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Hydrochemical Characterisation and Groundwater Suitability forIrrigation in Jam River Basin, Sinnar, Sangamner and Kopargaon Tehsil, Maharashtra, India

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Abstract

In order to determine the groundwater quality and its suitability for irrigation, hydrochemical analysis was conducted in the Jam River basin. According to their significance, sixty (60) representative groundwater samples were taken from various dug wells and bore wells in this context and analyzed. The irrigation indices like SAR, RSC, MAR, KR, PI, Na (%) and SSP were considered to evaluate groundwater aptness for irrigation. EC, TDS and chloride were also considered which ranges from excellent to unsuitable. According to SAR, %Na, KR, RSC and SSP classification majority of groundwater samples are suitable for irrigation. MAR ratio suggests 51.66 and 41.66% samples are unfit for irrigation during pre and post monsoon. According to Davies and DeWiest's classification (1966) for TDS, 8.33% samples are unfit for irrigation, As a result, the majority of the groundwater samples from this study attest to the area's aquifers' good use for irrigation. However, sample number 14 revealed that the study area's aquifer is problematic and requires specific corrective action in order to be useful.

Keywords: *Groundwater, Hydrogeochemical, Jam River, Irrigation*

Introduction:

The most significant source of household, industrial, and agricultural water supply in India is groundwater. A growing number of hazards to groundwater resources are attributable to human-made processes such population growth, trash generation, and inefficient agricultural land use management. Surface water has a lower mineral content than groundwater. (Wagh *et al.*, 2018; Mirabbasi, R. *et al.*2008). Evaluation of groundwater quality is crucial for the socioeconomic development of the area because the usefulness of groundwater to humans depends on its chemical status. Due to a lack of freshwater supplies, groundwater is crucial to the household, agricultural and industrial water delivery systems in arid and semi-arid areas. Worldwide groundwater consumption is anticipated to be 65% for drinking, 20% for irrigation, and 15% for industrial uses, according to Adimalla and Venkatyogi (2018). In general, both natural and anthropogenic factors, such as the quantity of precipitation, evapotranspiration rate, soil inputs, rock-water interaction, residence time, agricultural runoff, and discharges of residential and industrial wastes, etc., affect the chemical composition of groundwater. (Todd, 1980; Pawar *et al.,* 2008).The complete consideration of groundwater suitability for irrigation is significantly based on total ionic content of the water such as Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), Percent Sodium (% Na), Calcium (Ca), Chloride (Cl), Residual Sodium Carbonate (RSC), Magnesium Adsorption Ratio (MAR), etc. (Wagh *et al.,* 2016; Adimalla and Venkatayogi, 2018). Additionally, the loss of soil fertility and crop output is dependent on salt concentration, sodium content, nutrients rate, alkalinity, acidity, and hardness of water (Kirda, 1997). The physical state of the soil and excessive concentrations of dissolved ions in irrigation water would result in stunted plant growth and crop yield due to poor water quality (Ayers and Westcot, 1994; Zolekar and Bhagat, 2015). The current study focuses on the Jam River basin in Maharashtra's groundwater quality and its suitability for irrigation.

Study area:

The study area located between 74^{0}6'28" and 74^{0}25'56"E longitudes and 19^{0}44'27" to 19^{0}52'18"N latitudes in the Deccan plateau, an eastern extension of the Kalsubai range (Fig.1). In Kopargaon, in the Ahemednagar district, the Jam River meets with the Godavari River. It starts in Sinnar Tehsil's eastern region and travels 52.2 km till it reaches Kopargaon Tehsil, which is located in the Ahmednagar district of Maharashtra's southwest. The basin has a total area of 636.67 square kilometres. The research area has a semiarid environment and receives 483.9 mm of annual rainfall in Kopargaon, 510.57 mm in Sangamner, and an average of 568.6 mm in Sinnar from the south-west monsoonal winds that blow from June to September. With the exception of the south-west monsoon season, the district has a mainly dry environment. Some villages from Sinnar, Sangamner and Kopargaon tehsil have been brought under intensive cultivation with sugarcane as a single dominant crop as a result of the construction of the Nandur Madhemeshwar right canal. The study region is well renowned for its agricultural output of different seasonal vegetables. Therefore, it is crucial for this region in particular to monitor the quality of the groundwater and if it is suitable for irrigation.

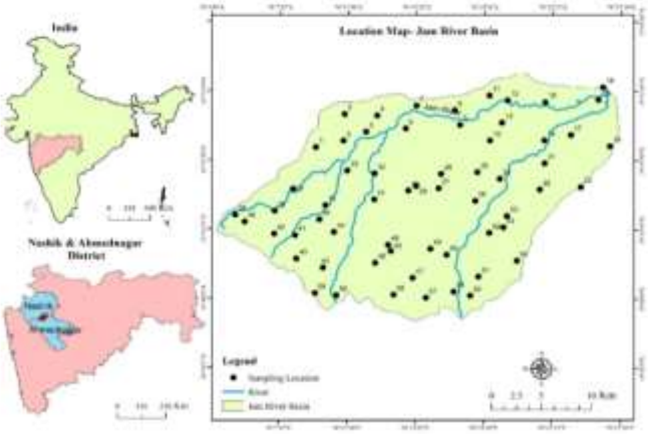

Fig. 1. Study area map with groundwater sampling sites

Materials and Methods:

The sixty (60) typical groundwater samples that were taken from both bore wells and dug wells that are used for irrigation and drinking purposes will be analysed before and after the monsoon to assist track the chemical changes in the features of groundwater. There are 49 samples from dug wells and 11 samples from bore wells. The locations of the water samples are established using the GPS (Geographical Positioning System), and the hydrological and spatial distribution maps are prepared using the Inverse Distance Weightage (IDW) approach. Based on a preliminary geological and hydro-geological reconnaissance of the research region, the sample locations were chosen. samples taken in May, just before the monsoon of 2021, and November, just after it. APHA, AWWA, and WPCF protocols (2005) were used to conduct the analysis in a lab setting. pH, EC and TDS were measured in situ by multi parameter tester. Titrimetric analysis was used to determine the amounts of chloride (Cl^-), total alkalinity ($CaCO_3$), calcium (Ca^{2+}), magnesium (Mg^{2+}), and total hardness. Alkali elements like sodium and potassium were tested using flame photometers, whereas nitrate, sulphate, phosphate, and fluoride were measured using spectrophotometric methods (Hitachi-2000). Ion balance errors (IBE) of the examined parameters that were within ±10% were regarded as legitimate (Berner and Berner, 1987).

Results and Discussion:

Table 1 provides a summary of the groundwater parameters. The entire ionic content of the water, such as EC, TDS, SAR, % Na, Ca, Cl, RSC, MAR, KR, and PI, is a major factor in determining the absolute appropriateness of groundwater for irrigation (Wagh *et al.*, 2018). Additionally, the loss of soil fertility and crop output is dependent on salt concentration, sodium content, nutrients rate, alkalinity, acidity, and hardness of water (Kirda, 1997). Due to its favorable climate, the area under examination is well known for its agriculture, hence it is crucial to understand the irrigation water quality. The impact of using such polluted water may result in a reduction in plant development and crop yield if groundwater quality is not adequately safeguarded (Ramesh & Elango, 2011). As a result, it has been attempted to determine the suitability of groundwater for irrigation based on different irrigation indices and their classification is shown in table 5.

Table 1. Physicochemical characteristics of groundwater samples in Pre-Monsoon season 2021

Sr. No.	pH	EC	TDS	TH	Ca	Mg	Na	K	T A	CO_3	HCO_3	Cl	F	SO_4	NO_3	PO_4
DW1	8.4	1830	931	1415	272.5	161.7	259.3	0.40	430	50	380	625.3	0.7	362.9	34.5	0.16
BW2	7.9	1400	731	400	240.5	48.8	100.5	0.24	470	70	400	107.9	0.7	159.2	28.9	0.14
DW3	7.3	1120	711	450	240.5	36.5	111.7	0.30	480	40	430	130.5	0.8	94.9	29.8	0.96
DW4	7.2	1230	781	475	320.6	88.6	106.7	1.32	400	30	370	185.2	0.8	106.4	21.1	0.56
BW5	7.9	4710	3020	2240	345.3	286.0	527.6	4.68	475	25	450	1580.8	0.7	730.6	27.8	0.12
BW6	7.7	3110	2060	889	300.6	195.8	189.4	2.68	315	40	275	1024.4	0.9	74.5	23.1	0.02
DW7	8.1	745	340	820	180.4	217.0	46.7	1.70	400	50	350	880.4	0.9	40.6	10.0	0.56
DW8	8.4	1510	750	1240	150.3	142.5	219.8	0.78	420	80	340	220.6	0.9	250.3	11.1	0.36
BW9	7.8	3590	2330	2635	164.3	217.0	157.9	0.72	500	40	460	953.7	0.9	299.6	24.1	0.76
DW10	8.4	647	481	1285	192.4	224.3	827.0	2.17	485	60	425	1136.0	0.5	150.9	32.2	1.46
DW11	7.9	3370	1920	1300	200.4	160.8	640.0	1.19	290	40	250	950.4	0.6	170.8	52.0	1.82
BW12	7.7	2820	1940	1405	350.7	230.7	971.2	4.62	310	40	270	750.0	0.5	323.7	55.4	1.19
DW13	8.4	639	393	675	124.2	410.8	994.4	2.06	500	60	440	681.6	0.4	154.4	31.9	1.92
DW14	8.2	531	339	560	168.3	29.2	1027.3	2.07	570	70	500	426.0	1.1	13.8	63.8	1.84
DW15	7.4	5700	3720	1375	348.7	173.3	1055.2	17.16	870	70	800	1180.0	1.2	929.0	66.7	1.32
DW16	7.9	7780	4590	1165	401.2	193.7	1121.0	9.90	615	40	575	1710.2	1.1	1209.7	45.9	1.37
DW17	7.8	3920	1920	1200	330.7	180.7	1070.2	2.07	775	50	725	682.2	1.1	286.9	35.4	1.64
DW18	7.3	5870	3470	3200	205.0	286.5	1041.0	6.24	725	50	675	710.0	1.2	1209.9	44.3	1.39
DW19	7.2	5810	3710	2850	392.8	272.9	790.8	3.37	790	40	750	724.5	1.0	364.9	58.9	1.74
DW20	7.4	381	293	1500	252.5	165.6	80.2	1.27	535	60	475	625.4	0.6	184.8	21.1	1.56
DW21	8.1	776	397	800	208.4	174.4	43.7	0.40	425	50	375	693.7	0.6	94.8	13.1	0.98
DW22	7.9	1070	532	1190	244.5	149.5	84.4	2.34	665	40	625	293.1	0.6	369.2	19.7	0.37
DW23	8.1	1560	898	1715	260.5	80.2	50.1	2.17	295	20	275	250.2	0.6	50.5	17.4	0.56
DW24	8.3	955	567	1000	240.5	65.6	76.8	3.45	335	60	275	368.7	0.6	132.5	35.0	1.54
DW25	7.7	2180	1600	2000	132.7	172.8	189.9	1.17	400	50	350	312.5	0.6	217.7	30.4	0.35
DW26	8.1	1550	912	810	164.3	90.4	147.1	1.25	420	70	350	250.6	0.6	64.8	13.4	1.56
BW27	7.9	855	507	780	236.5	43.6	72.4	0	475	50	425	79.7	0.6	40.7	25.3	0.33
DW28	8.1	1310	497	990	124.2	121.9	54.5	0.27	425	50	375	65.3	0.5	50.5	25.2	0.96
DW29	8.1	337	217	775	146.3	21.9	79.5	1.42	460	60	400	96.9	0.5	84.3	21.2	0.64
DW30	8.4	1820	1134	580	96.4	163.2	229.0	1.15	325	100	225	113.6	0.6	128.0	42.3	0.56
DW31	8.1	2130	1600	2465	72.3	111.2	219.8	0.90	475	100	375	198.8	0.6	164.3	58.1	0.54
DW32	8.00	1950	1130	1350	192.4	155.9	209.2	2.34	615	40	575	178.9	0.7	144.8	9.4	0.46
DW33	8.3	1570	986	1265	260.5	159.2	206.0	0.94	550	50	500	147.7	0.7	1224.2	19.1	0.32
DW34	8.2	3110	2150	1125	400.8	186.6	472.9	2.34	625	100	525	366.4	0.6	440.3	41.2	0.16
DW35	7.9	1860	1020	650	341.1	170.5	194.7	1.70	325	50	275	147.7	0.8	224.1	36.7	1.75
DW36	8.4	1580	981	1290	268.5	181.0	157.7	0.80	725	100	625	286.8	1.0	292.9	13.9	1.86
DW37	7.8	3050	2150	3245	537.1	88.7	352.4	2.34	390	40	350	383.4	0.6	321.0	0.8	0.32
BW38	7.4	1100	671	1110	196.4	135.8	58.2	0	330	30	300	85.2	0.1	96.8	15.9	0.16
DW39	8.00	1210	631	1065	172.3	151.0	91.0	0.10	405	30	375	164.7	0.9	119.8	9.3	1.84
DW40	8.3	984	574	730	184.4	75.3	57.9	0.38	475	50	425	90.9	0.5	94.1	17.4	1.69
DW41	8.1	1270	721	1335	112.2	112.4	64.4	0.48	560	60	500	99.4	0.6	74.4	7.3	1.63
DW42	8.3	981	617	800	136.3	160.8	59.8	0.25	575	25	550	124.6	0.6	132.5	7.8	1.56
BW43	7.9	978	551	825	252.5	150.6	52.2	0.18	320	70	250	93.7	0.5	164.5	40.0	1.86
DW44	7.9	1340	807	690	184.4	90.5	107.1	0.65	400	50	350	224.4	0.6	98.5	11.5	1.76
DW45	7.8	1280	819	975	63.1	132.8	62.1	0	470	70	400	105.1	0.6	157.7	9.1	0.34
DW46	8.00	1340	731	1290	330.7	70.8	174.7	0.27	505	30	475	17.0	0.5	124.6	10.0	1.76
DW47	7.6	1540	815	1455	84.5	48.6	73.1	0.28	520	20	500	122.1	0.7	146.7	48.1	1.13
BW48	7.4	1740	961	1880	306.6	54.7	32.9	1.28	400	25	375	164.7	0.6	234.3	19.2	1.64
DW49	8.1	1910	921	1250	172.5	119.4	178.4	0.88	425	50	375	142.0	0.5	176.2	2.9	1.14
DW50	8.4	921	409	765	146.3	127.9	23.2	0.45	200	50	150	42.6	0.6	195.4	27.7	1.30
BW51	8.1	1260	621	1095	138.3	126.2	91.7	0	450	25	425	113.6	0.6	173.3	20.1	0.32
BW52	8.1	1670	805	925	216.4	85.7	86.2	1.78	405	30	375	133.5	0.6	74.4	24.4	0.13
DW53	7.7	1610	930	850	168.3	41.3	88.7	2.23	480	30	450	184.8	0.6	85.5	11.2	1.46
DW54	8.00	1270	721	910	188.4	51.0	88.3	1.84	480	30	350	274.5	0.6	92.8	17.3	0.62
DW55	8.1	1120	661	1000	248.5	62.0	97.5	0.18	670	20	650	324.5	0.6	62.8	13.0	0.84
DW56	8.2	1130	561	965	186.4	75.3	74.5	0	500	30	470	90.9	0.6	195.5	22.0	0.19
DW57	8.4	745	361	825	232.5	77.8	44.8	1.38	470	70	400	76.7	0.7	50.2	24.7	1.00
DW58	8.1	878	415	775	132.3	123.7	55.9	1.17	330	80	250	56.8	0.6	55.2	10.4	0.16
DW59	8.2	817	502	925	142.4	88.6	111.7	2.23	295	25	270	86.7	0.5	36.8	9.5	0.14
DW60	8.1	826	508	890	132.3	77.9	70.9	1.98	375	40	335	88.6	0.5	44.8	17.4	0.18
MIN	7.2	337	217	400	63.1	21.9	23.2	0.00	200	20	150	17.0	0.1	13.8	0.8	0.02
MAX	8.4	7780	4590	3245	537.1	410.8	1121.0	17.16	870	100	800	1710.2	1.2	1224.2	66.7	1.92
AVG	7.96	1942.15	1158.52	1227.16	223.2	137.6	276.9	2.02	474.11	49.92	422.42	389.6	0.7	243.3	25.9	0.96

Note: 1. All values are expressed in mg/l, except pH and EC (μS/cm)
2. DW- Dug well, BW-Borewell, TH- Total hardness, TA- Total alkalinity

Table 2. Physicochemical characteristics of groundwater samples in post-Monsoon season 2021

Sr. No.	pH	EC	TDS	TH	Ca	Mg	Na	K	T A	CO_3	HCO_3	Cl	F	SO_4	NO_3	PO_4
DW1	7.9	1530	779	640	176.15	93.55	154.72	1.82	555	30	525	532.5	0.89	182.22	22.29	0.02
BW2	7.2	807	501	440	190.38	43.74	109.2	0.66	500	0	500	161.5	0.83	185.41	16.09	0.01
DW3	7.2	703	439	430	112.42	34.02	106.21	0.2	495	20	475	150.5	0.84	184.32	34.39	0.02
DW4	7.1	704	427	480	128.45	77.76	74.71	1.1	460	10	450	145.7	0.86	187.56	27.13	0.01
BW5	7.0	4730	3007	1760	268.53	182.62	472.9	0	555	30	525	1384.5	1.08	389.01	14.20	0.32
BW6	7.5	2980	1906	512	196.39	63.18	100.69	6.12	330	30	300	1128.25	0.89	192.58	37.93	0.03
DW7	7.5	225	184	804	112.22	70.47	103.18	2.1	465	15	450	428.5	0.87	168.26	11.18	0.04
DW8	8.1	1500	740	600	50.10	60.75	203.06	1.28	775	50	725	312.4	0.88	175.18	11.07	0.04
BW9	7.5	3440	2101	1020	140.28	120.28	139.04	2.02	560	20	540	969.15	0.84	283.86	27.12	0.90
DW10	7.7	326	207	460	178.35	126.36	778	2.26	620	120	500	248.5	0.55	274.61	35.17	0.89
DW11	7.2	3850	2401	1584	228.47	171.31	485.14	1.9	390	40	350	1136	0.59	276.34	55.07	0.91
BW12	7.5	2660	1702	500	120.24	26.73	601	2.07	265	15	250	1118.25	0.54	275.63	61.84	0.13
DW13	7.7	328	209	460	70.14	49.81	540	3.2	770	70	700	266.25	0.54	138.51	46.19	0.91
DW14	7.4	124	79	460	86.17	53.46	890.4	2.05	830	80	750	181.05	1.05	358.64	69.76	1.07
DW15	7.9	4810	3018	748	352.7	217.96	850	4.9	975	75	900	1256.7	1.35	345.81	67.12	1.09
DW16	7.8	6390	4109	1160	72.14	417.96	680.7	6.26	910	35	875	1668.5	1.13	421.45	75.67	1.01
DW17	8.0	3090	1877	540	182.9	55.89	620.18	2.1	1295	70	1225	692.25	1.06	516.61	68.11	0.98
DW18	7.4	4810	3018	1660	130.26	213.84	550	1.02	950	25	925	745.5	0.89	311.32	55.12	1.01
DW19	7.5	4800	3072	1760	150.3	78.97	370.2	2.09	1035	60	975	761.5	1.08	308.64	60.21	1.07
DW20	7.5	166	106	728	244.48	2.43	101	1.78	390	15	375	355	0.53	284.47	29.13	1.01
DW21	7.3	286	183	804	190.38	77.76	140.8	0.9	535	35	500	443.75	0.48	261.08	35.31	1.11
DW22	7.7	1110	711	544	128.25	46.17	55.44	0.8	495	20	475	177.5	0.51	78.23	7.80	0.07
DW23	7.6	1160	741	568	120.24	52.24	55.66	1.2	370	20	350	202.35	0.48	84.52	18.57	0.04
DW24	8.0	193	133	504	94.18	52.24	149.38	2.48	360	35	325	248.5	0.49	96.78	46.57	0.08
DW25	7.8	1450	928	560	104.6	154.9	166.32	1.28	485	60	425	276.9	0.49	116.08	56.96	0.05
DW26	7.6	1170	718	564	186.57	4.86	120.12	0.4	340	40	300	189.35	0.48	103.98	17.90	0.54
BW27	7.8	817	502	420	64.8	121.5	50.82	0.1	250	50	200	65.32	0.48	78.23	14.19	0.07
DW28	7.8	987	471	608	78.32	82.4	49.94	0.2	330	50	280	119.28	0.49	116.58	19.21	0.23
DW29	8.1	220	160	512	80.56	1.21	80.74	0.9	400	30	370	268.5	0.47	126.85	18.21	0.37
DW30	7.5	1850	984	292	70.16	2.43	190.4	2.2	390	50	340	397.6	0.49	153.41	45.22	0.44
DW31	7.5	3310	1818	544	40.48	24.3	160.2	0.20	375	25	350	709.5	0.49	106.78	61.39	0.23
DW32	7.7	947	606	440	124.44	13.36	114.28	2.56	420	70	350	278.32	0.63	44.41	17.43	0.11
DW33	8.0	1380	783	640	103.2	160.26	212.19	0	525	50	475	781	0.98	87.44	12.44	0.10
DW34	8.7	3110	1790	1440	160.32	206.55	137.06	1.7	495	20	475	420	0.75	46.08	47.79	0.13
DW35	7.8	830	531	440	200.8	81.21	104.76	0.4	300	50	250	432	0.69	52.36	35.04	0.87
DW36	8.1	1400	896	620	100.6	36.45	84.6	0.1	490	20	470	432.4	0.97	65.41	18.89	0.89
DW37	7.9	2870	1826	1560	125.25	70.71	276.79	0	495	70	425	721.8	0.72	92.26	40.66	0.09
BW38	7.3	1000	610	440	190.38	55.89	41.8	1.8	250	60	190	244.24	0.56	90.79	7.00	0.65
DW39	7.5	1180	613	936	220.44	1.21	49.94	0.2	260	40	220	710	0.83	103.019	11.07	0.32
DW40	7.7	870	546	448	160.32	1.21	49.06	0.6	420	45	375	725.4	0.48	101.43	27.76	0.12
DW41	7.5	1130	697	936	140.28	80.19	37	1.48	380	20	360	170.4	0.48	100.34	6.30	0.23
DW42	7.7	885	556	456	80.25	68.04	40.17	0.6	450	0	450	210.52	0.55	103.57	4.70	0.31
BW43	7.6	111	91	708	121.24	151.71	23.4	0	390	20	370	369.2	0.47	105.69	26.30	0.98
DW44	7.2	1300	790	752	120.64	3.64	64.2	1.26	510	10	500	369	0.56	110.52	11.17	0.76
DW45	7.1	1170	718	660	80.56	133.65	30.18	1.78	390	20	370	568	0.53	116.08	9.70	0.12
DW46	8.2	1180	744	756	180.36	41.31	120.2	1.6	370	20	350	789.52	0.51	170.33	11.40	0.17
DW47	7.5	1230	767	504	80.44	47.38	50.58	2.6	275	45	230	213	0.58	126.47	20.00	0.34
BW48	7.3	1200	758	740	160.72	57.1	8.24	3.09	425	0	425	326.6	0.47	37.49	17.21	0.24
DW49	7.5	1770	816	800	120.64	48.6	70	2.2	170	20	150	410.4	0.46	52.64	3.00	0.13
DW50	8.1	721	361	272	60.52	55.89	16.2	0.1	310	10	300	425.52	0.51	76.89	26.10	0.11
BW51	7.8	1230	581	1090	90.64	1.21	60.4	0.1	300	50	250	284	0.54	97.32	11.90	0.09
BW52	7.5	1340	807	1060	70.52	27.94	64.46	2.42	390	40	350	255.6	0.54	95.31	17.79	0.09
DW53	7.5	1150	726	1048	72.34	29.16	51.96	0.78	350	25	325	236.52	0.56	96.58	15.17	0.08
DW54	7.9	1220	602	1040	66.34	38.88	21.84	1.8	400	20	380	177.6	0.53	98.23	9.70	0.02
DW55	7.5	911	573	396	80.56	58.32	78.14	1.2	485	10	475	170.4	0.54	105.28	7.10	0.01
DW56	7.6	909	581	408	109.34	1.21	48.17	0.6	475	25	450	130.84	0.56	116.58	18.10	0.07
DW57	7.6	590	344	268	120.24	2.43	16.28	4.28	415	40	375	427.52	0.50	156.64	27.50	0.09
DW58	8.1	775	361	280	100.2	92.32	17.4	1.8	395	70	325	99.4	0.51	204.99	66.10	0.06
DW59	8.1	691	342	272	164.32	84.65	37.4	2.74	350	50	300	110.52	0.56	198.32	13.30	0.06
DW60	8.0	786	403	292	92.38	62.88	28.18	0.1	400	50	350	125.6	0.56	194.64	24.00	0.05
MIN.	7.1	111	79	268	40.48	1.21	8.24	0	170	0	150	65.32	0.46	37.49	3.00	0.01
MAX.	8.7	6390	4109	1760	352.70	417.96	890.4	6.26	1295	120	1225	1668.5	1.35	516.61	75.67	1.11
AVG.	7.65	1627.63	987.71	716.06	132.92	79.25	193.61	1.61	487.18	37.34	450.32	469.20	0.67	167.49	29.18	0.37

Note: 1. All values are expressed in mg/l, except pH and EC (µS/cm)
2. DW- Dug well, BW-Borewell, TH- Total hardness, TA- Total alkalinity

Table 3. Irrigation suitability indices for groundwater in Pre monsoon season 2021

Sample No.	SAR	RSC	MAR	KR	%Na	PI	SSP	CAI	CAII	GR Anion	GR Cation
DW1	3.09	-18.78	49.91	0.42	29.74	36.30	29.74	0.36	0.40	0.74	0.46
BW2	1.55	-6.92	25.43	0.28	21.68	34.35	21.68	-0.44	-0.10	0.32	0.27
DW3	1.79	-6.41	20.29	0.33	24.76	38.25	24.76	-0.32	-0.11	0.34	0.29
DW4	1.37	-15.95	31.69	0.20	16.88	25.69	16.88	0.11	0.06	0.46	0.23
BW5	5.10	-32.26	58.17	0.57	36.31	40.47	36.31	0.48	0.91	0.86	0.58
BW6	2.10	-25.01	52.24	0.27	21.22	26.51	21.22	0.71	2.67	0.87	0.36
DW7	0.56	-19.30	66.89	0.08	7.20	15.40	7.20	0.92	2.72	0.81	0.19
DW8	3.09	-10.86	61.42	0.50	33.41	41.60	33.41	-0.54	-0.24	0.53	0.57
BW9	1.91	-17.04	68.92	0.27	21.00	29.33	21.00	0.74	1.29	0.78	0.46
DW10	9.63	-18.93	66.19	1.29	56.36	60.46	56.36	-0.12	-0.31	0.82	0.79
DW11	8.20	-17.62	57.39	1.21	54.73	58.68	54.73	-0.04	-0.10	0.87	0.74
BW12	9.93	-30.42	52.48	1.17	53.94	56.55	53.94	-1.00	-1.57	0.83	0.71
DW13	9.68	-30.69	84.74	1.08	52.05	55.25	52.05	-1.25	-1.85	0.73	0.88
DW14	19.36	-0.12	22.53	4.20	80.77	85.92	80.77	-2.72	-2.75	0.59	0.84
DW15	11.59	-15.91	45.48	1.46	59.65	64.10	59.65	-0.39	-0.34	0.72	0.73
DW16	11.56	-24.85	44.77	1.37	57.92	61.43	57.92	-0.02	-0.01	0.84	0.71
DW17	11.81	-17.53	47.85	1.50	59.99	64.40	59.99	-1.42	-1.36	0.62	0.74
DW18	11.04	-20.90	70.12	1.35	57.47	61.60	57.47	-1.27	-0.65	0.64	0.82
DW19	7.53	-28.09	53.84	0.82	45.26	49.80	45.26	-0.69	-0.63	0.62	0.64
DW20	0.97	-16.22	52.41	0.13	11.93	21.29	11.93	0.80	1.02	0.69	0.22
DW21	0.54	-16.76	58.42	0.08	7.21	16.54	7.21	0.90	1.77	0.76	0.16
DW22	1.05	-12.71	50.65	0.15	13.31	24.58	13.31	0.55	0.24	0.45	0.24
DW23	0.70	-14.20	34.07	0.11	10.35	19.97	10.35	0.68	0.76	0.61	0.15
DW24	1.14	-10.68	31.42	0.19	16.63	26.61	16.63	0.67	0.73	0.70	0.23
DW25	2.57	-13.32	68.62	0.40	28.57	36.76	28.57	0.06	0.05	0.61	0.56
DW26	2.30	-7.43	48.02	0.41	29.33	40.17	29.33	0.09	0.07	0.55	0.44
BW27	1.14	-6.55	23.63	0.21	17.19	31.59	17.19	-0.40	-0.09	0.24	0.21
DW28	0.83	-8.31	62.22	0.15	12.85	26.22	12.85	-0.29	-0.06	0.23	0.28
DW29	1.63	-0.42	20.06	0.39	28.04	48.43	28.04	-0.28	-0.06	0.29	0.33
DW30	3.31	-11.13	73.97	0.55	35.49	42.26	35.49	-2.12	-0.65	0.46	0.68
DW31	3.79	-3.22	72.08	0.75	43.01	54.09	43.01	-0.71	-0.28	0.48	0.73
DW32	2.73	-11.50	57.64	0.41	29.15	38.80	29.15	-0.81	-0.29	0.35	0.49
DW33	2.49	-16.01	50.64	0.35	25.78	33.94	25.78	-1.16	-0.13	0.34	0.41
DW34	4.92	-23.07	43.88	0.59	37.08	42.29	37.08	-1.00	-0.47	0.55	0.51
DW35	2.16	-24.58	45.63	0.28	21.68	27.01	21.68	-1.04	-0.37	0.48	0.34
DW36	1.83	-14.48	53.08	0.24	19.69	28.81	19.69	0.15	0.06	0.44	0.34
DW37	3.74	-26.56	21.71	0.46	31.40	36.21	31.40	-0.42	-0.32	0.65	0.37
BW38	0.78	-14.89	53.73	0.12	10.84	20.34	10.84	-0.05	-0.02	0.33	0.21
DW39	1.23	-13.73	59.54	0.19	15.95	25.92	15.95	0.15	0.07	0.43	0.32
DW40	0.91	-6.61	40.69	0.17	14.24	29.05	14.24	0.01	0.00	0.27	0.22
DW41	1.03	-4.56	62.72	0.19	16.01	32.26	16.01	0.00	0.00	0.25	0.34
DW42	0.82	-10.06	66.45	0.13	11.57	24.89	11.57	0.26	0.07	0.28	0.28
BW43	0.64	-18.34	50.04	0.09	8.41	15.88	8.41	0.14	0.04	0.39	0.16
DW44	1.62	-9.08	45.18	0.28	22.10	33.36	22.10	0.26	0.17	0.52	0.34
DW45	1.02	-5.14	77.94	0.19	16.14	31.45	16.14	0.09	0.02	0.31	0.47
DW46	2.29	-13.25	26.44	0.34	25.66	35.06	25.66	-14.83	-0.62	0.06	0.32
DW47	1.58	0.72	49.13	0.39	28.13	53.37	28.13	0.07	0.02	0.30	0.43
BW48	0.46	-12.55	23.04	0.07	6.97	18.65	6.97	0.69	0.27	0.43	0.09
DW49	2.57	-10.47	53.76	0.42	29.85	39.31	29.85	-0.94	-0.32	0.39	0.48
DW50	0.34	-13.58	59.49	0.06	5.45	13.78	5.45	0.15	0.02	0.33	0.12
BW51	1.36	-9.37	60.51	0.23	18.86	31.33	18.86	-0.25	-0.07	0.32	0.37
BW52	1.26	-10.51	39.92	0.21	17.69	29.10	17.69	-0.01	0.01	0.38	0.26
DW53	1.60	-3.28	29.18	0.33	25.16	42.39	25.16	0.25	0.14	0.41	0.32
DW54	1.48	-6.70	31.26	0.29	22.44	36.09	22.44	0.50	0.44	0.57	0.30
DW55	1.44	-5.96	29.51	0.25	19.72	34.87	19.72	0.54	0.38	0.46	0.26
DW56	1.17	-6.63	40.43	0.21	17.44	32.38	17.44	-0.26	-0.05	0.25	0.26
DW57	0.65	-8.91	35.96	0.11	10.04	22.84	10.04	0.08	0.02	0.25	0.15
DW58	0.84	-9.90	61.09	0.15	12.86	23.33	12.86	-0.54	-0.10	0.28	0.28
DW59	1.82	-9.01	51.10	0.34	25.63	36.40	25.63	-1.01	-0.38	0.36	0.41
DW60	1.21	-6.08	49.72	0.24	19.54	33.94	19.54	-0.25	-0.07	0.31	0.33
Min	**0.34**	**-32.26**	**20.06**	**0.06**	**5.45**	**13.78**	**5.45**	**-14.83**	**-2.75**	**0.06**	**0.09**
Max	**19.36**	**0.72**	**84.74**	**4.20**	**80.77**	**85.92**	**80.77**	**0.92**	**2.72**	**0.87**	**0.88**
Average	**3.28**	**-13.38**	**49.09**	**0.49**	**26.83**	**36.63**	**26.83**	**-0.44**	**0.00**	**0.50**	**0.41**

All the values are expressed in epm

Table 4. Irrigation suitability indices for groundwater in Post monsoon season 2021

Sample No.	SAR	RSC	MAR	KR	%Na	PI	SSP	CAI	CAII	GR Anion	GR Cation
DW1	2.35	-6.73	47.14	0.41	29.32	41.90	29.32	0.55	0.61	0.64	0.44
BW2	1.87	-4.74	27.84	0.37	26.93	43.05	26.93	-0.05	-0.01	0.36	0.34
DW3	2.27	0.14	33.69	0.56	35.75	57.30	35.75	-0.09	-0.03	0.35	0.46
DW4	1.29	-4.99	50.41	0.26	20.52	37.41	20.52	0.20	0.07	0.36	0.34
BW5	5.48	-18.59	53.31	0.73	42.18	48.20	42.18	0.47	1.03	0.82	0.61
BW6	1.61	-8.91	35.07	0.30	23.43	34.35	23.43	0.86	2.62	0.87	0.32
DW7	1.89	-3.43	51.32	0.40	28.67	45.62	28.67	0.62	0.66	0.62	0.45
DW8	4.57	6.09	67.06	1.18	54.32	75.39	54.32	-0.01	0.00	0.43	0.78
BW9	2.09	-7.26	59.01	0.36	26.66	39.53	26.66	0.78	1.35	0.76	0.47
DW10	10.94	-6.95	54.33	1.77	63.91	69.27	63.91	-3.84	-1.45	0.46	0.79
DW11	5.93	-18.23	55.73	0.83	45.53	50.64	45.53	0.34	0.80	0.85	0.65
BW12	12.99	-3.50	27.18	3.23	76.39	82.27	76.39	0.17	0.48	0.89	0.82
DW13	12.10	6.27	54.39	3.12	75.77	86.62	75.77	-2.14	-0.91	0.40	0.87
DW14	18.65	6.33	51.02	4.49	81.81	89.19	81.81	-6.59	-1.43	0.29	0.90
DW15	8.81	-17.98	50.92	1.05	51.29	56.53	51.29	-0.05	-0.05	0.71	0.68
DW16	6.80	-22.43	90.68	0.78	43.97	49.44	43.97	0.37	0.69	0.77	0.89
DW17	10.36	8.84	33.91	1.99	66.58	77.59	66.58	-0.38	-0.22	0.49	0.75
DW18	6.91	-7.99	73.38	1.00	49.96	58.06	49.96	-0.14	-0.12	0.58	0.79
DW19	6.12	4.11	46.87	1.16	53.81	67.07	53.81	0.25	0.21	0.57	0.69
DW20	1.78	-5.54	1.64	0.36	26.70	41.46	26.70	0.56	0.43	0.62	0.27
DW21	2.18	-6.37	40.68	0.39	28.10	41.12	28.10	0.51	0.42	0.60	0.40
DW22	1.07	-1.64	37.67	0.24	19.43	41.62	19.43	0.51	0.26	0.39	0.28
DW23	1.07	-3.79	42.18	0.24	19.39	38.18	19.39	0.57	0.39	0.50	0.29
DW24	3.08	-2.42	48.22	0.73	42.39	57.13	42.39	0.06	0.06	0.57	0.59
DW25	2.42	-8.91	71.32	0.40	28.90	39.32	28.90	0.07	0.05	0.53	0.59
DW26	2.39	-3.30	4.19	0.55	35.42	50.39	35.42	0.02	0.01	0.52	0.36
BW27	0.86	-8.23	75.89	0.17	14.38	26.13	14.38	-0.20	-0.05	0.36	0.41
DW28	0.94	-4.37	63.85	0.20	17.01	33.72	17.01	0.35	0.13	0.42	0.36
DW29	2.47	3.01	2.46	0.87	46.61	79.02	46.61	0.53	0.41	0.56	0.47
DW30	6.14	3.60	5.50	2.28	69.62	89.27	69.62	0.26	0.27	0.67	0.71
DW31	4.94	2.58	50.20	1.75	63.64	85.49	63.64	0.65	1.33	0.78	0.78
DW32	2.62	0.87	15.27	0.69	41.16	60.52	41.16	0.36	0.32	0.58	0.45
DW33	3.06	-8.80	72.28	0.51	33.59	43.74	33.59	0.58	1.12	0.74	0.65
DW34	1.69	-16.41	68.39	0.24	19.46	28.40	19.46	0.49	0.58	0.60	0.43
DW35	1.59	-10.76	40.44	0.28	21.65	31.21	21.65	0.63	1.03	0.75	0.32
DW36	1.85	0.44	37.82	0.46	31.71	55.59	31.71	0.70	0.85	0.61	0.43
DW37	4.92	-2.66	48.66	1.01	50.17	61.16	50.17	0.41	0.70	0.75	0.66
BW38	0.69	-8.82	33.02	0.13	11.80	22.75	11.80	0.73	0.72	0.69	0.17
DW39	0.93	-5.97	0.91	0.20	16.64	31.13	16.64	0.89	2.46	0.85	0.17
DW40	1.07	-0.31	1.25	0.27	21.26	45.71	21.26	0.89	1.80	0.77	0.21
DW41	0.62	-6.91	48.97	0.12	10.89	26.77	10.89	0.66	0.37	0.45	0.19
DW42	0.80	-2.16	58.74	0.18	15.60	39.56	15.60	0.70	0.44	0.45	0.31
BW43	0.34	-11.70	67.75	0.06	5.23	17.90	5.23	0.90	1.00	0.63	0.15
DW44	1.58	2.31	4.82	0.45	31.25	62.79	31.25	0.73	0.69	0.56	0.32
DW45	0.48	-8.22	73.58	0.09	8.33	23.22	8.33	0.92	1.59	0.73	0.26
DW46	2.11	-5.84	27.78	0.43	30.09	43.64	30.09	0.76	1.69	0.80	0.37
DW47	1.11	-2.57	49.72	0.28	22.42	41.24	22.42	0.62	0.47	0.61	0.37
BW48	0.14	-5.61	37.36	0.03	3.36	23.17	3.36	0.95	1.11	0.57	0.05
DW49	1.37	-6.79	40.35	0.31	23.83	35.60	23.83	0.73	2.01	0.82	0.34
DW50	0.36	-2.32	60.79	0.09	8.55	35.33	8.55	0.94	1.55	0.71	0.19
BW51	1.74	1.22	2.19	0.58	36.66	64.87	36.66	0.67	0.67	0.66	0.37
BW52	1.65	1.31	39.95	0.49	33.24	60.73	33.24	0.60	0.48	0.56	0.45
DW53	1.31	0.21	40.36	0.38	27.72	55.66	27.72	0.66	0.53	0.56	0.39
DW54	0.53	0.44	49.60	0.15	13.37	46.55	13.37	0.80	0.45	0.45	0.23
DW55	1.63	-0.63	54.86	0.39	28.16	50.95	28.16	0.29	0.14	0.38	0.46
DW56	1.27	2.75	1.82	0.38	27.88	63.68	27.88	0.43	0.15	0.33	0.28
DW57	0.41	1.38	3.28	0.12	11.83	46.85	11.83	0.93	1.02	0.66	0.12
DW58	0.30	-4.85	60.74	0.06	6.03	23.10	6.03	0.71	0.16	0.34	0.14
DW59	0.59	-8.44	46.38	0.11	10.15	23.09	10.15	0.46	0.14	0.39	0.17
DW60	0.56	-2.30	53.33	0.13	11.24	33.13	11.24	0.65	0.20	0.38	0.21
Min	**0.14**	**-22.43**	**0.91**	**0.03**	**3.36**	**17.90**	**3.36**	**-6.59**	**-1.45**	**0.29**	**0.05**
Max	**18.65**	**8.84**	**90.68**	**4.49**	**81.81**	**89.27**	**81.81**	**0.95**	**2.62**	**0.89**	**0.90**
Average	**3.16**	**-4.11**	**42.46**	**0.68**	**32.03**	**48.84**	**32.03**	**0.25**	**0.54**	**0.58**	**0.44**

All the values are expressed in epm

Table 5. Classification groundwater samples of Pre and Post monsoon season of 2021 based on Irrigation indices

Classification Index	Category	Range	Pre 21	% of Samples	Sample numbers	Post 21	% of Samples	Sample numbers
SAR (Richards 1954)	Excellent	<10	55	91.66	1-13, 19-60	55	91.66	1-9, 11, 15-16, 18-60
	Good	10-18	4	6.66	15-18	4	6.66	10, 12-13, 17
	Doubtful	18-26	1	1.66	14	1	1.66	14
	Unsuitable	>26	--	--	--	--	--	--
% Na	Excellent	0-20	26	43.33	4, 7, 20-24, 27-28, 36, 38-43, 45, 48, 50-52, 55-58, 60	18	30	22-23, 27-28, 34, 38-39, 41-43, 45, 48, 50, 54, 57-60
	Good	20-40	23	38.33	1-3, 5-6, 8-9, 25-26, 29-30, 32-35, 37, 44, 46-47, 49, 53-54, 59	25	41.66	1-4, 6-7, 9, 20-21, 25-26, 33, 35-36, 40, 44, 46-47, 49, 51-53, 55-56
	Permissible	40-60	10	16.66	10-13, 15-19, 31	10	16.66	5, 8, 11, 15-16, 18-19, 24, 29, 32
	Doubtful	60-80	--	--	--	6	10	10, 12-13, 17, 30-31
	Unsuitable	>80	1	1.66	14	1	1.66	14
RSC (Richards 1954)	Good	<1.25	60	100	1-60	48	80	1-7, 9-12, 15-16, 18, 20-28, 32-43, 45-51, 53-55, 58-60
	Medium	1.25-2.5	--	--	--	2	3.33	52, 57
	Bad	>2.5	--	--	--	10	16.66	8, 13-14, 17, 19, 29-31, 44, 56
Magnesium Hazard (Paliwal 1972)	Suitable	<50	29	48.33	1-4, 14-17, 23-24, 26-27, 29, 34-35, 37, 40, 43-44, 46-48, 52-57, 60	35	58.33	1-3, 6, 12, 17, 19-24, 26, 29-30, 32, 35-41, 44, 46-49, 51-54, 56-57, 59
	Unsuitable	>50	31	51.66	5-13, 18-22, 25, 28, 30-33, 36, 38-39, 41-42, 45, 49-51, 58-59	25	41.66	4-5, 7-11, 13-16, 18, 25, 27-28, 31, 33-34, 42-43, 45, 50, 55, 58, 60
KR (Kelly 1951)	Suitable	<1	51	85	1-9, 19-60	48	80	1-7, 9, 11, 16, 20-29, 32-36, 38-60
	Unsuitable	>1	9	15	10-18	12	20	8, 10, 12-15, 17-19, 30-31, 37
SSP (Eaton 1950)	Good	<20	26	43.33	4, 7, 20-24, 27-28, 36, 38-43, 45, 48, 50-52, 55-58, 60	19	31.66	22-23, 27-28, 34, 38-39, 41-43, 45, 48, 50, 54, 57-60
	Permissible	20-40	23	38.33	1-3, 5-6, 8-9, 25-26, 29-30, 32-35, 37, 44, 46-47, 49, 53-54, 59	25	41.66	1-4, 6-7, 9, 20-21, 25-26, 33, 35-36, 40, 44, 46-47, 49, 51-53, 55-56
	Doubtful	40-80	10	16.66	10-13, 15-19, 31	15	25	5, 8, 10, 13, 15-19, 24, 29-32, 37
	Unsuitable	>80	1	1.66	14	1	1.66	14

Sodium Adsorption Ratio (SAR):

Since sodium content can reduce soil permeability and soil structure, the SAR ratio is used to measure the alkali/sodium hazard to the crop and is therefore regarded as a crucial metric for establishing the water's suitability for irrigation (Todd, 1980). SAR values in the research area vary from 0.34 to 19.36 (Avg. 3.28) and 0.14 to 18.65 (Avg. 3.16) in the pre- and post-monsoon seasons of 2021, respectively (Table 3 and 4). In general, the SAR value provides insight into how much sodium is being absorbed by soil. The magnesium and calcium in the soil may be displaced by the sodium in the water, which will have a long-term negative impact on the productivity of the soil. Water with a low SAR value is typically suitable for irrigation. 91.66 percent of the samples (sample nos. 1-13, 19-60), and 91.66 percent of the samples (sample nos. 1-9, 11, 15-16, 18-60) fall into the excellent water category for irrigation. While 6.66% samples fall into the good water category. only one sample number, 14 falls into the doubtful category. This sample comes from a region that has been excess irrigation. The sodium adsorption ratio's spatiotemporal maps show that the north-eastern parts of the research area have high sodium concentrations due to intensive irrigation (Fig.2).

Residual Sodium Carbonate (RSC):

The amount of bicarbonate and carbonate above alkaline earth affects whether water is suitable for irrigation. (Richards, 1968). RSC values in the research area vary from -32.26 to 0.72 (Avg. -13.38) and -22.43 to 8.84 (Avg. -4.11) in the pre- and post-monsoon seasons of 2021, respectively (Table 3 and 4). Accordingly, water with a high carbonate and bicarbonate content has a preference for precipitating calcium and magnesium, which concentrates the water in the soil and raises the sodium bicarbonate levels in the water (Sadashivaiah *et al*., 2008). RSC value (<1.25) according to Richards (1954) classification (Table 5), 100 percent of the samples (sample nos. 1-60), and 80 percent of the samples (sample nos. 1-7, 9-12, 15-16, 18, 20-28, 32-43, 45-51, 53-55, 58-60) fall into the good water category for irrigation. During post monsoon, 3.33% samples (sample nos. 52, 57) are from medium category and 10.66% samples (sample nos. 8, 13-14, 17, 19, 29-31, 44, 56) are from bad category. Most of the samples of bad category are from irrigated area. Spatiotemporal map show that the west and central portions of the research region had significant RSC content throughout the pre- and post-monsoon (Fig.3).

Magnesium Adsorption Ratio (MAR):

The excess of magnesium (Mg^{2+}) over calcium (Ca^{2+}) is known as the MAR. In most cases, the ion exchange of minerals from rocks and soils by water is the source of magnesium in groundwater (Mukherjee *et al*., 2005). The increase in soil alkalinity brought on by a high MAR (>50) has an impact on crop productivity. A wide range of MAR values are seen in the research area. The values in pre- and post-monsoon, were from 20.06 to 84.74, with an average of 49.09, and from 0.91 to 90.68, with an average of 42.46 (Table 3 and 4). MAR stands for magnesium excess over calcium. As per classification (Table 5) 48.33 percent of the samples (sample nos. 1-4, 14-17, 23-24, 26-27, 29, 34-35, 37, 40, 43-44, 46-48, 52-57, 60), and 58.33 percent of the samples (sample nos. 1-3, 6, 12, 17, 19-24, 26, 29-30, 32, 35-41, 44, 46-49, 51-54, 56-57, 59) fall into the suitable water category for irrigation in the pre- and post-monsoon. While the following samples fall into the unsuitable water category for irrigation in the pre- and post-monsoon seasons: 51.66% samples (sample nos. 5-13, 18-22, 25, 28, 30-33, 36, 38-39, 41-42, 45, 49-51, 58-59) and 41.66% samples (sample nos. 4-5, 7-11, 13-16, 18, 25, 27-28, 31, 33-34, 42-43, 45, 50, 55, 58, 60). The Magnesium

Adsorption Ratio's spatiotemporal variation map showed that a high MAR value had been recorded in the research area's south west. (Fig.4).

Kelley's Ratio (KR):

Kelley *et al.* (1951) suggests irrigation water's potential salt issue. The sodium content is measured in relation to calcium and magnesium using this ratio. This ratio is greater than one (>1), which denotes an excessive salt concentration that has negative impacts on the soil's characteristics and lowers soil permeability. In areas with intensive agriculture, Kelly's ratio has a high value (Fig.5). Groundwater is deemed suitable for irrigation when its Kelley's ratio is less than one (1). A wide range of KR values are seen in the research area. The values in pre- and post-monsoon; were from 0.06 to 4.20, with an average of 0.49, and from 0.03 to 4.49, with an average of 0.68, respectively (Table 3 and 4). As per classification (Table 5), 85 percent of the samples (sample nos. 1-9, 19-60), and 80 percent of the samples (sample nos. 1-7, 9, 11, 16, 20-29, 32-36, 38-60) fall into the suitable water category for irrigation in the pre- and post-monsoon seasons. While the following samples fall into the unsuitable water category for irrigation in the pre- and post-monsoon seasons: 15% samples (sample nos. 10-18) and 20% samples (sample nos. 8, 10, 12-15, 17-19, 30-31, 37).

Percent Sodium (%Na):

The % sodium criterion is essential for figuring out how much soluble sodium is present in the water and for identifying the sodium hazard. Sodium decreases soil permeability by replacing calcium in the soil through the base-exchange process (Obiefuna and Sheriff, 2011). In a study area during pre- and post-monsoon seasons %Na varies from 5.45 to 80.77, with an average of 26.83, and from 3.36 to 81.81, with an average of 32.03, respectively (Table 3 and 4). As per classification (Table 5), 43.33 percent of the samples (sample nos. 4, 7, 20-24, 27-28, 36, 38-43, 45, 48, 50-52, 55-58, 60), and 30 percent of the samples (sample nos. 22-23, 27-28, 34, 38-39, 41-43, 45, 48, 50, 54, 57-60) fall into the excellent water category for irrigation in the pre- and post-monsoon seasons. While the following samples fall into the good water category for irrigation in the pre- and post-monsoon: 38.33% samples (sample nos. 1-3, 5-6, 8-9, 25-26, 29-30, 32-35, 37, 44, 46-47, 49, 53-54, 59) and 41.66% samples (sample nos. 1-4, 6-7, 9, 20-21, 25-26, 33, 35-36, 40, 44, 46-47, 49, 51-53, 55-56).Whereas 16.66 percent of the samples (sample nos. 10-13, 15-19, 31), and 16.66 percent of the samples (sample nos. 5, 8, 11, 15-16, 18-19, 24, 29, 32) fall into the permissible water category. While the following samples fall into the doubtful water category for irrigation in post-monsoon seasons: 10% samples (sample nos. 10, 12-13, 17, 30-31). Only sample number 14 falls into the pre- and post-monsoon category that is inappropriate for irrigation. A few hotspots have been found in the northeast (Fig. 6). Percent sodium has a high value in areas with intensive agriculture.

Soluble Sodium Percentage (SSP):

The SSP ratio is used to determine the sodium hazard. Water with SSP levels exceeding 60% may lead to sodium accumulation, which may impair the physical properties of the soil. Regular irrigation with alkaline water degrades the soil's physical properties and reduces agricultural output (Fipps, 1998). In a study area during pre- and post-monsoon seasons SSP varies from 5.45 to 80.77, with an average of 26.83, and from 3.36 to 81.81, with an average of 32.03 (Table 3 and 4). As per classification (Table 5), 43.33 percent of the samples (sample nos. 4, 7, 20-24, 27-28, 36, 38-43, 45, 48, 50-52, 55-58, 60), 31.66 percent of the samples (sample nos. 22-23, 27-28, 34, 38-39, 41-43, 45, 48, 50, 54, 57-60), fall into the good water category for irrigation in the pre- and post-monsoon seasons. While the following samples fall into the permissible water category for irrigation in the pre- and post-monsoon seasons: 38.33% samples (sample nos. 1-3, 5-6, 8-9, 25-26, 29-30, 32-35, 37, 44, 46-47, 49, 53-54, 59) and 41.66% samples (sample nos. 1-4, 6-7, 9, 20-21, 25-26, 33, 35-36, 40, 44, 46-47, 49, 51-53, 55-56).Whereas 16.66 percent of the samples (sample nos. 10-13, 15-19, 31), and 25 percent of the samples (sample nos. 5, 8, 10, 13, 15-19, 24, 29-32, 37) fall into the doubtful water category for irrigation. Sample number 14 is the only sample from unsuitable category, therefore prohibited for irrigation. The spatio-temporal maps of the soluble sodium percent showed that the north-east part of the research area had a high value of SSP (Fig.7).

Permeability Index (PI):

Some elements of water reduce the permeability of the soil. Additionally, it can exacerbate nutritional problems, waterlogging, soil and water salinity, weed growth, and other problems. The amount of salt, calcium, magnesium, and bicarbonate in the soil has an impact on how permeable it is. The PI is therefore recognised as a critical parameter for determining whether groundwater is suitable for irrigation (Doneen, 1964). In a study area during pre- and post-monsoon seasons, the PI values range from 13.78 to 85.92, with an average of 36.63, and from 17.90 to 89.27, with an average of 48.84, respectively (Table 3 and 4). The figure (8) showed that a high permeability index value is seen in pre-monsoon season. While only a few patches are seen in the research area's centre, the north-east region has higher concentrations which is heavily irrigated area.

Chloroalkaline Indices (CA I and II):

These indices are used to understand how groundwater interacts with its host rock during ion exchange activities (Schoeller, 1967). Whereas negative results are related to the chloroalkaline disequilibrium, positive values confirm base-exchange processes. In the current study region, CA I values vary from -14.83 to 0.92 (avg. -0.44) in the pre monsoon season of 2021 and from -6.59 to 0.95 (avg. 0.25) in the post monsoon season (Table 3 and 4). In the pre-monsoon and post-monsoon seasons,2021 respectively, the CA II values range from -2.75 to 2.75 with an average of 0.00 and from -1.45 to 2.62 with an average of 0.54, respectively (Table 3 and 4).

Gibbs Ratios (GR I and GR II):

Gibbs ratio is used to determine the connection between aquifer lithological properties and water composition. (Gibbs, 1970). In the pre- and post-monsoon seasons, GR I values range from 0.06 to 0.87 (avg. 0.50) and 0.29 to 0.89 (avg.

0.58), respectively (Table 3 - 4). In the pre- and post-monsoon seasons, the GR II value ranges from 0.09 to 0.88 with an average of 0.41 and from 0.05 to 0.90 with an average of 0.44 (Table 3 and 4).

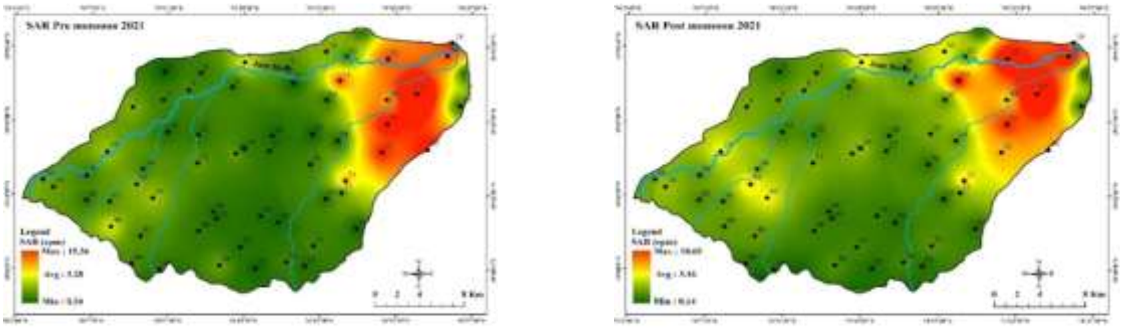

Fig. 2 Spatial variations of SAR in Pre and Post monsoon season of 2021

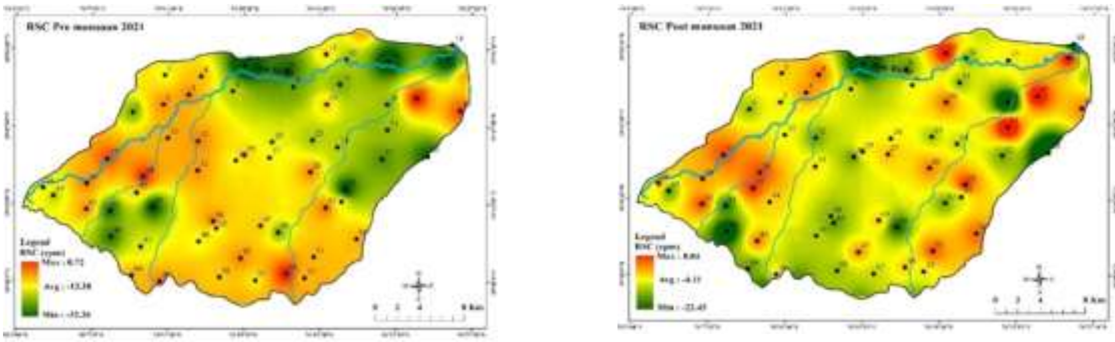

Fig. 3 Spatial variations of RSC in Pre and Post monsoon season of 2021

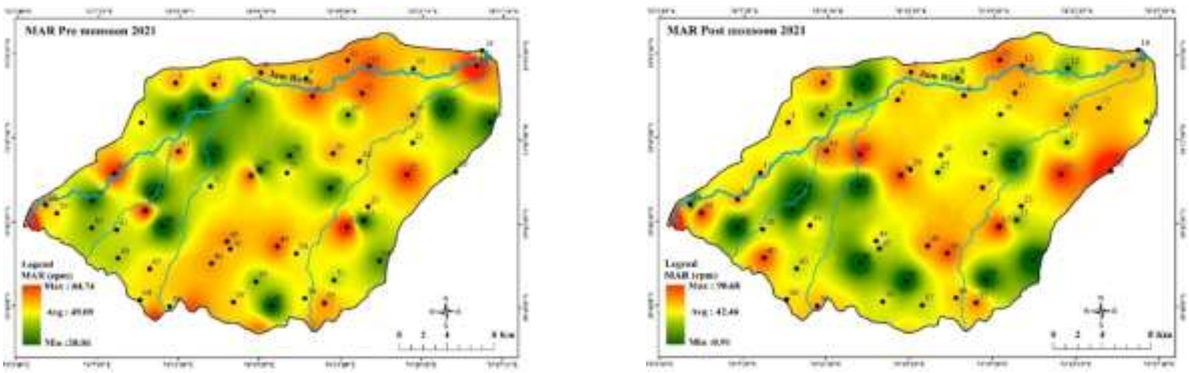

Fig. 4 Spatial variations of MAR in Pre and Post monsoon season of 2021

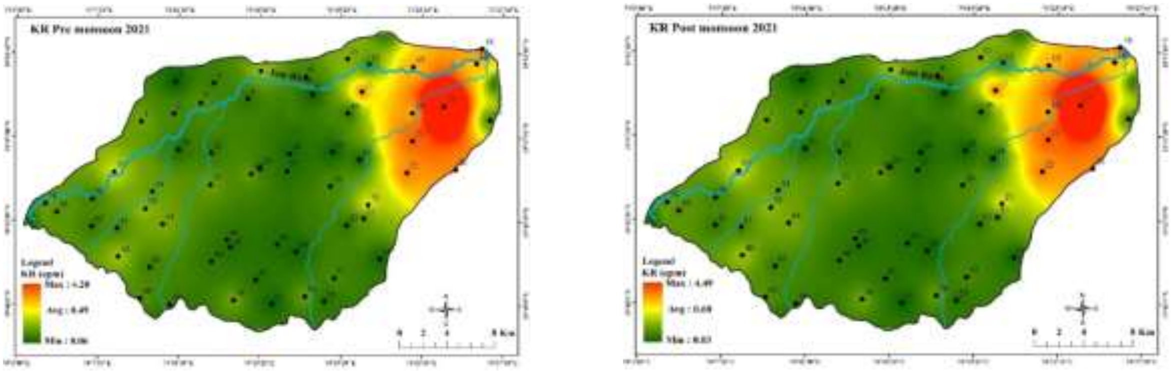

Fig. 5 Spatial variations of KR in Pre and Post monsoon season of 2021

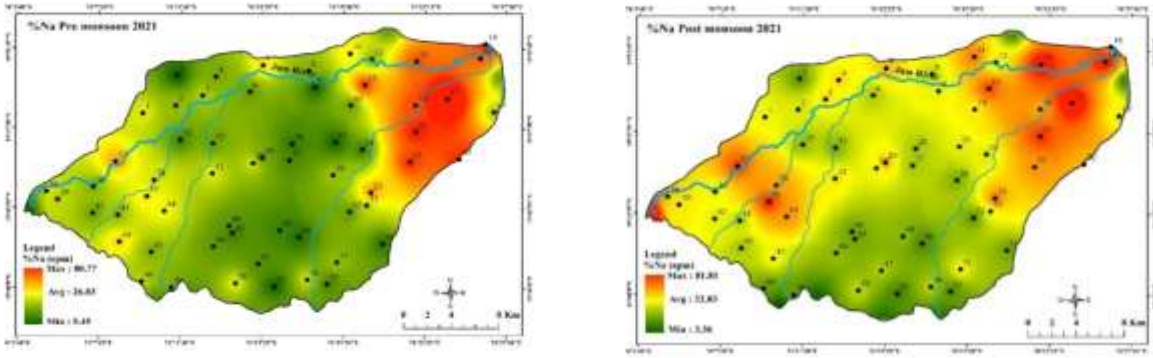

Fig. 6 Spatial variations of %Na in Pre and Post monsoon season of 2021

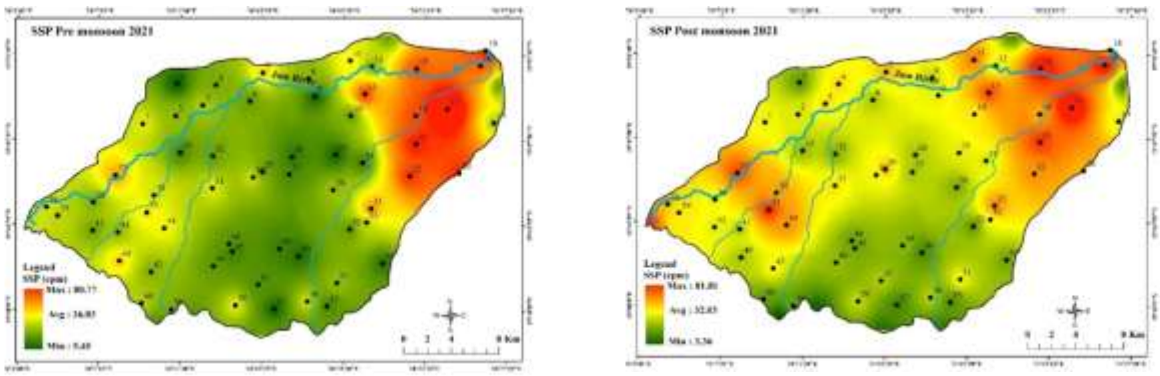

Fig. 7 Spatial variations of SSP in Pre and Post monsoon season of 2021

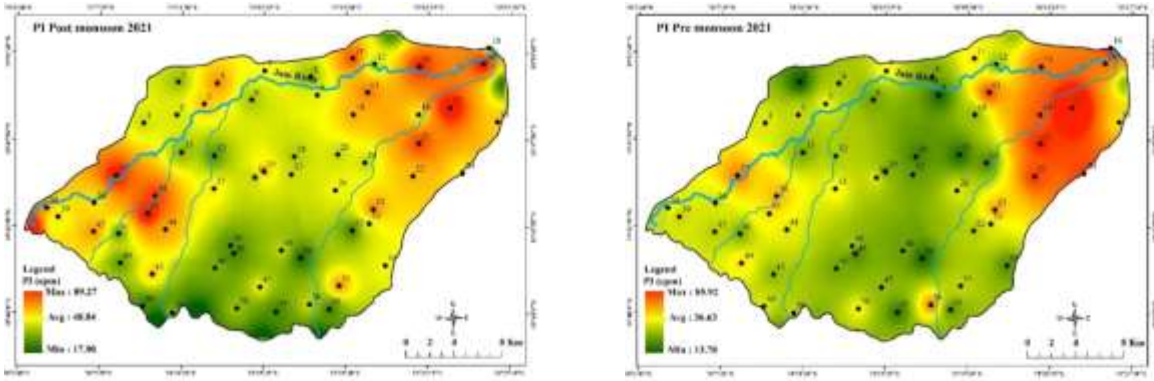

Fig. 8 Spatial variations of PI in Pre and Post monsoon season of 2021

EC based groundwater classification for irrigation:

This classification is given by Richards in 1954.

According to Richards' (1954) classification (Table 6), 10 % samples during post monsoon are excellent for irrigation. While 11.65, and 13.33% of the samples are good for irrigation. 65%, and 55% of the groundwater samples are permissible for agricultural use. However, groundwater samples are classified as doubtful in 5%, and 5% of the cases. 18.33% of groundwater samples (numbers 5-6, 9, 11, 15-19, 34, 37) and 16.66% of samples (numbers 5, 9, 11, 15-19, 31, 34) are not suitable for irrigation during the pre- and post-monsoon. Because of this, the research area's groundwater from these sample locations is unusable for cultivation.

The high concentration of EC in groundwater may have an effect on the risk of salt to water, which reduces soil permeability and crop productivity. Continued use of water with such a high salt concentration could result in saline conditions even in instances when drainage is adequate (Richards, 1954).

Table 6. Classification of groundwater samples based on electrical conductivity (EC) (after Richards, 1954)

Sr. No	Classification Category	Range	Pre 2021		Post 2021	
			No. of samples & (%)	Sample No.	No. of samples & (%)	Sample No.
1	Excellent	< 250	--	--	6 (10%)	7, 14, 20, 24, 29, 43
2	Good	250-750	7 (11.66%)	7, 10, 13-14, 20, 29, 57	8 (13.33%)	3-4, 10, 13, 21, 50, 57, 59
3	Permissible	750-2000	39 (65%)	1-4, 8, 21-24, 26-28, 30, 32-33, 35-36, 38-56, 58-60	33 (55%)	1-2, 8, 22-23, 25-28, 30, 32-33, 35-36, 38-42, 44-49, 51-56, 58, 60
4	Doubtful	2000-3000	3 (5%)	12, 25, 31	3 (5%)	6, 12, 37
5	Unsuitable	>3000	11 (18.33%)	5-6, 9, 11, 15-19, 34, 37	10 (16.66%)	5, 9, 11, 15-19, 31, 34

TDS based groundwater classification for irrigation:

This classification is given by Davies and DeWiest 1966.

Table 7. Groundwater classification based on TDS values (Davies and DeWiest 1966)

Sr. No	Classification Category	Range (mg/l)	Pre monsoon 2021		Post monsoon 2021	
			No. of samples and (%)	Sample Numbers	No. of samples and (%)	Sample Numbers
1	Useful for irrigation	1000-3000	12 (20%)	6, 9, 11-12, 17, 25, 30-32, 34-35, 37	8 (13.33%)	6, 9, 11-12, 17, 31, 34, 37
2	Unfit for irrigation	>3000	5 (8.33%)	5, 15-16, 18, 19	5 (8.33%)	5, 15-16, 18-19

According to Davies and DeWiest's classification (1966) (Table 7), Samples with TDS levels 1000-3000 mg/l in 20 % and 13.33% of them demonstrate their acceptability for irrigation in the pre and post-monsoon. While groundwater samples from 8.33% in the pre and post-monsoon seasons indicated TDS values >3000 mg/l, which are unfit for irrigation. According to Tiwari and Singh (2014), extended residence durations in an aquifer body, parent rock components that have weathered and the presence of soil salts all contribute to the high TDS concentration in groundwater. The primary source of TDS in the study area is weathered basalts.

Chloride based groundwater classification for irrigation:

This classification is given by Ayers and Westcot, 1985.

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Table 8. Classification of Chloride for Irrigation purpose water (Ayers and Westcot, 1985)

Sr. No	Classification Category	Range	Pre 2021		Post 2021	
			No. of samples & (%)	Sample No.	No. of samples & (%)	Sample No.
1	Safe for most plants	<2	4 (6.66%)	28, 46, 50, 58	1 (1.66%)	27
2	Sensitive plants show injury	2-4	19 (31.66%)	2-3, 27, 29-30, 38, 40-43, 45, 47, 49, 51-52, 56-57,59-60	5 (8.33%)	28, 56, 58-60
3	Moderately sensitive plants show injury	4-10	17 (28.33%)	4, 8, 22-23, 25-26, 31-33, 35-36, 39, 44, 48, 53-55	25 (41.66%)	2-4, 8, 10, 13-14, 20, 22-26, 29, 32, 38, 41-42, 47-48, 51-55
4	Can cause severe problem	>10	20 (33.33%)	1, 5-7, 9-21, 24, 34, 37	29 (48.33%)	1, 5-7, 9, 11-12, 15-19, 21, 30-31, 33-37, 39-40, 43-46, 49-50, 57

From the table 8, it is revealed that only 6.66% and 1.66% of the groundwater samples are safe for plants due to low chloride levels (2 meq/l), in accordance with Ayers and Westcot categorization from 1985. Groundwater samples taken in 2021 throughout the pre- and post-monsoon seasons (31.66% and 8.33%) may be sensitive to plants. 28.33%, and 41.66% of the groundwater samples are moderately sensitive for plants in the pre- and post-monsoon. 33.33%, and 48.33% of the samples in the study area can seriously harm plants in the pre- and post-monsoon. Both natural and man-made causes, including as agricultural runoff, the usage of chemical fertilizers, animal feed, landfill leachate, etc., contribute to the presence of chloride in groundwater. (Ayers and Westcot, 1985).

Conclusion:

The groundwater from the study area have been classified for irrigation purpose on the basis of SAR, KR, SSP, RSC, MAR, %Na, PI, EC, TDS and Chloride content. A hydrochemical investigation verified the alkaline and hard nature of groundwater. The spatial distribution map shows that the north-eastern portion of the study region is the most damaged as a result of impurities percolating and seeping into the aquifer. The majority of groundwater samples are appropriate for irrigation, according to the SAR, %Na, KR, and RSC categorization. MAR ratio suggests 51.66 and 41.66% samples are unfit for irrigation. (MAR >50). The high magnesium content results increase soil salinity and adverse effects on crop yield are probable in the study area. Moreover, SSP ratio shows that 43.33% samples are good, 38.33% are permissible, 16.66 are doubtful and 1.66% samples are from unsuitable category. KR ratio depicts wide suitability in 85% samples and only 15% samples come under unsuitable category. According to Davies and DeWiest's classification (1966) for TDS, 8.33% samples are unfit for irrigation. In basically, the findings support the hypothesis that ion exchange, silicate weathering, evaporation and anthropogenic inputs are the primary geogenic processes changing the composition of groundwater. As a result, the current research demonstrates that the majority of groundwater samples are suitable for irrigation. Few aquifers, nevertheless, are problematic and require specific corrective action.

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