JOURNAL OF CRITICAL REVIEWS

ISSN- 2394-5125 VOL 7, ISSUE 7, 2020

EVALUATION OF GROUNDWATER QUALITY IN AND AROUND BALANAGAR INDUSTRIAL AREA OF HYDERABAD CITY, TELANGANA STATE, INDIA

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ABSTRACT

The aim of the present study is to evaluate the groundwater quality in and around Balanagar industrial area of Hyderabad City, Telangana State, India and its suitability for drinking, irrigational and industrial use. Groundwater samples were collected from sixteen locations during pre-monsoon and post-monsoon season and analyzed for Physico-Chemical parameters such as pH, Electrical Conductivity, Total Dissolved Solids, Total Hardness, Total Alkalinity, Sodium, Potassium, Calcium, Magnesium, Carbonates, Bicarbonates, Chloride, Fluoride, Nitrates and Sulphates as per the American Public Health Association (APHA) Standard Methods for Examination of Water and Wastewater. Analytical results were compared with the Bureau of Indian Standards (BIS) 2012 standards for drinking water. Parameters such as Sodium Adsorption Ratio, Residual Sodium Carbonate, Sodium Percentage, Permeability Index and Kelly's Index were calculated to evaluate the groundwater use for irrigational purpose. For the industrial suitability, parameters such as Langelier Saturation Index, Ryznar Stability Index, Puckorius Scaling Index, Larson-Skold Index, Aggressive Index and Corrosive Ratio were calculated. Gibbs diagrams were plotted to understand the mechanisms influencing the groundwater chemistry and to understand the ion exchange processes between the groundwater and the aquifer environment chloroalkaline Indices were calculated. The analytical results indicate that most of the physico-chemical parameters are exceeding the prescribed limits of BIS 2012 and the groundwater is moderately suitable for irrigation purpose and has scaling tendency, little corrosive and non-aggressive in nature.

Keywords

Groundwater, Physico-Chemical parameters, APHA, BIS, Irrigation Suitability Parameters, Industrial Suitability Parameters

INTRODUCTION

Groundwater is the precious and vital natural resource. It is the largest reservoir of drinkable water for mankind. It has become the major source of water supply for domestic, industrial and agricultural sectors of many countries. In recent studies it is revealed that about 65% of groundwater in the world is used for drinking purposes, 20% for irrigation and 15% is used for industrial purposes (Adimalla and Venkatayogi, 2018). It is estimated that approximately one-third of the world's population use groundwater for drinking (UNEP, 1999). Groundwater quality in arid and semi-arid regions is controlled by local hydrogeology, topography, geological structures, evaporation, precipitation, rock-water interactions, weathering, industrial effluents, irrigation/cultivation, chemical fertilizers and largely anthropogenic activities (N. Subba Rao,

ISSN- 2394-5125 VOL 7, ISSUE 7, 2020

2002; Singh P. K et al., 2006). Contamination of groundwater by domestic sewage, industrial effluents and agricultural runoff is a serious problem faced by many developing countries like India. Rapid rise in the population, urbanization, industrial and agricultural activities, disposal of domestic wastewater, industrial wastewater and pesticide chemicals are highly contaminating the groundwater.

In recent days the groundwater quality is declining at an alarming rate due to increased industrial activity. Industry has emerged out to be an important part of the Indian economy, especially in the post-independence era starting 1947. There is inevitably an industrial area in every major city. Efforts are constantly made by the Indian Government to industrialize all smaller towns andsemi-urban areas where basic infrastructure facilities are easily available. With the population in the rising trend, small and medium-scale industries are largely promoted because they are labor intensive and create more jobs (Pradeep K. Naik et al., 2007). Rapid industrialization causes severe contamination of groundwater (N Subba Rao et al., 1998; B. S. Shankar et al., 2008; A. G. S. Reddy et al., 2012; Ravi Kumar Gumma et al., 2013; G Tamma Rao et al., 2014). Prolonged, persistent and perennial industrial activity with increasing industrial growth and inefficient waste management, have led to the increased levels of pollutants in the groundwaters (K.V. Srinivasa Rao et al., 2007). Dense unplanned industrial establishments have negatively affected the groundwater quality (Kamaldeep et al., 2011). Due to the inadequate sewerage system and treatment capacities, the domestic sewerage and industrial effluents are directly entering into the nalas and streams and industrial effluents through damaged effluent storage tanks and pipelines percolate into the ground causing severe ground water contamination (CGWB, 2011). Some industries are not having effluent treatment plants and disposing their effluents into public sewers or open land in their premises and some industries dump their solid waste in open fields, which on decomposition releases the leachate which percolates into ground causing ground water pollution (Y.C. Ho et al., 2012). Most of the industries discharge their effluents without proper treatment into nearby open pits or pass them through unlined channels, which move towards the low-lying depressions on land, resulting in the contamination of groundwater (R.P. Singh, 2001**;** Purandara and Varadarajan, 2003; Muhammad Aleem et al., 2018).

In the present study the evaluation of groundwater quality and its suitability for drinking, irrigation and industrial purposes has been carried out in and around Balanagar industrial area of Hyderabad city, Telangana State, India.

Details of the Study area

Hyderabad is the fastest growing city in India. Recent decades have witnessed the emergence of various industries in and around the Hyderabad city. One such industrially developed area is Balanagar industrial area which is in the north-western part of Hyderabad. According to the reports of District Industries Center (DIC) there are more than 434 small and tiny government and private industries established in this location. The prominent companies are Indian Drugs and Pharmaceuticals Limited (IDPL), National Remote Sensing Agency (NRSA), Hindustan Aeronautics Limited (HAL), Bharat Heavy Electronics Limited (BHEL), Hindustan Machine Tools (HMT), National Institute of Pharmaceutical Education and Research (NIPER), Central Institute of Tool Design (CITD), Cooperative Industrial Estates Limited and Micro-Small & Medium Enterprises Development Institute (MSME-DI). The range of products manufactured by these industries includes pharmaceuticals, biochemical, chemical reagents, synthetic chemicals, drugs, aircraft batteries, alloys, rubber products, organics, detergents and distillation products etc.

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The study area (Figure 1) lies in between North Latitude 17° 27' 54.02" and East Longitude 78° 27' 3.57" is covered in part of Topographic Sheet No E44M7 (56K/7). The neighborhood areas of Balanagar are Begumpet, Sanath Nagar, and Balkampet. Balanagar Industrial area includes Fathenagar, Adarsh Nagar, Bhagath Singh Nagar, Gandhi Nagar, Guatam Nagar, Indira Gandhi Nagar, Rajiv Gandhi Nagar, Kalyani Nagr, Sai Nagar, Raju Colony, Deendayal Nagar, Venkateswara Nagar, Prashanthi Nagar, IDPL Colony, Kukatpally Industrial Estate, Shobana Colony, Navajeevan Nagar and HAL Township.

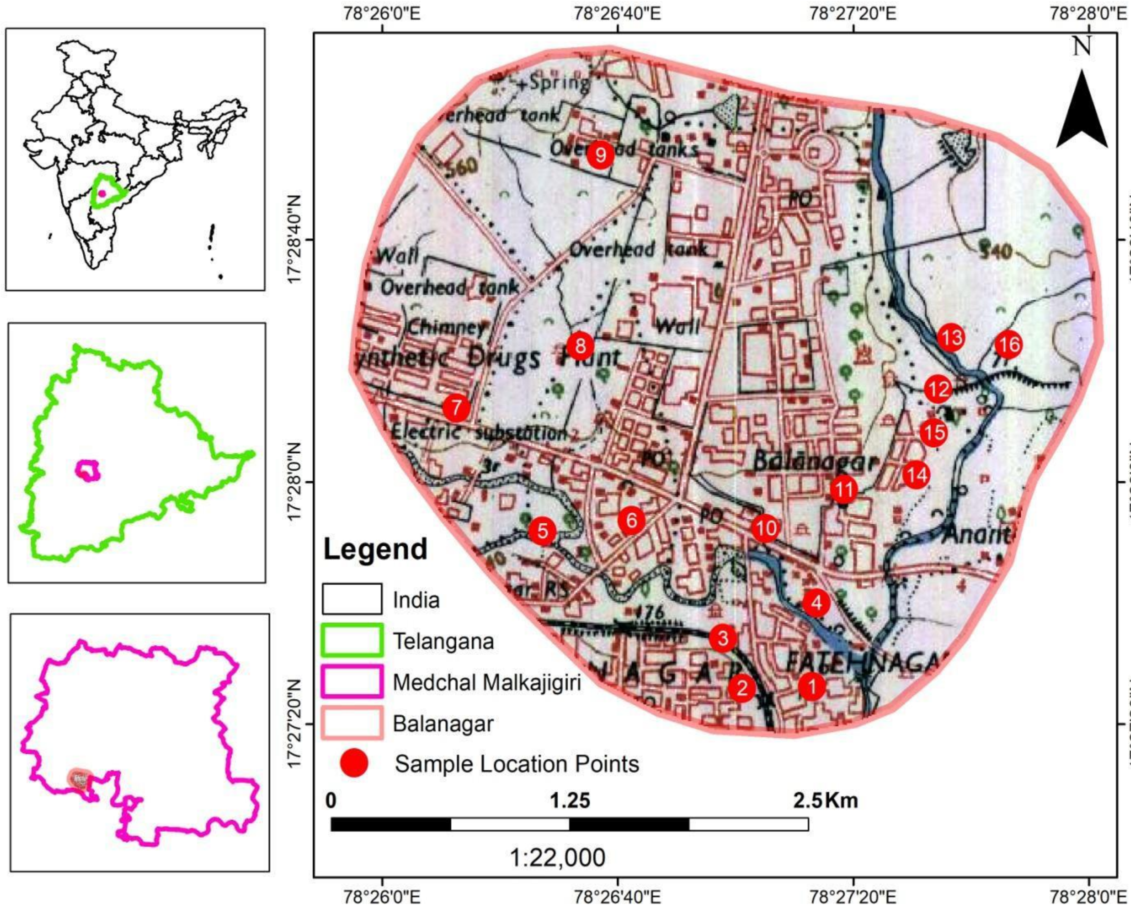

Figure 1: Location Map of the Study Area

Geology and Hydrogeology of the Study area

Geologically, it consists of granites and pegmatite of igneous origin belonging to the Archean age. The granites are pink and grey in color. They are hard massive to foliated and well-jointed. The soil cover is residual soil of weathered granite and that is well developed. The soil is yellowish to brown reddish. The soil is adequately permeable and the infiltration rate can absorb most of the rain water except for more intensive rains which can cause significant surface flow and erosion (G. Machender et al., 2011). Groundwater occurs under the groundwater table and in semi-confined conditions in the soil of weathered granite, decomposed granite and fractured solid bedrock. Though these rocks possess negligible primary porosity, due to deep fracturing and weathering they exhibit secondary porosity through this they rendered with a porosity and permeability which locally form potential aquifers.

Climate

The annual mean temperature of Medchal-Malkajgiri District is 29.6 ℃. Minimum temperature (19 ℃) is recorded during the month of December and maximum temperature (42 ℃) is recorded during the month of May. The annual rainfall measured was 866 mm and the highest rainfall was in the month of September (280.3 mm). Heavy rains generally occur during the South-West monsoon. The monthly rainfall distribution of Medchal-Malkajgiri district during 2019 is presented in Figure 2.

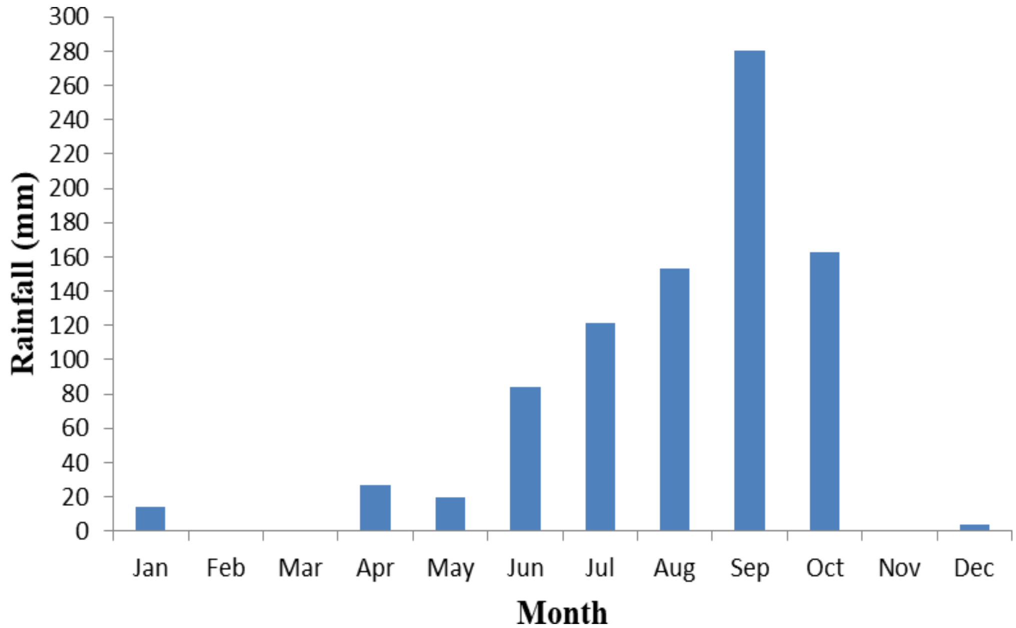

Figure 2: Monthly Rainfall Distribution of Medchal-Malkajgiri District (2019)
(**Source:** Chief Planning Office, Government of Telangana Sate.)

MATERIALS AND METHODS

Sample Collection

Sixteen groundwater samples were collected from six hand pumps and nine bore wells in and around Balanagar industrial area during Pre-Monsoon (May-2019) and Post-Monsoon (December-2019) seasons. The groundwater samples were collected in 1-liter pre-cleaned high-density polyethylene bottles (HDPE) with dilute HNO_3. Geographic locations of sampling sites were collected with a GPS and shown in the Table 1. The samples were transferred to the laboratory for the analysis of physico-chemical parameters.

Table 1: Details of the Sampling Locations

S. No	Site of the Sample	Latitude	Longitude	Source
1	Sri Siddi Vinayaka Kirana & General Store	17.45728	78.45362	Hand Pump
2	Sri Sai Fabrication Works	17.4572	78.45033	Hand Pump
3	Pochamma Temple	17.45949	78.44942	Hand Pump
4	Royal Precision Engineering Enterprises	17.46112	78.45385	Hand Pump
5	Deendayal Nagar	17.46441	78.44092	Hand Pump
6	Madhura Engineering Services	17.4649	78.44512	Bore well
7	Godavari Steel Works	17.47007	78.43686	Bore well

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8	Krismic Enterprises	17.47291	78.4427	Bore well
9	AE Office (TSSPDCL) Balanagar	17.48167	78.44366	Bore well
10	ACP Office Balanagar	17.46454	78.45144	Bore well
11	ESI Dispensary, Balanagar (Old)	17.46632	78.45514	Hand Pump
12	Vasavi Nilayam/Vanitha Clinic	17.47037	78.45948	Bore well
13	Sri Maniram Yadav Ji Nivas	17.4718	78.45991	Bore well
14	Venus Enclave	17.46699	78.45855	Bore well
15	Vaishnavi Nilayam	17.468932	78.459371	Bore well
16	BM Techno Solutions	17.47139	78.46105	Bore well

Methods of analysis

The physical parameters such as pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were determined in the field at the time of sample collection by using digital meters. The Chemical parameters such as Total Hardness (TH), Carbonates (CO_3^{2-}), Bicarbonates (HCO_3^-), Total Alkalinity (TA), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), Potassium (K^+), Chloride (Cl^-), Fluoride (F^-), Sulphate (SO_4^{2-}) and Nitrate (NO_3^-) were determined in the laboratory as per the Standard Methods for Examination of Water and Wastewater (APHA, 2017). The obtained results were compared with „Indian Standard Drinking Water Specification (IS 10500:2012) of Bureau of Indian Standards (BIS, 2012).

RESULTS AND DISCUSSION

The obtained analytical results of physico-chemical parameters are shown in Table 2 and Table 3 during pre-monsoon and post-monsoon seasons respectively, and season-wise comparison of the obtained results with Bureau of Indian Standards (BIS 2012) are shown in Table 4.

Table 2: Physico-Chemical Parameters of Balanagar Industrial Area (Pre-Monsoon)

S. No	pH	EC	TDS	TH	TA	Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	F^-	Cl^-	NO_3^-	SO_4^{2-}
1	8.3	1063	681	220	295	155	5	67	13	10	285	0.9	263	14	45
2	8.2	1228	786	240	450	194	7	73	14	20	430	0.9	231	9	75
3	8.0	1975	1264	265	445	342	4	80	16	30	415	1.2	554	18	43
4	8.4	1358	869	180	495	255	7	54	11	20	475	3.1	284	21	33
5	8.2	1380	883	270	470	215	5	82	16	20	450	1.1	309	17	39
6	7.9	4156	2660	615	470	642	4	186	37	10	460	1.3	1385	22	42
7	7.6	2894	1852	415	567	482	2	126	25	10	557	1.3	799	35	55
8	8.3	1229	787	305	385	161	6	92	18	20	365	2.4	270	28	27
9	8.1	1389	889	250	320	216	7	76	15	10	310	1.1	351	13	59
10	8.3	1301	833	105	529	308	8	32	6	20	509	1.4	231	15	15
11	8.2	983	629	220	395	151	5	67	13	20	375	1.2	202	8	37
12	8.3	1262	807	290	325	158	8	88	17	10	315	1.4	320	22	39
13	7.8	2038	1304	565	580	229	4	171	34	10	570	1.3	447	41	42
14	8.1	1229	787	130	365	231	9	39	8	10	355	0.9	288	19	44
15	8.1	1479	947	140	549	298	7	42	8	20	529	1.4	312	14	51
16	7.9	3284	2102	660	495	441	7	200	39	10	485	2.1	998	22	53

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Table 3: Physico-Chemical Parameters of Balanagar Industrial Area (Post-Monsoon)

S. No	pH	EC	TDS	TH	TA	Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	F^-	Cl^-	NO_3^-	SO_4^{2-}
1	8.2	650	416	150	320	106	9	45	9	10	310	0.9	92	15	21
2	8.1	1190	761	250	470	187	6	76	15	10	460	0.8	206	27	33
3	7.9	1926	1233	420	440	258	8	127	25	10	430	1.0	486	33	36
4	8.3	1059	678	180	520	192	9	54	11	20	500	3.0	178	12	24
5	8.2	1234	790	310	500	181	6	94	18	10	490	1.0	227	18	18
6	7.8	2279	1458	510	490	287	6	154	30	10	480	1.0	586	41	52
7	7.8	2503	1602	490	650	364	4	148	29	15	635	1.0	675	18	31
8	8.2	1106	708	330	420	133	5	100	20	20	400	2.0	231	12	25
9	8.0	1243	796	370	340	155	8	112	22	10	330	1.0	263	15	29
10	8.3	1209	774	197	590	223	7	59	12	20	570	1.0	209	19	12
11	8.1	1019	652	300	420	130	7	91	18	15	405	0.9	170	23	18
12	8.1	1168	748	340	380	148	6	103	20	10	370	1.0	263	11	15
13	7.7	2791	1786	920	650	218	5	278	55	10	640	1.0	714	40	46
14	8.1	1063	680	300	400	139	9	91	18	15	385	0.6	213	9	22
15	8.1	1613	1032	330	570	252	7	100	20	10	560	1.0	344	12	36
16	7.6	2645	1693	580	530	341	7	175	35	20	510	2.0	717	29	59

Table 4: Comparison of Physico-Chemical Parameters with BIS 2012 Standards

Parameters	BIS 2012	Pre-Monsoon				Post-Monsoon			
		Min	Max	Average	% of samples exceeding the limit	Min	Max	Average	% of samples exceeding the limit
pH	6.5-8.5	7.6	8.4	8.1	Nil	7.6	8.3	8.0	Nil
EC	1500	983	4156	1766	31	650	2791	1544	38
TDS	500	629	2660	1130	100	416	1786	988	94
TH	200	105	660	304	75	150	920	374	81
TA	200	295	580	446	100	320	650	481	100
Na^+	200	151	642	280	69	106	364	207	44
K^+	10	2	9	6	Nil	4	9	7	Nil
Ca^{2+}	75	32	200	92	56	45	278	113	81
Mg^{2+}	30	6	39	18	19	9	55	22	19
CO_3^{2-}	-	10	30	16	-	10	20	13	-
HCO_3^-	200	285	570	430	100	310	640	467	100
F^-	1.0	0.90	3.10	1.44	81	0.6	3.0	1.2	19
Cl^-	250	202	1385	453	81	92	717	348	50
NO_3^{2-}	45	8	41	20	Nil	9	41	21	Nil
SO_4^{2-}	200	15	75	44	Nil	12	59	30	Nil

(**Note**: All parameters in mg/l, except pH in pH units & EC in µS/cm)

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Suitability for Drinking purpose

The pH of groundwater samples in the study area ranges from 7.6 to 8.4 and 7.6 to 8.3 during pre-monsoon and post-monsoon seasons respectively. The results of pH indicates that all the groundwater samples fall within the acceptable limits according to BIS 2012 and are slightly alkaline in nature. The EC values of the groundwater ranges from 983 to 4156 and 650 to 2791 µS/cm during pre-monsoon and post-monsoon seasons, respectively. The EC values of the groundwater samples indicates that 31% of samples during pre-monsoon and 38% of samples during post-monsoon season are exceeding the acceptable limits of BIS 2012. The TDS values of groundwater ranges from 629 to 2660 and 416 to 1786 mg/l during pre-monsoon and post-monsoon seasons respectively. The TDS results indicates that all the samples during pre-monsoon season and 94% of samples during post-monsoon season are exceeding the acceptable limits of BIS 2012. The TH values of groundwater ranges from 105 to 660 and 150 to 920 mg/l during pre-monsoon and post-monsoon seasons, respectively. The results of TH indicates that 75% of samples during pre-monsoon and 81% of samples during post-monsoon season are exceeding the acceptable limit of BIS 2012. The TA values of groundwater ranges from 295 to 580 and 320 to 650 mg/l during pre-monsoon and post-monsoon seasons respectively. The results of TA indicates that all the samples are exceeding the acceptable limit of BIS 2012 during pre-monsoon and post-monsoon seasons. The Na^+ values of groundwater ranges from 151 to 642 and 106 to 364 mg/l during pre-monsoon and post-monsoon seasons respectively. The Na^+ values indicates that 69% of samples during pre-monsoon season and 44% of samples during post-monsoon season are exceeding the acceptable limit according to BIS 2012. The K^+ values of groundwater ranges from 2 to 9 and 4 to 9 mg/l during pre-monsoon and post-monsoon seasons respectively. The results of K^+ indicates that all the samples during pre and post monsoon seasons fall within the acceptable limit according to BIS 2012. The Ca^{2+} values of groundwater ranges from 32 to 200 and 45 to 278 mg/l during pre-monsoon and post-monsoon seasons respectively. The obtained values of Ca^{2+} indicates that 56% of samples during pre-monsoon season and 81% of samples during post-monsoon are exceeding the acceptable limit of BIS 2012. The Mg^{2+} values of groundwater ranges from 6 to 39 and 9 to 55 mg/l during pre-monsoon and post-monsoon seasons respectively. The values of Mg^{2+} indicates that 19% of samples are exceeding the acceptable limit of BIS 2012 in both pre-monsoon and post-monsoon seasons.

The HCO_3^- values of groundwater ranges from 285 to 570 and 310 to 640 mg/l during pre-monsoon and post-monsoon seasons respectively. The results of HCO_3^- indicates that all the samples are exceeding the acceptable limits during pre and post monsoon seasons according to BIS 2012. The F^- values of groundwater ranges from 0.9 to 3.1 and 0.6 to 3.0 mg/l during pre-monsoon and post-monsoon seasons respectively. The results of F^- indicates that 81% of samples during pre- monsoon season and 19% of samples during post-monsoon season are exceeding the acceptable limits of BIS 2012. The Cl^- values of groundwater ranges from 202 to 1385 and 92 to 717 mg/l during pre-monsoon and post-monsoon seasons respectively. The results of Cl^- indicates that 81% samples during pre-monsoon and 50% of the samples during post-monsoon season are exceeding the acceptable limits of BIS 2012. The NO_3^- values ranges from 8 to 41 and 9 to 41 mg/l during pre-monsoon and post-monsoon seasons respectively. The SO_4^{2-} values ranges from 15 to 75 and 12 to 59 mg/l during pre-monsoon and post-monsoon seasons, respectively. The results of NO_3^- and SO_4^{2-} indicates that all the samples during pre-monsoon and post-monsoon seasons fall within the acceptable limits of BIS 2012.

Hydrochemical facies

The hydrochemical evolution of groundwater can be understood by plotting the major cations and anions in the Piper trilinear diagram (Piper, 1944). This diagram is useful in bringing out chemical relationships among water in more definite terms (Walton, 1970).

The hydrochemical facies reflect the effect of chemical processes and flow patterns in the lithologicalenvironment of groundwater (Back, 1966; Freeze and Cherry, 1979). It can assist in elucidating mechanisms of flow and transport in groundwater systems, and unlock an archive of paleo- environmental information (Hem, 1991, Pierre et al., 2005). It reveals similarities and differencesamong water samples because those with similar qualities will tend to plot together as groups (Todd, 2001). The Piper trilinear diagram of Balanagar industrial area presented in Figure 3 and classification groundwater samples were presented in Table 5.

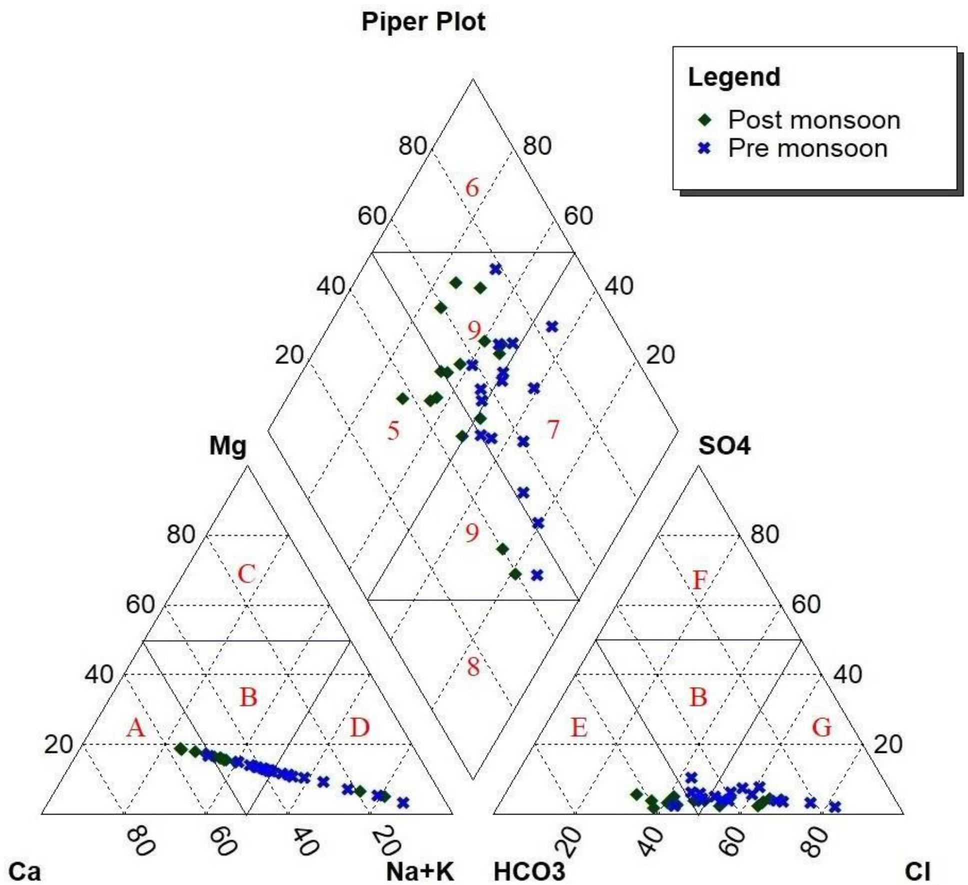

Figure 1: Piper trilinear diagram for Balanagar industrial area

Table 5: Classification of Balanagar groundwater samples based on Piper Diagram

Subdivisions of Diamond Shaped Field	Characteristics	% of samples (PRM)	% of Samples (POM)
Area 1	Alkaline Earths (Ca^{2+} + Mg^{2+}) exceed alkalis (Na^{+} + K^{+})	37.5	81
Area 2	Alkalis (Na^{+} + K^{+}) exceed alkaline earths (Ca^{2+} + Mg^{2+})	62.5	19
Area 3	Weak acids (CO_3^{2-} + HCO_3^{-}) exceed strong acids (SO_4^{2-} + Cl^{-})	6	44

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Area 4	Strong acids (SO_4^{2-} + Cl^-) exceed weak acids (CO_3^{2-} + HCO_3^-)	94	56
Area 5	Carbonate hardness (Secondary alkalinity) exceeds 50%	Nil	31
Area 6	Non carbonate hardness (Secondary Salinity) exceeds 50%	Nil	Nil
Area 7	Non carbonate alkali (primary salinity) exceeds 50%	56	6
Area 8	Carbonate alkali (primary alkalinity) exceeds 50%	Nil	Nil
Area 9	None of the cation or anion pair exceeds 50%	44	63

(**Note**: PRM = Pre-Monsoon, POM = Post-Monsoon)

Suitability for Irrigation purpose

The composition of dissolved constituents and its concentration determines the water quality for irrigation purpose. The evaluation of groundwater for irrigation suitability has been carried out based on Wilcox diagram, Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Sodium percentage (Na%), Kelly's Index (KI), Permeability Index (PI), Gibbs Ratio I (for anions), Gibbs Ratio II (for cations) and Chloroalkaline indices.

The Wilcox diagram is shown in Figure 4 and the calculated irrigation suitability parameters during pre-monsoon and post-monsoon seasons are shown in Table 6 & Table 7 respectively, and classification of groundwater samples based on irrigation parameters are shown in Table 8.

Table 6: Irrigation Suitability Parameters of Balanagar Industrial Area (Pre-Monsoon)

S. No	SAR	RSC	Na%	PI	KI	Gibbs Ratio–I (For anions)	Gibbs Ratio–II (For cations)	CAI–1	CAI–2
1	4.5	0.61	61	80	1.5	0.61	0.67	0.07	0.09
2	5.4	2.92	64	84	1.8	0.48	0.70	-0.33	-0.22
3	9.1	2.51	74	87	2.8	0.70	0.79	0.04	0.07
4	8.3	4.86	76	95	3.1	0.51	0.81	-0.41	-0.34
5	5.7	2.65	64	82	1.7	0.54	0.70	-0.09	-0.08
6	11.3	-4.42	70	76	2.3	0.84	0.75	0.28	1.21
7	10.3	1.18	72	82	2.5	0.71	0.77	0.07	0.13
8	4.0	0.55	54	72	1.1	0.56	0.61	0.06	0.06
9	5.9	0.42	66	81	1.9	0.66	0.72	0.03	0.05
10	13.1	6.91	87	105	6.4	0.44	0.90	-1.09	-0.74
11	4.4	2.42	60	83	1.5	0.48	0.67	-0.17	-0.13
12	4.0	-0.30	55	72	1.2	0.64	0.62	0.21	0.29
13	4.2	-1.62	47	61	0.9	0.57	0.54	0.20	0.23
14	8.8	3.55	80	99	3.9	0.58	0.84	-0.27	-0.29
15	11.0	6.54	82	101	4.6	0.50	0.86	-0.49	-0.41
16	7.5	-4.91	59	68	1.5	0.78	0.66	0.31	0.90

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Table 7: Irrigation Suitability Parameters of Balanagar Industrial Area (Post-Monsoon)

S. No	SAR	RSC	K	Na%	PI	KI	Gibbs Ratio–I (For anions	Gibbs Ratio–II (For cations)	CAI–1	CAI–2
1	3.8	2.42	582	62	90	1.5	0.34	0.68	-0.86	-0.37
2	5.1	2.88	285	62	83	1.6	0.43	0.69	-0.43	-0.28
3	5.5	-1.01	141	58	71	1.3	0.66	0.64	0.17	0.26
4	6.2	5.26	310	70	94	2.3	0.38	0.76	-0.72	-0.37
5	4.5	2.17	270	56	76	1.3	0.44	0.63	-0.25	-0.18
6	5.5	-1.99	120	55	67	1.2	0.68	0.62	0.23	0.39
7	7.2	1.12	101	62	74	1.6	0.65	0.68	0.16	0.26
8	3.2	0.63	292	47	67	0.9	0.50	0.54	0.09	0.07
9	3.5	-1.65	255	48	64	0.9	0.58	0.55	0.06	0.07
10	6.9	6.08	264	72	94	2.5	0.39	0.77	-0.67	-0.38
11	3.3	1.14	365	49	71	0.9	0.42	0.56	-0.21	-0.13
12	3.5	-0.40	258	49	67	0.9	0.55	0.56	0.11	0.12
13	3.1	-7.56	107	34	46	0.5	0.66	0.41	0.52	0.84
14	3.5	0.82	306	51	71	1.0	0.49	0.58	-0.05	-0.04
15	6.0	2.92	183	63	80	1.7	0.51	0.69	-0.15	-0.14
16	6.2	-2.56	98	56	67	1.3	0.71	0.63	0.26	0.48

Table 8: Classification of Groundwater based on Irrigation Water Quality Standards

Parameter	Range	Class	% Of Samples	
			PRM	POM
SAR (Richards 1954)	0-10	Excellent	75	100
	10-18	Good	25	-
	18-26	Permissible	-	-
	>26	Unsuitable	-	-
RSC (Eaton 1950)	<1.25	Suitable	50	62.5
	1.25-2.5	Marginally Suitable	6	12.5
	>2.5	Unsuitable	44	25
Na% (Wilcox 1955)	<20	Excellent	-	-
	20-40	Good	-	6
	40-60	Permissible	25	56
	60-80	Doubtful	62.5	38
	>80	Unsuitable	12.5	-
KI (Kelly 1963)	<1	Suitable	6	31
	>1	Unsuitable	94	69
PI (Doneen 1962)	>75	Good	75	37.5
	25-75	Moderate	25	62.5
	<25	Poor	-	-

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Classification based on Wilcox Diagram

In the study area during pre-monsoon season 12.5%, 6.25%, 56.25%, 12.5% and 12.5% of samples fall under C4S1 (very high salinity with low sodium), C4S2 (very high salinity with medium sodium), C3S1 (high salinity with low sodium), C3S2 (high salinity with medium sodium) and C3S3 (high salinity with high sodium) categories respectively. During post-monsoon season 6.25%, 75%, 12.5% and 6.25% of samples fall under C4S1 (very high salinity with low sodium) C3S1 (high salinity with low sodium), C3S2 (high salinity with medium sodium) and C2S1 (medium salinity with low sodium) categories respectively. It reveals that majority of the samples fall in high salinity with low alkali hazard category.

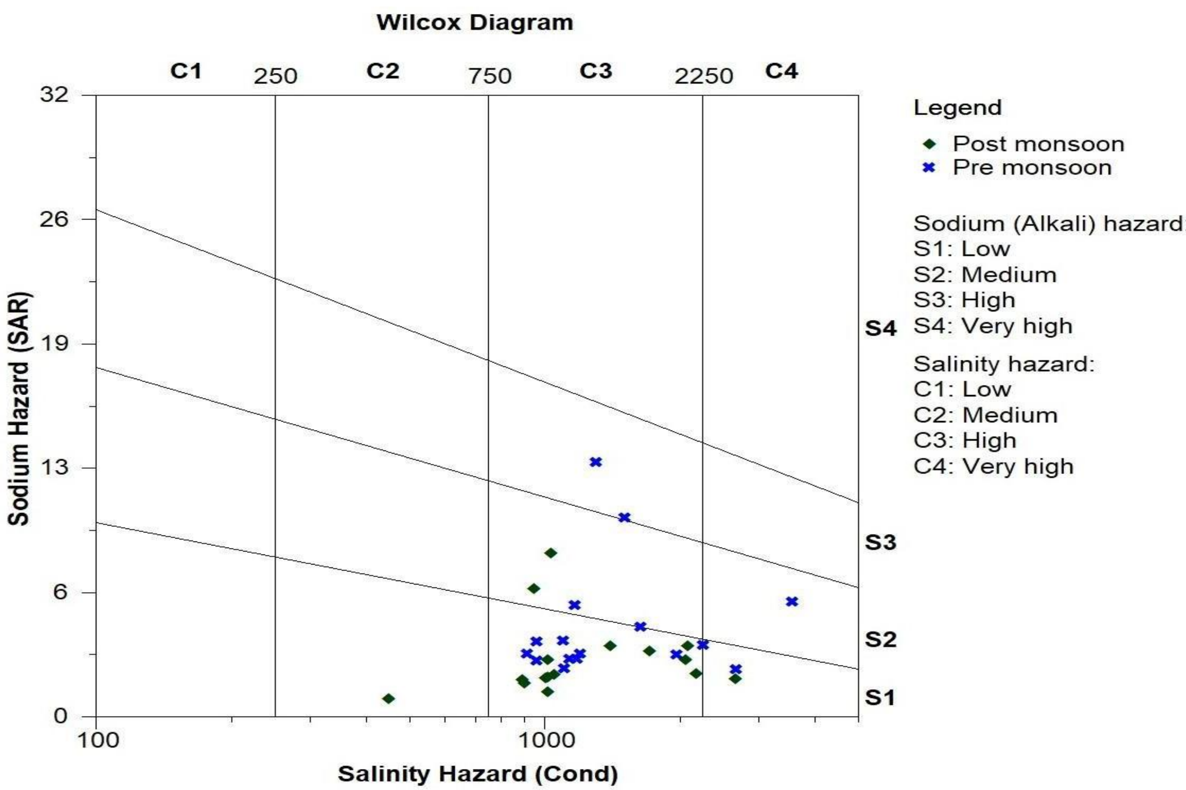

Figure 4: Classification of Groundwater based on Wilcox diagram

Sodium Adsorption Ratio (SAR)

The SAR is most useful parameter in the evaluation of groundwater for irrigation purpose as it measures the sodium hazard. It is calculated using the formula:

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

(Where all ionic concentrations are expressed in meq/l)

In the study area during pre-monsoon season 75% of samples fall under excellent and 25% of the samples in good categories. During post monsoon season all the samples fall under excellent category.

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Residual Sodium Carbonate (RSC)

The concentration of CO_3^{2-} and HCO_3^- as related to the concentration of Ca^{2+} and Mg^{2+} referred as residual sodium carbonate (RSC). It is calculated using following formula:

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

(Where all ionic concentrations are expressed in meq/l)

In the study area during pre-monsoon season 50%, 6% and 44% of samples fall under suitable, marginally suitable and unsuitable category respectively. During post-monsoon season 62.5%, 12.5% and 25% of samples fall under suitable, marginally suitable and unsuitable category respectively.

Sodium Percentage (Na%)

Wilcox (1955) have determined the hazardous effect of sodium on quality of groundwater for irrigation usage in terms of sodium percentage (Na%). It is calculated using following the formula:

$$Na\% = \frac{\left(Na^+ + K^+\right) \times 100}{\left(Ca^{2+} + Mg^{2+} + Na^+ + K^+\right)}$$

(Where all ionic concentrations are expressed in meq/l)

In the study area during pre-monsoon season 25%, 62.5% and 12.5% of samples fall under permissible, doubtful and unsuitable category respectively. During post-monsoon season 6%, 56% and 38% of samples fall under good, permissible and doubtful category respectively. It indicates that majority of the samples during pre-monsoon and post-monsoonseasons fall under doubtful and permissible category respectively.

Kelly's Index (KI)

Kelly (1940) have determined the hazardous effect of sodium on water quality for irrigation purpose using Na^+, Ca^+ and Mg^{2+} in terms of Kelly's ratio (KR). The KI calculated using following formula:

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

(Where all ionic concentrations are expressed in meq/l)

In the study area 94% and 69% of samples fall under unsuitable category during pre-monsoon season and post-monsoon season respectively.

Permeability Index (PI)

Doneen (1964) proposed Permeability Index (PI) to classify the groundwater for irrigation purpose. The PI is calculated using the following formula:

$$PI = \frac{Na^+ \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^{2+}} \times 100$$

(Where all ionic concentrations are expressed in meq/l)

In the study area during pre-monsoon season 75% of samples fall under good and 25% of samples fall under moderate category. During post-monsoon season 37.5% samples fall under

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good and 62.5% of samples fall under moderate category.

Gibbs Ratio

Gibbs (1970) proposed a diagram to understand the relationship of the chemical composition of the groundwater from their respective aquifer lithologies. The disintegration of rocks in the subsurface is the main criteria for controlling the composition of groundwater as it seeps down and becomes more and more concentrated with respect to the major ions. The Gibbs ratio for anions and cations is calculated using the following formulae:

$$\text{Gibbs Ratio - I (for anion)} = \frac{Cl^-}{\left(Cl^- + HCO_3^-\right)}$$

$$\text{Gibbs Ratio - II (for cation)} = \frac{\left(Na^+ + K^+\right)}{\left(Na^+ + K^+ + Ca^{2+}\right)}$$

(Where all ionic concentrations are expressed in meq/l)

Calculated Gibbs ratio-I and Gibbs ratio-II values are plotted against their respective TDS (Figure 5) to know the chemistry of groundwater whether it is due to rock dominance or evaporation dominance or precipitation dominance. The sample points on Gibbs diagrams suggests that the chemistry of groundwater is mainly controlled by rock weathering dominance and to some extent evaporation crystallization.

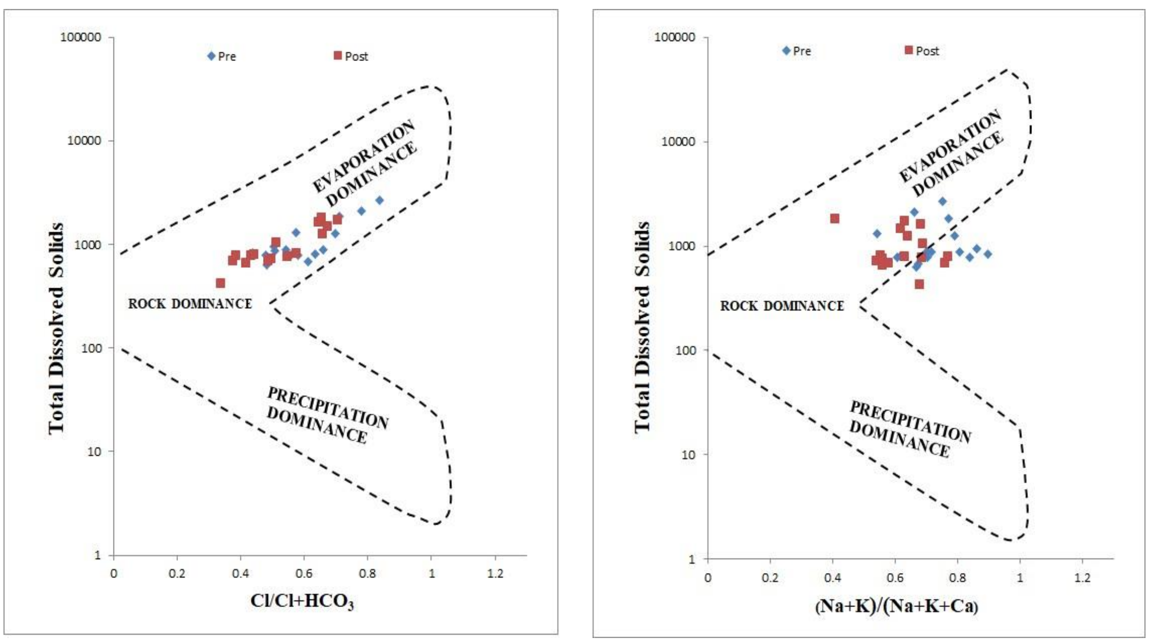

Figure 5: Gibbs diagrams showing the mechanisms influencing the groundwater chemistry

Chloroalkaline Indices

Schoeller (1967) proposed the Base Exchange index called Chloro-alkaline indices, CAI-1 and CAI-2. These indices are determined based on the exchange phenomenon of cations such as Na^+ and K^+ and the anions such as SO_4^{2-}, CO_3^{2-}, HCO_3^- and NO_3^-. The chemical reactions in which ion exchange between the groundwater and the aquifer environment occurs during the periods of residence and movement may be understood through the study of chloroalkaline

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indices. These in turn determine the quality of water. Chloroalkaline indices calculated using following formulae:

$$CAI\ 1 = \frac{Cl - (Na + K)}{Cl}$$

$$CAI\ 2 = \frac{Cl - (Na + K)}{(SO_4 + CO_3 + HCO_3 + NO_3)}$$

(Where all ionic concentrations are expressed in meq/l)

The CAI-1 & CAI-2 may be positive or negative depending upon the exchange of Na^+ ions and K^+ ions from rock with Ca^{2+} ions and Mg^{2+} ions in water and vice versa. If CAI ratio is positive, it is called as direct exchange, it means there is exchange between Na^+ ions and K^+ ions in water with Ca^{2+} ions and Mg^{2+} ions in rocks. If the CAI ratio is negative, it is called as reverse exchange, means there is exchange between Ca^{2+} ions and Mg^{2+} ions in water with Na^+ ions and K^+ ions in rocks. In the study area during pre-monsoon 44% of samples showing negative ratio and 56% of samples showing positive ratio. During post-monsoon 50% samples are showing positive ratio and 50% samples showing negative ratio.

Suitability for Industrial Purpose

The corrosive and scaling tendency of water determines the water quality for industrial purpose. The suitability of groundwater for industrial purpose is evaluated based on Langelier Saturation Index (LSI), Ryznar Stability Index (RSI), Puckorius Scaling Index (PSI), Larson-Skold Index (L-S Index), Aggressive Index (AI) and Corrosive Ratio (CR). The calculated values are shown in Table 9 and Table 10 during pre-monsoon and post-monsoon season respectively. The classification of groundwater based on industrial suitability parameters is shown in Table 11.

Table 9: Industrial Suitability Parameters of Balanagar Industrial Area (Pre-Monsoon)

S. No	LSI	RSI	PSI	L-S Index	AI	Corrosive Ratio
1	0.62	7.06	7.2	1.12	12.99	1.4
2	0.74	6.73	6.5	0.75	13.11	0.9
3	0.55	6.89	6.5	1.55	12.95	1.9
4	0.85	6.70	6.6	0.70	13.23	0.9
5	0.80	6.60	6.3	0.81	13.18	1.0
6	0.81	6.28	5.7	3.17	13.24	4.2
7	0.44	6.72	5.8	1.56	12.85	2.1
8	0.87	6.56	6.5	0.86	13.25	1.1
9	0.50	7.10	7.0	1.37	12.88	1.7
10	0.54	7.21	7.0	0.50	12.92	0.6
11	0.65	6.90	6.8	0.67	13.02	0.8
12	0.78	6.75	6.8	1.18	13.15	1.5
13	0.80	6.21	5.4	0.87	13.19	1.2
14	0.28	7.54	7.3	0.96	12.65	1.2
15	0.48	7.14	6.7	0.71	12.86	0.9
16	0.87	6.15	5.6	2.21	13.29	2.9

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Table 10: Industrial Suitability Parameters of Balanagar Industrial Area (Post-Monsoon)

S. No	LSI	RSI	PSI	L-S Index	AI	Corrosive Ratio
1	0.37	7.4	7.4	0.38	12.72	0.5
2	0.63	6.8	6.4	0.53	13.01	0.7
3	0.60	6.7	6.1	1.24	12.99	1.6
4	0.78	6.7	6.5	0.42	13.01	0.5
5	0.84	6.5	6.1	0.51	13.22	0.7
6	0.62	6.5	5.8	1.36	13.03	1.8
7	0.72	6.3	5.4	1.14	13.13	1.5
8	0.81	6.5	6.3	0.67	13.18	0.8
9	0.60	6.8	6.5	0.91	12.98	1.2
10	0.87	6.6	6.3	0.40	12.96	0.5
11	0.71	6.7	6.4	0.48	13.08	0.6
12	0.74	6.6	6.4	0.77	13.11	1.0
13	0.89	5.9	4.9	1.21	13.30	1.6
14	0.71	6.7	6.5	0.64	13.08	0.8
15	0.82	6.4	5.9	0.69	13.20	0.9
16	0.51	6.5	5.6	1.58	12.92	2.0

Table 11: Classification of Groundwater based on industrial suitability parameters

Index	Range	Classification & Interpretation	% Of samples	
			PRM	POM
LSI	LSI <0	Water is not saturated and has corroding tendency	-	-
	LSI=0	Water is saturated and has no scaling tendency	-	-
	LSI>0	Water is supersaturated and has scaling tendency	100	100
RSI	RSI<5.5	Water has rigorous scaling tendency	-	-
	5.5-6.2	Water has scaling tendency	6	6
	6.2-6.8	Water is balanced and has no scaling or corrosive tendencies	50	88
	6.8-8.5	Water has corrosive tendency	44	6
	RSI>8.5	Water has rigorous corrosive tendency	-	-
PSI	PSI<6	Water has scaling tendency	25	31
	6.0-7.0	Water has little scaling and corrosive tendencies	63	63
	PSI>7.0	Water has significant corrosive tendency	12	6
L-S Index	<0.8	Water has scaling tendency	31	63
	0.8-1.2	Higher corrosion rates can be obtained	38	12

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	>1.2	High rates of localized corrosion can be expected	31	25
AI	<10	Water is severely corrosive (highly aggressive)	-	-
	10-12	Water is moderately corrosive	-	-
	>12	Water has scaling tendency and has non-aggressive tendency	100	100
CR	<1	Non-Corrosive	31	56
	>1	Corrosive	69	44

Langelier Saturation Index (LSI)

Langelier (1936) proposed a calcium carbonate ($CaCO_3$) saturation index called as Langelier Saturation Index (LSI). It is used to evaluate or predict the degree of scale forming and scale dissolving tendency of water. LSI is calculated using following formula:

$$LSI = pH - pH_{(S)}$$

pH is the measured value of groundwater pH

$pH_{(S)}$ is the saturation pH which is measured by following equation

$$pH_{(S)} = (9.3 + a + b) - (c + d)$$

$$a = \frac{(\log_{10}[TDS] - 1)}{10}$$

$$b = -13.12 \log_{10}(^{o}C + 273) + 34.55$$

$$c = \log_{10}(Ca^{2+} \text{ as } CaCO_3, \text{ mg/L}) - 0.4$$

$$d = \log_{10}(\text{alkalinity as } CaCO_3, \text{ mg/L}).$$

In the study area all samples fall under LSI>0 range, it means groundwater is supersaturated and has scaling tendency but not corrosive.

Ryznar Stability Index (RSI)

Ryznar (1944) has designed an empirical method to determine stability index called as Ryznar Stability Index (RSI) of water for industrial usage by predicting scaling tendencies of water. RSI is calculated by following formula:

$$RSI = 2pH_{(S)} - pH$$

In the study area 50% of samples during pre-monsoon season and 88% of samples during post-monsoon season are balanced and have no significant scaling or corrosive tendencies and 44% of samples during pre-monsoon and 6% of samples during post-monsoon season have corrosive tendency and 6% of samples during both seasons has scaling tendency.

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Puckorius Scaling Index (PSI)

Paul Puckorius (1983) proposed the Puckorius scaling index (PSI). It is used to account the buffering capacity and the maximum quantity of precipitation that can form in bringing water to equilibrium (Davil et al., 2009). Puckorius has used an equilibrium pH rather than the actual system pH to account for the buffering effects.

$$PSI = 2pH_{(S)} - pH_{eq}.$$

Where pH_{eq} is measured by following formula

$$pH_{eq} = 1.465 \log_{10}\left(\text{alkalinity as } CaCO_3,\ \text{mg/L}\right) + 4.54$$

In the study area 63% of samples during pre-monsoon and post-monsoon season has little scaling and corrosive tendencies and 25% of samples during pre-monsoon season and 31% of samples during post-monsoon has scaling tendency and 12% samples during pre-monsoon season and 6% samples during post-monsoon season has significant corrosive tendency.

Larson – Skold Index (L-S Index)

Larson and Skold (1958) proposed an index to evaluate the industrial usage of water. Larson–Skold index (L-S Index) is the ratio of sulphate and chloride to the alkalinity in the form of bicarbonate and carbonate. The L-S index is calculated by using the following formula.

$$\text{L-S Index} = \frac{\left(SO_4^{\ 2-} + Cl^-\right)}{\left(HCO_3^{\ -} - CO_3^{\ 2-}\right)}$$

(Where all ionic concentrations are expressed in meq/l)

In the study area during pre-monsoon 31% samples has scaling tendency, 38% of samples has higher corrosion rates and 31% of samples are high rates of localized corrosion. During post-monsoon season 63% of samples has scaling tendency, 12% of samples has higher corrosion rates and 25% of samples has high rates of localized corrosion.

Aggressive Index (AI)

Aggressive index (AI) is a parameter of water corrosiveness which is often used as an alternative method for LI. It depends on the pH, total alkalinity and calcium hardness (Kalyani DS et al., 2017). The major advantage of this index is that the calculation does not need the temperature and TDS values and thus it is simpler than LI. On the other hand, AI is less accurate than LI, so it is considered as a general indicator rather than a quantitative measurement. AI is calculated using following formula.

$$\text{Aggressive Index (AI)} = pH + \text{Log10}\ (\text{Alkalinity} \times Ca^{2+}\ \text{Hardness})$$

In the study area during pre-monsoon and post monsoon season all the samples has scaling tendency and non-aggressive tendency.

Corrosive Ratio (CR)

The Corrosive Ratio (CR) is used to evaluate the corrosive tendency of groundwater on metallic pipes (Balasubramanian, 1986). Corrosivity ratio (CR) denotes susceptibility of groundwater to corrosion and is expressed as ratio of alkaline earths to saline salts in groundwater (N. Janardhan Raju et al., 2011). CR is calculated using the following formula:

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$$\text{Corrosive Ratio} = \frac{\left\{\left(\frac{Cl^-}{35.5}\right) + 2\left(\frac{SO_4^{\ 2-}}{96}\right)\right\}}{\left\{2\left(\frac{CO_3^{\ 2-} + HCO_3^{\ -}}{100}\right)\right\}}$$

(Where all ionic concentrations are expressed in mg/l)

In the study area 31% and 56% of samples are non-corrosive during pre-monsoon and post-monsoon season respectively and 69% and 44% of samples has corrosive nature.

CONCLUSIONS

The present study assessed the groundwater quality and its suitability for drinking, irrigation and industrial purposes in and around Balanagar industrial area using the various physico-chemical parameters. The order of abundance of major cations during the pre-monsoon is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ during post-monsoon. The abundance of major anions during pre-monsoon is $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^- > CO_3^{2-}$ and $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > CO_3^{2-}$ during the post-monsoon. Comparative analysis with BIS standards revealed that the EC, TDS, TH, TA, Ca^{2+}, Na^+, HCO_3^-, F^- and Cl^- are higher than the prescribed acceptable limits in most of the samples and the values of pH, NO_3^- and SO_4^{2-} are within the acceptable limits. It indicates that the groundwater is not suitable for drinking purpose. The high concentration of TH and Chlorides can be attributed to the untreated or improperly treated sewage and industrial effluents. Higher concentration of Fluorides may be due to the natural processes and also due to the use of fluoride salts in steel, aluminum and brick industries. Gibbs diagrams indicates that rock weathering and evaporation are the dominant processes controlling the chemical composition of groundwater. The suitability of groundwater for irrigation purpose was assessed using Wilcox diagram, SAR, RSC, Na%, KI and PI. Wilcox diagram indicates majority of the samples fall in the C3S1 which indicate high salinity and low sodium type which can be used for irrigation on almost all types of soils with little danger of exchangeable sodium. SAR values were found to be in excellent and good range. As the RSC, Na%, KI and PI values were found to be in both suitable and unsuitable categories and therefore the groundwater cannot be used directly for irrigation unless it is treated. The suitability of groundwater for industrial purpose was assessed using LSI, RSI, PSI, L-SI, AI and CR and the values indicate that the groundwater has scaling tendency and little corrosive and non-aggressive in nature.

ACKNOWLEDGMENT

The Authors extend their special thanks to University Grants Commission (UGC), for providing financial assistance through RGNF for doctoral research work and Head of the Department, Applied Geo-Chemistry and Coordinator of Department of Environmental Science, University College of Science, Osmania University for their enormous support.

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