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Recent Monitoring of Ground Water Quality in and Around Industrial area of Vellore City at two Different Monsoon Periods, South India

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ABSTRACT

The present study focuses on the assessment of seasonal variation in groundwater quality of in and around industrial area of Vellore City. The samples were collected seasonally and are categorized as premonsoon, monsoon and post-monsoon during April 2022 and March 2023. Eighteen physicochemical parameters were assessed for forty eight different samples collected along the region of in and around industrial area of Vellore City at two different Monsoon periods. The analysis of the water quality parameters, including pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^-, CO_3^{2-}, SO_4^{2-}, and heavy metals, was done in accordance with BIS and WHO standards. The results of these surveys were used to pinpoint the geochemical processes taking place in this area. According to the analytical findings, there were significant variations in the water quality inclinations between samples and locations. Water management and treatment policy decisions can be made with the support of water quality analysis which can also help to identify potential health issues.

Keywords: Vellore city, Groundwater quality, Premonsoon and post monsoon, Industrial areas.

INTRODUCTION

Different processes, including organic matter degradation, rock-water interactions, aerobic respiration, iron reduction, mineral dissolution, weathering, industrial discharge effluents, and mixing of fresh and salt water, have been connected to variations in groundwater quality indicators. In many places of the world, water shortage has resulted from rising water demand over time. India is currently on the verge of a groundwater disaster, primarily as a result of poor management of water resources and environmental damage. On the quality of the groundwater and water contamination in Tamil Nadu, there is scant study[1-3]. The lakes provide the majority (80%) of Chennai's drinking water. Pumping stations used to draw drinking water from wells near river basins supply around 25% of the world's population. The purpose of the current study is to look into the hydro-chemical changes, repercussions, and appropriateness of groundwater from March 2022 to April 2023.

MATERIALS AND METHODS

48 samples of groundwater (bore well) were taken over the course of a year close to an industrial sector. All reagents and solutions were made using AR grade chemicals and double distilled water. At the sampling site itself, measurements of temperature, pH, electrical conductivity, and TDS concentrations were made. The usual methods have been used to measure total hardness, chloride, calcium, magnesium, alkalinity, sulphate, and bicarbonate[4-6]. Flame photometers have been used to measure sodium and potassium. WQI [7&8] and correlation analysis have also been used to assess the quality of groundwater for potable uses and the interplay of chemical trends. In order to comprehend the effects of hydro-geochemistry and human involvement on groundwater quality, graphical approaches including Piper-Trilinear, Durov, Principal Component Analysis, Factor analysis, Gibbs ratio, SAR, and Corrosive ratio have also been used.

RESULTS AND DISCUSSION

Seasonal variations

The results of the physico-chemical parameters of groundwater samples are presented in tables 1 through 3. The pH values between 6.7 and 8.5 fell within those recommended for residential use, which were 6.5 to 9.0 (USEPA, 1975), 5.5 to 9.0 (ICMR, 1975), and 7.0 to 9.0 (ICMR). Seasonal oscillations show that the pH value is highest during the monsoon and lowest during the pre-monsoon. The groundwater samples seldom have an alkaline pH. It was discovered that the EC values ranged from 502 to 1217 mhos/cm. It indicates the presence of pollutants when the EC of water abruptly rises. Dug wells are normally between 28 and 38 metres deep, although tube wells can reach depths of over 50 metres. There aren't many differences in the EC of samples from tube wells and dug wells. The salinity of Chennai's groundwater rises as you move south. However, there is some salinity distribution variability seen. The EC noted changes in the research area's groundwater quality, which according to field observations are caused by companies and dumping grounds. The rise in conductivity shows how many ions the salinity values can support [8 & 9].

Table 1: Physicochemical Parameters of Groundwater Samples of Vellore City (Pre Monsoon)

Sample Code	pH	TDS	CO_3^{2-}	HCO_3^{2-}	EC	Free CO_2	Cl^-	Nit.	SO_4^{2-}	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	COD
S1	6.96	986	166	46	774	26	152	16	108	234	68.4	28.8	385.0	10.9	98
S2	7.17	912	212	52	721	32	134	14	98	212	64.8	24.9	262.7	61.4	112
S3	6.92	1128	154	42	918	24	176	22	182	414	127.2	48.4	401.4	55.2	134
S4	7.74	986	250	112	774	38	164	16	112	232	76.8	24.9	84.2	55.4	98
S5	7.13	896	220	78	672	28	112	12	72	184	45.6	25.9	96	15.7	94
S6	7.18	1432	214	98	1118	30	194	28	218	580	142.8	82	186.5	82.9	128
S7	6.99	1521	234	62	1206	28	198	28	224	520	136.8	71.5	243.3	25.9	146
S8	7.86	987	282	132	896	46	167	24	112	284	85.2	34	108.5	1.9	188
S9	8.02	976	296	296	889	48	142	22	104	224	75.6	23.5	201.4	2.4	132
S10	7.98	898	292	292	684	46	124	18	78	192	52.8	24.9	186.5	45.4	116
S11	8.11	1413	254	368	1196	54	182	32	212	582	147.6	80.6	719.3	46.6	94
S12	7.76	1623	202	312	1217	44	214	34	238	640	163.2	88.3	734.9	10.9	192
S13	7.02	1112	212	102	918	28	170	26	114	408	117.6	50.8	543.0	61.4	154
S14	7.23	988	278	108	743	32	166	18	118	288	91.2	32.6	367.5	55.2	96
S15	8.02	994	292	296	774	52	172	20	128	310	117.6	27.3	677.7	55.4	142
S16	7.84	1256	264	268	923	42	198	24	152	432	130.8	51.3	581.3	15.7	188
C1	7.49	912	182	54	684	28	124	14	48	192	50.4	25.9	543.2	82.9	98
C2	7.98	983	281	102	714	36	142	16	72	234	58.8	32.6	308.5	25.9	134
C3	7.25	1112	176	48	897	22	178	22	114	342	86.4	47.5	802.4	43.7	146
C4	7.37	1167	204	44	916	32	182	24	124	356	91.2	48.9	686.4	25.1	228
C5	7.13	1217	146	40	987	18	188	32	148	412	100	58.5	719.3	91.1	98
C6	7.32	1002	222	76	814	28	164	28	98	296	64.8	45.1	512	79.0	112
C7	7.26	1008	218	74	817	26	166	28	98	312	74.4	45.1	496.2	2.9	142
C8	7.16	1078	222	64	854	24	170	30	114	372	82.8	56.1	412.2	4.2	198

Units: All the parameters are given in ppm, excluding EC- .mhos/cm, pH

Table 1: Continue.......

Sample Code	pH	TDS	CO_3^{2-}	HCO_3^{2-}	EC	Free CO_2	Cl^-	Nit.	SO_4^{2-}	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	COD
C9	7.98	1438	282	186	1102	52	186	36	178	486	118.8	69.1	560.0	65.9	168
C10	8.14	1457	226	386	1023	58	190	34	182	512	128.4	71.5	420.3	72.5	232
C11	8.12	994	244	354	798	58	152	18	86	256	61.2	36.9	617.7	36.1	146
C12	7.89	1530	198	298	1147	44	198	38	198	532	140.4	71	886.1	16.1	218
C13	7.21	997	178	168	788	36	152	22	86	254	58.8	37.4	622.7	114.8	196
C14	7.45	1312	250	162	996	42	178	28	146	458	117.6	62.8	813.7	152.4	178
C15	7.54	1325	304	208	1104	54	182	32	152	456	110	65.2	887.9	102.9	98
C16	8.23	1289	270	368	998	62	178	28	138	424	100	61.4	730.7	32.8	112
W1	6.84	792	148	48	593	14	134	12	48	214	52.8	30.2	70.9	1.9	88
W2	6.79	798	150	48	598	18	146	14	52	214	52.8	30.2	84.3	8.0	96
W3	6.98	886	150	62	688	26	152	24	68	252	58.8	36.9	82.0	8.4	112
W4	6.77	912	154	38	723	14	168	28	74	312	67.2	48	196.8	10.9	98
W5	7.12	884	226	92	662	32	148	24	58	246	55.2	36.9	178.3	5.5	124
W6	6.78	787	154	44	590	18	114	14	46	212	51.6	30.2	99.3	7.9	86
W7	7.42	1212	280	104	964	38	162	36	112	424	79.2	70	591.4	10.3	142
W8	7.02	1108	216	96	886	32	154	28	98	388	74.4	63.3	527.4	67.9	186
W9	7.67	986	306	142	677	42	172	32	84	324	68.4	50.4	457.0	106.3	178
W10	7.13	987	260	64	672	28	172	28	88	328	68.4	51.3	83.2	0.9	98
W11	7.24	1321	266	68	1102	30	180	40	124	496	88.8	83.52	783.5	44.2	204
W12	6.82	1486	242	56	1114	28	187	42	147	546	92.4	94.4	834	74.8	214
W13	7.81	1234	319	193	977	44	158	32	114	432	79.2	72	645.6	54.7	202
W14	7.98	799	368	218	512	46	118	16	54	244	64.8	26	613.2	54.2	98
W15	6.96	1218	194	98	993	24	164	32	126	428	81.6	70	628.4	44.6	114
W16	7.14	896	300	82	617	28	148	26	62	298	70.8	43	512.2	10.2	156

Units: All the parameters are given in ppm, excluding EC- .mhos/cm,pH

Table 2: Physicochemical Parameters of Groundwater Samples of Vellore City (Monsoon)

Sample Code	pH	TDS	CO_3^{2-}	HCO_3^{2-}	EC	Free CO_2	Cl^-	Nit.	SO_4^{2-}	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	COD
S1	7.05	946	154	44	724	32	126	8	92	228	67.2	27	392.0	8.8	86
S2	7.23	892	180	58	707	36	108	8	78	202	61.2	24	268.2	54.2	106
S3	6.98	1108	144	38	897	26	154	8	162	398	124	46	424.2	43.1	124
S4	7.88	963	224	112	747	44	144	10	96	218	74.8	22	88.2	51.1	92
S5	7.27	846	170	98	567	30	88	8	58	178	43	25	104.2	9.8	88
S6	7.28	1403	226	76	1108	34	166	12	188	564	140	79	196.2	81.2	116
S7	7.09	1497	205	67	1082	36	168	16	192	512	134	69	256.2	25.1	138
S8	7.94	962	272	126	798	48	148	12	84	272	81.2	33	112.4	1.2	178
S9	8.23	951	354	218	792	54	124	16	88	214	72.4	23	211.1	1.8	126
S10	8.03	857	360	208	518	54	102	12	52	184	50.2	24	198.2	35.4	108
S11	8.44	1392	316	292	1106	64	146	18	190	574	142	81	749.1	41.1	88
S12	7.98	1584	306	196	1118	62	164	22	192	590	158.4	78	814.2	10.2	184
S13	7.13	1089	220	86	884	42	152	14	102	394	115.4	48	543.3	58.4	144
S14	7.48	953	260	102	693	34	138	8	106	286	89	33	398.2	51.2	94
S15	8.22	964	362	212	713	58	154	10	108	302	117.2	25	712.9	54.4	140
S16	7.91	1227	330	184	887	48	164	10	138	416	124.6	50	598.4	1.6	176
C1	7.62	892	180	48	627	34	106	8	24	184	49.2	24.4	554.2	78.9	94
C2	8.12	967	249	123	677	38	108	8	52	228	54.6	33	318.2	22.9	126
C3	7.37	1096	170	38	846	28	146	8	98	336	84.2	47	832.3	42.7	132
C4	7.52	1136	180	52	884	44	164	12	102	334	89.6	44	706.2	21.1	212
C5	7.23	1198	134	36	936	20	154	20	118	402	96.2	58	749.7	90.1	86
C6	7.39	978	172	102	774	30	148	18	72	284	63.2	43	556	77.0	104
C7	7.42	984	188	96	784	28	148	16	68	298	71.2	43	532.1	2.1	136
C8	7.33	1062	210	62	802	32	154	16	96	384	80.2	60	442.4	3.8	196

Units: All the parameters are given in ppm, excluding EC- .mhos/cm, pH

Table 2: Continue.......

Sample Code	pH	TDS	CO_3^{2-}	HCO_3^{2-}	EC	Free CO_2	Cl^-	Nit.	SO_4^{2-}	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	COD
C9	8.04	1412	308	138	1012	68	162	22	156	474	104	72	584.2	59.2	164
C10	8.31	1413	310	286	1013	72	174	26	168	498	124.2	70	418.2	61.2	216
C11	8.22	973	310	264	782	74	124	14	62	242	58.4	34.8	636.6	27.1	138
C12	7.99	1456	266	212	1019	48	172	18	172	498	132	66	916.2	9.1	218
C13	7.46	972	216	108	763	44	128	12	68	236	57.2	33	637.1	98.8	192
C14	7.61	1278	280	118	934	48	142	16	122	452	114.8	62	816.6	110.4	164
C15	7.68	1313	354	142	1084	68	164	18	138	446	107.2	64	888.8	89.9	96
C16	8.54	1278	332	282	984	84	162	18	116	420	97.4	62	732.3	23.4	108
W1	6.92	787	143	39	524	24	112	6	32	210	48.2	31	81.9	0.8	86
W2	6.83	774	147	39	536	24	118	8	34	212	47	32	86.4	6.4	88
W3	7.13	867	160	44	664	28	134	8	42	244	56	36	88.1	7.5	102
W4	6.82	897	142	36	685	26	126	12	58	308	65.4	48	206.1	6.8	92
W5	7.34	861	230	72	615	38	124	8	44	232	54.2	34	179.8	4.2	116
W6	6.93	737	149	43	515	20	94	10	28	208	47.3	31	102.3	6.8	82
W7	7.63	1197	266	108	914	40	138	18	94	412	72.4	70	598.6	7.8	138
W8	7.23	1087	232	66	835	38	124	20	72	356	76.8	59	536.4	61.2	178
W9	7.82	963	194	232	623	48	148	16	68	308	64.2	48	487.1	92.5	166
W10	7.18	974	206	102	617	34	134	20	78	312	64	49	85.1	0.5	86
W11	7.39	1302	196	118	965	32	152	26	112	474	82	81	788.6	32.8	196
W12	6.98	1412	208	64	988	34	158	30	128	512	88.6	88	892.1	67.4	202
W13	7.88	1202	254	244	925	52	122	22	102	408	74.6	68	652.1	49.2	194
W14	8.24	773	268	264	502	58	96	6	36	214	61.6	27	663	46.2	86
W15	7.14	1198	204	64	976	34	132	18	108	412	78.2	68	631.7	34.5	106
W16	7.19	877	266	98	584	36	118	12	48	292	67.4	43	518.1	7.9	148

Units: All the parameters are given in ppm, excluding EC- .mhos/cm,pH

Table 3: Physicochemical Parameters of Groundwater Samples in Vellore City (Post- Monsoon)

Sample Code	pH	TDS	CO_3^{2-}	HCO_3^{2-}	EC	Free CO_2	Cl^-	Nit.	SO_4^{2-}	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	COD
S1	7.02	952	138	62	731	26	128	12	96	202	63	23	412.2	8.1	82
S2	7.19	898	172	72	709	32	114	12	82	185	58	21	269.4	53.1	102
S3	6.95	1112	144	42	902	24	162	18	166	366	112	43.2	448.3	43	118
S4	7.79	974	236	112	752	40	146	14	102	198	72	18.7	102.2	49.6	84
S5	7.21	861	192	84	581	28	96	10	66	154	38	21	121.1	9.2	76
S6	7.24	1413	210	94	1109	32	172	16	192	532	136	73	216.3	76.3	102
S7	7.07	1503	196	82	1114	28	172	20	202	493	126	67.9	259.4	19.2	124
S8	7.89	974	270	134	823	46	152	18	96	248	78	40.8	132.2	0.8	164
S9	8.14	959	344	238	836	50	128	18	92	388	68	65.7	242.1	0.8	114
S10	8.03	869	354	218	577	48	104	14	64	158	48	18.7	199.1	23.4	94
S11	8.18	1402	326	288	1147	62	152	20	198	556	136	79	782.8	38.2	82
S12	7.83	1598	314	192	1136	48	174	26	208	562	156	72	827.1	9.8	176
S13	7.04	1094	210	98	892	30	152	18	106	362	112	42	583.1	52.1	132
S14	7.35	967	248	126	705	32	144	14	108	262	87	28	401.4	49.8	84
S15	8.08	979	292	284	728	52	158	16	112	286	112	24	723.9	51.4	132
S16	7.85	1234	260	262	906	44	166	16	142	398	116	49	601.2	0.8	164
C1	7.54	896	140	88	639	28	106	12	32	152	48	17.2	565.2	75.2	88
C2	8.03	978	240	138	692	36	112	10	56	202	53.4	27	323.4	21.2	116
C3	7.32	1102	131	83	854	24	148	12	98	308	78	42.7	838.3	39.8	128
C4	7.49	1142	151	85	898	32	168	16	112	312	88	40	718.4	18.7	202
C5	7.19	1203	136	38	952	18	168	24	122	378	94	53	755.1	87.2	78
C6	7.38	989	180	102	789	28	152	20	74	268	61	40	578.5	75.2	94
C7	7.32	992	156	132	791	26	152	18	68	272	67.2	38.4	538.5	1.8	128
C8	7.27	1066	160	118	817	26	154	20	102	362	78.4	55.6	448.1	2.9	182

\Units: All the parameters are given in ppm, excluding EC- .mhos/cm,pH

Table 3: Continue.......

Sample Code	pH	TDS	CO_3^{2-}	HCO_3^{2-}	EC	Free CO_2	Cl^-	Nit.	SO_4^{2-}	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	COD
C9	8.03	1421	290	162	1057	54	164	28	163	448	92	70.8	532.3	57.1	144
C10	8.23	1429	304	298	1015	62	174	30	170	452	112	63.8	421.1	59.3	208
C11	8.17	979	354	228	789	62	128	16	62	228	52	34	648.1	26.2	132
C12	7.96	1478	376	108	1097	44	176	28	174	462	126	60	918.9	8.7	208
C13	7.32	983	202	124	779	36	132	18	72	212	54.6	29	754.1	98.2	182
C14	7.52	1287	270	132	952	42	156	20	126	434	112	59	878.8	110	158
C15	7.61	1314	356	148	1097	58	164	22	140	424	102.4	60	945.2	88	88
C16	8.44	1281	322	294	986	68	164	20	122	396	94.5	56.4	743.2	22.1	98
W1	6.88	790	142	46	554	22	116	10	36	206	47	30.4	91.1	0.7	82
W2	6.81	782	136	56	552	22	122	12	36	208	46	31.6	91.2	6.2	78
W3	7.04	874	148	58	678	24	138	16	46	232	52	34.8	89.3	7.1	98
W4	6.81	908	133	47	696	22	132	24	62	298	64.3	45.8	223.2	6.1	88
W5	7.29	869	204	102	634	32	128	12	44	218	51.2	31	184.2	3.8	102
W6	6.86	758	140	54	544	18	102	10	32	196	44.4	29.2	112.2	6.2	76
W7	7.54	1204	232	`146	932	38	142	20	98	398	66.2	69	606.2	7.1	124
W8	7.05	1094	198	104	848	36	126	22	82	324	62.4	53	537.1	58.2	162
W9	7.71	972	232	198	646	46	154	22	74	292	63.6	44	488.1	91.4	152
W10	7.15	981	200	112	637	30	142	22	80	294	62.8	45	86.3	0.4	84
W11	7.29	1308	193	123	988	30	156	30	114	446	78	75.8	796.2	32.1	184
W12	6.93	1432	182	98	992	30	164	36	132	492	86	83	894.2	66.8	188
W13	7.83	1218	266	232	944	46	132	24	104	384	72	63	658.1	49	187
W14	8.11	779	280	264	508	48	98	10	40	202	57	25.4	677.1	45.8	78
W15	7.04	1204	142	130	979	26	134	26	112	392	74	44	635.1	33	98
W16	7.15	886	225	143	591	30	126	20	52	278	63.2	41.5	542.1	7.7	132

Units: All the parameters are given in ppm, excluding EC- .mhos/cm,pH

Correlation Analysis

By calculating the correlation coefficient, one may anticipate how an ion will explain the properties of other ions10. Between water quality metrics, the correlation coefficient (r) has been calculated 15 tables 1 to 3. It shows a strong association between the various metrics of water quality. Ions are strongly connected when the Correlation coefficient[11] value is either +1 or -1. The ions are not correlated if the correlation coefficient is 0, and are said to be well correlated if the ratio is larger than 0.7 and moderately correlated if the ratio is 0.7 to 0.5. With the exception of bicarbonates and carbonate, total dissolved solids are shown to have good season-to-season correlation with cations and anions. Pre-monsoon has the highest pre-monsoon correlation coefficient for cationic concentration vs. total dissolved solids and the lowest monsoon correlation value. Total hardness was correlated with calcium, magnesium, chloride, Sulphates, carbonate, and bicarbonate, with correlation coefficients of 0.87, 0.95, 0.86, 0.88, 0.06, and 0.34, respectively, indicating that permanent hardness predominated in the study area throughout all seasons. Only nitrate and chloride have a moderate correlation with chemical oxygen demand (COD). Between overall hardness and electrical conductivity, a very strong positive association (0.95) was found.[10-12].

Piper and Durov analysis

It is commonly known that interpretive diagrams can be used to better understand the nature and origin of various water quality. In this instance, the relationship between various points in the systems and potential drivers can be expressed using the Durov[12] and Piper diagram. The quality of the groundwater in the research area is depicted by the Durov diagram in Fig. 1. The fact that the water in later boreholes has a higher Na-K-HCO_3 character than calcium, magnesium, or Sulphates dominations could mean that sodium and chloride are neutralising the acidity in the subsurface throughout pre-, monsoon, and post-monsoon. By graphing the percentages of chemical elements in a Piper diagram, groundwater is further assessed to identify the facies[13–14]. The seasonal plot shows a sporadic distribution with slight differences in their chemical properties Fig. 2. Although the number of samples varied, the groundwater was of the kinds Na-CO_3, NaCl, Ca-MgCO_3 and Ca-MgCl, as shown by the groundwater samples S4, C5 and W10. However, there were considerable differences in the percentage of samples that belonged to different types of water. There are only a few samples (S4, C5, and W10) that fall into both Ca-CO_3 and Na-Cl sub-blocks in the figure. Plots provide evidence that the groundwater was mixed type and that several processes contributed to its evolution[15–18]. Plots also showed that Na is the most abundant cation in groundwater, followed by Ca and Mg, and Cl is the most abundant anion. The main sources of ions are Na_2CO_3 and Na_2SO_4, which are extensively employed in the paper industry and in the production of small-scale dyes at various stages of the process. The study area's groundwater types were identified and categorized according on where they fell on a Piper diagram. The Na-CO_3 dominated facies was clearly visible in the majority of the sample.

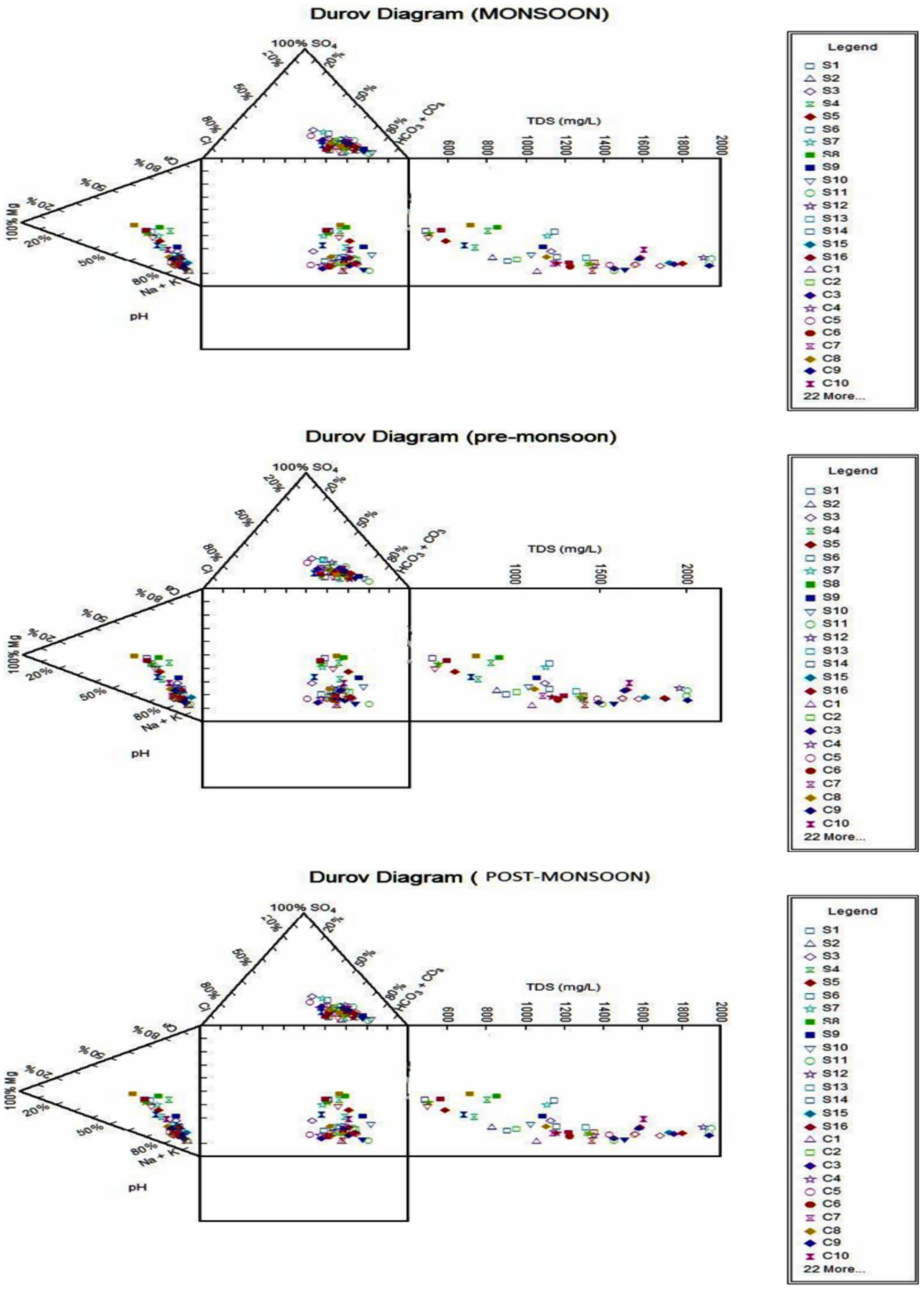

Fig. 1. Durov Diagram of WQPs of Vellore city, South India

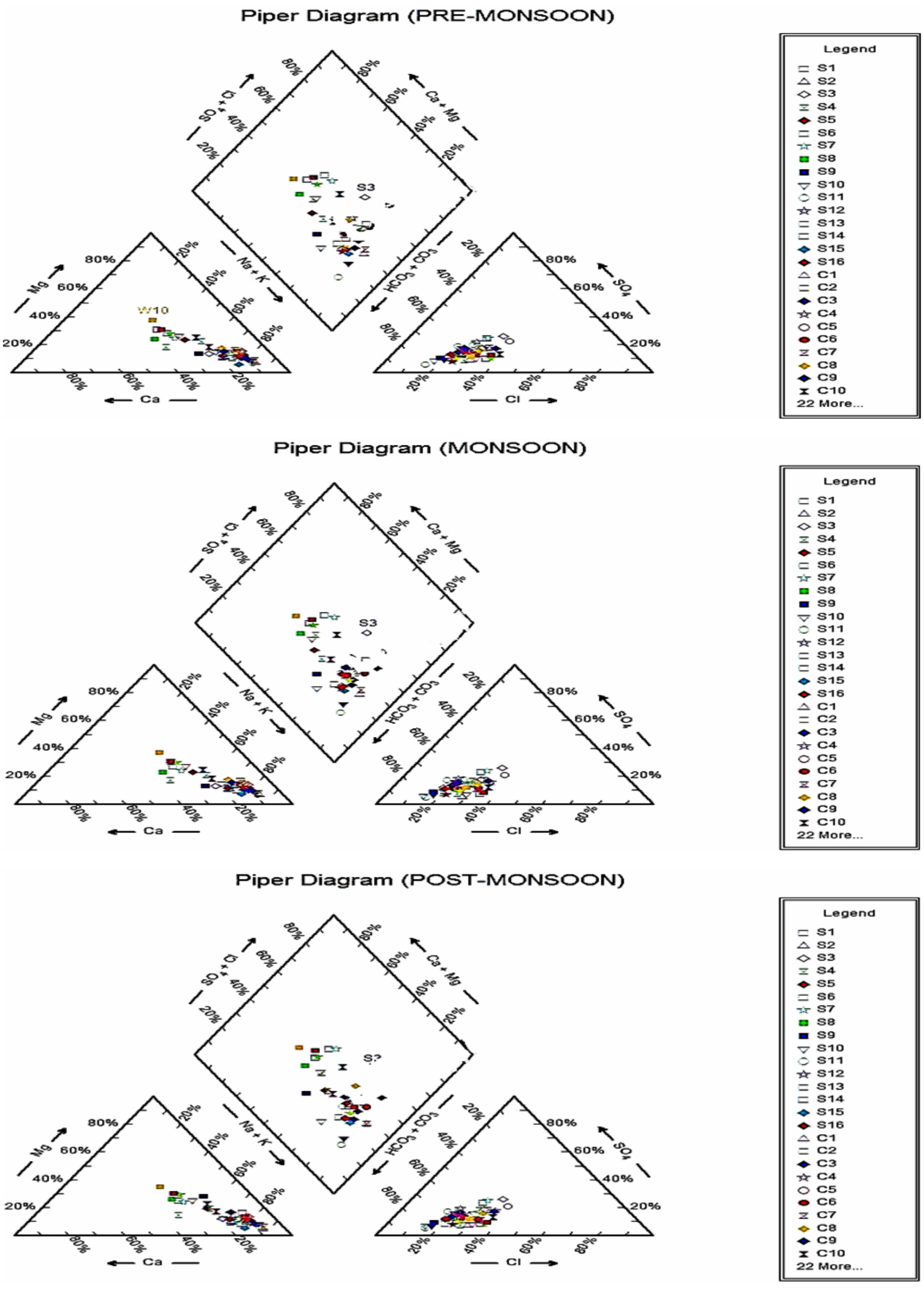

Fig. 2. Piper-Trilinear Diagram of WQPs of Vellore City, South India

Geochemical process

It is crucial to recognize and comprehend the hydro-geochemical processes in order to assess the reasons for changes in groundwater quality and plan for groundwater protection. Gibbs plot[14] Fig. 4.3 was used to pinpoint the mechanisms governing the chemistry of the groundwater. The majority of the data points, with the exception of a few in the evaporation zone, are plotted in the rock dominance zone, indicating that the interaction of aquifer material and water is the primary process regulating the chemistry of groundwater.

The Na/Cl ratio plot and the Na/Cl ratio against EC plot Fig. 4. 4 a and b demonstrate that evaporation is not a significant process. Assuming that no mineral species precipitate, concentration by evaporation would leave the ratio of Na/Cl constant.

Another Na/Cl versus EC diagram would result in a horizontal line[15]. Groundwater has a wide range of Na/Cl ratios Fig. 4a. The connection between the Na/Cl ratio and EC Fig. 4b is slightly sloped, which suggests that evaporation is not the major process. Na levels in groundwater are slightly higher, which suggests that silicate weathering is more likely to be the main cause than evaporation.[19-25].

Table 4: Correlation Coefficient matrix for ground waters of Vellore city, South India (Pre-monsoon)

Variables	pH	TDS	CO_3^{2-}	HCO_3^{2-}	EC	Free CO_2	Cl^-	NO_3^{2-}	SO_4^{2-}	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	
pH	1														
TDS	0.255	1													
CO_3^{2-}	0.644	0.099	1												
HCO_3^{2-}	0.858	0.379	0.454	1											
EC	0.227	0.959	0.062	0.341	1										
Free CO_2	0.906	0.372	0.668	0.895	0.348	1									
Cl^-	0.147	0.841	0.004	0.252	0.812	0.226	1								
NO_3^{2-}	0.100	0.774	0.181	0.190	0.752	0.220	0.740	1							
SO_4^{2-}	0.257	0.916	0.039	0.387	0.905	0.353	0.845	0.593	1						
TH	0.145	0.951	0.084	0.308	0.909	0.271	0.858	0.825	0.883	1					
Ca^{2+}	0.289	0.853	0.080	0.436	0.825	0.370	0.846	0.550	0.945	0.871	1				
Mg^{2+}	0.025	0.895	0.058	0.180	0.852	0.165	0.764	0.891	0.736	0.952	0.680	1			
Na^+	0.302	0.589	0.220	0.367	0.571	0.375	0.482	0.578	0.424	0.580	0.464	0.565	1		
K^+	0.108	0.270	0.127	0.083	0.244	0.227	0.187	0.195	0.218	0.240	0.205	0.226	0.468	1	
COD	0.230	0.532	0.170	0.231	0.476	0.285	0.505	0.569	0.377	0.496	0.386	0.504	0.453	0.142	1

Table 5: Correlation Coefficient matrix for ground waters of Vellore city, (monsoon)

Variables	pH	TDS	CO_3^{2-}	HCO_3^{2-}	EC	Free CO_2	Cl^-	NO_3^{2-}	SO_4^{2-}	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	COD
pH	1														
TDS	0.246	1													
CO_3^{2-}	0.635	0.079	1												
HCO_3^{2-}	0.852	0.367	0.456	1											
EC	0.218	0.958	0.038	0.328	1										
Free CO_2	0.905	0.364	0.666	0.891	0.339	1									
Cl^-	0.151	0.845	0.004	0.237	0.818	0.226	1								
NO_3^{2-}	0.085	0.771	0.157	0.184	0.747	0.210	0.744	1							
SO_4^{2-}	0.260	0.920	0.040	0.382	0.910	0.355	0.842	0.598	1						
TH	0.134	0.950	0.063	0.300	0.907	0.264	0.861	0.823	0.887	1					
Ca^{2+}	0.296	0.859	0.090	0.434	0.833	0.376	0.842	0.560	0.946	0.879	1				
Mg^{2+}	0.003	0.895	0.020	0.170	0.851	0.151	0.776	0.889	0.747	0.953	0.696	1			
Na^+	0.288	0.585	0.188	0.339	0.567	0.360	0.496	0.564	0.426	0.571	0.470	0.553	1		
K^+	0.104	0.264	0.124	0.089	0.237	0.225	0.179	0.192	0.216	0.236	0.205	0.221	0.451	1	
COD	0.233	0.518	0.256	0.244	0.453	0.281	0.512	0.532	0.379	0.470	0.375	0.466	0.459	0.088	1

Table 6: Correlation Coefficient matrix for ground waters of ground waters of Vellore city, (post- monsoon)

Variables	pH	TDS	CO_3^{2-}	HCO_3^{2-}	EC	Free CO_2	Cl^-	NO_3^{2-}	SO_4^{2-}	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	COD
pH	1														
TDS	0.261	1													
CO_3^{2-}	0.859	0.340	1												
HCO_3^{2-}	0.822	0.219	0.757	1											
EC	0.250	0.956	0.300	0.181	1										
Free CO2	0.912	0.352	0.895	0.857	0.334	1									
Cl-	0.160	0.792	0.177	0.132	0.796	0.218	1								
NO_3^{2-}	0.077	0.718	0.208	0.158	0.663	0.219	0.630	1							
SO_4^{2-}	0.257	0.913	0.353	0.239	0.903	0.349	0.802	0.544	1						
TH	0.176	0.926	0.306	0.234	0.910	0.300	0.775	0.725	0.872	1					
Ca^{2+}	0.260	0.831	0.360	0.289	0.820	0.332	0.815	0.448	0.928	0.841	1				
Mg^{2+}	0.135	0.838	0.264	0.167	0.822	0.269	0.661	0.769	0.711	0.938	0.630	1			
Na^+	0.298	0.558	0.251	0.299	0.550	0.305	0.442	0.486	0.398	0.501	0.455	0.427	1		
K^+	0.064	0.220	0.002	0.080	0.214	0.111	0.192	0.218	0.178	0.144	0.179	0.087	0.415	1	
COD	0.231	0.520	0.234	0.230	0.462	0.255	0.507	0.577	0.381	0.442	0.364	0.464	0.467	0.097	1

Corrosive ratio & ion exchange reaction

The corrosive ratio of a groundwater sample is greater than 1, regardless of the season. If the CR is less than 1, the water is not corrosive; if the CR is greater than 1, the water is. This is brought on by the interaction of surface moieties and industrial wastewater. The significant geochemical processes that regulate the occurrence and distribution of ions in groundwater are known as cation exchange reactions. The rise in sodium in a gneissic environment is probably caused by ion exchange or industrial or agricultural contaminations[17]. Cation exchange reactions are demonstrated by a high concentration of Na relative to Cl or a depletion of Na relative to Cl[18]. Ca is kept in the aquifer material during a typical ion exchange event, while Na is discharged into the water. Cl does not counteract the excess Na produced by the ion exchange reaction; instead, alkalinity or SO_4 do. Similar to this, in a reverse ion exchange, Ca is released to water while Na is kept by aquifer minerals. In this instance, Ca and Mg balance off the excess Cl over Na. In light of this, an excess of Na over Cl or Cl over Na is a reliable indicator of ion exchange processes. The depletion of Na values relative to Cl in this region Fig. 4a is indicative of an ion exchange reaction. Every other sampling site groundwater sample uses the ion-exchange reaction with a slow rate of seasonal fluctuations, with the exception of this location (S4, S11, W2, W7, W8, W10, W11). Figure 4b.

Principal Component Analysis

Pre-monsoon season causes factor 1 to be very highly loaded with TDS, TH, and strongly loaded with EC, chloride, NO_3, SO_4, Ca, and Mg Table 4.7 and Fig. 4.9. The moderate loading of Cu, Zn, Pb, and COD accounts for 46.03% of the data set's variability. Anthropogenic pollution and a decline in the groundwater table are the two processes that are suggested. Without recharge, the groundwater table lowers during the summer because significant concentrations of chloride and Sulphates were observed. Due to the presence of NO_3 in this factor, anthropogenic pollution is proposed as the additional contributing process. Livestock waste and municipal landfills may be sources of nitrogen. Factor 2 accounts for 14.64% of variability and contains the variables PH, alkalinity, and free CO_2. If PH and free CO_2 have somewhat higher positive loadings than alkalinity, this indicates that groundwater in the research area is primarily contaminated by wastewater discharge on a regular basis. Because the pH rises as a result of the creation of acids caused by the decomposition of organic material, this component is known as the degradation factor.[25-29].

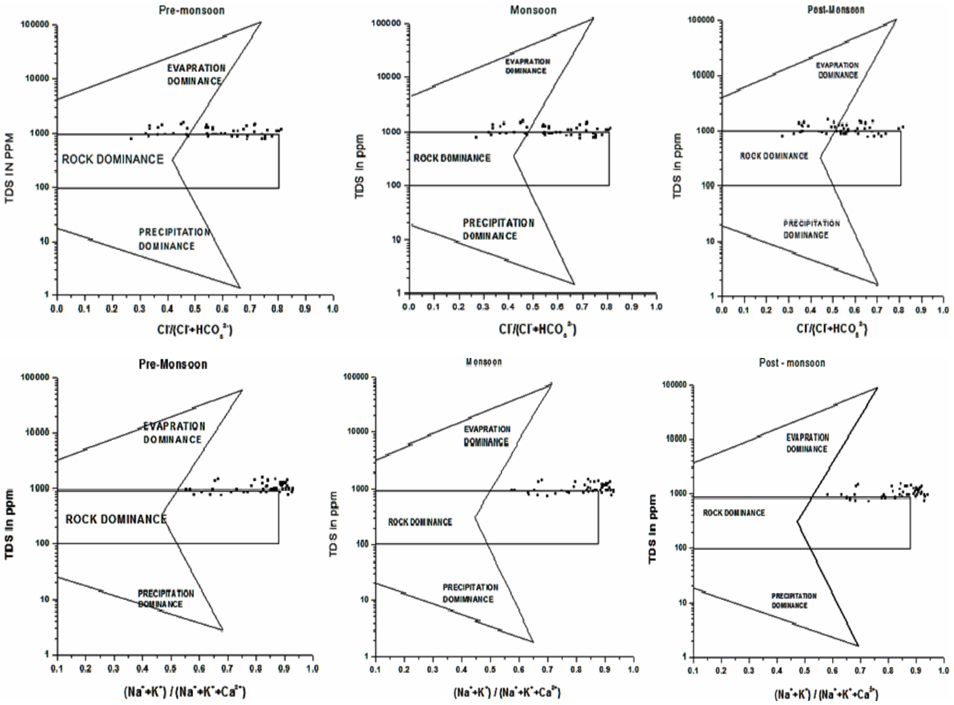

Fig. 3. Gibbs diagram for groundwater with respect to anion and cation

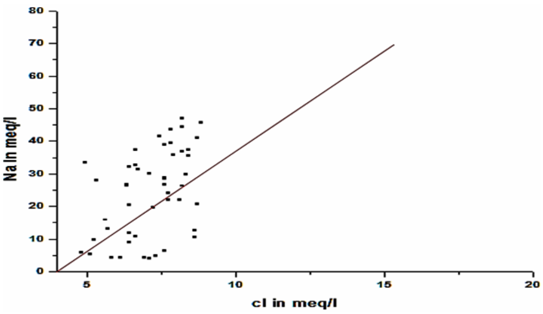

Fig. 4(a). Relation between Na (meq/l) and Cl (meq/l).

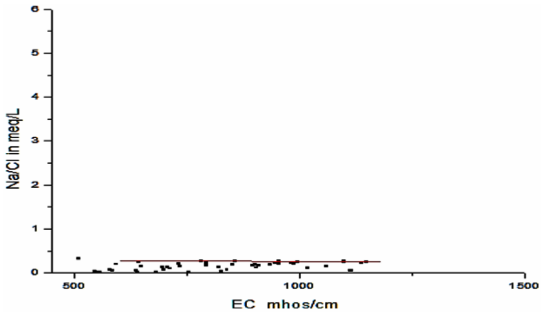

Fig. 4(b). Relation between Na/Cl versus EC (mho/cm)

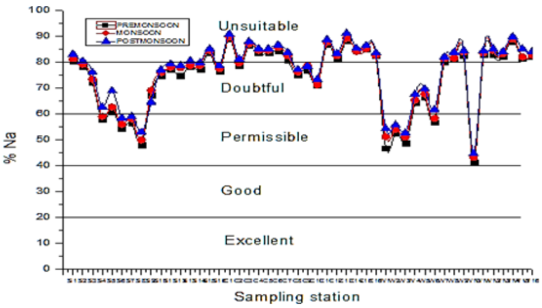

Fig. 5. % of Na in groundwater, Vellore city, South India

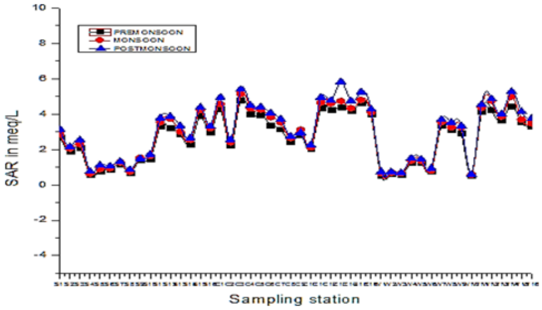

Fig. 6. SAR in groundwater, Vellore city, South India

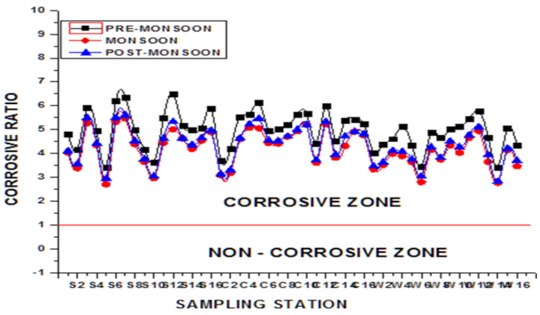

Fig. 7. Corrosive ratio of groundwater in Vellore city, South India

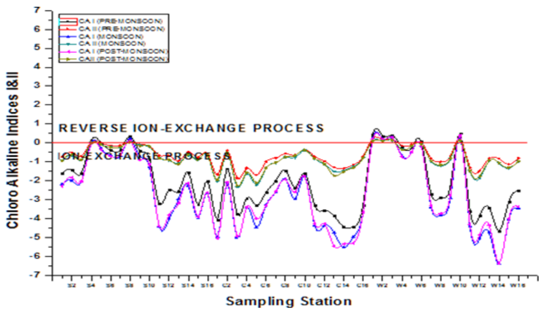

Fig. 8. Chloro-Alkaline indices of groundwater in Vellore city, South India

Aluminium has a modest link with factor 3 and mercury and cadmium have a moderate correlation. Factor 3 contributes 11.6% of variability. These numbers suggest that the concentration of heavy metals decreases over the summer. Factor 4-organic matter degradation/iron reduction process-explains 6.34% of the variability and includes only a moderate association of ferrous. Iron reduction is connected to the microbial breakdown of organic substances in the aquifer (1).

The factor 1 is extremely significantly connected with TDS during monsoon season Table 8 and Fig. 10, while EC and TH are strongly correlated with chloride, nitrate, Sulphates, calcium, and magnesium. Cu, Zn, and COD have a moderate association and account for 46.03% of the data set's variability. Since chloride, nitrate, and Sulphates have lower positive correlations than the other two seasons and consequently have a negative effect on TDS, this may be owing to the recharge effect of rainwater. For this reason, this component is referred to as a solid factor. Factor 2 accounts for 14.72 percent of the data set's variability and adds to the modest correlation of Al, Pb, and Hg. This element is thought to be a heavy metal dissolution element. The dissolving of metal during the aquifer's recharge by rainfall may be the cause of the trace amounts of Al, Pb, and Hg that are released into groundwater. Factor 3 is responsible for 12.47 percent of the variability and includes strongly positive loadings of pH, alkalinity, and free CO_2. The water's pH may alter, most commonly as a result of continuous water inflow, and this variation may have an impact on the free CO_2 level. When monsoon season arrives, the pH changes as a result of an abrupt influx of fresh rainwater in the research area. Alkalinity is directly impacted by pH variation. This element is known as the pH factor. Factor 4 explains 7.4% of the variability and has a moderately positive loading of Fe and Cd; this may be because ferrous metal dissolves during microbial degradation with the help of organic matter derived from waste water in the environment. The factor 1 is very significantly linked with TDS, EC, and TH in the post-monsoon table 9 and Fig. 11, as well as with strong positive loadings of chloride, nitrate, Sulphates, calcium, and magnesium. Strong association between Cu and Pb and moderately positive loading of Zn, Hg, and COD explain 44.18% of the data set's variability.

Table 7: PCA studies of Physic-chemical parameters (Pre-Monsoon)

Variable	F1	F2	F3	F4
pH	0.369	0.747	-0.474	0.032
TDS	0.936	-0.230	-0.155	-0.006
TA	0.477	0.749	-0.332	0.211
EC	0.894	-0.273	-0.221	-0.004
Free CO_2	0.502	0.727	-0.378	0.106
Chloride	0.843	-0.312	-0.105	-0.050
Nit.	0.841	-0.181	0.291	0.047
SO_4^{2-}	0.847	-0.273	-0.371	-0.040
TH	0.925	-0.317	-0.071	0.056
Ca	0.829	-0.216	-0.376	-0.021
Mg	0.866	-0.351	0.129	0.091
Cu	0.529	0.368	0.149	-0.308
Zn	0.605	0.238	0.071	-0.376
Al	0.278	0.426	0.488	-0.385
Fe	0.359	0.183	0.159	0.610
Pb	0.559	0.227	0.537	-0.080
Hg	0.553	0.224	0.560	0.027
Cd	0.394	0.106	0.565	0.561
COD	0.635	0.111	0.225	-0.228
Eigen value	8.747	2.782	2.209	1.205
Variability (%)	46.037	14.640	11.628	6.341
Cumulative (%)	46.037	60.676	72.304	78.645

Table 8: PCA studies of Physico-chemical parameters (Monsoon)

Variable	F1	F2	F3	F4
pH	0.408	0.366	0.775	-0.137
TDS	0.926	-0.304	-0.023	0.008
All.	0.505	0.391	0.723	0.080
EC	0.890	-0.350	-0.006	-0.011
Free CO_2	0.558	0.371	0.686	0.031
Chloride	0.798	-0.301	-0.051	-0.138
Nit.	0.798	0.210	-0.302	0.165
SO_4^{2-}	0.831	-0.487	0.122	-0.065
TH	0.906	-0.339	-0.119	0.075
Ca	0.790	-0.492	0.198	-0.074
Mg	0.851	-0.189	-0.307	0.168
Cu	0.552	0.497	-0.187	-0.287
Zn	0.640	0.125	0.082	-0.328
Al	0.246	0.681	-0.296	-0.225
Fe	0.336	0.176	0.192	0.690
Pb	0.557	0.537	-0.346	0.001
Hg	0.539	0.467	-0.404	-0.112
Cd	0.335	0.307	-0.202	0.732
COD	0.636	0.219	-0.170	-0.177
Eigen value	8.521	2.811	2.369	1.414
Variability (%)	44.845	14.793	12.470	7.440
Cumulative (%)	44.845	59.638	72.108	79.547

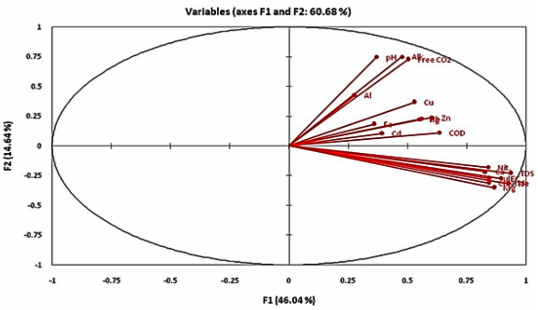

Fig. 9. PCA distribution diagram of physicochemical parameter of groundwater in Vellore City (Pre-monsoon) South India

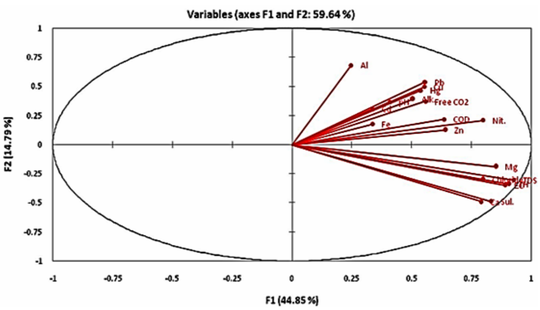

Fig. 10. PCA distribution diagram of physicochemical parameter of groundwater in Vellore City (Monsoon), South India

Since the content of chloride and Sulphates is decreased, this process is responsible for the dilution of groundwater. The substantial positive loading of nitrate, which is very low compared to other seasons, may be due to the monsoon's end's recharge effect on rainwater. The weathering or evaporation of groundwater reduces the calcium concentration, and the change in overall hardness affects the calcium level. Alkalinity, pH, and free CO_2 have a moderately favorable association and account for 14.09% of the variability. The post-monsoon season is when free CO_2 levels are at their highest. The presence of free CO_2, which changes pH, has an impact on the level of alkalinity. One parameter, the moderately correlated Cd, was produced by factor 3 and accounts for 12.7% of the variability. This is the process that causes heavy metal to dissolve. Factor 4 contributes 7.4% of the variability, resulting in a moderately positive ferrous loading; the process attributed may be the process of iron reduction or the decomposition of organic matter.

Factor analysis

The assessment criterion for groundwater environmental quality is applied, and the standard evaluation indexes are produced using PCA as well[19–25]. The total score for each standard level is displayed in Table 10 and Fig. 12. The quality of the groundwater in samples W1, W3, W4, W7, W11, W13, S1, S5, S8, S9, S10, S11, S13, S14, S15, and S16 is good, and W2, W5, W16, S2 and S4 are better; the groundwater there satisfies the requirements of the II and III water function zones W6, W8, W9, W14, W15, and S3.

Table 9: PCA studies of Physico-Chemical parameters (Post-Monsoon)

Variable	F1	F2	F3	F4
pH	0.413	0.601	-0.616	0.025
TDS	0.927	-0.261	-0.030	0.012
TA	0.515	0.621	-0.506	0.179
EC	0.904	-0.297	-0.088	-0.009
Free CO_2	0.549	0.603	-0.494	0.175
Chloride	0.816	-0.332	-0.012	-0.121
Nit.	0.781	0.003	0.458	0.084
SO_4^{2-}	0.849	-0.390	-0.251	-0.025
TH	0.911	-0.309	0.033	0.159
Ca	0.808	-0.378	-0.308	-0.075
Mg	0.850	-0.213	0.204	0.259
Cu	0.495	0.423	0.055	-0.433
Zn	0.623	0.173	-0.084	-0.381
Al	0.060	0.474	0.380	-0.287
Fe	0.395	0.238	-0.001	0.606
Pb	0.486	0.366	0.482	-0.109
Hg	0.572	0.345	0.530	-0.103
Cd	0.189	0.304	0.634	0.562
COD	0.623	0.173	0.238	-0.347
Eigen value	8.395	2.677	2.425	1.425
Variability (%)	44.184	14.091	12.763	7.498
Cumulative (%)	44.184	58.275	71.039	78.536

Table 10: Factor analysis of ground water in Vellore city

Sample code	F1	F2	Factor score	Rank	Grade
S1	-1.692	0.736	-0.956	1	II
S2	-1.543	0.529	-1.014	2	III
S3	-1.17	0.545	-0.625	1	II
S4	-0.818	1.087	0.269	1	II
S5	-1.116	-0.182	-1.298	2	III
S6	-2.182	0.244	-1.938	3	III
S7	0.238	-0.021	0.217	1	II
S8	0.155	0.651	0.806	3	IV
S9	-0.526	-1.186	-1.712	3	III
S10	-0.485	-0.083	-0.568	1	II
S11	1.026	1.043	2.069	4	IV
S12	1.756	1.421	3.177	4	V
S13	0.496	-0.82	-0.324	1	II
S14	0.864	-0.009	0.855	3	IV
S15	0.518	1.441	1.959	3	IV
S16	-0.569	-0.647	-1.216	2	III
C1	-0.674	0.927	0.253	1	II
C2	-0.937	-0.059	-0.996	2	III
C3	-0.037	1.976	1.939	3	IV
C4	-0.581	-0.396	-0.977	2	III
C5	-1.785	-0.242	-2.027	1	I
C6	0.915	1.822	2.737	4	V
C7	0.85	1.43	2.28	4	V
C8	-0.154	-0.464	-0.618	1	II
C9	-0.303	-1.767	-2.07	1	I
C10	-1.313	-2.441	-3.754	1	I
C11	1.192	-0.771	0.421	1	II
C12	2.324	0.473	2.797	4	V
C13	-0.068	0.365	0.297	1	II
C14	-0.51	-0.209	-0.719	1	II
C15	-0.543	-1.977	-2.52	1	I
C16	0.473	-0.68	-0.207	1	II
W1	-1.758	-0.09	-1.848	3	III
W2	-1.251	-1.02	-2.271	1	I
W3	-0.063	1.251	1.188	3	IV
W4	0.267	0.936	1.203	3	IV
W5	0.597	1.974	2.571	4	V
W6	-0.258	0.543	0.285	1	II
W7	0.059	-0.005	0.054	1	II
W8	0.117	0.343	0.46	1	II
W9	1.154	-0.301	0.853	3	IV
W10	1.748	-1.643	0.105	1	II

Table 10: Continue.......

Sample code	F1	F2	Factorscore	Rank	Grade
W11	-0.109	-1.868	-1.977	1	I
W12	2.108	0.008	2.116	3	IV
W13	0.096	-0.725	-0.629	1	II
W14	1.065	-0.126	0.939	3	IV
W15	1.485	-0.443	1.042	3	IV
W16	0.945	-1.571	-0.626	1	II

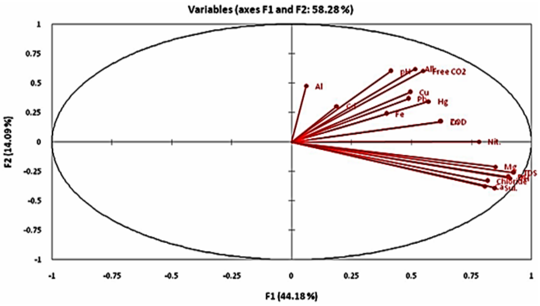

Fig. 11. PCA distribution diagram of physicochemical parameter of groundwater in Vellore City (Post-monsoon), South India

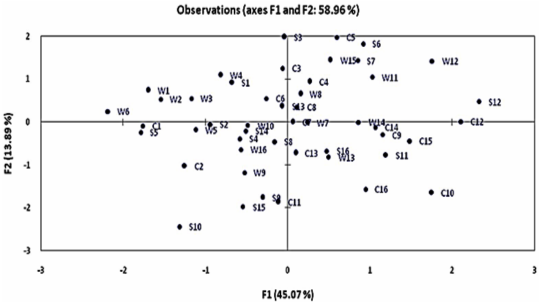

Fig. 12. Factor analysis of physicochemical parameter of groundwater in Vellore City (Post-monsoon), South India.

CONCLUSION

Studies on the trends in groundwater quality are being conducted in the Vellore area close to industrial areas. Na, Ca, Mg, and K were the four cations that predominated in the research region, whereas CO_3, Cl^-, HCO_3^{2-}, and SO_4^{2-} were the four anions. The cation exchange process regulates the chemistry of groundwater. The correlation between the different water quality parameters (TDS, TH, Ca^{2+}, Mg^{2+}, and Cl^-, SO_4^{2-}, etc.) was good. Ion exchange reactions along the groundwater flow direction result in the release of Ca^{2+} and the adsorption of Mg and Na, according to hydro chemical modeling. Based on the primary ion chemistry of groundwater, four hydro chemical facies have been discovered, with Na-K-HCO_3 and Na-CO_3 being the two major facies. A small number of groundwater samples from coastal areas in the pre-monsoon season (April 2023) exhibit the Na-Cl facies. However, during the monsoon, these samples eventually become diluted to Ca-Mg-HCO_3 or Na-K-HCO_3 facies. The study locations' potential for agricultural activities is constrained by high SAR and Na%. The pollutant load was definitely higher during the summer and lower during the monsoon, according to the PCA study. According to factor analysis, the water function zones for the groundwater quality in 29 places are II and III, while the other 19 locations are IV and V.

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Conflict of interest

The authors declare no conflict of interest.

REFERENCES

1. Krishnamoorthy, N.; R. Thirumalai.; M. Lenin Sundar.; M. Anusuya.; P. Manoj Kumar.; E. Hemalatha.; M. Mohan Prasad, and Neha Munjal; *Urban Climate.*, **2023**, *49*, 101436.
2. Kistan, A.; Kanchana V.; *Indian J. of Environmental Protection.*, **2020**, *40*(5), 527–532.
3. Senthilkumar.; Mohanavelu, and Devadasan Gnanasundar.; *Environmental Earth Sci.*, **2022**, *81*(6), 187.
4. Reddy, D. V.; Devender Kumar, and Kiran Kumar Bhukya.; *Environmental Earth Sci.*, **2023**, *82*(13), 335.
5. Anjum.; Rukhsar.; Sk Ajim Ali.; Mansoor Alam Siddiqui.; Farhana Parvin.; Zainab Khan.; Nishat Khan.; Zeba Khanam, and Mohammad Nafees. *Chemical Engineering Journal Advances.*, **2023**, *16*, 100547.
6. Srihari, S.; T. Subramani.; V. N. Prapanchan.; and Peiyue Li. Hum. *Ecol. Risk Assess.*, **2022**, *29*, 1-12.
7. Gogoi.; Ashini.; Shaik Mahamad.; Dipjyoti Gogoi, and G. Bhaskaran. *Arabian Journal for Science and Engineering.*, **2023**, *48*(6), 7985-8000.
8. Sangaré.; Lamine Ousmane.; Sidy Ba.; Oumou Diallo.; Diakalia Sanogo, and Tong Zheng. *Environmental Monitoring and Assessment.*, **2023**, *195*(6), 1-19.
9. Libina, R. S.; K. Prakash.; R. Jegankumar.; S. P. Dhanabalan, and M. A. Arya. In Adv., in Water Resource Planning and Sustainability, Singapore: Springer Nature Singapore, **2023**, 203-221.

10. Rajendiran.; Anbuchezhian.; *Envi., Monitoring and Assessment*., **2023**, *195*(7), 883.
11. Subramanian.; Keerthivarman G.; Manikandavelu Dhanushkodi.; Aruna Satyapriyan.; Muralidharan Nagarajan.; and Govarthanan Muthusamy. *Molecular Biotechnology*., **2023**, 1-12.
12. Manju, A.; K. Kalaiselvi.;V. Dhananjayan.; M. Palanivel.; G. S. Banupriya.; M. H. Vidhya.; K. Panjakumar, and B. Ravichandran; Air Quality, *Atmosphere & Health.,* **2018**, *11*, 1179-1189.
13. Kistan, A.; V. Kanchana, L. Sakayasheela.; J. Sumathi.; A. Premkumar, and A. Selvam.; *Orient. J. Chem*., **2018**, *34*(2), 1000-1010,. http://dx.doi.org/10.13005/ojc/340250.
14. Senthilkumar, S.; K. Vinodh.; G. Johnson Babu.; B. Gowtham, and V. Arulprakasam.; *Applied Water Science*., **2019**, *9*, 1-20.
15. Dhamodharan, A.; S. Shanthakumar, and G. P. Ganapathy.; *Global NEST Journal*., **2016**, *18*(3), 527-545.
16. Chaurasia.; Abhishek Kumar.; H. K. Pandey.; S. K. Tiwari.; Ram Prakash.; Prashant Pandey.; and Arjun Ram. *J. of the Geological Soci of India*., **2018**, *92*, 76-82.
17. Mohanakavitha, T.; K. Shankar.; R. Divahar.; T. Meenambal, and R. Saravanan. *Archives of Agriculture and Environmental Science*., **2019**, *4*(4), 379-387.
18. Madhavan.; Shanmugam.; Srinivasa Raju Kolanuvada.; Vinothkumar Sampath.; Priyadarsi Debajyoti Roy.; Prabhakaran Moorthy.; Logesh Natarajan, and Lakshumanan Chokkalingam.; *Environmental Monitoring and Assessment*., **2023**, *195*(2), 272.
19. Packialakshmi, S., and N. K. Ambujam. "The peri-urban to urban groundwater transfer and its societal implications in Chennai, south India-A case study." *Indian Journal of Agricultural Research*., **2017**, *51*(2), 135-141.
20. A Kistan.; Andiyappan.; V. Kanchana.; Asian *J. Chem*., **2023**, *35*(8), 1899-1906., https://doi.org/10.14233/ajchem. 2023.27792
21. Sathish, S., and L. Elango.; *Arabian J of Geosciences*., **2016**, *9*, 1-17.
22. Debsarma.; Chitrangada.; Paulami Sahu, and M. H. Kalubarme.; *Envir., Monitoring and Assessment*., **2023**, *195*(9), 1-24.
23. Ramachandran, A.; R. R. Krishnamurthy, M. Jayaprakash, and A. Shanmugasundharam.; *Acta Ecologica Sinica*., **2019**, *39*(2), 125-132.
24. A Kistan, A.; A. Premkumar & amp; V. Kanchana.; *Asian J. Chem*., **2022**, *34*(7), 1698-1702 https://doi.org/10.14233/ajchem.2022.23699.
25. Gnanachandrasamy, G.; T. Ramkumar, S. Venkatramanan.; S. Vasudevan.; S. Y. Chung.; and M. Bagyaraj.; *Applied Water Sci*., **2015**, *5*, 39-55.
26. Natarajan, Surendar.; *Nature Environment & Pollution Technology.,* **2023**, *22*, 3.
27. Alagarsamy.; Vijaya Anandan Veerasamy.; Kistan Andiyappan.; Saral Abdul Kadar Avuliya and Thaminum Ansari Abubacker; *Orient. J. Chem*., **2018**, *34*(1), 381. http://dx.doi.org/10.13005/ojc/340141.
28. Senthilkumar, M.; D. Gnanasundar, and E. Sampath Kumar. *Clean and Sustainable Groundwater in India*., **2018**, 25-38.
29. Guruge, Keerthi S.; P. Goswami, I. Watanabe.; S. Abeykoon.; V. P. Prabhasankar.; K. R. Binu.; D. I. Joshua.; K. Balakrishna.; Masato Akiba.; and N. Munuswamy.; *Int., J., of Environmental Sci and Tech*., **2017**, *14*, 1-18.