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Groundwater Quality Assessment from a Hard Rock Terrain Kundalika River Basin, Beed District, Maharashtra, India

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Abstract:
In the study area, the primary source of water is groundwater for the drinking and irrigation purpose. For the assessment of groundwater quality results of 48 groundwater samples in post& pre monsoon season for the year 2021 & 2022 were carried out from Kundalika River basin Beed District, Maharashtra. The pH values of groundwater reveal that slightly alkaline in nature. The electric conductivity varies from 290 to 2640 µS/cm; the total dissolved solids (TDS), alkalinity, total hardness, calcium, magnesium, sodium, potassium, chloride measured. Most of TDS values of groundwater samples less 1000 mg/l indicate suitable for drinking and irrigation purpose. In the piper trilinear diagram, it is observed that 80% groundwater samples in post monsoon season 2021 and pre monsoon season 2022 fall in the Ca-HCO_3 region and remaining 20 % groundwater samples of both season falls in mixed type such as Ca-Na-HCO_3 region. According to Wilcox's diagram all groundwater samples are good for irrigation purpose except 2 % samples of post monsoon season 2021 and pre monsoon season 2022 are doubtful to unsuitable area for irrigation use. Various water quality indices like: EC, SAR, SSP, RSC, MAR and KR shows that most water samples are suitable for irrigation uses. U. S. Salinity Laboratory Diagram shows that all the groundwater samples belongs to C2-S1,C3-S1,C3-S1 and C3-S2 category suggesting a medium to high salinity and alkalinity; this can be good for irrigation purpose, with few exceptions under specific conditions.

Keywords: *Groundwater Quality, Hydro-geochemistry, Drinking water, Irrigation Suitability, Kundalika River Basin, Beed District, Maharashtra.*

INTRODUCTION

Groundwater is a life sustaining resource which fulfils substantial part of domestic and agricultural needs of the country. Due to unsustainable depletion of groundwater has been documented on both regional and global scales (Tiwari et al., 2022; Chaudhary et al., 2018; Rodell et al., 2009; Gleeson et al., 2012; MacDonald et al.,2016). The quality of groundwater is equally import to quantity owing to the suitability of water for various purposes (Kumar et al., 2009). In the recent years, intensive agricultural activities activities, domestic and industrial discharge, over-exploitation, uneven rainfall and mismanagement of groundwater raised serious concern regarding groundwater contamination (Jain et al. 2010; finko et al.2010; Salifu et al. 2013). Irrigated farming is a world largest abstractor and primary use of user of groundwater assets, with groundwater irrigating approximately 65 percent of total agricultural land. Since groundwater is the primary source for various purposes in the study area, including drinking and irrigation, it's critical to evaluate its hydro-chemical characteristics and suitability for drinking, domestic and irrigation. Water quality plays vital role in promote agricultural production and standard of human health (K. Panigrahi et al. 2022; Shingh et al. 2020). For the assessment and management of groundwater resources, it is essential to understand the hydro-geological and hydro-geochemical properties of aquifer (Umer et al. 2001). The geochemical composition of groundwater is mainly influenced by natural factors such as wet and dry soil deposition, precipitation, evapotranspiration, soil matrix, rock-water interaction, residence time, etc. and anthropogenic factors which include human activities related to the surface runoff and groundwater recharge from agricultural uses and the generation and disposal of industrial wastes, leaches form solid waste dumping, on-site sanitation systems, and disposal of domestic waste (Todd 1980; toth1999; Sefie et al. 2018; Karroum et al.2017; Barbieri et al.2014; Mukate et al. 2017; Wagh et al. 1019). The rapid increase in water diversion from aquifers over last 15 years has resulted in groundwater depletion, also known as long-term water- level reductions. On the other hand, recent changes in agricultural land use and irrigation could result in groundwater contamination from agricultural fertilizers and pesticides applied to fields. Understanding the quality of irrigation ground water is also critical for evaluating the necessary management changes for long-term productivity. As a result, having a detailed understanding of region's groundwater situation is critical. Groundwater quality is presently as significant as its quantity. Geological and climatic condition conditions are the primary determinants of groundwater quality. Groundwater quality in many parts of India is affected by high concentrated of Nitrate (NO_3^-) derived from anthropogenic sources (Ingewar et al., 2021). Increasing water withdrawals and consumption, intensive urbanization, industrial growth, over use of fertilizers and pesticides in agricultural regions, human and animal wastage and unplanned drainage systems are some of the important causes for the deterioration of the quality of groundwater (Adimala et al. 2018; Aher et al.2014). The importance of groundwater quality in maintaining groundwater protection and excellence cannot be overstated. As a result, deciding the quality of groundwater is important not only for current but also for potential use. Groundwater quality with respect to groundwater table differs from season to season and place to place (Gabr et al. 2021). Geology, the degree of chemical weathering of different rock types, the consistency of recharge water, and water-rock interaction all have an effect on groundwater quality.

The present study focuses on to gain the better understanding of groundwater quality and its suitability for drinking and agriculture in the Kundalika River basin, Beed District, Maharashtra state, India. The samples collected during post and pre monsoon season 2021-22 from the study area.

STUDY AREA

The Beed district, forming part of Marathwada region of central Maharashtra, is bounded on the north by the Godavari River, on the south by Manjra River and on the west by the Sina River. It has an aerial extent of about 11,000 sq. km lying between the north latitudes 18°25′N and 19°27′N and the east longitudes 74°49′E and 76°45′E. The study area of Kundalika river basin situated in Beed district in the latitude 19°43′00″ N to 19°10′30″ N longitude 76°00′00″ E to 76°12′30″ E. It has an aerial extent of about 410 sq. km.

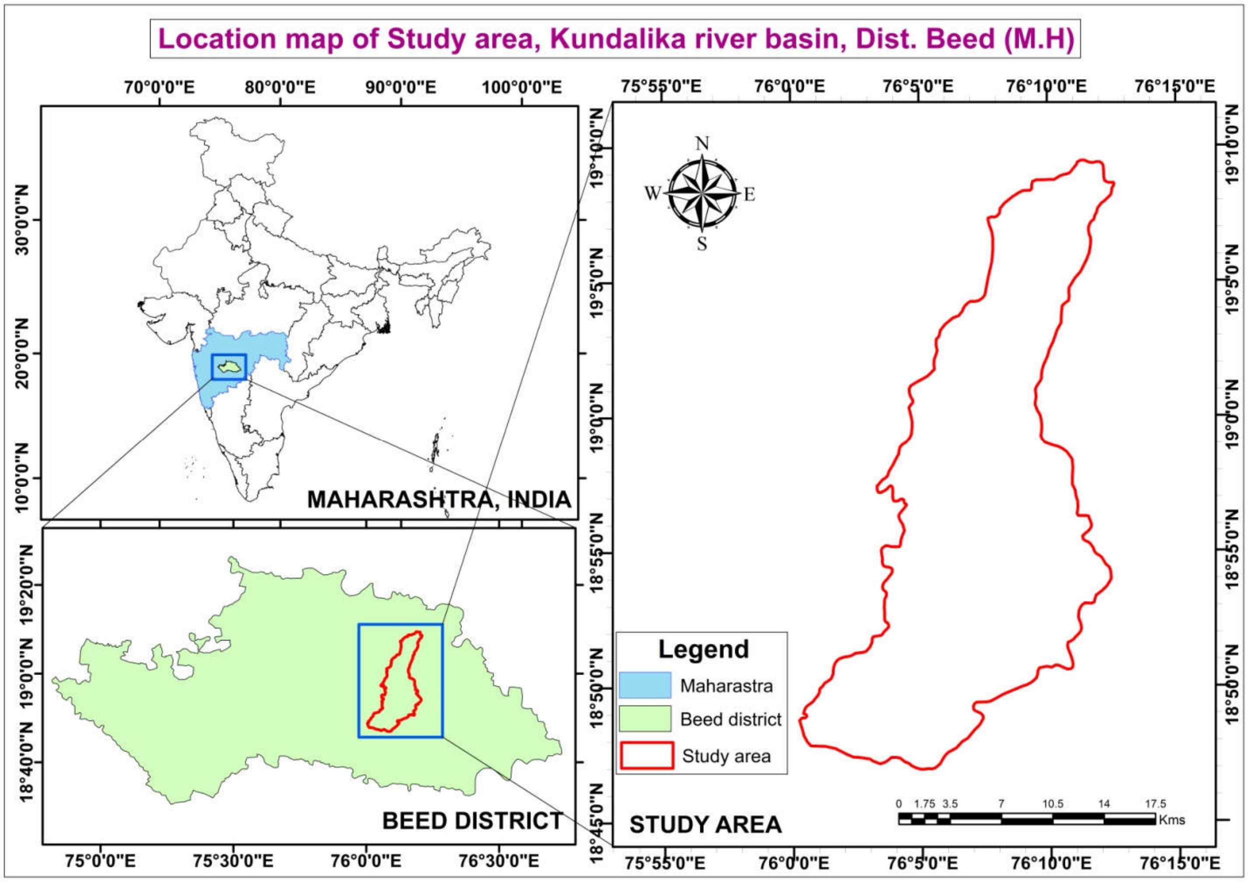

Figure 1: Location map of study area

Geology of Study Area

The Beed district occupied by Basalt formations belonging to Deccan trap of Cretaceous-Eocene age. The basalt formations belong to the type called "Plateau Basalts" and uniform in composition corresponding to that of Dolerite or Basalt with dark grey to dark greenish grey in colour. Soil constitutes the basis of an agricultural enterprise and plays a very important role in the agriculture economy of a region. Difference in soil texture, drainage and fertility are of major importance in explaining contrast in the agriculture from one region to another. The soil in the district can be classified into four main categories on the basis of depth and structure, a) Shallow soil (with depth <7 inches), b) Moderate depth black soil (7-9 inches), c) Medium depth black soil (9-27 inches), d) Very deep black soil (27-45 inches).

METHODOLOGY

In the present work 48 groundwater samples were collected from in dugwells, which were in use for drinking, Domestic and irrigation purposes. The samples collected in clean 1 liter polyethylene bottles during post and pre monsoon season during 2021-22. Before collecting the samples in the field, the bottles were again rinsed with water of respective dugwells (Pophare et al. 2019; Handa, 1967). These samples were analysed for physic-chemical parameters pH, EC, TDS, TH Ca^{2+},

Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-}, SO_4^{2-}, pH and EC were measured using digital instruments. Other chemical parameters were analysed using measured using standard hydrochemical analytical techniques (APHA. 2019; APHA1995). The parameter like Ca^{2+}, Mg^{2+}, $Cl^{-}$and HCO_3^{-}, were determined by titration. While Na^{+} and K^{+} were determined by using flame photometer; SO_4^{2-} were analysed by using visible spectrometer (Table 2-3). The results obtained were compared with the specifications given by BIS (2003) and WHO (1997) suitability for drinking and domestic uses (Table 4). The suitability of groundwater for irrigation purpose was evaluated using the sodium adsorption ratio, soluble sodium percentage, Kelly's ratio, magnesium ratio, residual sodium carbonate.

Table 1: **Location of Collected Groundwater Samples in the study area**

Sr. No.	Name of Village	Latitude	Longitude	Elevation M
1	Chondi	18°54′26.8″	76°07′43.2″	519
2	Sonimoha	18°53′37.4″	76°06′47.4″	530
3	Jahagir Moha	18°25′51.5″	76°07′07.5″	534
4	Bhayjali	18°51′17.7″	76°07′19.7″	583
5	Aranwadi	18°51′51.1″	76°04′25.7″	547
6	Gavandara	18°51′16.8″	76°03′53.2″	561
7	Choramba	18°53′48″	76°04′46.7″	538
8	Kari	18°56′43.6″	76°10′15.7″	550
9	Katewadi	18°55′54″	76°10′30.4″	513
10	Bhogalwadi	18°54′37″	76°10′38″	547
11	Bhogalwadi	18°54′14.4″	76°10′13.3″	566
12	Kalechiwadi	18°53′56″	76°09′23″	584
13	Bhogalwadi	18°55′41.8″	76°10′07.11″	537
14	Gavandara	18°56′07.3″	76°08′26.7″	504
15	Gavandara	18°56′30.7″	76°07′54.6″	489
16	Gavandara	18°56′39.4″	76°07′51.3″	488
17	Upali	18°57′41″	76°07′03.6″	488
18	Upali	18°57′38.9″	76°07′25.7″	482
19	Upali	18°57′59″	76°07′34.33″	479
20	Upali	18°57′46.6″	76°07′53.9″	463
21	Ambewadgaon	18°55′14.6″	76°07′18.7″	491
22	Ambewadgaon	18°54′51.2″	76°06′46.3″	513
23	Bavi Tanda	18°58′59.4″	76°08′04.7″	469
24	Kuppa	19°00′02.9″	76°08′23.6″	472
25	Dukadegaon	19°01′59.3″	76°08′19.9″	453
26	Chinchala Wasti	19°01′45.1″	76°07′17.4″	469
27	Chinchala Tigaon Fata	19°01′57.7″	76°06′53.6″	468
28	Jaisunaik Tanada	19°03′41″	76°07′41.8″	452
29	Dhanora	19°03′00.4″	76°08′22.7″	449
30	Kendepimpari Tanda	19°03′25.1″	76°08′24.8″	447
31	Kendepimpari	19°03′33.3″	76°08′31″	436
32	Dhoragaon / Khanapur	19°07′39.9″	76°11′34.7″	422
33	Dhunakwad	18°56′11.5″	76°05′28.2″	472
34	Dhunakwad	18°56′07.4″	76°05′04.5″	488
35	Pahadidahiphal	18°55′57.3″	76°04′23.8″	497
36	Sonimoha	18°54′23.1″	76°05′52.6″	532
37	Laul No 1	19°04′36.5″	76°09′36.5″	454

38	Khaparwadi	19°04′42.3″	76°07′22.3″	459
39	Pardi- Deogaon raod	19°05′00.9″	76°07′57.8″	446
40	Chinchala	19°02′36.2″	76°07′04.9″	446
41	Tigaon	19°01′20.8″	76°06′40.6″	460
42	Pusra	18°59′54.7″	76°06′27.8″	470
43	Pusra near h temple	18°59′31.1″	76°06′29.8″	468
44	Hiwargvhan near R Brij	18°58′41.8″	76°06′05.4″	459
45	Hiwargvhan	18°58′20.9″	76°06′03.8″	486
46	Pardi- Laul raod	19°04′44.4″	76°09′11.5″	450
47	Dhagewadi	18°53′35.3″	76°04′01.3″	582
48	Dharur	19°49′15.8″	76°06′38.7″	745

RESULT AND DISCUSSION

The result of the research work used to assess the suitability of groundwater in the study area for drinking and irrigation purpose. Further down the major ions (Ca, Mg, Na, K, HCO3, So4,Cl), as well as important physical parameters such as pH, EC, TDS, TH and solubility of groundwater in the study area, are discussed. The obtained results were evaluated in accordance with the norms prescribed under 'Indian standard drinking water specification IS10500 (BIS, 1991; Shankar et al., 2008; Panigrahi and Bhumika., 2022).

The relative concentration of hydrogen ions in water indicates its acidic or alkaline nature (Bower, 1978; Karanth, 1987; Mondal et al. 2002). The observed pH of the study area ranges from 7.20 to 7.92 in the post- monsoon season during 2021 (table 2). Where as in pre-monsoon season 2022, it is observed that pH values ranges from 7.12 to 7.83 (Table3). Hence based on result it is observed that the pH of groundwater in the study area slightly alkaline in nature, as prescribed by BIS 2012 and WHO 2009 all samples observed in below desirable limit (Table no4). EC measures the degree of salinity in water, which affect the taste and has significant impact on quality of water, as per WHO (1997) (Aher et al. 2014). EC is an indirect measure of salinity in groundwater, WHO classified the groundwater as excellent (0-333mg/l), good (333-500mg/l), permissible (500-1100mg/l), brackish (1100-1500mg/l) and saline (1500-10000mg/l). According to this classification, 9 samples of the post monsoon season 2021 and 18 samples of pre monsoon season 2022 fall in good water quality, while 37 samples of the post monsoon season 2021 and 29 samples of pre monsoon season 2022 lie in the permissible water quality category, remaining sample are above permissible limit. The total dissolved solid (TDS) are important parameter for drinking water quality and irrigation suitability due to contained ionic constituents (Davies and De Wiest 1966). The TDS has a wide range in study area of 185.60 to 1689.60 mg/l in post monsoon season 2021 and 185.60 to 1491.20 mg/l in pre monsoon season 2022 (Table 2&3). According to BIS (2012), the highest optimal level of TDS is 500 mg/l, and the maximum permissible level is 2000 mg/l (table4). On the basis of this classification, 22.91% of samples in post monsoon season 2021 and 47.91% of samples in pre monsoon season 2022 fall within the maximum acceptable range, while 77.08% samples of post monsoon season 2021 and 52.08% samples of pre monsoon season fall in exceed the maximum allowable limit (Table 4). According to Davis and De Wiest (1966) classification, TDS value below 500 mg/l is desirable for drinking, if TDS value ranges between 500-1000 mg/l is permissible for drinking and TDS value between 1000-3000mg/l it is useful for irrigation purpose. Based on this classification, groundwater of the study area is suitable for drinking and irrigation purpose (Panigrahi & Bhumika, 2022; Adimalla, 2019). The desirable limit of Ca^{2+} is 75mg/l for drinking purpose, beyond this limit it leads to calculus layer in water supply structures. The permissible limit is extended up to 200 mg/l (WHO, 1997; BIS, 2003). The calcium concentration in the groundwater of the study area ranges from 39.58 to 154.71 mg/l in the post monsoon season 2021 and 28.06 to 132.26 mg/l, where as in the pre monsoon season 2022. The BIS has set the permissible limit 200 mg/l for calcium contents in drinking water (Table no 4). As per BIS standards, all the groundwater samples from both post monsoon 2021 and pre monsoon season 2022 are within safe limits. The magnesium content range from 1.37 to 57.69 mg/l in post monsoon season 2021 and -3.66 to 47.52 mg/l in pre monsoon season 2022 (Table no 2&3). Hence all samples of post monsoon 2021 and pre monsoon 2022 season lie within permissible limit of 100 mg/l of the BIS (Table no 4).

Total Hardness (TH)

The hardness is an important criterion for determining the usability of water for drinking and other domestic use. The principle cations imparting hardness to water are Ca^{2+} and Mg^{2+}. The TH for post monsoon season 2021 ranges from 212 to 610 mg/l in and 186 to 552 mg/l in pre monsoon season 2022 (Table 2&3). The desirable limit of TH is 200mg/l, which may be extended up to permissible limit 600mg/l (BIS, 2012). Hence 98% groundwater samples of post monsoon season 2021 within permissible limits and 100% groundwater samples pre of monsoon season 2022 of within permissible limits BIS (2012).

Sodium (Na^+)

Na^+ is the most abundant of the alkali metals forming the constituent of much igneous rock salt (Kanagarj et al. 2014). Na^+ concentration varies from 16 to 200 mg/l on post monsoon season 2021 and 18 to 176 mg//l in pre monsoon season 2022 (Table no). The permissible of Na^+ in drinking water is 200 mg/l (WHO, 1997). Hence all values are well within permissible limits of WHO (1997).

Potassium (K^+)

K^+ concentration ranges from 0 to 65 mg/l in post monsoon season 2021 and 0 to 15 mg/l in pre monsoon season 2022 (Table 2&3). The main source of potassium in groundwater includes rain water, extensive use of potash fertilizers and use of surface water for irrigation (Aher et al. 2014).

Chloride (Cl^-)

Cl^- in groundwater is due to their movement through salt bearing strata and other anthropogenic sources such as fertilizers, manure, human and animal waste. In drinking water, high chloride content may lead to laxative effect (Bhardwaj et al. 2010).The 250 mg/l desirable limit and 1000 mg/l permissible limit given by BIS (2003). The Cl^- content in the groundwater of study area varies from 45.44 to 281.16 mg/l in post monsoon season 2021 and 29.82 to 266.96 mg/l in pre monsoon season 2022 (Table 2&3).

Bicarbonate (HCO_3^-)

HCO_3^- are derived mainly from neutralization of CO_2 originated either by adsorption from the atmosphere and from the decomposition of organic matter in the recharge area (Reddy et al.2014). The concentration of HCO_3^- varies from 160 to 760 mg/l in post monsoon season 2021 and 100 to 725 mg/l in pre monsoon season 2022 (Table 2&3). The acceptable limit of bicarbonate is 200 mg/l while maximum permissible limit is 600 mg/l (BIS, 2003). It is observed that 3 samples in post monsoon season 2021 and 4 samples in pre monsoon season 2022 are exceeding maximum permissible limit, apart from this all groundwater samples within permissible limit as prescribed by BIS and WHO (Table 4).

Sulphate (SO_4^{2-})

Concentration of sulphate SO_4^{2-} varies from 8.97 to 184.41 mg/l in post monsoon season 2021 and 8.97 to 178.34 mg/l in pre monsoon season 2022 (Table 2&3). The desirable limit of sulphate 200 mg/l and maximum permissible limit of sulphate is 400 mg/l as specified by BIS (2003) (Table 4). It is observed that all samples of groundwater are within permissible limit.

Table 2: Physico-chemical parameter of post-monsoon season 2021

Sr. No.	Ph	EC	TDS	Ca	TH	Mg	Cl	HCO3	Na	K	SO4
Unit		μm/cm	Mg/l								
1	7.57	1000.00	640.00	97.80	460.00	32.06	69.58	275.00	49.00	1.00	50.21
2	7.36	1010.00	646.40	107.41	484.00	36.47	116.44	485.00	38.00	0.00	48.97
3	7.45	650.00	416.00	76.15	410.00	21.89	53.96	445.00	31.00	1.00	40.97
4	7.49	760.00	486.40	90.58	366.00	33.25	73.84	420.00	29.00	2.00	39.59
5	7.58	600.00	384.00	77.76	444.00	20.85	49.70	390.00	26.00	1.00	35.72
6	7.34	740.00	473.60	86.57	306.00	34.38	59.64	410.00	30.00	1.00	21.38
7	7.40	900.00	576.00	81.76	346.00	29.09	78.10	470.00	38.00	1.00	44.14
8	7.21	880.00	563.20	84.97	328.00	32.10	80.94	425.00	59.00	17.00	43.72
9	7.38	650.00	416.00	85.77	336.00	32.12	45.44	390.00	28.00	5.00	31.59
10	7.46	870.00	556.80	95.39	464.00	30.36	49.70	470.00	41.00	2.00	21.52
11	7.40	790.00	505.60	98.60	412.00	35.39	65.32	410.00	25.00	1.00	59.17
12	7.20	690.00	441.60	101.80	434.00	36.03	49.70	410.00	21.00	1.00	27.31
13	7.39	990.00	633.60	95.39	364.00	36.29	55.38	420.00	44.00	1.00	51.17
14	7.41	1160.00	742.40	90.58	356.00	33.85	51.12	475.00	29.00	1.00	22.21
15	7.52	1450.00	928.00	83.37	338.00	30.54	59.64	420.00	33.00	0.00	41.52
16	7.47	1340.00	857.60	76.15	408.00	22.01	66.74	550.00	70.00	0.00	34.90
17	7.37	1200.00	768.00	107.41	346.00	44.65	90.88	345.00	34.00	1.00	87.86
18	7.55	1270.00	812.80	92.99	352.00	35.54	80.94	405.00	59.00	0.00	67.45
19	7.40	880.00	563.20	113.03	484.00	39.88	90.88	460.00	36.00	1.00	59.59
20	7.32	1310.00	838.40	121.84	396.00	50.44	149.10	510.00	85.00	9.00	144.28
21	7.20	970.00	620.80	122.64	428.00	49.03	142.00	560.00	74.00	2.00	99.72
22	7.50	1020.00	652.80	89.78	448.00	27.91	105.08	460.00	44.00	2.00	76.69
23	7.56	1140.00	729.60	71.34	368.00	21.47	161.88	705.00	143.00	1.00	95.72
24	7.55	1170.00	748.80	103.41	522.00	31.79	201.64	660.00	164.00	2.00	139.31
25	7.42	1800.00	1152.00	113.83	344.00	48.66	181.76	475.00	125.00	5.00	184.41
26	7.43	1610.00	1030.40	45.69	358.00	6.50	218.68	400.00	106.00	3.00	151.86
27	7.29	1590.00	1017.60	127.45	342.00	57.05	71.00	310.00	27.00	6.00	8.97
28	7.87	550.00	352.00	86.57	224.00	39.24	103.66	760.00	193.00	2.00	52.28
29	7.25	540.00	345.60	117.84	504.00	41.61	173.24	485.00	138.00	2.00	138.21
30	7.35	1710.00	1094.40	80.96	568.00	15.44	113.60	320.00	104.00	1.00	100.00
31	7.50	2130.00	1363.20	96.19	486.00	29.55	241.40	400.00	150.00	2.00	137.93
32	7.92	1260.00	806.40	39.28	282.00	7.11	116.44	590.00	200.00	3.00	137.93
33	7.45	820.00	524.80	60.92	452.00	10.16	72.42	355.00	57.00	11.00	72.41
34	7.37	1230.00	787.20	81.76	350.00	28.85	106.50	500.00	101.00	1.00	90.34
35	7.44	1420.00	908.80	85.77	344.00	31.64	115.02	670.00	69.00	1.00	76.28
36	7.71	990.00	633.60	97.80	384.00	36.56	61.06	475.00	55.00	0.00	48.41
37	7.53	1530.00	979.20	77.76	444.00	20.85	123.54	570.00	115.00	1.00	84.83
38	7.35	1800.00	1152.00	133.07	412.00	56.30	163.30	365.00	101.00	65.00	102.34
39	7.38	290.00	185.60	44.09	428.00	1.37	53.96	160.00	16.00	6.00	17.38
40	7.65	870.00	556.80	72.95	390.00	21.13	72.42	340.00	34.00	1.00	52.14
41	7.55	920.00	588.80	104.21	388.00	40.22	89.46	325.00	28.00	0.00	63.17
42	7.50	670.00	428.80	114.63	212.00	56.97	59.64	315.00	31.00	0.00	51.72
43	7.57	1490.00	953.60	92.18	458.00	28.77	156.20	460.00	80.00	0.00	106.76
44	7.48	1060.00	678.40	108.22	424.00	40.51	83.78	360.00	45.00	13.00	79.72

45	7.51	1070.00	684.80	80.96	418.00	24.34	88.04	385.00	64.00	14.00	56.97
46	7.64	1380.00	883.20	67.33	416.00	16.19	117.86	520.00	72.00	1.00	57.38
47	7.87	610.00	390.40	61.72	356.00	16.34	45.44	355.00	44.00	1.00	16.14
48	7.23	2640.00	1689.60	154.71	610.00	57.69	281.16	410.00	135.00	1.00	120.14
Min	**7.20**	**290.00**	**185.60**	**39.28**	**212.00**	**1.37**	**45.44**	**160.00**	**16.00**	**0.00**	**8.97**
Max	**7.92**	**2640.00**	**1689.60**	**154.71**	**610.00**	**57.69**	**281.16**	**760.00**	**200.00**	**65.00**	**184.41**
Average	**7.47**	**1112.92**	**712.27**	**91.63**	**399.88**	**31.88**	**103.28**	**443.23**	**69.17**	**4.02**	**70.68**

Table 3: Physico-chemical parameter of pre-monsoon season 2022

Sr. No.	**Ph**	**EC**	**TDS**	**Ca**	**TH**	**Mg**	**CL**	**HCO3**	**NA**	**K**	**SO4**
Unit		**µm/cm**					**Mg/l**				
1	7.49	650.00	416.00	57.72	420.00	10.12	55.38	225.00	40.00	1.00	47.17
2	7.24	890.00	569.60	110.46	462.00	39.62	99.40	450.00	29.00	0.00	43.03
3	7.39	810.00	518.40	63.33	384.00	15.65	38.34	400.00	28.00	2.00	38.34
4	7.42	570.00	364.80	77.76	344.00	26.78	56.80	375.00	29.00	1.00	37.10
5	7.48	510.00	326.40	63.33	424.00	13.28	35.50	345.00	22.00	0.00	33.38
6	7.30	480.00	307.20	52.10	286.00	14.65	45.44	365.00	22.00	1.00	45.38
7	7.31	540.00	345.60	46.49	326.00	8.88	62.48	430.00	32.00	2.00	50.76
8	7.19	790.00	505.60	67.33	314.00	22.23	62.48	370.00	47.00	8.00	42.48
9	7.29	520.00	332.80	65.73	292.00	22.57	31.24	350.00	27.00	3.00	30.76
10	7.36	720.00	460.80	60.12	428.00	11.10	35.50	420.00	33.00	1.00	19.59
11	7.40	690.00	441.60	105.81	390.00	41.07	48.28	365.00	25.00	0.00	57.52
12	7.20	690.00	441.60	81.76	406.00	25.53	35.50	355.00	18.00	2.00	25.66
13	7.39	910.00	582.40	89.78	316.00	35.73	41.18	380.00	36.00	1.00	50.07
14	7.41	760.00	486.40	66.53	344.00	19.97	34.08	425.00	27.00	1.00	20.28
15	7.52	780.00	499.20	60.92	314.00	18.34	42.60	370.00	31.00	0.00	40.55
16	7.47	890.00	569.60	56.91	386.00	11.64	52.54	500.00	57.00	0.00	32.97
17	7.37	740.00	473.60	66.53	296.00	22.82	76.68	295.00	34.00	2.00	84.83
18	7.55	790.00	505.60	49.70	316.00	11.42	66.74	350.00	47.00	0.00	64.83
19	7.40	680.00	435.20	53.71	430.00	7.09	76.68	405.00	36.00	1.00	58.48
20	7.32	1010.00	646.40	89.78	358.00	33.24	134.90	455.00	65.00	9.00	136.41
21	7.20	730.00	467.20	58.52	366.00	13.80	127.80	505.00	61.00	2.00	98.62
22	7.43	670.00	428.80	41.68	348.00	4.66	90.88	415.00	34.00	2.00	74.90
23	7.51	1010.00	646.40	59.32	360.00	14.64	147.68	655.00	105.00	1.00	93.52
24	7.49	1090.00	697.60	43.29	476.00	-1.96	190.28	610.00	151.00	2.00	136.69
25	7.40	1220.00	780.80	80.96	312.00	30.62	167.56	425.00	92.00	3.00	178.34
26	7.36	1410.00	902.40	36.87	324.00	3.16	207.32	350.00	97.00	3.00	140.69
27	7.14	790.00	505.60	72.95	308.00	25.99	56.80	245.00	23.00	2.00	8.97
28	7.74	450.00	288.00	44.09	204.00	14.65	89.46	725.00	176.00	2.00	52.14
29	7.14	470.00	300.80	85.77	462.00	24.65	159.04	485.00	133.00	2.00	122.76
30	7.32	1320.00	844.80	69.74	532.00	10.77	99.40	275.00	95.00	1.00	98.34
31	7.34	1990.00	1273.60	53.71	460.00	5.31	227.20	350.00	139.00	2.00	129.24
32	7.83	1400.00	896.00	28.06	246.00	2.44	102.24	550.00	168.00	2.00	134.48
33	7.37	770.00	492.80	49.70	434.00	4.42	58.22	300.00	57.00	5.00	71.31
34	7.31	1170.00	748.80	71.34	312.00	24.78	92.30	450.00	101.00	1.00	81.24
35	7.37	900.00	576.00	45.69	304.00	9.70	100.82	625.00	69.00	1.00	68.28
36	7.64	960.00	614.40	65.73	364.00	18.30	44.02	430.00	52.00	0.00	42.76
37	7.47	1410.00	902.40	65.73	420.00	14.98	110.76	530.00	87.00	1.00	80.97
38	7.37	1270.00	812.80	81.76	374.00	27.43	149.10	315.00	79.00	15.00	95.31

39	7.31	290.00	185.60	32.87	398.00	-3.66	35.50	100.00	27.00	2.00	13.66
40	7.52	820.00	524.80	60.92	362.00	15.50	58.22	285.00	85.00	1.00	48.14
41	7.49	770.00	492.80	39.28	252.00	8.89	73.84	275.00	23.00	0.00	51.03
42	7.44	530.00	339.20	85.77	186.00	41.01	42.60	265.00	67.00	0.00	38.62
43	7.47	1340.00	857.60	69.74	390.00	19.19	142.00	400.00	53.00	0.00	95.45
44	7.43	960.00	614.40	78.56	394.00	24.30	68.16	310.00	41.00	9.00	64.41
45	7.45	770.00	492.80	71.34	328.00	23.84	73.84	350.00	47.00	8.00	51.03
46	7.57	830.00	531.20	59.24	366.00	14.24	103.66	470.00	57.00	1.00	49.10
47	7.77	530.00	339.20	52.99	314.00	13.53	29.82	300.00	40.00	1.00	12.83
48	7.12	2330.00	1491.20	132.26	552.00	47.52	266.96	355.00	115.00	1.00	102.48
Minimum	**7.12**	**290.00**	**185.60**	**28.06**	**186.00**	**-3.66**	**29.82**	**100.00**	**18.00**	**0.00**	**8.97**
Max	**7.83**	**2330.00**	**1491.20**	**132.26**	**552.00**	**47.52**	**266.96**	**725.00**	**176.00**	**15.00**	**178.34**
Average	**7.41**	**887.92**	**568.27**	**65.08**	**362.17**	**18.01**	**88.48**	**395.42**	**61.65**	**2.19**	**66.56**

Table 4: Water quality sanders of WHO and BIS

Parameters	**Unit**	**WHO (2011)**		**BIS (2012)**	
	-	**Desirable**	**Permissible**	**Desirable**	**Permissible**
pH	-	7.0-8.5	6.5-9.2	6.5-8.5	8.5-9.5
EC	µm/cm	750	1500	-	-
TDS	Mg/l	500	1500	500	2000
TH	Mg/l	100	500	200	600
Ca	Mg/l	75	200	75	200
Mg	Mg/l	30	150	30	100
Na	Mg/l	50	200	-	-
K	Mg/l	100	200	-	-
HCO3	Mg/l	200	600	200	600
Cl	Mg/l	250	600	250	1000
SO4	Mg/l	200	600	200	400

Hydro-geochemical evaluation

To develop the hydro-geochemical evaluation within an area, it is important to know the major ion chemistry of shallow and deeper level groundwater and to understand the active hydro-geochemical processes occurring along the flow path from up-stream to downstream within a groundwater basin. During groundwater transportation within a basin, the chemical composition of groundwater chemically and biologically react with and is altered through the naturally occurring rock-water interactions such as biological and chemical reaction in soil and groundwater, various type of weathering as well as significant impacts by anthropogenic activities (Todd 1980). Therefore it is essential to understand the groundwater geochemistry to identify the contributing sources through hydro-geochemical fancies, rock water interactions, and dissolution and precipitation reactions (Wagh et al. 2019).

Piper's trilinear diagram is very useful to understand the geochemical evolution of groundwater (Piper, 1953). The piper's diagram consists of three discrete fields, two triangular fields and a one diamond shaped field. The overall characteristics of the water are represented in the diamond shaped field by projecting the position of the plots in the triangular fields. The analytical values obtained from the groundwater samples of the study area are plotted on Piper trilinear diagram to understand the hydro chemical regime, which clearly explains the variations of cation and anion concentration.

The plot of chemical data on Piper diagram shows that the groundwater samples of post-monsoon season 2021 fall in $CaHCO_3$, $CaNaHCO_3$ and mixed CaMgCl. Where as in pre-monsoon season 2022 groundwater samples fall in $CaHCO_3$, NaCl, mixed $CaNaHCO_3$ in the study area (Fig. 2a &2b).

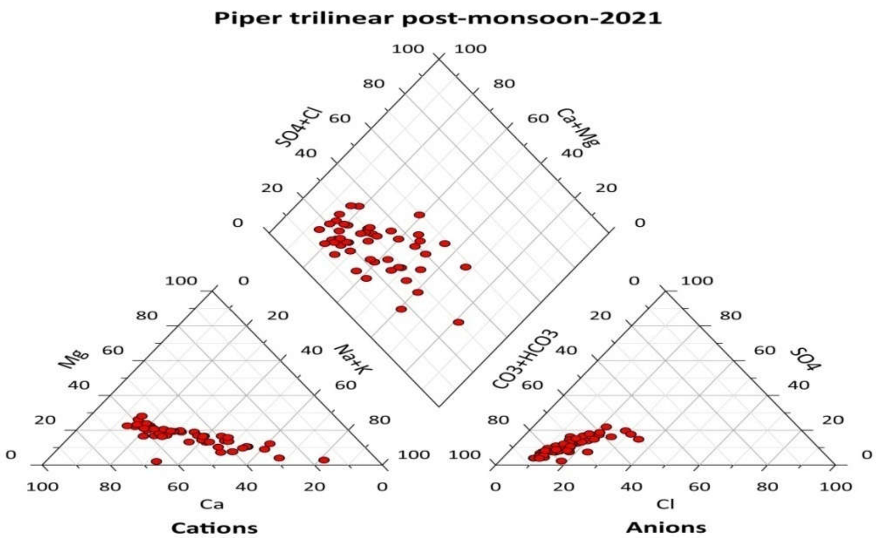

Figure 2a: Piper trilinear diagram for groundwater samples post monsoon season 2021

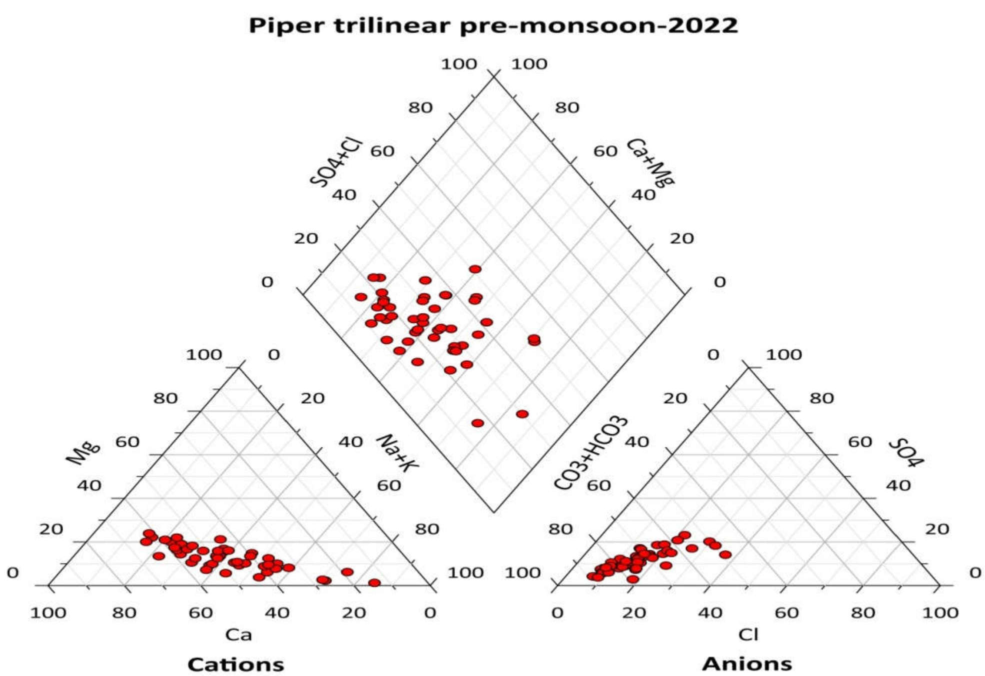

Figure 2b: Piper trilinear diagram for groundwater samples pre monsoon season 2022

Wilcox's diagram

To determine the suitability of water for irrigation, Wilcox (1955) proposed a diagram in which sodium percentage (Na %) is plotted against electrical conductivity. This diagram classified water into five types with increase in salinity hazards: Excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable and unsuitable. The present study, Wilcox classification diagram (fig. 3a & 3b) shows that 18.75% samples of post monsoon season 2021 and 22.91% samples of pre monsoon season 2022 are belonging to excellent to good, 75% samples of post monsoon season 2021 and 68.75% of post monsoon season 2022 are fall good to permissible type, 4.16% samples of post monsoon season 2021 and 6.25% samples in the permissible to doubtful category and only 2 % samples of post monsoon season 2021 and pre monsoon season 2022 are doubtful to unsuitable area for irrigation use. Hence based on the Wilcox's diagram majority groundwater samples are good for irrigation purpose.

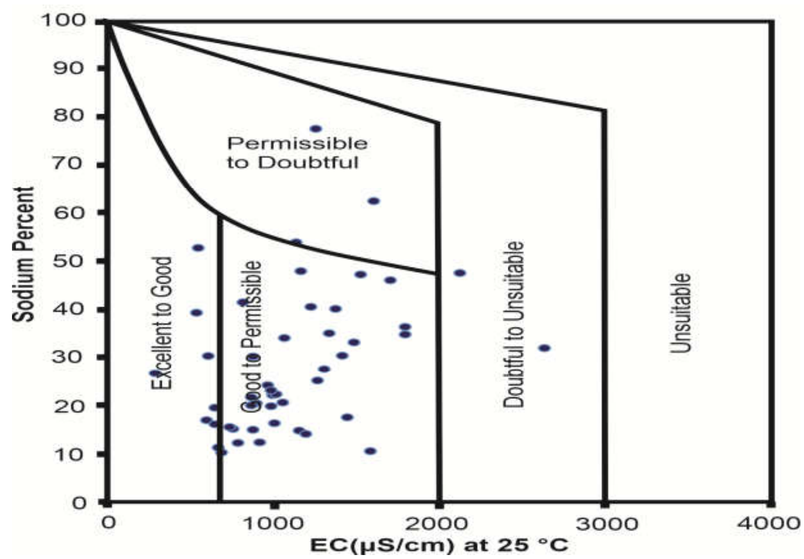

Figure3a: Wilcox's diagram of post monsoon season 2021

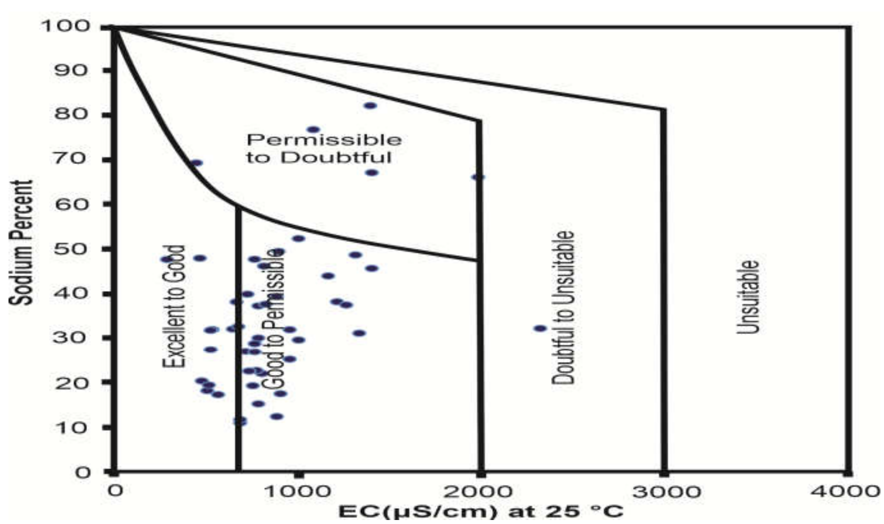

Fig. 3b: Wilcox's diagram of pre monsoon season 2022

Irrigation Use

Groundwater is widely used for irrigation and its quality influence the growth of plant and fertility of soil. The salt present in the water affect the soil structure, permeability and ultimately the plant growth. The suitability of groundwater of study area for irrigation is determined using different factors like sodium adsorption ratio, soluble sodium percentage, Kelly's ratio, magnesium ratio, residual sodium carbonate (Table no 5 & 6).

Sodium Adsorption Ratio (SAR)

Irrigation purpose, suitability of groundwater has been checked using the sodium adsorption ratio (SAR). High SAR values may damage to soil. If excessive soluble salt or exchangeable sodium is allowed to accumulate in the soil, then the soil that was originally not saline and non-alkaline may develop saline and alkaline character (USSL, 1954). The SAR for water is calculated using the following formula.

$$SAR = \frac{NA}{\sqrt{(Ca+mg)/2}} \qquad (1)$$

Water with SAR values ≤10 is consider as excellent quality, between 10-18 is good 18- 26 fair and above 26 are unsuitable for irrigation (USSL,1954). The SAR values of 100% groundwater samples of post monsoon season 2021 and pre monsoon season 2022 fall in excellent category; hence ground water is excellent quality for irrigation (Table 5, 6 &7).

Soluble Sodium Percentage (SSP)

Evaluation of suitability of groundwater quality for irrigation, SSP (%Na) is widely used (Wilcox, 1955). It is calculated using following expression.

$$\%Na = \frac{(Na+K)X\ 100}{Ca+Mg+Na+K} \qquad (2)$$

High %Na in irrigation water causes exchange of Na in water and exchange of Ca and Mg contents in soil having poor internal drainage. In this case, the groundwater is classified in to five categories: excellent (SSP < 20 %), good (20 – 40%), permissible (40-60%), doubtful (60-80), Unsuitable (SSP > 80%). In the present study area 17 groundwater samples in post monsoon season 2021 and 9 groundwater samples in pre monsoon season 2022 fall in excellent category, 21 groundwater samples in post monsoon season 2021 and 25 groundwater samples in pre monsoon season 2022 fall in good category, where as 8 groundwater samples in post monsoon season 2021 and 10 groundwater samples in pre monsoon season 2022 fall in permissible category, while 2 groundwater samples in post monsoon season 2021 and 3 groundwater samples in pre monsoon season 2022 fall in doubtful and 1 sample of pre monsoon season 2022 is unsuitable category (Table 7). On the basis of above classification of groundwater in the study area are suitable for irrigation.

Residual Sodium Carbonate (RSC)

RSC is considered to be superior to SAR as measure of sodicity, particularly at low salinity levels. High RSC values (meq/l) leads to increase in the adsorption of sodium on soil (Eton, 1950). It is calculated as

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \qquad (3)$$

Groundwater having 1.25 meq/l is safe for irrigation purpose, water having 1.25 to 2.5 meq/l is marginally suitable for irrigation, whereas water having >2.5 meq/l of RSC is not suitable for irrigation (Richard, 1954). In the study area 35 groundwater samples of post monsoon season 2021 and 21 water samples of pre monsoon season 2022 fall within 1.25 meq/l these are safe for irrigation, 4 samples of post monsoon season 2021 and 12 samples of pre monsoon season 2022 fall between 1.25 to 2.5 meq/l these are marginally safe for irrigation and remaining 9 samples of post monsoon season 2021 and 15 samples of pre monsoon season 2022 are above 2.5 meq/l are not suitable for irrigation (Table 5, 6 &7).

Kelly's Ratio (KR)

Sodium measure against Ca^{2+} and Ma^{2+} is used to calculate KR (kally's et al. 1940; Paliwal, 1972). It is expressed as

$$KR = \frac{Na^+}{Ca^+ + Mg^+} \qquad (4)$$

Water with KR values ≤ 1 is considered good for irrigation where as water with the values ≥ 1 is unsuitable for irrigation (Kelly's, 1951). In the study area 44 groundwater samples of post monsoon season 2021 and 42 groundwater samples of pre monsoon season 2022 have KR suitable values ≤ 1 suitable category for irrigation. Whereas 3 groundwater samples of post monsoon season 2021 and 3 groundwater samples of pre monsoon season 2022 Shows KR values in permissible limit. While reaming 1 groundwater samples of post monsoon season 2021 and 3 groundwater samples of pre monsoon season 2022 show unsuitable for irrigation (Table 7).

Magnesium Adsorption Ratio (MAR)

MR is an excess amount of Mg over a Ca amount, where otherwise normally the level of Ca and Mg will be in a state of equilibrium (Sreedevi, 2002). The excess of Mg is due to the presence of exchangeable Na^+ in irrigated soils. This excess of Mg^{2+} adversely affects the soil quality. Szabolcs and Darab (1964) have proposed a magnesium ratio for irrigation water which is calculated as

$$MAR = \frac{Mg^{2+}\ X\ 100}{Ca^{2+} + Mg^{+}} \quad (5)$$

Groundwater having MAR values ≤ 50 are suitable, while MR values ≥ 50 are unsuitable for irrigation. In the study area, all groundwater samples values of post monsoon season 2021 and pre monsoon season 2022 ranges MAR ≤ 50, hence these are suitable for irrigation purpose (Table 5, 6 &7).

Table 5: Irrigation water quality parameter of Post-monsoon season 2021

Sample NO.	SAR	MAR	KR	RSC	SSP
1	1.10	35.08	0.28	-3.01	22
2	0.81	35.89	0.20	-0.41	17
3	0.81	32.16	0.24	1.69	20
4	0.66	37.71	0.17	-0.37	15
5	0.68	30.66	0.20	0.80	17
6	0.69	39.57	0.18	-0.43	16
7	0.92	36.97	0.26	1.23	21
8	1.38	38.38	0.37	0.08	30
9	0.65	38.17	0.18	-0.53	16
10	0.94	34.42	0.25	0.44	20
11	0.55	37.18	0.14	-1.11	12
12	0.46	36.85	0.11	-1.33	10
13	0.97	38.55	0.25	-0.86	20
14	0.66	38.12	0.17	0.48	15
15	0.79	37.65	0.22	0.21	18
16	1.82	32.27	0.54	3.40	35
17	0.70	40.67	0.16	-3.38	14
18	1.32	38.66	0.34	-0.93	25
19	0.74	36.78	0.18	-1.38	15
20	1.63	40.57	0.36	-1.87	28
21	1.43	39.73	0.32	-0.98	24
22	1.04	33.88	0.28	0.76	22
23	3.81	33.16	1.17	6.23	54
24	3.62	33.64	0.92	3.04	48
25	2.47	41.34	0.56	-1.90	36
26	3.89	18.99	1.64	3.74	62

27	0.50	42.46	0.11	-5.97	11
28	4.32	42.77	1.11	4.91	53
29	2.78	36.80	0.65	-1.35	39
30	2.78	23.93	0.85	-0.07	46
31	3.43	33.62	0.90	-0.68	48
32	7.71	22.99	3.42	7.12	78
33	1.78	21.57	0.64	1.94	42
34	2.45	36.78	0.68	1.74	41
35	1.62	37.82	0.44	4.10	31
36	1.20	38.14	0.30	-0.10	23
37	2.99	30.66	0.89	3.75	47
38	1.85	41.09	0.39	-5.29	35
39	0.65	4.89	0.30	0.31	27
40	0.90	32.33	0.27	0.19	22
41	0.59	38.89	0.14	-3.18	13
42	0.59	45.04	0.13	-5.24	11
43	1.86	33.98	0.50	0.57	33
44	0.94	38.17	0.22	-2.83	21
45	1.60	33.14	0.46	0.27	34
46	2.04	28.39	0.67	3.83	40
47	1.29	30.39	0.43	1.39	30
48	2.35	38.07	0.47	-5.75	32
Minimum	**0.46**	**4.89**	**0.11**	**-5.97**	**10**
Max	**7.71**	**45.04**	**3.42**	**7.12**	**78**
Average	**1.68**	**34.77**	**0.49**	**0.07**	**29**

Table 6: Irrigation water quality parameter of Pre-monsoon season 2022

Sample NO.	**SAR**	**MAR**	**KR**	**RSC**	**SSP**
1	1.28	22.42	0.47	-0.02	32
2	0.60	37.16	0.14	-1.40	13
3	0.82	28.95	0.27	2.11	22
4	0.72	36.22	0.21	0.06	17
5	0.66	25.70	0.23	1.40	18
6	0.69	31.68	0.25	2.18	21
7	1.13	23.95	0.46	4.00	32
8	1.27	35.25	0.39	0.87	30
9	0.73	36.14	0.23	0.60	20
10	1.03	23.34	0.37	2.97	27
11	0.52	39.02	0.13	-2.68	11
12	0.45	33.99	0.13	-0.36	12
13	0.81	39.62	0.21	-1.19	18
14	0.75	33.10	0.24	2.00	19
15	0.89	33.18	0.30	1.51	23
16	1.80	25.22	0.65	4.40	39
17	0.92	36.12	0.28	-0.36	23
18	1.56	27.47	0.60	2.32	37
19	1.23	17.88	0.48	3.37	33
20	1.49	37.91	0.39	0.24	30
21	1.86	28.00	0.65	4.22	40

22	1.33	15.56	0.60	4.34	38
23	3.16	28.93	1.10	6.57	52
24	6.57	-8.06	3.29	8.00	77
25	2.21	38.41	0.61	0.41	38
26	4.12	12.39	2.01	3.64	67
27	0.59	37.01	0.17	-1.76	15
28	5.87	35.40	2.25	8.48	69
29	3.26	32.15	0.92	1.64	48
30	2.80	20.29	0.95	0.14	49
31	4.84	14.02	1.94	2.62	66
32	8.17	12.53	4.57	7.41	82
33	2.08	12.79	0.87	2.07	48
34	2.63	36.42	0.78	1.78	44
35	2.42	25.92	0.98	7.16	50
36	1.46	31.46	0.47	2.26	32
37	2.52	27.31	0.84	4.17	46
38	1.93	35.61	0.54	-1.17	38
39	1.44	-22.46	0.88	0.30	48
40	2.52	29.55	0.86	0.36	46
41	0.86	27.17	0.37	1.82	27
42	1.49	44.08	0.38	-3.31	28
43	1.45	31.21	0.46	1.50	31
44	1.04	33.77	0.30	-0.84	25
45	1.23	35.52	0.37	0.21	29
46	1.73	28.38	0.60	3.57	38
47	1.27	29.63	0.46	1.16	32
48	2.18	37.20	0.48	-4.69	32
Minimum	**0.45**	**-22.46**	**0.13**	**-4.69**	**11**
Max	**8.17**	**44.08**	**4.57**	**8.48**	**82**
Average	**1.92**	**27.80**	**0.73**	**1.75**	**36**

Table 7: Classification of groundwater for Irrigation Post-monsoon season 2021 and pre-monsoon season 2022

Parameters	**Range**	**Classification**	**Number of samples in post monsoon 2021**	**Number of samples in pre monsoon 2022**
Salinity hazard (EC) (µS/cm)	< 250	Excellent	Nil	Nil
	250 - 750	Good	9	18
	750 - 2000	Permissible	37	29
	2000 - 3000	Doubtful	2	1
	> 3000	Unsuitable	Nil	Nil
Sodium Adsorption Ratio (SAR)	< 10	Excellent	48	48
	10 - 18	Good	Nil	Nil
	18 - 26	Doubtful	Nil	Nil
	> 26	Unsuitable	Nil	Nil
Soluble Sodium Percentage (SSP) (%)	< 20 %	Excellent	17	9
	20% < SSP < 40%	Good	21	25
	40% < SSP < 60%	Permissible	8	10
	60% < SSP < 80%	Doubtful	2	3

	SSP > 80%	Unsuitable	Nil	1
Magnesium Adsorption Ratio (MAR) (%)	< 50	Permissible	48	48
	> 50	Unsuitable	Nil	Nil
Residual sodium carbonate (RSC)	RSC < 1.25	Safe for irrigation	35	21
	1.25 < RSC < 2.5	Potentially hazardous	4	12
	RSC > 2.5	Unsuitable	9	15
Kelly's Ratio (KR)	KR < 1	Suitable	44	42
	1 - 2	Permissible	3	3
	> 2	Unsuitable	1	3

U.S. Salinity Diagram

By using the values of SAR and specific conductance, the water can be classified for irrigation by graphically plotting these values on the U. S. Salinity Laboratory Diagram (1954). The diagram classifies the water quality into 16 areas to assess the degree of suitability of water quality into 16 areas to assess the degree of suitability of water for irrigation, in which salinity hazard is divided into four areas such as low salinity (C1: < 250 µS/cm), medium salinity (C2 : 250 – 750 µS/cm), high salinity (C3:750 – 2,250 µS/cm), very high salinity (C4: > 2500 µS/cm); and sodium hazard is also divided in to four sub areas, such as low sodium (S1: < 10), Medium sodium hazard (S2: 10-18), high sodium hazard (S3:18-26), and very high sodium hazard (S4:>26), USSL diagram shown in fig.4a & 4b.

It is observed in the post monsoon season 2021 that is 22.91% of groundwater samples fall in C2-S1 category indicating water of medium salinity and low sodium hazard, 72.91% of groundwater samples fall in C3-S1 category indicating water of high salinity and low sodium hazard, 2.08% of groundwater samples fall in C4-S1 category indicating water of very high salinity and low sodium hazard and another 2.08% of groundwater samples fall in C3-S2 category indicating water of high salinity and medium sodium hazard. Similarly in pre monsoon season 2022 shows the 35.41% of groundwater samples fall in C2-S1 category indicating water of medium salinity and low sodium hazard while 56.25% of groundwater samples fall in C3-S1 category indicating water of high salinity and low sodium hazard another 2.08% of groundwater samples fall in C4-S1 category indicating water of very high salinity and low sodium hazard and remaining 6.25% of groundwater samples fall in C3-S2 category, indicating water of high salinity and medium sodium hazard. Overall, the plots of post monsoon season 2021 and pre monsoon season 2022 indicates that the groundwater can be used for irrigation on almost all soils and plants (Fig.4a, 4b).

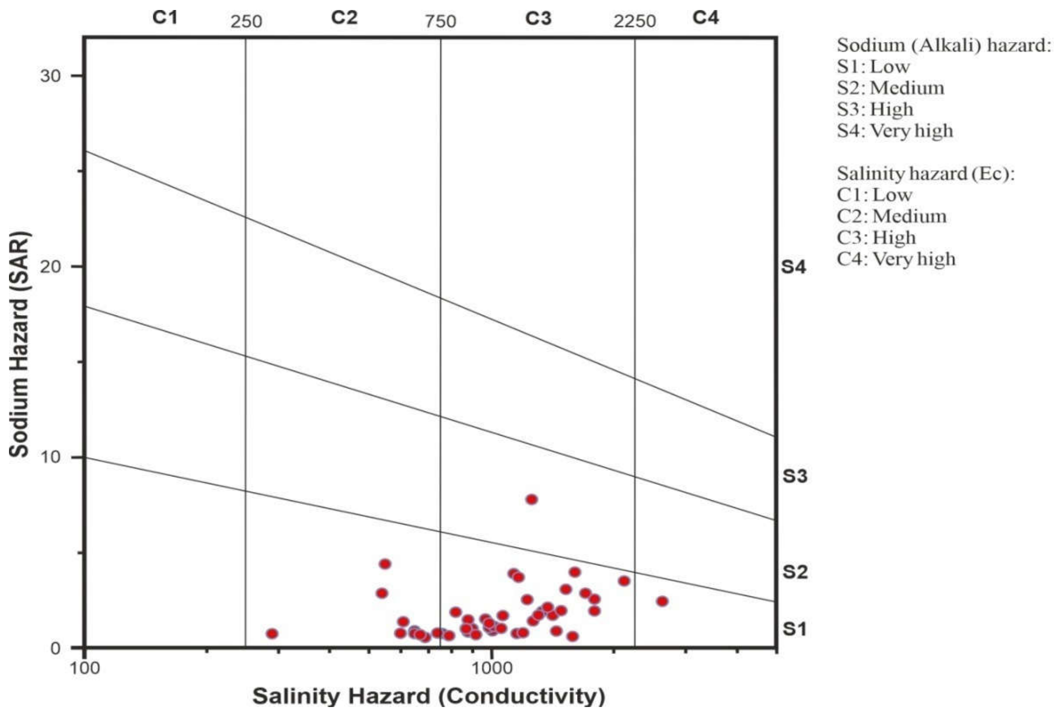

Figure 4a: USSL post monsoon Season 2021

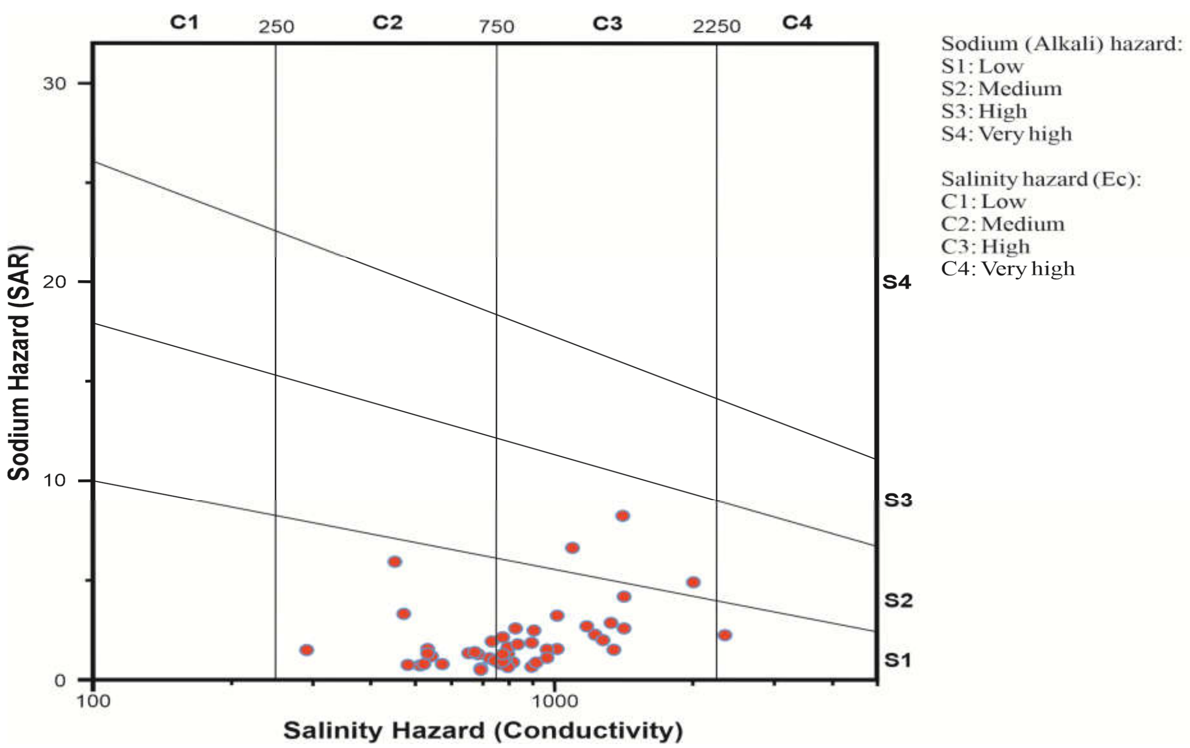

Figure 4b: USSL pre monsoon season 2022

CONCLUSION

The main aim of the study area to observe the groundwater quality for drinking and irrigation purpose to obtained from Kundalika river basin Beed district, Maharashtra, India. Using various physico-chemical parameters of 48 groundwater samples was analysed. The concentration of different parameters was compared with specification recommended by BIS (2012) and WHO (2011). Most of groundwater samples are slightly alkaline in nature. The average values of hardness in groundwater of post monsoon season and pre monsoon season 2021 & 2022 is within permissible limit only 2.08% of the groundwater sample exceeding maximum permissible limit. In the study area TH majority of groundwater samples observed hard to very hard category. The entire groundwater sample has TDS are observed within the permissible limit. From the piper trilinear diagram, it is observed that 80% groundwater samples in post monsoon season 2021 and pre monsoon season 2022 fall in the Ca-HCO_3 region and remaining 20 % groundwater samples of both season falls in mixed type such as Ca-Na-HCO_3 region indicating groundwater are shallow and fresh. According to Wilcox's diagram majority of groundwater samples fall in good category for irrigation purpose. Only 2 % of groundwater samples of post monsoon season 2021 and pre monsoon season 2022 fall in doubtful to unsuitable category for irrigation use. As irrigation aspect various water quality indices like EC, SAR, SSP, RSC, MAR and KR shows that the majority water samples are suitable for irrigation uses. U. S. Salinity Laboratory Diagram shows that all the groundwater samples of post monsoon season 2021 and pre monsoon season 2022 belongs to C2-S1,C3-S1,C3-S1 & C3-S2 category indicate the medium to high salinity and alkalinity. The above studies will be beneficial in determining the quality of groundwater condition drinking and irrigation purpose.

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