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ASSESSMENT OF GROUNDWATER QUALITY FOR DRINKING AND IRRIGATION USES: A CASE STUDY OF DILAWARPUR, TELANGANA, INDIA

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ABSTRACT

The evaluation of groundwater quality and suitability for drinking and irrigation is presented in this study. A thirty eight groundwater samples were collected and analyzed for the major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, F^-). The potential water abstraction for irrigation was assessed using the sodium absorption ratio (SAR), sodium percentage (Na%), Kelly ratio (KR), Residual sodium carbonate (RSC) and Permeability index (PI). According to the findings, the majority of the samples had higher EC, TDS, and TH levels. According to the USSL (United States Salinity Laboratory) diagram, most of the samples fall under the S1-C2, S1-C3 and S1-C4 low to high salt categories. This study suggests that the groundwater in the study area is unfit for drinking purposes. However, most of the groundwater is suitable for irrigation. The Water Quality Index of the study area suggests that majority of the groundwater samples are excellent to good quality in pre and post-monsoon seasons.

Keywords: Groundwater quality, Drinking and Irrigation and Water quality Index

1. Introduction

Groundwater is an essential natural resource essential for the life of plants, animals, and people and can be found in almost every geological formation under the surface of the Earth (Miller et al. 2021; Perrigo et al. 2020). In terms of meeting their drinking water demands, almost one-third of the world's population today relies on groundwater supplies (Jain and Vaid 2018). Water contamination occurs in many parts of the world as a result of groundwater pollution brought on by natural environmental changes and human activities such as agricultural and industrial practices (Adimalla and Qian 2021; Di Baldassarre et al. 2018). India has the second-largest population in the world and that it is challenging to provide for such a vast population's drinking water needs, the situation there is much more serious. As a result, drinking contaminated water causes a lot of deaths in India each year (Biswas and Mandal 2010; Daniels et al. 2018).

Agriculture is the most populous economic sector of India and plays an important role in the ultimate socioeconomic development of the nation (Bassi et al. 2014). The contribution of agriculture to India's gross domestic product (GDP) has been falling steadily in recent years with rates of 5.0, 1.7, 3.8, and 1.1 in 1996–2000, 2001–2005, 2006–2010, and 2011–2015, respectively (Chaudhary and Satheeshkumar 2018). India has become the world's seventh-largest agricultural exporter due to advances in irrigation, infrastructure, seed quality, innovative agricultural automation, chemical fertilizers, and pesticides. The quality of groundwater and soil health has been affected by the widespread use of chemical fertilizers and pesticides (Baweja et al. 2020; Pahalvi et al. 2021). The rapid decline in the quality of groundwater is also caused by the disposal of solid waste products; therefore, monitoring of ground water quality is required for accurate assessment of associated health hazards (Adimalla and Qian 2021; Warhate et al. 2006). Apart from drinking, the groundwater supply is widely used for irrigation and other domestic needs in the study area. This means that the residents of Dilawarpur are largely dependent on groundwater (Lata 2019). Water contamination in the study area is mostly caused by the flow of agricultural fertilizers, sewage, and hospital waste. Water borne diseases and related health issues include cholera, typhoid, fluorosis, and jaundice.

Freshwater is available in the study area of the Nirmal district of Telangana State (TS) and is used for residential and irrigation activities. Approximately, 90% of drinking and agricultural water comes from the ground, and agricultural and domestic use of natural groundwater renders this resource susceptible to a variety of pollutants. Furthermore, only 1% of the available fresh water is suitable for drinking thus making groundwater resources even more important for survival (Kadam et al. 2020; Karthika and Dheenadayalan 2015). The geological formation of the catchment, as well as the chemistry of rock-forming materials and anthropogenic activities, generally affects groundwater ions (Yang et al. 2016). One of the most pressing environmental challenges in developing nations in recent decades has been the pollution of freshwater bodies by significations (Goher et al. 2014; Iglesias 2020). Each groundwater system has its own chemical makeup, and any change is influenced by a variety of variables including rock–water stream interaction, mineral dissolution, soil–water interactions, interaction times, temperature, and anthropogenic activity. Groundwater geochemistry determines the suitability of groundwater for domestic and irrigation applications (Giri et al. 2021). Groundwater quality measures should be taken to avoid waterborne infections that dam age sensitive crops and affect soil health (Adjei-Mensah and Kusimi 2020; Chaudhary and Satheeshkumar 2018).

Analysis of contamination of groundwater is acknowledged as one of the top issues of water contamination (Adams et al. 2001; Laxman et al. 2021). Groundwater is the only source of water available for human use, drinking, and agricultural purposes. One-third of the world's population is estimated to be drinking groundwater (Adimalla and Qian 2019). The terrain containing groundwater and associated drainage systems have been altered by urban development and unrestrained population growth, which has a direct impact on the quality and quantity of groundwater. The chemical composition of rainwater naturally changes when it interacts with the atmosphere. It is affected by water contact with rocks before reaching the surface and is converted by both direct and indirect anthropogenic pollutants before reaching the surface. In the long run, environmental changes are affected by establishing a balance between geogenic (Jalali 2009), anthropogenic (Gemitzi 2012; Laxman et al. 2021), and climate change (Singh et al. 2020).

Groundwater quality measures have been used in several studies conducted around the world to evaluate the accept ability of groundwater for irrigation, drinking, and domestic use (Madhav et al. 2018; Adimalla and Venkatayogi, 2017). Srivastava and Parimal (2020) examined the hydrochemistry of groundwater and evaluated the viability of water for irrigation using a variety of weathering indices. Anbazhagan and Nair (2004) employed geographic information system Environmental Science and Pollution Research (GIS) to depict the spatial variation of several geochemical components in the watershed Dilwarpur area of Nirmal district, Telangana State, India.However, no attempt has been made so far to determine whether the groundwater is suitable for drinking and irrigation in the light of the present study area. Therefore, the main objective of the present study is to evaluate the water quality indicators for irrigation and drinking purpose of Dilwarpur area. Consequently, a hydro-geochemical study was conducted to assess the chemistry of groundwater and its appropriateness for irrigation and drinking.

2. The Study Area

The study area covering about 97 sq.km falls in the Dilawarpur regon, Nirmal district of Telangana State. It is located 15 km from Nirmal and lies in between North Latitudes 19° 04' 09" to 19° 07' 23" and East Longitudes 78° 13' 11" to 78° 15' 33" (Fig. 1) and falls in the Survey of India Toposheet No.s 56 I/4, 56 I/8 and 56 J/5 (1:50, 000 scale). The study area receives average annual rainfall of 989 mm during the year 2011 to 2021 by southwest, northeast, winter and summer monsoons. The climate of the study area is generally hot. Average temperature in summer is 42^0C and in winter it is 10^0C.

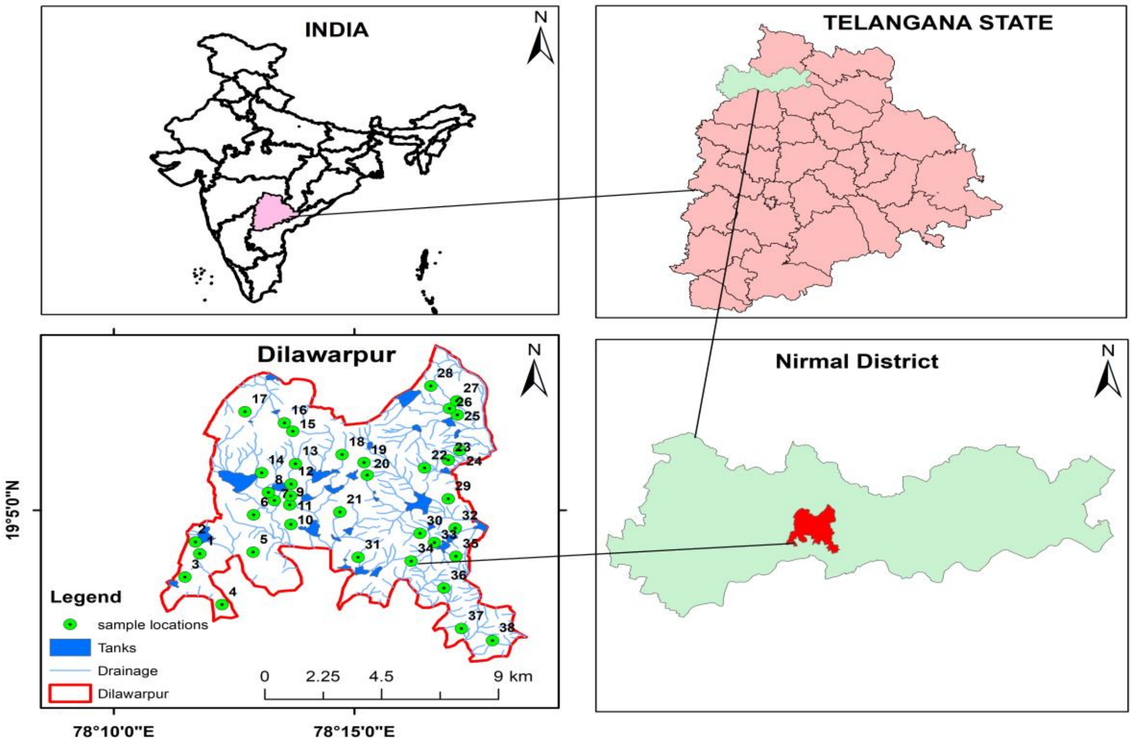

Fig. 1 Study area with groundwater sample location

3. Geology and hydrology of the study area

The geology consists of granites and gneisses of Archaean, Schistose rocks are of Dharwar Supergroup of Archaean-Proterozoic, granitoids, younger acidic and basaltic intrusives of Lower Proterozoic, Deccan Traps of Upper Cretaceous- Lower Eocene, laterite of Pleistocene and Recent alluvium. The drainage pattern is dendric to sub-dendric (CGWB, 2014).

Geology of the area is relatively homogenous comprising of Precambrian granite mostly pink and grey granites. Basic enclaves, aplite, pegmatite, epidote and quartz veins and dolerite dykes frequently traverse the area. The granite covers a major part of Dilawarpur area with porphyritic feldspars. Granites are intruded by quartz and dolerite dykes of several generations and are well exposed in northern and western part of the study area. These dykes form important structural feature controlling the movement of groundwater in the region.

4. Materials and Methods

In order to assess the groundwater quality, thirty eight groundwater samples were collected in pre-cleaned polyethylene containers for pre (May-2020) and post-monsoon (November-2020) seasons. They were analyzed for pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Carbonate (CO_3^{2-}), Bicarbonate (HCO_3^{-}), Chloride (Cl^{-}), Sulphate (SO_4^{2-}), Nitrate (NO_3^{-}) and Fluoride (F^{-}) using standard methods (APHA, 2012) (Table 1).

Ionic-balance error (IBE; Eq. 1) between the total concentrations of cations (TCC; Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and total concentrations of anions (TCA; CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}) expressed in milliequivalent per liter (meq/l) is within the acceptable limit (±10%).

$$\text{Ionic-Balance Error } (IBE) = \left[\frac{(TCC - TCA)}{(TCC + TCA)}\right] x100$$

Table 1 Standard procedure of major ions of groundwater in the study area

Parameter	Method, instrument (make)	Reagents	References
pH	pH/EC meter (Hanna	pH 4, 7 and 9.2 (buffer tablets)	(APHA 2012)
EC (µS/cm)	pH/EC meter (Hanna	Potassium chloride (KCl)	(APHA 2012)
TDS (mg/l)	ECx0.64	Calculation	(APHA 2012)
Na^{+}(mg/l)	Flame photometer (Elico) (Systronics, 128)	Sodium chloride (NaCl), KCl and Calcium carbonate ($CaCO_3$)	(APHA 2012)
K^{+}(mg/l)	Flame photometer (Elico) (Systronics, 128)	Sodium chloride (NaCl), KCl and Calcium carbonate ($CaCO_3$)	(APHA 2012)
TH as $CaCO_3$ (mg/l)	Titrimetric	Hydrochloric Acid (HCl) and Standard EDTA solution	(APHA 2012)
Ca^{2+} (mg/l)	Titrimetric with EDTA	EDTA, Sodium hydroxide (NaOH) and Murexide	(APHA 2012)
Mg^{2+}(mg/l)	TH-Ca^{2+}	Calculation	(APHA 2012)
HCO_3^{-}(mg/l)	Titrimetric	Hydrosulfuric acid (H_2SO_4), Methyl orange	(APHA 2012)
CO_3^{-}(mg/l)	Titrimetric	Hydrosulfuric acid (H_2SO_4), Phenolphtalein pink	(APHA 2012)
Cl^{-}(mg/l)	Titrimetric	Silver nitrate, Potassium chromate	(APHA 2012)

SO_4^{2-}(mg/l)	UV-Visible spectrophotometer (Spectronic 21, BAUSCH and LOMB)	Glycerol, HCl, ethyl alcohol, NaCl, $BaCl_2$, sodium sulphate	(APHA 2012)
NO_3^- (mg/l)	UV-Visible spectrophotometer (Spectronic 21, BAUSCH and LOMB)	Brucine-sulpanilic acid, KNO_3 and H_2SO_4	(APHA 2012)
F^- (mg/l)	Ion Selective Electrode, (Orion analyzer)	TISSB- III, F stock solution	(APHA 2012)

Table 2 Statistics of physical and chemical parameters of groundwater samples in pre and post-monsoon seasons

Variables	**Pre-monsoon season**					**Post-monsoon season**				**BIS (2012) Acceptable limit**
	Minimum	**Maximum**	**Mean**	**% of samples exceeded the limits**		**Minimum**	**Maximum**	**Mean**	**% of samples exceeded the limits**	
pH	7.09	8.28	7.89	-		7.49	8.32	8.03	-	**6.5 - 8.5**
EC (µS/cm)	431	3157	1320	-		376	2362	1044	-	**-**
TDS (mg/l)	276	2020	831	92		241	1512	668	61	**500**
Na^+ (mg/l)	58	536	142	-		25	278	134	-	**-**
K^+ (mg/l)	1	17	8	-		1	11	4	-	**-**
TH as CaCO3 (mg/l)	120	1000	394	90		140	820	358	84	**200**
Ca^{2+} (mg/l)	16	208	52	8		40	160	82	50	**75**
Mg^{2+} (mg/l)	15	146	64	82		5	141	38	50	**30**
CO_3^- (mg/l)	0	0	0	-		0	30	2	-	**-**
HCO_3^- (mg/l)	90	360	220	-		50	430	255	-	**-**
Cl^- (mg/l)	40	470	193	32		20	340	255	13	**250**
SO_4^{2-} (mg/l)	84	959	165	13		20	372	134	18	**200**
NO_3^- (mg/l)	4	137	50	42		3	209	61	47	**45**
F^- (mg/l)	0.23	3.28	0.92	45		0.08	1.84	1.08	63	**1**
SAR (meq/l)	1.48	7.38	3.13	-		0.67	5.63	3.04	-	**-**
Na% (meq/l)	30	61	46	-		18	63	46	-	**-**
KR (meq/l)	0.43	1.55	0.84	-		0.21	1.72	0.84	-	**-**
RSC (meq/l)	-14.90	-0.39	-4.26	-		-10.27	1.09	-3.0	-	**-**
PI (meq/l)	43	78	56	-		45	85	62	-	

NOTE: Min-Minimum, Max-Maximum, Mean, SAR-Sodium Adsorption Ratio, KR-Kelley's Ratio, RSC-Residual Sodium Carbonate and PI-Permeability Index

Table 3 Classification of groundwater for drinking, irrigation suitability and % of samples falling in various categories

Based on TDS (mg/l)	Ranges	Pre-monsoon (%)	Post-monsoon (%)
Fresh water	0 – 1,000	81	95
Brackish water	1,000 – 10,000	19	5
Saline water	10,000 – 1,,00000	00	00
Brine	>1,00,000	00	00
Based on Hardness (mg/l)	Ranges	Pre-monsoon (%)	Post-monsoon (%)
Soft	0 -75	Nil	Nil
Moderate to Hard	75 – 150	3	3
Hard	150 – 300	47	52
Very Hard	>300	50	45

5. Results and Discussion

5.1 General groundwater characteristics

The groundwater analyzed results of the study region are compared with recommended standard drinking water specifications (BIS 2012). The pH value of the groundwater ranges from 7.09 to 8.28 with a mean of 7.89 and 7.49 to 8.32 with a mean of 8.03 in pre and post-monsoon seasons (Table 2), which is indicating basic/alkaline conditions. The allowable limit of pH is 6.5 to 8.5 (BIS 2012) for drinking water in the study region is within the limits. The range and mean of EC in the groundwater of the study area are 431 to 3157 µS/cm and 376 to 2362 µS/cm, 1320 µS/cm and 1044 µS/cm respectively in pre and post-monsoon seasons.

5.1a Total dissolved solids and Total hardness

To ascertain the suitability of groundwater for any purposes, it is essential to classify the groundwater depending upon their hydrochemical properties based on their TDS values (Todd, 2001). The TDS of groundwater in the study area varies between 276 to 2020 mg/l with an average of 831 mg/l and 241 to 1512 mg/l with an average of 668 mg/L, during pre and post-monsoon seasons (Table 2). The highest desirable limit of TDS is up to 500 mg/l (WHO, 2011). Total dissolved solids of the study area which classified in to fresh water is 81% and 95%, brackish water 19% and 5% in pre and post-monsoon seasons respectively (Table 3).

The Total hardness of groundwater samples varying between 120 to 1000 mg/l with an average of 394 mg/l and 140 to 820 mg/l with an average of 358 mg/l, during pre and post-monsoon seasons (Table 2). The desirable limit of Total hardness as $CaCO_3$ is up to 500 mg/l (WHO, 2011). The Sawyer et al., 2003 classification of the total hardness about 3%, 47% and 50% of the groundwater samples are fall in the moderate to hard, hard and very hard water category in pre-monsoon season. In post-monsoon season, the groundwater samples are fall in moderate to hard 3%, hard 52% and very hard 45% (Table 3), which indicates the hardness of the water is due to the presence of alkaline earth such as calcium and magnesium.

5.1b Cations

The calcium values vary from 16 to 208 mg/l with a mean of 52 mg/l and 40 to 160 mg/l with a mean of 50 mg/l (Table 2). About 8% and 50% water samples are a non-acceptable limit of Ca^{+2} is 75 mg/l (BIS 2012). This is the dominance of plagioclase feldspars occurring in the host rock (Laxman et al. 2019). The magnesium values vary from 15 to 146 mg/l with a mean of 64 mg/l and 5 to 141 mg/l with a mean of 38 mg/l in pre and post-monsoon seasons (Table 2). About 64% and 50% of groundwater samples are a non-acceptable limit of Mg^{+2} is 30 mg/l prescribed for drinking water (BIS 2012). The study region is due to the dissolution and ion exchange of plagioclase feldspars minerals are in the origin of granitic terrain. The sodium values are ranges between 58 to 536 mg/l with a mean of 142 mg/l and 25 to 278 mg/l with a mean of 134 mg/l (Table 2). The potassium values are ranges between 1 to 17 mg/l with a mean of 8 mg/l and 1 to 11 mg/l with a mean of 4 mg/l (Table 2) respectively

5.1c Anions

The bicarbonate values vary from 90 to 360 mg/l with a mean of 220 mg/l and 50 to 430 mg/l with a mean of 255 mg/l in pre and post-monsoon seasons (Table 2). The chloride values vary from 40 to 470 mg/l with a mean of 193 mg/l and 20 to 340 mg/l with a mean of 255 mg/l in pre and post-monsoon seasons (Table 2). The non-acceptable level of Cl^- is 250 mg/l (BIS 2012) Indian standard specification which is specified for drinking water, about 32% and 13% of groundwater samples respectively. The predominance of chloride levels in groundwater in the study region including mineral weathering of granitic rock of apatite and other causes of municipal sewages, industrial effluents which contributes to the leachable in groundwater (Laxman et al. 2021). Sulphate concentrations range from 84 to 959 mg/l with a mean of 165 mg/l and 20 to 372 mg/l with a mean of 134 mg/l, respectively. During both monsoon seasons, one sample (17) is exceeding the acceptable limit of sulphate level is 200 mg/L (BIS 2012). The groundwater trend was cumulative last few past decades in nitrate pollutants, because of the fast development of urban growth expansion, industrial development, in addition, uses of nitrate on fertilizers and horticulture purposes. The NO_3^- values vary from 4 to 137 mg/l with a mean of 50 mg/l and 3 to 209 mg/l with a mean of 61 mg/l in pre and post-monsoon seasons. The high concentrations of nitrates are due to leaching of organic substances from the weathered soil (Sudarshan and Sravanthi, 1996). Fluoride in the study area varies in the range of from 0.23 to 3.28 mg/l, with a mean of 0.92 mg/l and 0.08 to 1.84 mg/l with a mean of 1.08 mg/l in pre and post-monsoon seasons. The maximum tolerance limit fluoride in groundwater is 1.0 mg/l. Ingestion of high fluoride water with more than tolerance limit results in Fluorosis (Madhnure et al., 2007). The high fluoride distribution is identified in western and southeastern parts of the region; the alkaline nature of water increases the anionic exchange in controlling the fluoride content in the aquifer regime (Saxena and Ahmed 2003). The study region dominance for anions in groundwater is $SO4>HCO_3>Cl>NO_3>F$ and for cations it is Na>Mg>Ca>K in the study area respectively.

5.2 Drinking Water Quality Index (WQI)

The evaluations of general suitability of groundwater for drinking purposes for each sample were achieved by estimating their respective water quality index (WQI). According to Sahu and Sikdar, 2008; WQI reflects the composite influence of different water quality parameters on picture of the quality of groundwater for most domestic uses. The estimation of WQI requires the utilization of appropriate influential parameters (IPs) dictated by the purpose to which the water is required.

In the case of groundwater, certain cations and anions as well as heavy metals may impose health implications on human health. The selected IPs for this study include pH, TDS, Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^- and F^- used in this study. The highest weight of five (5) was assigned to pH, TDS, NO_3^- and F^- due to their health significance to human health. The WQI for each sampled groundwater was estimated using the below equations, and results compared to the criteria defined by Sahu and Sikdar, 2008.

$$W_i = \frac{w_i}{\sum_{n=1}^{n} w_i}$$

where, W_i is the relative weight; w_i is the assigned weight to an influential parameter relative to its impact on the overall quality for drinking purpose in terms of health implications to humans. The water quality rating (q_i), according to Sahu and Sikdar, 2008 is given by:

$$q_i + \frac{C_i}{S_i} x100$$

where, q_i is referred to as the water quality rating; C_i and S_i represent the measured concentration in sampled groundwater and the respective standard (WHO 2011) of the ith influential parameter. The water quality sub-index for each of the influential parameter (SI_i) is estimated as

$$SI_i = q_i x W_i$$

where, the symbols have their usual meanings.

$$WQI = \sum_{i=1}^{n} SI_i$$

In determining the overall water quality of groundwater in the study area, the results for w_i, W_i, SI_i and WQI using the selected IPs for each of the forty two selected point sources are shown in **Table 4** and **Table 5** respectively.

Table 4 Assigned weights, relative weights and respective (WHO 2011) standards of IPs.

Parameter	pH	TDS	Na^+	K^+	Ca^{+2}	Mg^{+2}	HCO_3^-	Cl^-	SO_4^{-2}	NO_3^-	F^-
S_i	8.5	500	200	12	75	50	500	250	200	45	1.5
w_i	4	5	2	2	2	1	3	3	4	5	5
W_i	0.111	0.139	0.056	0.056	0.056	0.028	0.083	0.083	0.111	0.139	0.139

Table 5 Estimated WQI and respective classification of drinking water

No. of Sample	Latitude	Longitude	Pre-monsoon		Post-monsoon	
			WQI	Class	WQI	Class
1	19.3525	78.11557	**109**	**Poor water**	95	Good water
2	19.463	78.12137	**109**	**Poor water**	94	Good water
3	19.4089	78.12164	**108**	**Poor water**	91	Excellent water
4	19.403	78.1295	**110**	**Poor water**	**111**	**Poor water**
5	19.428	78.14243	60	Good water	27	Excellent water
6	19.5382	78.14369	77	Good water	45	Excellent water
7	19.585	78.13573	65	Good water	65	Good water
8	19.5272	78.15297	76	Good water	52	Good water
9	19.5309	78.14311	76	Good water	45	Excellent water
10	19.4294	78.14268	61	Good water	89	Good water
11	19.5365	78.14213	70	Good water	49	Excellent water
12	19.535	78.14119	72	Good water	60	Good water
13	19.5142	78.13689	78	Good water	64	Good water
14	19.518	78.14112	74	Good water	63	Good water
15	19.3106	78.14845	46	Excellent water	34	Excellent water
16	19.389	78.1552	48	Excellent water	49	Excellent water
17	19.3584	78.12128	**178**	**Poor water**	**108**	**Poor water**
18	19.594	78.1497	61	Good water	44	Excellent water
19	19.5267	78.15276	59	Good water	47	Excellent water
20	19.587	78.1472	60	Good water	42	Excellent water
21	19.5124	78.13403	73	Good water	78	Good water
22	19.3142	78.1507	39	Excellent water	38	Excellent water
23	19.1172	78.26943	61	Good water	74	Good water
24	19.1189	78.27455	25	Excellent water	78	Good water
25	19.1193	78.27476	56	Good water	56	Good water
26	19.1198	78.27439	59	Good water	57	Good water
27	19.1165	78.27099	59	Good water	74	Good water
28	19.1189	78.27363	54	Good water	59	Good water
29	19.3572	78.15174	56	Good water	**105**	**Poor water**
30	19.5303	78.15376	83	Good water	50	Excellent water
31	19.0175	78.18313	55	Good water	69	Good water
32	19.0282	78.18394	54	Good water	71	Good water
33	19.0244	78.18417	58	Good water	70	Good water
34	19.0185	78.18314	59	Good water	72	Good water
35	19.0264	78.18435	58	Good water	69	Good water
36	19.0232	78.18392	60	Good water	76	Good water

37	19.0382	78.18813	57	Good water	76	Good water
38	19.0364	78.1832	52	Good water	70	Good water

The estimated WQIs for the area ranged from 25 to 178 with a mean value of 69 and 27 to 111 with mean of 66 for pre and post-monsoon seasons (**Table 5**). According to WQI drinking water is considered excellent if WQI is less or equal to 50; it is considered 'Good water' if WQI is greater than 50 but less than 100; 100-200 are considered 'poor water'; 200-300 'very poor' and above 300 are unsuitable for drinking by human (Sahu and Sikdar, 2008). It is evident that in the pre-monsoon season four groundwater samples are excellent with WQI values ranging from (25-48); twenty nine samples are good water quality with WQI values ranging between (52-83); five samples showed poor water quality with WQI ranging from (108 to 178) (Table 5.10). In the post-monsoon period eleven groundwater samples are excellent with WQI values ranging from (27-50); twenty-four groundwater samples are 'good quality' with WQI range from (52-95) and three groundwater samples are showed poor water quality range from (105 to 111) in the study area respectively The current study reveals that about 13% and 8% of the groundwater samples in the Dilawarpur region has 'poor water quality' that is not suitable for drinking purpose and the rest of 87% and 92% of the samples are in the area has 'excellent to good water quality' in pre and post-monsoon seasons respectively. This study is helpful in proper planning and management of available water for drinking purpose in the study area (**Table 5**).

5.3 Sodium absorption ratio (SAR)

SAR reflects the presence of a sodium hazard and is a measure of the amount of sodium (Na) in a saturated soil paste with respect to calcium (Ca) and magnesium (Mg). It is the square root of one-half of the Ca + Mg concentration, divided by the Na concentration which is expressed in the following equation (Eq.):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

When the SAR is more than 3, the water is sodic, which might raise the soil's exchangeable sodium percentage (ESP). The sodium absorption ratio is a critical metric for assessing irrigation water appropriateness (Richards 1954a, b).

The estimated SAR value varied from 1.48 to 7.38 meq/l, with a mean value of 3.13 meq/l and 0.67 to 5.63 meq/l, with a mean of 3.04 meq/l in the pre and post-monsoon seasons. The data is shown in the salinity diagram for the United States (**Fig. 2**). In S1C2, S1C3 and S1C4 in pre-monsoon season and post-monsoon season are S1C1, S1C2, S1C3 and S2C3 class of the EC evaluated the salt hazard and SAR as hazardous alkalinity, suggesting that groundwater is widely suitable for agriculture.

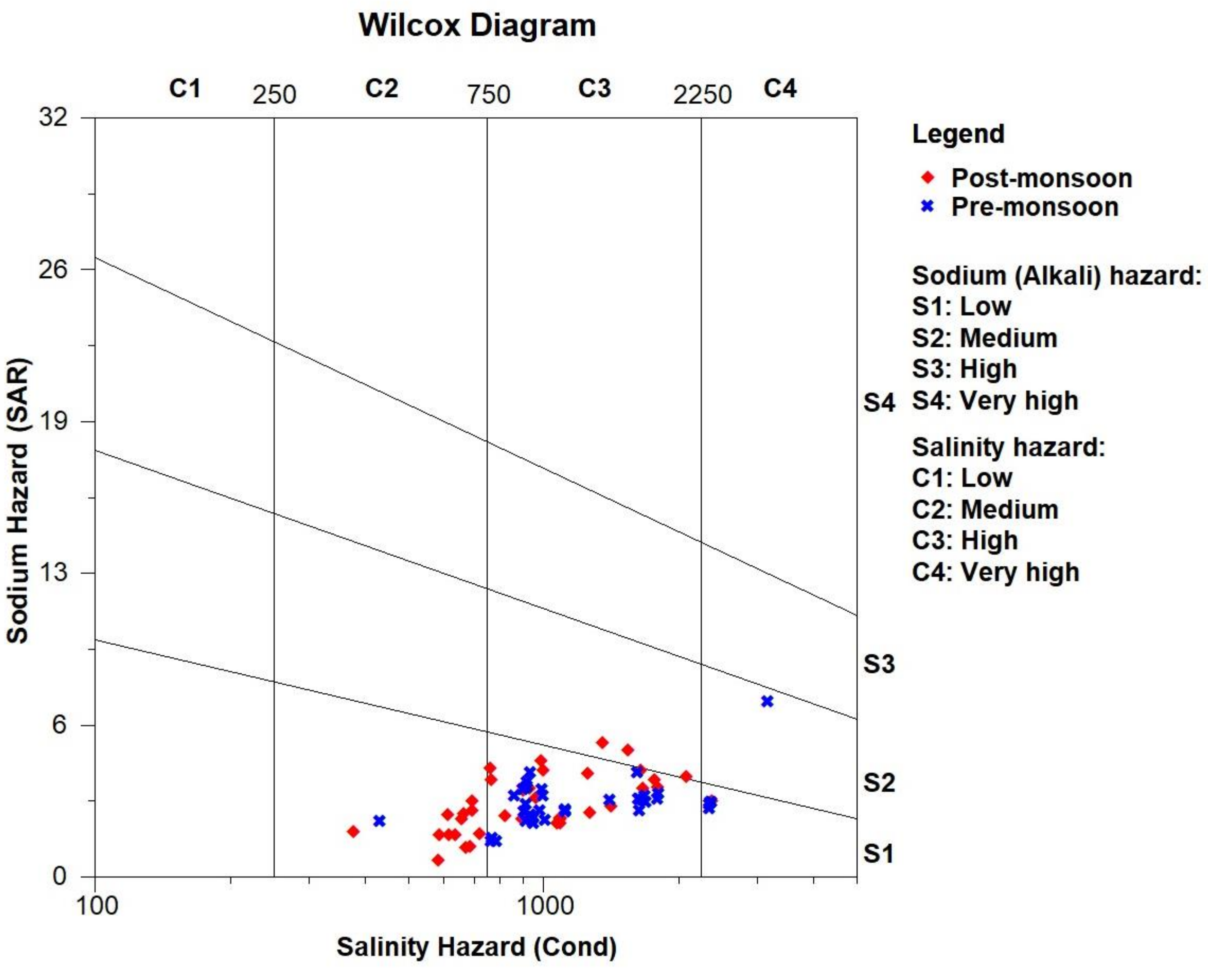

Fig.2 USSL classification of groundwater in pre and post-monsoon seasons

5.4 Sodium percentage (Na%)

Irrigation water containing large amounts of sodium is of special concern due to sodium's effects on soil and poses a sodium hazard. Excess sodium in water produces the undesirable effects of changing soil properties and reducing soil permeability (Li et al. 2018; Subba Rao, 2006). Hence, the assessment of sodium percentage is necessary while considering the suitability for irrigation, which is calculated using the formula and expressed in meq/L.

$$\%Na = \frac{(Na^{+} + K^{+})}{Ca^{+2} + Mg^{+2} + Na^{+} + K^{+}} x100$$

The sodium percentage values vary from 27 to 58 meq/l with a mean of 46 meq/l in the pre-monsoon season and 31 to 60 meq/l with a mean of 46 mg/l in the post-monsoon season (**Table 1**). Based on this classification, about 5%, 68% and 11% of the groundwater samples are excellent, good to permissible and permissible to doubtful category in pre-monsoon seasons and post-monsoon seasons; 27% excellent, 68% good to permissible and permissible to doubtful 5% of the study area respectively for irrigation purposes (**Fig. 3**).

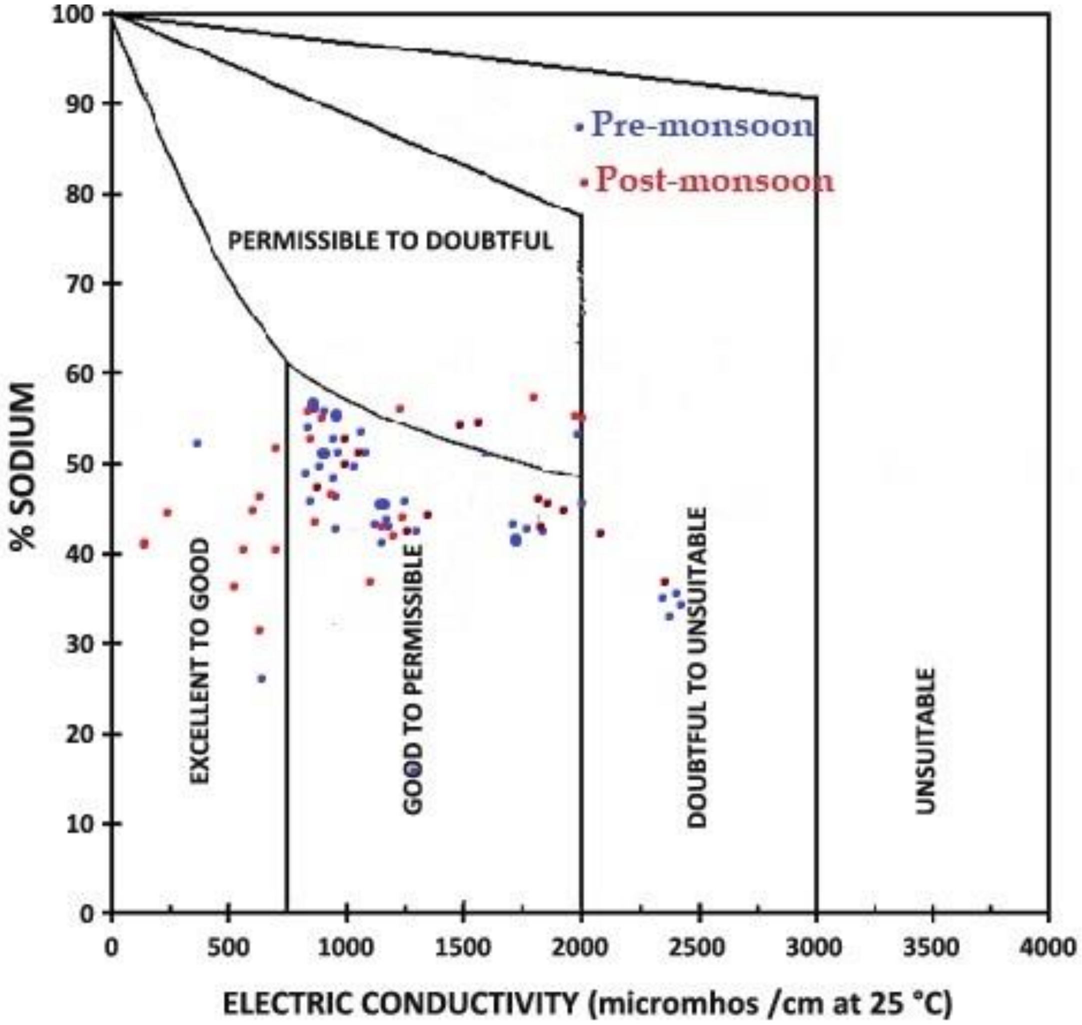

Fig. 3 Rating of Groundwater samples on the basis of Electrical Conductivity and Percent of Sodium ratio

5.4 Kelley's Ratio

The level of Na^+ measured against Ca^{+2} and Mg^{+2} is known as Kelly's ratio, based on which irrigation water can be rated (Kelly, 1946). The concentration of Na^+ in irrigation water is considered to be one of the prime roles in making the water unsuitable. The Kelly's ratio is <1 suitable, marginal is 1-2 and unsuitable is >2. The Kelly's ratio is calculated using the formula given below and expressed in meq/L.

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

The Kelly ratio values range from 0.43 to 1.55 meq/l with a mean of 0.84 meq/l and 0.21 to 1.72 meq/l with a mean of 0.84 meq/l in pre and post-monsoon seasons (**Table 1**), which indicates that 71% and 68% suitable for pre and post-monsoon seasons, moderate suitable is 29% and 32% pre- and post-monsoon seasons for irrigation purposes (**Table 2**).

5.5 Residual sodium carbonate (RSC)

The RSC index of irrigation water or soil water determines the alkalinity hazard to the soil. The RSC index is used to assess whether water is acceptable for irrigation or not in clay soils with high cation exchange capacity (Murtaza et al. 2021). The following equation expresses RSC (Eq. 3):

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

RSC should be less than 1.25 and preferably less than 0.5 for irrigation suitability. The RSC values range from -14.90 to -0.39 meq/l with a mean of -4.26 meq/l in pre-monsoon season and -10.27 to 1.09 meq/l with a mean of -3.0 meq/l in post-monsoon season respectively (**Table 1**). The study area which is classified on the basis of RSC values is presented in (**Table 2**) all of the groundwater samples are fall in the safe category for irrigation in pre and post-monsoon seasons.

5.6 Permeability index (PI)

The PI is a qualitative assessment of expected rates of upward water flow from the ground level to the unconfined aquifer, which is the area between the land surface and the water table (Reddy 2013). The formula for calculating the PI is expressed in Eq. 2:

$$PI = \frac{(Na^{+} + K^{+})}{(Ca^{+2} + Mg^{+2} + Na^{+} + K^{+})} x100$$

The PI levels of irrigated water can be categorized as class I (>75%), class II (25–75%), or class III (25%) (Ramesh and Elango 2012). The PI values of the study area varied from 43 to 78 meq/l with a mean of 56 meq/l and 45 to 85 meq/l with a mean of 62 meq/l in pre and post-monsoon seasons (**Table 1**). According to the classification PI values about 48% and 52% groundwater samples fall in class I and II categories in pre-monsoon season. About 38%, 52% and 10% of groundwater samples fall in categories respectively I, II and III classes of a post-monsoon season (**Fig. 4**).

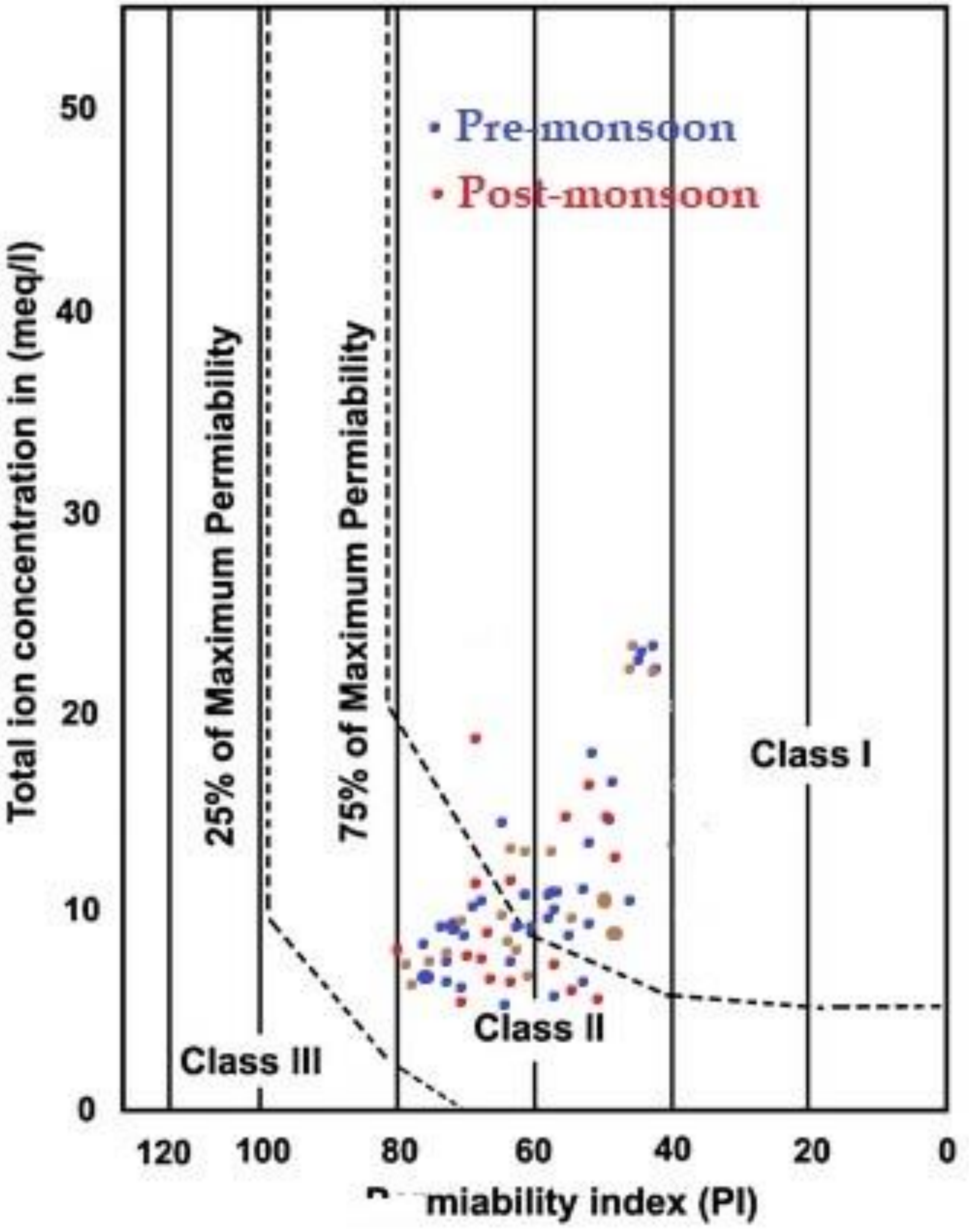

Fig. 4 Doneen classification of Irrigation water based on the Permeability Index in pre and post-monsoon seasons

Conclusions

The present study of assessment of groundwater geochemistry revealed that the groundwater of the Dilawarpur area is moderate to very hard, fresh to brackish and alkaline in nature. Total Hardness is high in the groundwater thereby, causing the groundwater in one-third of the study area to be unsuitable for drinking purposes. WQI suggests that the 10%, 85% and 5% groundwater samples for pre-monsoon and 43%, 52% and 5% of groundwater samples for post-monsoon were excellent, good and poor water quality index. Physico chemical parameters reveal that groundwater quality for irrigation and drinking, contradictory locations exist which are majorly caused by the anthropogenic activities such as sewage discharge and agricultural activities.

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