The district lies between 29^0 10' 40" - 29^0 42' 33" latitudes and 77^0 23' 10" -78^0 08' 10" longitude. Muzaffarnagar has total geographic area of 2958.08 km^2. The normal annual rainfall in the district is 869 mm. About 737 mm, 80% of rainfall takes place from June to September. During monsoon surplus water is out there for deep percolation to groundwater. The climate is sub humid and it's characterised by general dryness except in the brief period during the monsoon season. Summer is hot and winter is pleasant cold season. May is the hottest month. The mean daily maximum temperature is about 40 ^{0}C, mean daily minimum temperature is about 24 ^{0}C and maximum temperature some time rises to 44 ^{0}C. With the onset of southern monsoon by the end of June, there is appreciable drop in temperature. January is the coldest month with mean daily maximum temperature at about 20 ^{0}C and mean daily minimum temperature at about 7 ^{0}C. The mean monthly relative humidity is 67%. About 80% of the total geographical area of the district is cultivated area. The main rabi crops are wheat and oil seeds, while paddy and pulses are the main kharif crops. The abundantly produced sugarcane is a perennial crop. The area is characterized under Indo-Gangetic alluvium group of soils and is represented predominantly by sandy loam soils (CGWB, 2017) [2].

2.2 Sampling of groundwater

Seventy seven water samples were collected from Muzaffarnagar district. The samples were collected in 500 ml polyethylene bottles from tube wells water. Before sampling, bottles soaked in 1:1 HCl for 24 hrs were rinsed with distilled water followed by deionised water. At the time of sampling, the sampling bottles were thoroughly rinsed two to three times using the groundwater to be sampled. Water samples from tube wells were collect directly from outlet point after running the tube well for about half an hour to drain out the water retained in pipe. The sample bottles were labelled, tightly packed, transported immediately to the laboratory and stored at 4 ^{0}C for chemical analysis. During the analysis, blanks and standard were run at the start of analysis. These water samples were analysed for chemical properties viz., pH, electrical conductivity (EC), potassium, sodium, calcium, magnesium, carbonate, nitrate, chloride, sulphate, fluoride and boron with standard methods of water chemical analysis (APHA, 1995) [1].

Total dissolved solids (TDS) was calculated from electrical conductivity by using the formula TDS (mg/L) =EC (dsm^{-1}) x 640. The total alkalinity (TA) is a measure of HCO_3^- and CO_3^{2-} ions. In this study, the TA was caused by HCO_3^- ion only, as the pH were between 7.1 to 8.0. The total hardness (TH) was calculated by using formula TH (mg/L) = 2.5 (Ca^{2+} in mg/L) + 4.1 (Mg^{2+} in mg/L) as the Ca^{2+} and Mg^{2+} were the principal ions responsible for total hardness. Based on the TA and TH, the groundwater quality are often classified as carbonate hardness (CH), non-carbonate hardness (NCH) and excess alkalinity (EA), following the Indian Standard Institute (ISI, 1963) [9] and Chow (1964) [3]. The criterion followed as (a) the values, which are lowest (between) TA and TH) is placed under CH, (b) when the value of TA is greater than TH, the difference (TA-TH) value is considered as excess alkalinity (EA) and (c) when TH is greater than TA, the difference value (TH-TA) is considered as NCH.

Suitability of groundwater for irrigation was assessed with the assistance of various criteria like magnesium ratio (MR), sodium percentage (Na %), residual sodium carbonate (RSC), sodium adsorption ratio (SAR), soluble Doneen's permeability index (PI) and Kelly's index (KI).

An index for calculating the magnesium hazard (magnesium ratio) was developed by Paliwal (1972) [14] calculated using the formula: MR = (Mg^{2+} x 100)/ (Ca^{2+} + Mg^{2+}).

Residual sodium carbonate was calculated to work out the hazardous effect of carbonate and bicarbonate on the quality of water used for agricultural activities (Raju, 2007) [17].

RSC = (CO_3^{2-} + HCO_3^-) – (Ca^{2+} + Mg^{2+}), Where all ions are expressed in meq/L.

Percentage of sodium is widely used for assessing the suitability of water for irrigation purposes (Wilcox, 1955) [26]. The sodium percentage was computed with respect to relative proportion of cations present in water by using the formula:

Na % = [(Na^+ + K^+)/(Ca^{2+} + Mg^{2+} + Na^+ + K^+)] x 100, Where all the ions are expressed in meq/L.

The sodium or alkali hazard within the water for irrigation is decided by absolutely the and relative concentration of cations and is expressed as the sodium adsorption ratio. Sodium adsorption ratio was calculated based on the formula (Richard, 1954) [18] as given below:

SAR = Na^+/ [√ (Ca^{2+} + Mg^{2+})/2], where all the ions are expressed in meq/L.

The permeability of soil is affected by long term use of irrigation water and is influenced by sodium, calcium, magnesium and bicarbonate contents in soil. Doneen (1964) [5] has evolved a criterion for assessing the suitability of water for irrigation based on permeability index (PI). It was calculated by using the formula:

PI = [(Na^+ + √ HCO_3^-) x 100 / [(Ca^{2+} + Mg^{2+} + Na^+)], Where all the ions are expressed in meq/L.

Sodium measured against calcium and magnesium is taken into account for calculating the Kelly's index (KI). Kellys's index was calculated by using the formula:

KI = Na^+ / (Ca^{2+} + Mg^{2+}), Where all the ions are expressed in meq/L.

Statistical methods were used to compute the central tendency (arithmetic mean), dispersion (standard deviation) and coefficient of variation for eighteen chemical parameters (pH, EC, TDS, TA, TH, CH, NCH, EA, K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, NO_3^-, SO_4^{2-}, F^-, Cl^-, and B^-) of seventy seven groundwater samples.

3. Results and Discussion

3.1 Chemical characteristics of groundwater

3.1.1 pH

The value of groundwater samples of Muzaffarnagar district was varied from 7.1 to 8.0 (Table 1). The maximum value of 8.0 was found in Sikhera, Rampur, Kawal, Kurthal and Shahadabber locations, whereas minimum value of 7.1was found in Shilajuddi location. By comparing obtained pH values with normal pH range for irrigation water standard of FAO, it has been found that 100% samples of the district were within the normal range (6.5 to 8.4) of pH. Irrigation water with a pH outside the traditional range may cause a nutritional imbalance or may contain a toxic ion.

3.1.2 Electrical conductivity and total dissolved solids

The most common parameters used for determining the irrigation water quality, in relation with its salinity are TDS and EC. The EC values of groundwater samples of Muzaffarnagar district varied from 0.23 to 1.49 dsm^{-1} (Table 1). The utmost value of 1.49 dsm^{-1} was recorded at Ysufpur location while minimum value of 0.23 dsm^{-1} was recorded at Makhiali and Goela locations. By comparing EC values with standard as purposed by FAO, it had been found that the 75.3% samples were below 0.75 dsm^{-1} of EC and remaining 24.7% samples were within the range of 0.76 to 1.5 dsm^{-1} of EC, which is that the permissible limit of irrigation water suitable for irrigation purpose. Similar findings were also reported by Pramod Kumar *et al*. (2018) [15] in groundwater of Muzaffarnagar district.

The TDS of groundwater samples was between 150 and 960 mg/L in the Muzaffarnagar district (Table 1). The most TDS of 960 mg/L was recorded at Yusufpur location, whereas minimum TDS of 150 mg/L was noticed at Makhiali and Goela locations. The degree of groundwater quality can be classified as fresh, if the TDS is below 1000 mg/L; brackish, if the TDS is between 1000 and 10000 mg/L; saline, if the TDS is varied from 10000 to 1000000 mg/L; and brine, if the TDS is over 1000000 mg/L (Todd, 1980) [24]. Consequently, the quality of groundwater within the present study all the samples were classified as fresh.

3.1.3 Total alkalinity and total hardness

The total TA in groundwater samples of Muzaffarnagar district was observed from 90 to 390 mg/L (Table 1). The observed value of TH in groundwater of Muzaffarnagar was between 100 and 490 mg/L (Table 1). The TH can be classified as soft, if the TH is below 75 mg/L; moderately hard, if the TH is varied from 75 to 150 mg/L; hard, if the TH is over 300 mg/L (Davis and Dewiest, 1966) [4]. Consistent with the classification of TH, 7.8% of samples in Muzaffarnagar district were come under the moderately hard category, 68.8% of samples under the hard category and remaining 23.4% of samples under the category of very hard.

The CH was varied from 90 to 390 mg/L in groundwater samples of Muzaffarnagar (Table 1). The NCH (10 to 120 mg/L) was observed in 55 groundwater samples of Muzaffarnagar (Table 1). It had been also noted that the EA was varied from 10 to 90 mg/L in groundwater samples of Muzaffarnagar (Table 1). Out of 77 samples, the EA was observed only in 16 samples. Which can be flow to the salts of $NaHCO_3$, where the TA was more than TH in the groundwater. But the EA was not observed in the groundwater samples where the TH was more than TA.

3.1.4 Sodium and potassium

The concentration of Na^+ was varied from 4.60 to 161.69 mg/L in groundwater samples of Muzaffarnagar (Table 1). It was noted that the mean contribution of Na^+ in total cations was approximately 27.7%. The concentration of Na^+ was low in compared to concentration of Ca^{2+} and Mg^{2+} in all groundwater samples of the district. The high concentration of Na^+ was typically found within the samples having high EC. It means that the concentration of Na^+ was increased with increased within the EC and TDS of the groundwater samples.

The concentration of $K^+$to the whole cations was lowest in all groundwater samples of the district. The concentration of K^+ was between 1.96 and 23.46 mg/L (Table 1). The contribution of K^+ to the total cations was approximately 1.7 to 19.8%. Generally, the potassium ion content in numerous sources of irrigation water remained low except only few locations. It's going to flow from to the smallest amount cation in groundwater of district exhibiting good quality in terms of potassium concentration.

3.1.5 Calcium and Magnesium

The concentration of Ca^{2+} was between 18.05 to 95.84 mg/L in groundwater samples of Muzaffarnagar (Table 1). Among the cations present in groundwater samples, the concentration of Ca^{2+} was highest within the district. The mean contribution of Ca^{2+} to the entire cations was 39%. The concentration of Ca^{2+} in groundwater samples comparatively exhibited higher values at location within the vicinity of industrial units on account of blending of contaminants with the water bodies.

The concentration of Mg^{2+} between 6.8 and 66.83 mg/L in groundwater samples of Muzaffarnagar (Table1). It had been ascertained that Mg^{2+} was the second most contributing ions after the Ca^{2+}within the groundwater samples of the district. The mean contribution of Mg^{2+} to the total cations was approximately 28.7%. The high concentration of Mg^{2+} in irrigation water will adversely affect the crop yield because the soils become more alkaline. In this study, the concentration of Mg^{2+} in irrigation water was found appropriate for irrigation purpose.

3.1.6 Bicarbonate

The value of HCO_3^- was ascertained from 102.48 to 471.53 mg/L (Table 1). Which was the dominant anion as well as ion. The lowest concentration of HCO_3^- (102.48 mg/L) was noticed in the groundwater sample of Goela, whereas the highest concentration of HCO_3^- (471.53 mg/L) was observed in the groundwater sample of Tisa. The typical contribution of HCO_3^- was 74.5% to the total anions. According to FAO standard normal range of bicarbonate in irrigation water is 0 to 610 mg/L (0-10 meq/L), so the quality of groundwater in study area is suitable for irrigation purpose in terms of HCO_3^- concentration.

3.1.7 Chloride

The concentration of Cl^- was between 10.65 to 161.53 mg/L (Table 1). The chloride was the third largest anion after bicarbonate and nitrate. The maximum concentration of chloride ion (161.65 mg/L) was found in the groundwater sample of Jaula location. The contribution of Cl^- to the total anions was approximately 2.8% (lowest) to 41.9% (highest). The most of the samples showed low chloride concentration in groundwater except one sample of Jaula. It may be due to the chloride contribution from town discharge was concerning this location. Results compared with FAO standard for chloride ion concentration showed that all the groundwater samples are suitable for irrigation purpose without any restriction in terms of chloride.

3.1.8 Nitrate

The value of NO_3^- in groundwater was observed between 3.72 to 267.22 mg/L (Table 1). The NO_3^- was the second largest anion after bicarbonate. The maximum concentration of NO_3^- was obtained in the groundwater sample of Yusufpur location. Out of the 77 samples, 53 samples showed more than 10 mg/L concentration of NO_3^-, which may be due to the indiscriminate use of higher nitrogenous fertilizers for higher crop yield within the study area.

3.1.9 Sulphate

The content of SO_4^{2-} was ascertained from 13.93 to 133.58 mg/L (Table 1). The highest SO_4^{2-} content was recorded in the groundwater sample of Baroud location, whereas the lowest content of SO_4^- was noticed in the Rampur and Gangdaspur locations. The contribution of SO_4^{2-} to the total anions was approximately 3.6% to 34.67% in the study area. The High values of SO_4^{2-} cannot be expected from geological source as the soil type in this region does not support the existence of gypsum, which is a likely source of sulphate in irrigation water. Under these conditions, anthropogenic source of sulphate in irrigation water may be the main contributor (Umar *et al*., 2006) [25].

3.1.10 Floride

In the groundwater samples, the concentration of F^- was 0.23 to 2.26 mg/L (table 1). The maximum F^- content was obtained in the groundwater sample of Kasauli location. Out of the 77 groundwater samples studied, 70 (90.9%) samples were below the concentration of < 1.0 mg/L, while the concentration in seven samples were above the 1.0 mg/L contents. According to FAO standards, concentration of F^- in groundwater sample up to 1.0 mg/L is safe for irrigation water in long term use, while concentration of F^- up to 15 mg/L in irrigation water can be used for short term. However, neutral to alkaline pH of the soil inactivate the higher concentration of F^-. So, the groundwater of the study area is rated as satisfactory in terms of fluoride hazard.

3.1.11 Boron

The content to B^- was recorded from 0.35 to 2.84 mg/L (Table 1). The highest B^- (2.84 mg/L) was obtained in the groundwater sample of Mahelki location. Out of 77 groundwater samples, 64 (83.1%) were below the 2.0 mg/L contents of B^-, 12 (15.6%) groundwater samples were nil in B^- contents and remaining one groundwater sample was above the 2.0 mg/L B^- in content. Although B^- is a very important micronutrient for plant growth, its concentration of > 2.0 mg/L in irrigation water is harmful to most of the crops. Its concentration primarily depends upon its mineralogical source, nature of soil strata through which it percolates and pollution of water by boron rich industrial effluents. So, the irrigation water of study area is suitable for irrigation purpose in relation to boron contents.

3.2 Standard deviation in geochemistry of groundwater

The chemical parameters showed a narrow range of standard deviation (Table 1). The TDS (145.44), HCO_3^- (85.83), TH (75.66), TA (69.74), CH (69.04) and NO_3^- (48.27) have more standard deviation, followed by NCH (29.25), EA (27.29), Na^+ (28.52), Cl^- (25.30), SO_4^{2-} (17.21), Ca^{2+} (16.99), and Mg^{2+} (11.89), compared with other chemical parameters, EC, pH, K^+, F^- and B^-, that have the standard deviation from 0.22 to 0.42. The variations within the standard deviation among the chemical parameters suggested that the narrow dispersion of salts in the groundwater system by the source of salt from geogenic and anthropogenic, and by the processes of mineral dissolution, mineral solubility, ion exchange and evaporation.

3.3 Suitability of the groundwater for irrigation

3.3.1 Residual sodium carbonate

According to Eaton (1950) [6], on the premise of RSC the water is split into three classes I.e., good (RSC <1.25 meq/L), medium (RSC 1.25 to 2.50 meq/L) and harmful (RSC > 2.5 meq/L). According to this classification 96.1% groundwater samples were found in good category (out of 77 samples, 57 samples showed negative values of RSC), while remaining 3.9% groundwater samples were in medium category as specified in table 2. So, the groundwater is suitable for irrigation purpose in terms of RSC.

3.3.2 Sodium adsorption ratio

To classify the irrigation water, Sodium concentration is incredibly vital. If the water employed in irrigation is high in Na^+ and low in Ca^{2+}, the cation exchange complex may become saturated with Na^+. The exchange process of sodium in water for magnesium and calcium in soil reduces permeability and eventually leads to in soil with poor drainage. Thus, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Saleh *et al*., 1999) [19]. Rhichard (1954) [18] classified the sodium hazard in irrigation water into four categories on the basis of SAR. The sodium hazard classes include: Low, S1 (SAR<10); medium, S2 (SAR 10-18); high, S3 (SAR 18-26) and very high, S4 (SAR > 26). The calculated SAR in 100 percent groundwater samples were come in the class S1, indicated that no sodium hazard in the groundwater samples of the study area. Therefore, it's showed that the groundwater of the area are good for irrigation purpose.

3.3.3 Sodium percentage

The computed value of Na% had been varied from 8.47 to 61.63 in the groundwater samples of the study area (Table 2). Generally, the Na% should not be 60 or more in the irrigation water for better crop yield. Approximately 98.7% (out of 77 groundwater samples, 76 samples were low in Na%) of the whole groundwater samples have Na% less than 60, while 1.3% (just one groundwater sample at Sandhawali) groundwater samples had Na% more than 60. Thus, groundwater of study area are good for irrigation purpose in terms of Na%.

3.3.4 Magnesium ratio

Generally Ca^{2+} and Mg^{2+} maintain a state of equilibrium in most groundwater (Hem, 1991) [8]. During equilibrium more Mg^{2+} in groundwater can adversely have an effect on the soil quality rendering it alkaline resulting in decrease of crop yield (Kumar *et al*., 2007) [11]. Magnesium hazard is likely to be developed in the soil when this ratio exceeds 50%. The degree of hazardous effects would increase with the rise of Mg^{2+}/Ca^{2+} ratio. However, the harmful effect of Mg^{2+} of irrigation water on soil is probably going to be reduced by the discharge of Ca^{2+} on dissolution of $CaCO_3$ if present in the soil. In present study area, the MR values was varied from 28.62 to 70.21 (Table 2). The about 68.8% of the total groundwater samples exceeded the permissible limit of 50, while remaining 31.2% of the groundwater samples were less than the permissible limit of MR. High MR groundwater samples might adversely have in effect on the crop yield by creating soil more alkaline (Paliwal, 1972; Subba Rao *et al*., 2012 and Singh and Kumar, 2015) [14, 22, 20].

3.3.5 Permeability index

The soil permeability is affected by long term irrigation influenced by Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- contents of the soil. The PI values indicate the suitability of groundwater for irrigation. The PI of less than 60 is considered suitable for irrigation, and more than 60 indicates the groundwater is unsuitable for irrigation. The PI values vary from 35.16 to 99.34 within the groundwater samples of the present study area (Table 2). According to the classification of PI approximately 83.1% (in 64 samples) of the groundwater samples come under the class I (suitable) and the rest 16.9% (in 13 samples) of the groundwater samples come under the class II (marginally suitable) for irrigation.

3.3.6 Kelly's index

Kelly's index is employed for the classification of water for irrigation purposes. Sodium measured against calcium and magnesium is taken into account to calculate this parameter. A KI > 1 indicates an excess level of sodium in water (Kelly, 1940) [10]. Therefore, water with a KI < 1 is appropriate for irrigation, while those with greater ratio are unsuitable (Sundaray *et al*., 2009) [23]. The KI in the present study varied between 0.069 to 1.540 (Table 2). According to the classification of KI approximately 96.1% (in 74 samples) of the groundwater samples were below the < 1 (suitable) and the remaining 3.9% (in 3 samples) of the groundwater samples were above the > 1 (unsuitable) for irrigation purpose.

3.4 Interrelationships of chemical parameters

The interrelationships among the chemical parameters were evaluated, using a correlation coefficient (r) to assess the source of dissolved salts in the groundwater. The EC and TDS were significantly positively correlated with TA, TH, CH, NCH, K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, NO_3^- SO_4^{2-} and Cl^-, indicating that the groundwater is controlled by K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, NO_3^- SO_4^{2-} and Cl^- ions (Table 3), which depend upon the mineral dissolution, mineral solubility, ion exchange, evaporation and anthropogenic activities (Subba Rao *et al*., 2012) [22]. The TA had significant positive correlation with TH, CH, Ca^{2+}, Mg^{2+}, K^+, Na^+, and Cl^- ; the TH with CH, NCH, K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, NO_3^-, Cl^- and SO_4^{2-}; the CH with K^+, Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, and Cl^- .; the NCH with Ca^{2+}, Mg^{2+}, NO_3^-, Cl^- and SO_4^{2-}; the EA with Na^+ (Table 3). These relations indicated that the Ca^{2+},Mg^{2+},K^+, Na^+,HCO_3^-, Cl^-, SO_4^{2-} and NO_3^- contributed towards the TH, CH and NCH, in which the TH was caused by CH, NCH, Ca^{2+}, Mg^{2+},Na^+, and K^+ of HCO_3^-, Cl^-, SO_4^{2-}, and NO_3^-; the CH was caused by Ca^{2+}, Mg^{2+}, K^+ and Na^+ of HCO_3^- and Cl^- and the EA by Na^+, However, EC and TDS had significant negative correlation with pH; the TA with F^-; the TH with EA and the NCH with EA.

The K^+ had significant positive correlation with Na^+, Ca^{2+}, Mg^{2+},HCO_3^- and Cl^-; the Na^+ with Ca^{2+}, HCO_3^-, NO3$^-$ and Cl^-; the Ca^{2+} with Mg^{2+}, HCO_3^-, NO_3^-, Cl^- and SO_4^{2-}; the Mg^{2+} with HCO_3^-, NO_3^-, Cl^- and SO_4^{2-}; the HCO_3^- with Cl^- and the F^- with B^-, reflecting the influence of Ca^{2+}, Mg^{2+} and Na^+ bearing minerals and source of anthropogenic. The HCO_3^- had significant positive correlation with Cl^-, while F^- had significant positive correlation with B^-, indicating that HCO_3^- and Cl^- were the dominant anions in the groundwater and the F^- concentration related to the B^- concentration in water. It may be due to the influence of evaporation and agricultural activities on groundwater system.

Table 1: Chemical composition of groundwater in the Muzaffarnagar district, Uttar Pradesh

S. No.	Location	EC	pH	TDS	TA	TH	CH	NCH	EA	K^+	Na^+	Ca^{2+}	Mg^{2+}	HCO_3^-	NO_3^-	Cl^-	SO_4^{2-}	F^-	B^-
		dsm^{-1}		mgL^{-1}															
1	Simarthi	0.49	7.6	320	190	240	190	50	-	4.69	8.51	35.69	35.84	226.31	21.7	13.14	44.69	0.73	1.1
2	Kutubpur	0.47	7.8	310	190	220	190	30	-	7.43	12.19	37.09	29.65	221.43	9.3	16.69	48.05	0.47	0.71
3	Abdulpur	0.52	7.7	340	250	260	250	10	-	6.65	13.11	42.11	35.48	301.34	13.64	15.27	19.7	0.42	0.63
4	Makhiali	0.23	7.4	150	110	130	110	20	-	2.35	4.83	21.05	17.25	125.05	8.06	11.01	22.58	0.56	0.84
5	Pachenda	0.49	7.5	320	220	230	220	10	-	3.91	11.27	34.29	34.99	257.42	9.3	13.49	24.51	0.48	0.72
6	Rohanakhurd	0.51	7.8	330	230	230	230	-	-	4.69	14.72	44.31	26.97	273.28	7.44	11.36	17.78	0.72	1.08
7	Datiyana	0.73	7.4	470	170	180	170	10	-	4.69	84.87	36.29	21.26	205.57	33.48	88.75	52.37	0.62	0.93
8	Badkali	0.69	7.5	450	290	300	290	10	-	5.08	24.84	45.11	44.71	349.53	21.7	19.88	33.15	0.66	0.99
9	Kasauli	0.42	7.8	270	130	220	130	90	-	1.96	10.12	33.48	31.23	150.67	77.5	28.4	15.38	2.26	-
10	Jarauda	0.67	7.5	430	270	280	270	10	-	5.08	28.52	42.51	41.07	326.96	17.98	36.21	25.47	0.52	-
11	Budhinakalan	0.38	7.9	250	170	180	170	10	-	3.91	10.35	34.89	21.87	198.86	3.72	19.53	19.22	0.47	-
12	Kukra	0.82	7.5	530	250	350	250	100	-	5.47	35.19	46.52	54.8	300.73	81.22	48.28	34.6	0.31	-
13	Bhikki	0.69	7.7	450	290	290	290	-	-	7.04	27.6	36.49	47.63	345.26	22.32	28.05	28.35	0.63	0.95
14	Sikheda	0.47	8	310	150	220	150	70	-	5.87	11.96	36.09	31.47	173.85	76.88	20.24	22.1	0.65	0.98
15	Rampur	0.43	8	280	180	200	180	20	-	5.08	10.35	31.48	28.55	209.23	27.28	23.79	13.93	0.74	1.11
16	Barwala	0.8	7.3	520	290	200	200	-	90	8.21	94.07	50.13	16.89	342.82	78.74	30.89	17.78	0.66	0.99
17	Molaheri	0.41	7.6	270	150	200	150	50	-	2.35	8.51	29.47	28.55	173.85	17.98	21.3	21.62	1.07	1.61

18	Dhudhli	0.47	7.6	310	220	230	220	10	-	1.96	10.81	34.89	32.93	258.03	6.2	12.07	19.7	0.46	0.69
19	Akhlour	0.44	7.8	290	180	210	180	30	-	5.08	8.97	33.88	28.67	216.55	15.5	18.82	27.39	0.68	1.02
20	Vehlana	0.57	7.8	370	230	280	230	50	-	4.3	12.88	36.09	44.59	277.55	44.02	23.79	20.18	0.61	0.92
21	Harsoli	0.71	7.5	460	270	330	270	60	-	8.99	14.03	46.12	51.03	329.4	21.7	32.31	28.35	0.46	0.69
22	Pinna	0.46	7.5	300	160	210	160	50	-	6.26	13.11	30.08	31.95	189.1	57.66	22.01	15.38	0.37	0.56
23	Aminnagar	0.62	7.6	400	190	280	190	90	-	7.04	19.55	41.7	42.04	225.09	96.72	27.69	32.19	0.32	-
24	Shernagar	0.51	7.7	330	200	210	200	10	-	5.87	23.92	37.69	28.07	238.51	7.44	20.59	24.51	0.29	-
25	Shilajuddi	1.03	7.1	660	370	490	370	120	-	5.87	28.06	89.62	63.18	445.3	47.74	49.7	86.49	0.38	-
26	Bilaspur	0.49	7.5	320	180	210	180	30	-	2.35	19.09	36.09	29.16	214.11	9.92	29.47	30.27	0.47	0.79
27	Sandhawli	0.49	7.6	320	190	100	100	-	90	5.08	70.15	28.27	6.8	231.19	6.82	22.01	29.31	0.72	1.23
28	Sahawali	0.53	7.6	340	210	240	210	30	-	6.26	23	29.27	40.34	250.1	13.64	16.69	48.53	0.49	0.74
29	Nirana	0.76	7.5	490	300	330	300	30	-	6.26	12.42	51.33	47.99	354.41	6.2	23.79	39.4	0.38	0.51
30	Sarwat	0.81	7.3	520	330	340	330	10	-	6.65	24.38	70.38	38.15	397.11	9.3	28.4	24.03	0.26	0.36
31	Bhopa	0.61	7.4	400	180	240	180	60	-	5.87	34.73	37.89	33.41	209.84	98.58	23.79	34.12	1.26	1.89
32	Kasimpur	0.63	7.5	410	250	190	190	-	60	5.08	64.17	36.09	22.72	298.9	25.42	20.24	38.92	0.29	0.44
33	Salarpur	0.79	7.7	510	270	290	270	20	-	2.74	50.6	46.12	42.53	319.03	119.66	17.75	24.99	0.32	0.48
34	Mirapur	0.56	7.6	360	260	240	240	-	20	5.47	27.6	41.1	31.59	311.1	16.12	14.2	14.42	0.33	0.5
35	Kelapur	0.77	7.5	500	300	330	300	30	-	5.87	29.9	47.12	51.03	359.9	76.26	24.85	16.82	0.49	0.74
36	Mandaud	0.72	7.6	470	280	210	210	-	70	5.08	71.53	33.68	30.5	339.16	35.34	29.82	19.7	0.53	0.8
37	Tissa	1.04	7.5	670	390	330	330	-	60	6.26	97.06	67.17	37.67	471.53	68.2	45.8	25.95	0.51	0.77
38	Athai	0.88	7.2	570	290	280	280	-	10	5.87	73.6	44.11	41.31	348.31	143.22	26.63	14.9	0.43	0.65
39	Talda	0.83	7.5	540	220	300	220	80	-	6.26	66.93	48.12	42.65	256.81	242.42	12.78	14.42	0.36	-
40	Bhumma	0.69	7.3	450	310	290	290	-	20	5.47	27.6	44.11	43.74	375.15	8.68	15.98	24.03	0..85	-
41	Belda	0.62	7.5	400	260	270	260	10	-	3.91	23.92	57.54	30.38	315.98	27.9	21.3	19.22	0.64	0.96
42	Gangadaspur	0.83	7.3	540	320	300	300	-	20	5.87	57.96	58.55	36.45	380.03	75.02	32.31	13.93	0.45	0.68
43	Sambhalhera	0.71	7.5	460	300	280	280	-	20	5.87	41.4	63.16	27.95	361.73	57.66	17.75	14.42	0.88	1.32
44	Ahmadwala	0.51	7.7	330	200	220	200	20	-	4.3	25.53	50.13	21.26	234.85	16.74	26.27	32.19	0.23	0.35
45	Yusufpur	1.49	7.4	960	320	400	320	80	-	8.6	161.69	95.84	38.27	380.03	267.22	114.31	39.4	0.56	0.84
46	Kawal	0.39	8	250	200	120	120	-	80	3.52	48.3	28.87	9.6	232.41	9.3	13.85	14.9	0.48	0.72
47	Vazidpur	1.15	7.2	740	350	400	350	50	-	23.46	74.98	90.43	40.7	421.51	26.66	139.16	28.35	0.44	0.66
48	Nizampur	0.69	7.8	450	290	290	290	-	-	5.47	34.5	68.37	27.95	353.8	12.4	33.73	25.95	0.57	0.86
49	Rasulpur	0.75	7.4	480	320	320	320	-	-	5.87	29.9	78.2	28.55	389.79	11.78	28.4	21.62	0.71	1.07
50	Firojpur	0.71	7.6	460	280	290	280	10	-	5.08	34.27	70.38	26.61	330.01	40.3	32.31	18.74	1.08	1.62
51	Tisang	1.08	7.4	700	370	330	330	-	40	6.26	98.9	66.17	38.88	445.91	98.58	46.15	33.15	0.74	1.11
52	Behedaassa	0.83	7.3	540	330	300	300	-	30	5.87	63.25	43.11	46.66	397.11	65.72	36.21	15.86	0.57	0.86
53	Lalpur	0.81	7.4	520	220	290	220	70	-	6.26	59.8	44.11	42.53	265.96	109.12	32.31	60.54	0.39	0.59
54	Mahelki	0.71	7.3	460	350	320	320		30	3.91	27.6	42.11	51.03	423.95	8.06	10.65	19.22	1.89	2.84
55	Jatwada	0.62	7.6	400	280	260	260		20	3.13	29.9	54.14	29.16	334.89	22.32	17.75	19.22	0.44	0.66
56	Ghatayan	0.83	7.4	540	310	340	310	30	-	6.26	44.16	62.56	42.65	374.54	89.28	31.95	14.42	0.48	0.72
57	Purshotampur	0.72	7.3	470	280	310	310	30	-	6.26	27.6	66.37	32.81	331.23	68.82	13.85	31.71	0.5	0.75
58	Manfoda	0.51	7.8	330	210	210	210	-	-	4.3	25.3	34.09	30.38	251.93	16.12	24.14	28.83	0.74	1.11
59	Barouda	0.92	7.5	590	240	360	240	120	-	7.82	52.9	68.77	44.96	281.82	60.14	42.6	133.58	0.8	1.2
60	Kurthal	0.39	8	250	170	130	130	-	40	3.91	34.73	23.06	17.01	197.64	16.74	14.56	14.42	0.77	1.16
61	Jaula	1.3	7.3	840	390	490	390	100	-	5.47	81.42	83.21	66.83	475.8	9.3	161.53	28.83	1.1	1.65
62	Madinpur	0.67	7.8	430	260	300	260	40	-	5.47	14.26	46.12	44.96	317.2	8.68	37.63	26.43	0.71	1.07
63	Nagwa	0.49	7.5	320	190	230	190	40	-	4.69	9.2	36.09	33.41	224.48	63.86	12.07	14.42	0.63	0.95
64	Garhi	0.46	7.2	300	190	210	190	20	-	6.26	11.5	31.08	30.38	231.8	6.2	17.75	21.62	0.84	1.26
65	Toda	0.43	7.8	280	160	210	160	50	-	1.96	9.2	34.09	30.38	189.1	8.06	29.11	24.99	0.72	1.08
66	Raipur Aterna	0.33	7.2	220	120	150	120	30	-	2.74	4.83	18.05	25.52	138.47	9.92	12.78	20.18	1.08	1.62
67	Chhajpur	0.48	7.3	310	180	200	180	20	-	2.74	19.55	29.07	30.38	219.6	9.3	21.66	22.1	0.93	1.4
68	Gangeroo	0.51	7.8	330	190	240	190	50	-	5.08	9.2	33.08	37.67	227.53	12.4	26.63	33.64	0.99	1.49
69	Bhabhissa	0.63	7.5	410	260	260	260	-	-	6.26	29.9	28.07	44.96	306.83	14.88	17.75	43.25	1.39	0.75
70	Durganpur	0.74	7.3	480	300	350	300	50	-	7.04	11.5	44.11	57.71	359.9	6.2	31.95	38.44	0.78	1.17
71	Allem	0.8	7.4	520	340	370	340	30	-	6.26	26.45	81.2	38.88	414.8	8.06	31.95	31.23	0.71	1.07
72	Etawah	0.48	7.8	310	190	210	190	20	-	5.87	14.95	52.13	18.23	224.48	6.82	26.63	14.42	0.47	-
73	Shahdabber	0.37	8	240	130	170	130	40	-	5.47	13.8	42.11	13.97	157.99	24.8	28.4	19.22	0.95	-
74	Atali	0.49	7.5	320	190	230	190	40	-	4.69	8.28	56.14	20.66	231.8	5.58	23.08	24.03	0.98	1.47
75	Sarai	0.48	7.3	310	190	210	190	20	-	6.26	13.8	50.13	19.44	220.21	16.12	15.98	24.03	1.11	1.67
76	Kakra	0.52	7.5	340	220	240	220	20	-	6.26	13.8	57.94	22.48	258.03	14.26	17.75	19.22	0.99	1.49
77	Goela	0.23	7.2	150	90	120	90	30	-	2.74	4.6	27.07	11.3	102.48	10.54	12.78	14.42	1.61	-
	Mean	0.64	7.54	415.19	240.26	260.00	231.56	40.36	43.75	5.48	32.83	46.28	34.04	287.06	39.48	29.36	27.73	0.68	0.99
	SD	0.23	0.22	145.44	69.74	75.66	69.04	29.25	27.29	2.59	28.52	16.99	11.89	85.83	48.27	25.30	17.21	0.36	0.42
	CV	35.39	2.93	35.03	29.03	29.10	29.81	72.46	62.39	47.28	86.87	36.72	34.93	29.90	122.27	86.19	62.05	52.68	42.29

SD = Standard deviation; CV = Cofficient variation

Table 2: Computed value of RSC, SAR, Na%, MR, PI and KI of ground water in the Muzaffarnagar district, Uttar Pradesh

S. No.	RSC ($meqL^{-1}$)	SAR	Na%	MR	PI	KI
1	-1.06	0.34	9.32	62.60	44.66	0.078
2	-0.70	0.51	14.28	57.12	50.16	0.123
3	-0.12	0.51	12.76	58.41	49.58	0.113
4	-0.44	0.27	9.79	57.73	60.81	0.084
5	-0.41	0.46	11.31	62.97	49.69	0.106
6	0.02	0.61	14.56	50.36	54.02	0.143
7	-0.22	3.90	51.51	49.40	75.94	1.029
8	-0.25	0.88	16.83	62.29	49.19	0.181
9	-1.81	0.43	10.28	60.86	42.65	0.103
10	-0.19	1.05	19.81	61.69	52.37	0.224
11	-0.31	0.48	13.36	51.09	56.15	0.126
12	-1.96	1.17	19.51	66.25	44.53	0.222
13	-0.13	1.00	19.24	68.51	51.18	0.207
14	-1.58	0.49	13.15	59.24	44.64	0.117
15	-0.52	0.45	12.80	60.18	52.28	0.114
16	1.71	4.13	52.35	35.96	80.72	1.045
17	-1.00	0.38	10.05	61.75	48.74	0.096
18	-0.26	0.44	10.39	61.14	50.96	0.105
19	-0.53	0.39	11.30	58.51	50.84	0.096
20	-0.97	0.48	10.83	67.31	44.29	0.101
21	-1.16	0.48	11.36	64.84	40.93	0.093
22	-1.07	0.56	14.92	63.90	49.21	0.137
23	-1.90	0.72	15.57	62.69	43.04	0.152
24	-0.31	1.01	21.99	55.38	57.32	0.246
25	-2.45	0.78	12.33	54.02	35.76	0.125
26	-0.72	0.81	17.37	57.39	53.38	0.196
27	1.81	4.33	61.63	28.62	99.34	1.540
28	-0.73	0.91	19.39	69.67	51.93	0.207
29	-0.76	0.42	9.64	60.91	41.52	0.082
30	-0.19	0.82	15.52	47.46	46.55	0.158
31	-1.24	1.40	26.19	59.51	54.37	0.323
32	1.20	2.90	44.13	51.20	77.12	0.754
33	-0.62	1.82	27.96	60.58	55.74	0.376
34	0.41	1.11	22.23	56.16	58.74	0.256
35	-0.71	1.01	18.00	64.35	47.15	0.197
36	1.33	3.03	43.40	60.15	74.54	0.736
37	1.23	3.31	40.27	48.31	65.32	0.649
38	0.06	2.69	37.23	60.95	63.17	0.567
39	-1.75	2.38	34.00	59.63	55.94	0.488
40	0.30	0.99	18.64	62.30	52.19	0.205
41	-0.23	0.89	17.41	46.81	51.42	0.192
42	0.27	2.06	30.92	50.92	59.12	0.422
43	0.44	1.54	26.22	42.45	58.12	0.328
44	-0.43	1.07	22.19	41.41	57.02	0.259
45	-1.75	4.98	47.60	39.96	63.46	0.881
46	1.57	2.80	49.40	35.66	93.29	0.936
47	-1.00	2.32	32.80	42.86	52.70	0.412
48	0.05	1.25	22.20	40.52	53.93	0.261
49	0.10	1.04	18.74	37.83	50.44	0.207
50	-0.33	1.24	22.02	38.66	52.80	0.260
51	0.76	3.36	40.52	49.48	64.56	0.657
52	0.47	2.24	32.43	64.34	60.29	0.455
53	-1.39	2.17	32.44	61.64	56.15	0.452
54	0.59	0.95	16.98	66.88	50.76	0.189
55	0.35	1.15	21.18	47.30	56.60	0.253
56	-0.54	1.49	23.74	53.19	51.13	0.287
57	-0.62	0.98	18.35	45.17	48.68	0.198
58	-0.11	1.07	22.22	59.76	58.70	0.260
59	-2.57	1.72	25.82	52.14	46.91	0.320
60	0.67	1.88	38.52	55.14	81.12	0.587
61	-1.93	2.27	27.44	57.24	47.72	0.364
62	-0.85	0.50	11.16	61.90	43.47	0.102
63	-0.91	0.37	10.18	60.67	46.47	0.087
64	-0.29	0.49	13.92	61.96	53.41	0.122
65	-1.14	0.39	9.61	59.76	46.60	0.094
66	-0.76	0.24	8.47	70.21	53.00	0.069

67	-0.39	0.85	18.76	63.53	56.82	0.213
68	-1.06	0.37	9.96	65.49	44.89	0.083
69	-0.12	1.15	22.09	72.75	54.93	0.252
70	-1.11	0.38	8.84	68.56	38.98	0.071
71	-0.50	0.85	15.22	44.38	44.47	0.158
72	-0.45	0.64	16.25	36.82	53.78	0.158
73	-0.68	0.66	18.46	35.61	57.09	0.184
74	-0.73	0.34	9.59	38.02	47.24	0.079
75	-0.52	0.59	15.56	39.26	52.89	0.145
76	-0.54	0.55	13.75	39.27	49.47	0.126
77	-0.62	0.26	10.53	41.03	59.96	0.087

Table 3: Correlation coefficient of analysed chemical parameters of groundwater in the Muzaffarnagar district, Uttar Pradesh

	EC	**pH**	**TDS**	**TA**	**TH**	**CH**	**NCH**	**EA**	**K^+**	**Na^+**	**Ca^{2+}**	**Mg^{2+}**	**HCO_3^-**	**NO_3^-**	**Cl^-**	**SO_4^{2-}**	**F^-**	**B^-**
EC	1	0.46*	1*	0.834*	0.854*	0.823*	0.26*	0.089*	0.521*	0.777*	0.796*	0.623*	0.834*	0.541*	0.719*	0.312*	-0.21	0.005
pH		1	0.456*	0.419*	-0.423*	-0.431*	-0.099	0.013	0.259*	-0.291*	-0.36	0.338*	0.419*	-0.172	-0.268*	-0.168	-0.035	-0.13
TDS			1	0.834*	0.854*	0.823*	0.26*	0.089	0.521*	0.777*	0.796*	0.623*	0.834*	0.541*	0.719*	0.312*	-0.21	0.005
TA				1	0.819*	0.951*	-0.1	0.198	0.413*	0.522*	0.734*	0.623*	1*	0.175	0.432*	0.112	0.237*	0.071
TH					1	0.913*	0.423*	-0.257*	0.45*	0.345*	0.795*	0.849*	0.819*	0.321*	0.564*	0.355*	-0.162	-0.008
CH						1	0.026	-0.108	0.425*	0.383*	0.779*	0.73*	0.951*	0.189	0.452*	0.159	-0.222	0.042
NCH							1	-0.391*	0.166	-0.015	0.249*	0.435*	-0.1	0.368*	0.361*	0.506*	0.1	-0.125
EA								1	-0.01	0.491*	-0.093	-0.316	0.198	0.015	-0.055	-0.128	-0.059	0.088
K^+									1	0.351*	0.504*	0.255*	0.413*	0.168	0.536*	0.187	-0.223	-0.071
Na^+										1	0.476*	0.117	0.522*	0.621*	0.602*	0.151	-0.173	0.001
Ca^{2+}											1	0.354*	0.734*	0.296*	0.593*	0.25*	-0.15	-0.006
Mg^{2+}												1	0.623*	0.237*	0.353*	0.33*	-0.119	-0.008
HCO_3^-													1	0.175	0.432*	0.112	0.237*	0.071
NO_3^-														1	0.22	0.051	-0.127	-0.179
Cl^-															1	0.224	-0.02	0.033
SO_4^{2-}																1	-0.081	-0.009
F^-																	1	0.504*
B^-																		1

* Significant

4. Conclusion

From this study, it is concluded that the groundwater are good and appropriate for irrigation purpose. However, because of increasing pressure of population, intensive agriculture and increasing industrial units within the area might cause to the declination of water quality in future. Therefore, some management measures with the participation of public and government authorities ought to be taken to keep the water quality for sustainable use.

5. Acknowledgement

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6. References

1. APHA. Standard methods for examination of water and waste water. Washington, DC: American Public Health Association, 16th Edition, New York, 1995.
2. CGWB. Report on aquifer mapping and groundwater management plan, Muzaffarnagar district, Uttar Pradesh, 2017.
3. Chow VT. Hand book of applied hydrology. New York: McGraw Hill.1964, 1453.
4. Davis SN, Dewiest RJM. Hydrology. New York: Wiley, 1966, 463.
5. Doneen LD. Notes on water quality in agriculture. Water science and Engineering paper 4001.California, 1964.
6. Eaton FM. Significance of carbonate in irrigation water. Soil Science. 1950; 69(2):123-133.
7. Frengsted B, Banks D. Evolution of high pH Na-HCO_3 ground waters in anorthosites: Silicate weathering or cation exchange; In: Silslo *et al*. (Eds.): Groundwater: Past achievements and future challenges; Proc. XXXIInd Congress of the International Association of Hydrogeologists, Cape Town, South Africa. Balkema, Rotherdam. 2000, 493-498.
8. Hem JD. Study and interpretation of the chemical characteristics of natural water, 2254, Scientific Publishers, Jodhpur, India. 1991, 263.
9. ISI. Indian standard methods of sampling and tests (physical and chemical) for water used in industry. India: Indian Standard Institute. 1963, 22.
10. Kelly WP. Permissible composition and concentration of irrigation waters. Procedings of the ASCF. 1940, 66.
11. Kumar M, Kumari K, Ramanathan AL, Saxena R. A comparative evaluation of groundwater suitability for irrigation and drinking purposes in two intensively cultivated districts of Punjab, India. Environmental Geology. 2007; 53:553-674.
12. Naik PK, Awasthi AK, Anand AVSS, Behra PN. Hydro geochemistry of the Koyna river basin. India. Environmental Earth Science. 2009; 59:613-629.
13. Nickson RT, McArthur JM, Shrestha B, Kyaw-Nyint TO, Lowrt D. Arsenic and other drinking water quality issues. Muzaffargarh district, Pakistan. Applied Geochemistry. 2005; 20:55-68.
14. Paliwal KV. Irrigation with Saline Water. IARI, Monograph no. 2 (new series), New Delhi, 1972.
15. Pramod Kumar, Ashok Kumar, Sumit Raizada, Shiv Kumar, Savita Arya. Evaluation of groundwater quality for drinking and irrigation purpose of the left side of the

Ganga Canal, Muzaffarnagar to Ghaziabad, Uttar Pradesh, India. Journal of Pharmacogynosy and Phytochemistry. 2018; 21(3):3177-3176.

16. Raju KCB. Importance of recharging depleted aquifers: state of the art of artificial recharge in India. Journal of the Geological Society of India. 1998; 5:429-454.
17. Raju NJ. Hydro geochemical parameters for assessment of groundwater quality in the upper Gunjanaeru river basin. Cuddapah district, Andhra Pradesh, South India. Environmental Geology. 2007; 52:1067-1074.
18. Richard LA. Diagnosis and improvement of saline and alkali soils. Agriculture hand book 60, Washington, DC. USDA. 1954, 160,
19. Saleh A, Al-Ruwaih F, shahta M. Hydro geochemical processes operating within the main aquifers of Kuwait. Journal of Arid Environment. 1999; 42:195-209.
20. Singh AK, Kumar SR. Quality assessment of groundwater for drinking and irrigation use in semi-urban area of Tripura, India. Eco. Envio. & Conservation. 2015; 21(1):97-108.
21. Subba Rao N. Geochemistry of groundwater in parts od Guntur district, Andhra Pradesh, India. Environmental Geology. 2002; 41:552-562.
22. Subba Rao N, Surya Rao P, Venktram Reddy G, Nagamani M, Vidyasagar G, Satyanarayana NLVV. Chemical characteristics of groundwater and assessment of groundwater quality in Varaha river basin, Visakhapatnam district, Andhra Pradesh, India. Environ. Monit. Assess. 2012; 184:5189-5214.
23. Sundaray SK, Nayak BB, Bhatta D. Environmental studies on river water quality with reference to suitability for agricultural purposes: Mahanadi river estuarine system, India- a case study. Environmental Monitor. Assess., 2009, 155:227-243.
24. Todd DK. Groundwater Hydrology. Wiley, New York. U.S. Salinity Laboratory Staff 1954. Diagnosis and improvement of Saline and Alkaine Soils; USDA Hand book no. 60. ronmental Geology. 1980; 46:999-1008.
25. Umar R, Khan MMA, Absar A. Groundwater hydrochemistry of a sugarcane cultivation belt in parts of Muzaffarnagar district, Uttar Pradesh, India, 2006.
26. Wilcox LV. Classification and use of irrigation waters. U.S. Dept. Agric. Circular 969, Washington, USDA, DC. 1955, 19.