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Characterization of Groundwater Suitability for Industrial and Irrigation Potential in Shahada Tehsil, Nandurbar District, Maharashtra, India

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Abstract:
The study of subsurface water quality to evaluate its aptness for agricultural, industrial practice has become essential due to the variability in rainfall intensity and uncertainty in its distribution. In view of this, the geochemical properties of 45 groundwater samples, including electrical conductivity (EC), pH, total dissolved solids, major cations, and anions, are measured and evaluated suitability. The suitability for irrigation purpose advised by appraisal of various cultivation water quality parameters such as sodium percentage (Na%), sodium adsorption ratio (SAR), Kelly's ratio (KR), residual sodium carbonate (RSC), magnesium adsorption ratio (MAR), and permeability index (PI). The industrial applicability was analysed using the Langelier saturation index (LSI), Ryznar stability index (RSI) and Larson–Skold index (LSkI). Geographic information systems (GIS) used the analytical results to produce the numerical spatial dispersion of the indexes. The comprehensive technique of suitability evaluation indicates that subsurface water in the research region is ideal for cultivation. Also, the spatial variation maps of LSI, RSI and LSkI illustrations that most pre-monsoon period samples were largely unaffected by minor scaling and corrosive potentials. Hence study indicates that, continuous monitoring of quality groundwater resources can play major role for achieving the goal of sustainable development of the region.

Keywords: *Water quality, Agriculture, Industry, Shahada Tehsil, India*

INTRODUCTION

Subsurface water is a renewable source of water that will be used for domestic needs, crop growing purpose, economic growth, which leads to growth of nations globally (Scanlon et. al., 2023; Bierkens et. al., 2019, Lamsoge et. al., 2019). All over the world the subsurface water provides about 43% of farming water, which will be fit for farming than treated wastewater. Groundwater degradation is a severe hazard to future generations for a variety of reasons (Mishra et. al., 2023; Khan et. al., 2022). Groundwater quality is declines due the industrialization, suburbanisation, and significant agricultural operations (Bartarya et. al., 2022; Selvakumar et. al., 2017; Priyan et. al., 2021). The Groundwater occurrence and distribution are primarily determined by natural and manmade processes (Rajaveni et. al., 2017). Numerous aspects namely, rock-water interaction, petrology, agricultural fertiliser and pesticide use, and climatic conditions all have a significant impact on groundwater quality (Dubey et. al., 2021; Balamurugan et. al., 2020; Şener et. al., 2021; Abanyie et. al., 2023). Surface and subsurface water reserve demand in India has raised over the last several years as the country's population has grown. There is significant burden on shallow aquifers because of contamination and urban expansion aspects such as increased population, economic development, and cultivation activities (Deshpande et. al., 2022; Mushtaq et. al., 2020; Sengupta et. al., 2017; Kadam et. al., 2021). These economic developments reduce irrigation water availability (Nunes et. al., 2017). As a result, it is vital to assess subsurface water supplies, variability of water resource availability throughout the year (Abd et. al., 2018; Mirdashtvan et. al., 2021; Subramani et. al., 2021). Industrial developments and wastes, as well as the applications of fertilisers, herbicides, and animal manure, reduce the vital use of subsurface water resources (Singh et. al., 2020; Sun et. al., 2012; Ullah et. al., 2013). The amount of primary physicochemical parameter and trace ions in groundwater is regulated by hydrogeochemical processes such as erosion, dilution, solute dispersal, and ion transfer (Sako et. al., 2021; Li et. al., 2020; Khan et. al., 2021; Sharma et. al., 2023).

Several studies have been performed in various parts of the globe to evaluate the standard of subsurface water quality for domestic, economic, industrial, and cultivation practice. (Gaikwad et. al., 2020; Thabrez et. al., 2023; Naidu et. al., 2021) investigated the geochemical mobility of ions in subsurface water in India's western coastal area and concluded that SAR, %Na, and Kelly ratio are the primary parameters to assess the suitability of subsurface water for agricultural use. The infiltrated form surface flow recharged water relates with the physical, chemical, and biological processes occurring in the soil, as well as mineral dissolution triggered by interactions with water and moisture in the soil and rocks, hydrogeochemical studies are vital to recognise the hydrogeologic processes regulating subsurface water chemistry. In general, the hydrogeochemical aspects that affect the chemical composition of subsurface water differ in region and time. The Inclusive hydrogeochemical analysis is required to investigate, recognise, and evaluate the vital applications of subsurface water for household, cultivation, and industrial objectives. The following are the primary objectives of this research: (1) Evaluation of temporal variation in agricultural suitability with the help of parameters such as the sodium adsorption ratio (SAR), sodium percentage (Na%), permeability index (PI), residual sodium carbonate (RSC), Kelley's ratio (KR), magnesium adsorption ratio (MAR) (2) Industrial applicability assessment using the Langelier saturation index (LSI), Ryznar saturation index (RSI) and Larson-Skold index (LSkI). The study's findings are intended to assist government officials, water managers in developing groundwater management strategies in research region.

STUDY AREA

Shahada is a tehsil in the Nandurbar District of Maharashtra State, India. It is located in north-eastern region of the Nandurbar District (Fig.1). Shahada tehsil is hub for many renowned organisations working in economical, industrial and educational sectors in the North Maharashtra region. Shahada tehsil has mostly occupied scheduled tribe population lives about 88 percent of the total population. Total population of Shahada tehsil is 335,346 living in 63,120 houses, spread across total 207 villages and 147 panchayats. The microclimate of the area is categorized by a warm summer and overall aridness through the year expect during rainy season month, i.e., June to September. The change in temperature is high-lowest temperature is about 15°C and while the extreme temperature is 42°C in the year. The normal yearly precipitation in the area under study is about 650 mm. The subsurface water level of study region is fluctuating from 5 to 10m bgl and 10-20 m bgl in pre and post monsoon period respectively.

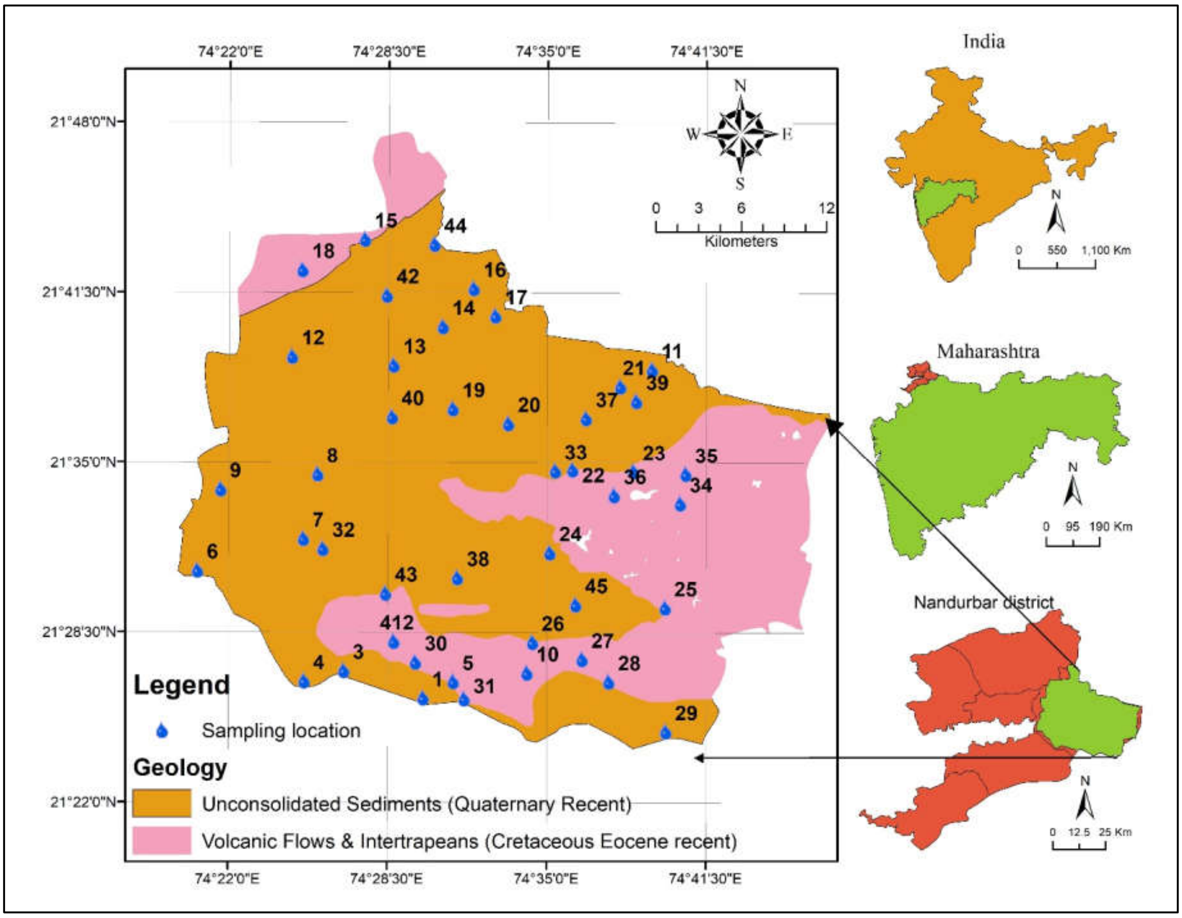

Figure 1: Geological outline of Shahada Tehsil denoting the water sample collection site

Geological outline:

The study area mainly has the basaltic terrain overlain with alluvium deposit originate from Volcanic Flows and Intertrapeans (Cretaceous Eocene recent) age from Deccan trap (Satpura Group). Deccan Trap having different flows of basalt coming from the volcanic fissure action. Which is mainly of two different types namely "Compound" and "Compound Pahoehoe flows (non-porphyritic to highly porphyritic)" present in eastern and western part of study area (Vaidyanadhan et., al., 2008; Ray et., al., 2007). About 70% area forms shallow alluvium deposits of Unconsolidated Sediments Quaternary Recent period. Significant geological formation of intratrappean Lameta bed is observed in central part of study area which mainly showing recent alluvial deposit in study area, while upper part mainly having older alluvium plain showing high clay content constituents in it (Fig. 1). The northern part of the area is having dark brown to yellowish brown sandy thin to moderate deep soils, with clayey loamy soils. Hydrogeology is primarily concerned with the formation, distribution, circulation, and chemistry of groundwater in the context of the geological environment. Basaltic and bazada part of study area are acts as recharge zone and alluvium part is acts as discharged zone or storage zone (Tahama et, al., 2022).

METHODOLOGY

Sample assemblage:

The field data assemblage was carried out in Shahada tehsil of Nandurbar District, Maharashtra State, using a toposheet no. 46K published by Survey of India. During the pre-monsoon season in 2021, Total 45 subsurface water samples were collected from multiple sites within the research region. After repeatedly pumping out for 30 minutes, water samples were taken from the dug/tube wells. The samples were collected in 1 litre clean polythene bottles, and they were fully sealed after collection (Wagh et., al., 2018; Kadam et., al., 2021; Muniraj et., al., 2021; Panneerselvam et., al., 2021). Till the evaluation was finished, the samples were stored in a refrigerator at 4°C. The study region was determined using the Geographical Information System software (Arc GIS version: 10.8 software). The Global Positioning System (GPS) was utilized to pinpoint groundwater sample locations in the field (Fig.1). Using Arc GIS software, the sites are then marked on the geo-referenced map. Linear Imaging Self Scanning (LISS III) pictures were used to create thematic maps for the research region.

Evaluation of collected samples:

Using a field water testing kit, the indices such as pH, TDS, EC, and temperature were measured immediately in the field (Balamurugan et., al., 2020; Panneerselvam et., al., 2020). Using 0.01 N of sulfuric acid (H_2SO_4), the sample's CO_3^{2-} and HCO_3^- content was determined. Cl^- was determined by titration using 0.05 N silver nitrate ($AgNO_3$). By titrating with 0.05 N ethylenediamine tetra acetic acid (EDTA), Ca^{2+} and Mg^{2+} concentrations were assessed. The reflux technique was used to determine the amount of dissolved oxygen. According to protocol, spectrophotometric analysis was used to detect NO_3^-, SO_4^{2-}, and F^- (APHA, 1995). Flame photometry was used to calculate Na^+ and K^+. Ion balancing was carried out according to protocol in order to assess the correctness of the results. In order to calculate ion balancing, the parameter concentrations were changed from mg/l to meq/l (Mallick et., al., 2021; Mallick et., al., 2018). The cation summation contains Ca^{2+}, Mg^{2+}, Na^+, K^+, and Fe concentrations displayed in meq/l. The sum of anions comprises parameters like NO_3^-, HCO_3^-, Cl^-, F^-, SO_4^{2-}, PO_4^{2-}, and NH^{3-} expressed in meq/l. In the sample appraisal, the mean % difference between the main ions was 2.37%. The samples were discovered to placed inside the appropriate range of ±10 meq/l.

Subsurface water quality indicators for irrigation and industry:

The following formulas have been applied for SAR, Na %, RSC, MAR, KR and PI indices along with Langelier saturation index (LSI), Ryznar saturation index (RSI) and Larson-Skold index (LSkI) valuation (Mallick et., al., 2021; Taghavi et., al., 2019). Table no.1 illustrates the highest, lowest, and mean values of cultivation and industrial water quality indices: Grapher Golden program was used to create irrigation water quality depiction illustrations such as USSL, Wilcox.

$$SAR = \frac{Na^+}{\sqrt{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})/2}} \tag{1}$$

$$Na\% = \frac{Na^+ + K^+}{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + Na^+ + K^+} \times 100 \tag{2}$$

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

$$MAR = \frac{\mathrm{Mg}^{2+}}{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})} \times 100 \tag{4}$$

$$KR = \frac{Na^{+}}{(Ca^{2+} + Mg^{2+})} \quad (5)$$

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100 \quad (6)$$

$$LSI = pHa - pHs \quad (7)$$

$$RSI = 2(pH_S) - pH \quad (8)$$

$$LSkI = \frac{Cl^{-} + SO_4^{2-}}{HCO_3^{-} + CO_3^{2-}} \quad (9)$$

Table 1: Concentration of subsurface water quality indicators for irrigation and industry

ID	Na%	PI	RSC	KR	MAR	SSP	CAI 1	CAI 2	SAR	LSI	RSI	LSkI
Unit	%	-	meq/l	-	%	-	-	-	-	-	-	-
1	19.18	34.85	-5.12	0.22	46.86	18.22	0.68	0.75	1.02	-0.093	7.4	1.094545
2	21.77	30.93	-5.66	0.25	41.37	20.16	0.01	0.00	1.07	0.37	6.7	0.235417
3	17.99	30.57	-3.70	0.21	44.60	17.32	0.40	0.19	0.85	-0.059	7.4	0.509091
4	24.65	32.36	-3.94	0.32	43.59	23.98	-0.80	-0.20	1.31	0.89	6.2	0.203448
5	28.45	38.36	-7.20	0.39	36.89	28.04	0.49	0.46	2.58	1.3	5.4	1.116013
6	21.77	30.93	-1.66	0.25	41.37	20.16	0.01	0.00	1.07	0.64	6.4	0.217308
7	24.19	39.08	1.07	0.31	39.15	23.82	0.49	0.23	1.33	-0.41	7.6	0.851852
8	26.99	42.28	2.75	0.36	44.02	26.60	0.41	0.16	1.45	-0.27	7.6	0.807692
9	23.18	37.60	2.96	0.29	38.24	22.52	0.48	0.16	1.22	-0.053	7.3	0.677966
10	30.85	46.49	5.22	0.44	34.37	30.35	0.42	0.16	1.78	0.018	7.2	0.720471
11	20.62	30.43	1.72	0.25	36.06	20.17	0.18	0.04	1.20	0.42	6.6	0.5075
12	27.63	43.75	7.34	0.37	41.66	27.16	0.40	0.11	1.41	-0.025	7.6	0.845161
13	26.85	41.39	7.17	0.36	41.74	26.28	0.45	0.15	1.54	0.2	7	0.817143
14	23.11	36.43	7.10	0.29	51.79	22.56	0.45	0.14	1.29	0.25	6.9	0.440191
15	22.66	32.35	8.12	0.28	44.00	21.67	-0.17	-0.02	1.10	0.057	7.4	0.430769
16	21.77	30.93	8.34	0.25	41.37	20.16	0.01	0.00	1.07	0.38	6.6	0.226
17	26.99	42.28	11.75	0.36	44.02	26.60	0.41	0.10	1.45	0.023	7.4	0.777778
18	26.08	37.12	11.01	0.34	36.25	25.52	0.02	0.00	1.42	0.52	6.5	0.245909
19	26.09	40.38	13.06	0.34	42.89	25.50	0.43	0.10	1.45	0.28	6.9	0.446809
20	18.82	34.18	13.64	0.22	45.77	17.87	0.68	0.21	1.01	0.31	6.9	1.094545
21	22.37	33.03	12.82	0.28	40.00	21.89	0.18	0.03	1.26	0.32	6.7	0.502475
22	26.74	41.22	16.12	0.36	41.51	26.18	0.45	0.10	1.53	0.21	7.1	0.80791
23	22.48	34.50	15.78	0.28	43.92	22.12	0.27	0.04	1.22	0.07	7.1	0.511111
24	21.03	32.04	15.88	0.26	39.50	20.69	0.24	0.03	1.17	0.13	6.7	0.580822
25	15.45	24.31	15.45	0.16	55.41	13.48	0.41	0.05	0.75	-0.071	7.1	0.504762
26	26.74	41.22	20.12	0.36	41.51	26.18	0.45	0.09	1.53	0.21	7	0.707921
27	30.61	37.42	15.17	0.37	25.94	27.01	0.34	0.12	2.28	1.5	5.2	0.728358
28	22.66	32.35	21.12	0.28	44.00	21.67	-0.17	-0.01	1.10	0.036	7.3	0.430769
29	21.77	30.93	21.34	0.25	41.37	20.16	0.01	0.00	1.07	0.58	6.4	0.23299
30	26.99	42.28	24.75	0.36	44.02	26.60	0.41	0.06	1.45	-0.21	7.6	0.65625
31	26.08	37.12	24.01	0.34	36.25	25.52	0.02	0.00	1.42	0.13	6.9	0.256509
32	26.09	40.38	26.06	0.34	42.89	25.50	0.43	0.07	1.45	0.25	6.9	0.5
33	27.51	37.83	22.17	0.37	27.38	26.81	0.46	0.14	2.20	1.4	5.2	0.7625
34	39.64	47.24	26.46	0.55	38.62	35.52	0.10	0.02	2.79	0.8	6.1	0.564142
35	26.51	41.52	29.55	0.35	42.96	26.12	0.41	0.05	1.44	-0.16	7.5	0.807692

36	16.90	28.71	28.65	0.19	41.37	16.26	0.40	0.03	0.82	-0.35	7.6	0.452632
37	19.20	29.66	29.37	0.23	36.82	18.60	0.16	0.01	0.97	-0.078	7.3	0.452941
38	15.93	26.53	30.16	0.18	40.46	15.29	0.32	0.02	0.77	-0.096	7.3	0.416216
39	22.00	35.56	32.06	0.27	34.37	21.41	0.50	0.06	1.22	0.41	6.6	0.430833
40	22.05	35.79	33.84	0.27	42.70	21.43	0.41	0.04	1.11	0.065	7.3	0.731544
41	23.58	36.66	34.29	0.30	42.66	23.20	0.36	0.03	1.29	0.45	6.7	0.44878
42	29.40	40.46	32.77	0.40	30.04	28.68	0.46	0.11	2.31	0.97	5.9	0.995918
43	20.60	33.41	36.09	0.25	39.15	20.01	0.41	0.03	1.06	-0.071	7.3	0.756944
44	22.61	35.81	37.08	0.28	35.61	22.01	0.44	0.05	1.24	0.82	6.2	0.339636
45	25.63	38.27	38.29	0.34	46.39	25.17	0.28	0.02	1.43	-0.04	7.3	0.471795
Max	39.64	47.24	38.29	0.55	55.41	35.52	0.68	0.74	2.79	1.5	7.6	1.116013
Mini	15.45	24.31	-7.20	0.16	25.94	13.48	-0.80	-0.20	0.75	-0.41	5.2	0.203448
Mean	24.00	36.15	15.85	0.31	40.69	23.16	0.29	0.09	1.37	0.267178	6.873333	0.584824

RESULTS AND DISCUSSION

Hydrochemistry of Shahada tehsil:

The highest, lowest, and mean values of major physiochemical parameters have been denoted in table 2 and 3. The pH of subsurface water samples ranges from 6.9 to 8.1, with a mean value of 7.34, indicating that groundwater is mildly alkaline in this region. The EC values vary from 850 to 3110 µS/cm, with a mean of 1442 µS/cm. With an average of 889 mg/l, the total dissolved solids (TDS) value was between the range of 520 and 1950 mg/l. The range of the sodium ion concentration was 38 to 196 mg/l, with a mean of 72 mg/l. With a mean of 6 mg/l, the potassium ion concentration in groundwater varied from 2 to 53 mg/l. The average bicarbonate content in groundwater was 344 mg/l, ranging from 198 to 620 mg/l. With a mean concentration of 120 mg/l, the calcium ion in groundwater varied from 83 to 282 mg/l. The mean sulphate content was 42 mg/l, with a range of 6.8 to 87 mg/l. With a mean value of 48 mg/l, the magnesium ion concentration in groundwater varied from 35 to 98 mg/l. The chloride ion concentration varied from 56 to 600 mg/l, with a mean of 185 mg/l. The concentration of nitrate in groundwater varied from 4.7 to 91 mg/l, with a mean of 58 mg/l. Fluoride levels varied from 0.1 to 1.6 mg/l, with a mean of 0.4 mg/l.

Table 2: Major physicochemical parameters of groundwater samples w.r.t. WHO 2011

Parameters	**Unit**	**Mini**	**Max**	**Mean**	**% of Water samples beyond permissible limit**	**WHO 2011**
EC	µs/cm	850	3110	1442	18	1500
TDS	mg/l	520	1950	889	100	500
pH	-	6.9	8.1	7.3	0	6.5-8.5
Ca	mg/l	83	282	120	9	200
Mg	mg/l	35	98	48	0	150
Na	mg/l	38	196	71	0	200
K	mg/l	2.1	53	6	7	12
Cl	mg/l	56	600	185	29	200
NO3	mg/l	4.7	91	58	78	45
SO4	mg/l	6.8	87	42	0	200
F	mg/l	0.1	1.6	0.4	7	1.5

Table 3: Details of physicochemical parameters of subsurface water samples

ID	pH	Ca	Mg	Na	K	HCO3	SO4	Cl	NO3	F	TDS	EC
Unit	-	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	Mg/l	μs/cm
1	7.2	112	60	54	6	225	21	280	49	0.6	815	1310
2	7.4	105	45	52	9	460	24	89	80	0.7	875	1450
3	7.2	92	45	40	3.2	280	60	108	52	0.9	695	1120
4	7.9	98	46	63	4	510	62	56	46	0.9	905	1460
5	7.9	276	98	196	6.7	612	83	600	87	0.4	1950	3110
6	7.6	105	45	52	9	460	24	89	80	0.7	875	1200
7	6.9	110	43	65	2.3	220	30	200	51	0.1	720	1290
8	7.1	90	43	67	2.3	220	30	180	54	0.3	690	1100
9	7.1	109	41	59	3.8	294	60	180	81	0.1	835	1340
10	7.2	110	35	84	3.4	300	14.96	230	89	0.4	865	1360
11	7.4	143	49	65	3.1	380	77	126	91	0.1	950	1510
12	7.4	83	36	61	2.5	198	49.6	160	51	0.1	650	1050
13	7.4	108	47	76	3.8	310	66	220	48.3	0.1	880	1410
14	7.4	95	62	66	3.6	370	16.89	190	20	0.1	835	1340
15	7.4	88	42	50	5	210	42	70	11.95	0.1	520	850
16	7.4	105	45	52	9	460	24	89	80	0.7	870	1400
17	7.4	90	43	67	2.3	220	30	180	54	0.3	685	1150
18	7.6	110	38	68	3.4	364	9.02	110	8.36	0.8	720	1215
19	7.4	103	47	71	3.8	370	12	198	41	0.12	855	1360
20	7.6	117	60	54	6	225	21	280	49	0.6	820	1310
21	7.4	121	49	65	3.1	374	77	126	91	0.1	920	1470
22	7.4	109	47	76	3.8	304	66	220	48.3	0.1	900	1450
23	7.2	103	49	60	2.1	350	54	130	29	0.4	795	1250
24	7.4	121	48	60	2.1	350	87	125	29	0.1	830	1355
25	7.4	102	77	41	12	345	87	125	81	0.3	890	2100
26	7.4	109	47	76	3.8	304	66	220	50	0.1	895	1450
27	8.1	282	60	162	53	620	38	450	84	1.6	1750	2855
28	7.4	88	42	50	5	210	42	70	11.95	0.1	525	855
29	7.6	105	45	52	9	460	24	89	80	0.7	875	1420
30	7.2	90	43	67	2.3	220	30	180	54	0.3	690	1100
31	7.2	110	38	68	3.4	364	9.02	110	8.36	0.8	720	1150
32	7.4	103	47	71	3.8	370	12	198	41	0.12	870	1410
33	8.1	262	60	152	9.3	590	38	450	84	1.6	1660	2650
34	7.7	157	60	162	53	487	35	330	69	1.6	1380	2200
35	7.2	94	43	67	2.3	220	30	180	54	0.3	720	1175
36	6.9	105	45	40	3.2	280	64	108	69	0.3	735	1190
37	7.1	113	40	47	3.2	310	64	90	81	0.6	755	1215
38	7.1	109	45	38	3.2	310	64	90	81	0.4	760	1230
39	7.4	132	42	63	3.8	450	6.8	200	52	1.1	970	1550
40	7.4	95	43	52	3.3	223	78	140	73	0.3	730	1200
41	7.6	104	47	63	2.3	310	30	154	72	0.2	800	1310
42	7.8	230	60	152	9.3	390	38	450	84	0.9	1430	2200
43	7.2	110	43	52	3.3	223	78	140	73	0.3	740	1055
44	7.8	125	42	63	3.8	450	6.8	180	4.7	0.9	890	1450

45	7.2	97	51	70	2.9	290	31	153	81	0.2	770	1265
Max		282	98	196	53	620	87	600	91	1.6	1950	3110
Min		83	35	38	2.1	198	6.8	56	4.7	0.1	520	850
Mean		120.6	48.51	71.8	6.633	344.3	42.49	185.4	57.98	0.479	889.1	1442

EC and TDS:

Electrical conductivity (EC) and total dissolved solid (TDS) are the two most vital factors influencing groundwater quality. When an excessive quantity of salt is present in groundwater, it can have a negative impact on plant development and productivity (Gupta et., al., 2020; Adimalla et., al., 2019). An indicator of whether subsurface water is suitable for agricultural use and presence of an ionic concentration in the water is electrical conductivity (Balamurugan et., al., 2020; Nagavinothini et., al., 2020; Vijayasurya et., al., 2020; Giri et., al., 2022). The variation in the electrical conductivity values has been denoted in Fig. 2. In Shahada tehsil, about 93% of samples lies in high saline category while 7% of samples were listed as very high saline category for cultivation purpose (Table no.4). The irrigation water has been classified as 'no saline' for <450 mg/l, 'slight-to-medium' for 450-2000 mg/l, and 'critical saline' for >2000 mg/l based on TDS. The variation in the TDS has been denoted in Fig. 3. As per the TDS values, all samples in research region lies within the 'slight-to-medium' category for irrigation purposes.

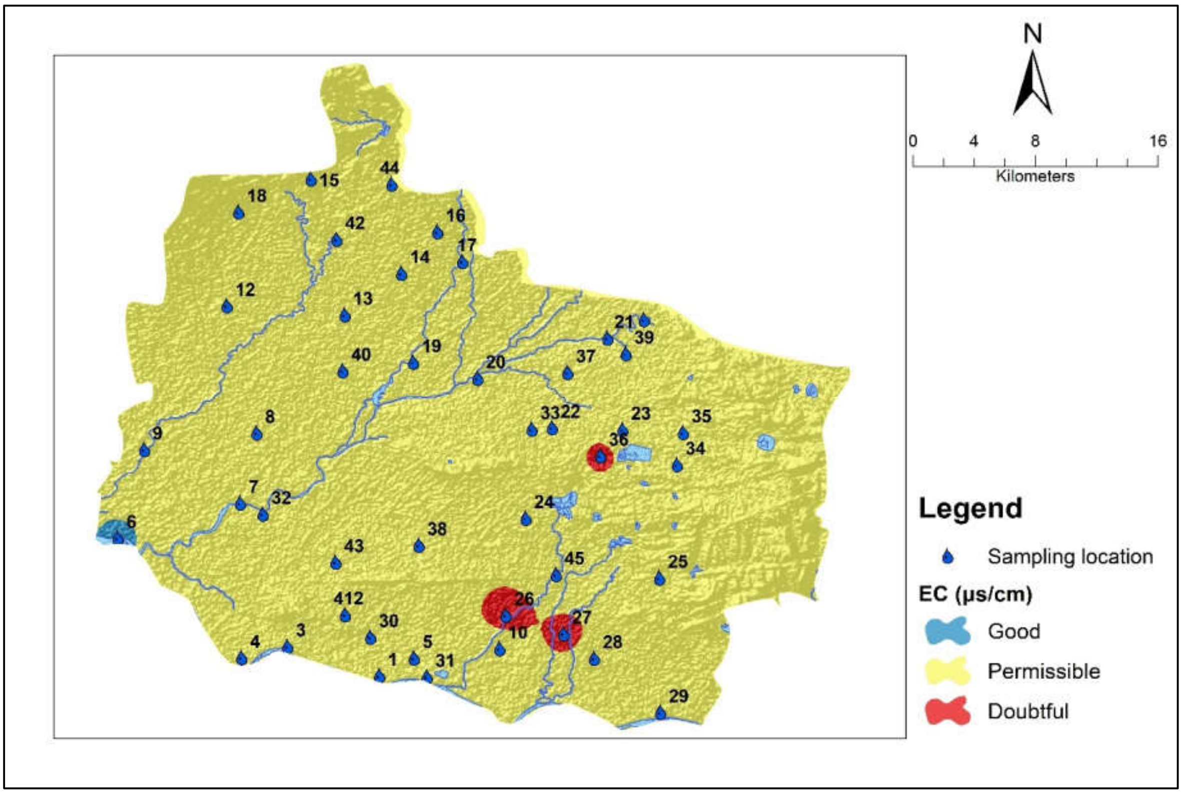

Figure 2: Distribution of EC in the research region

Table 4: Subsurface water classification according to Handa

EC µs/cm	Classification	No. of respective samples	% of samples
Less than 250	Brilliant	Nil	Nil
250-750	Good	Nil	Nil
750-2250	Permissible	42	93
2250-5000	Doubtful	3	7

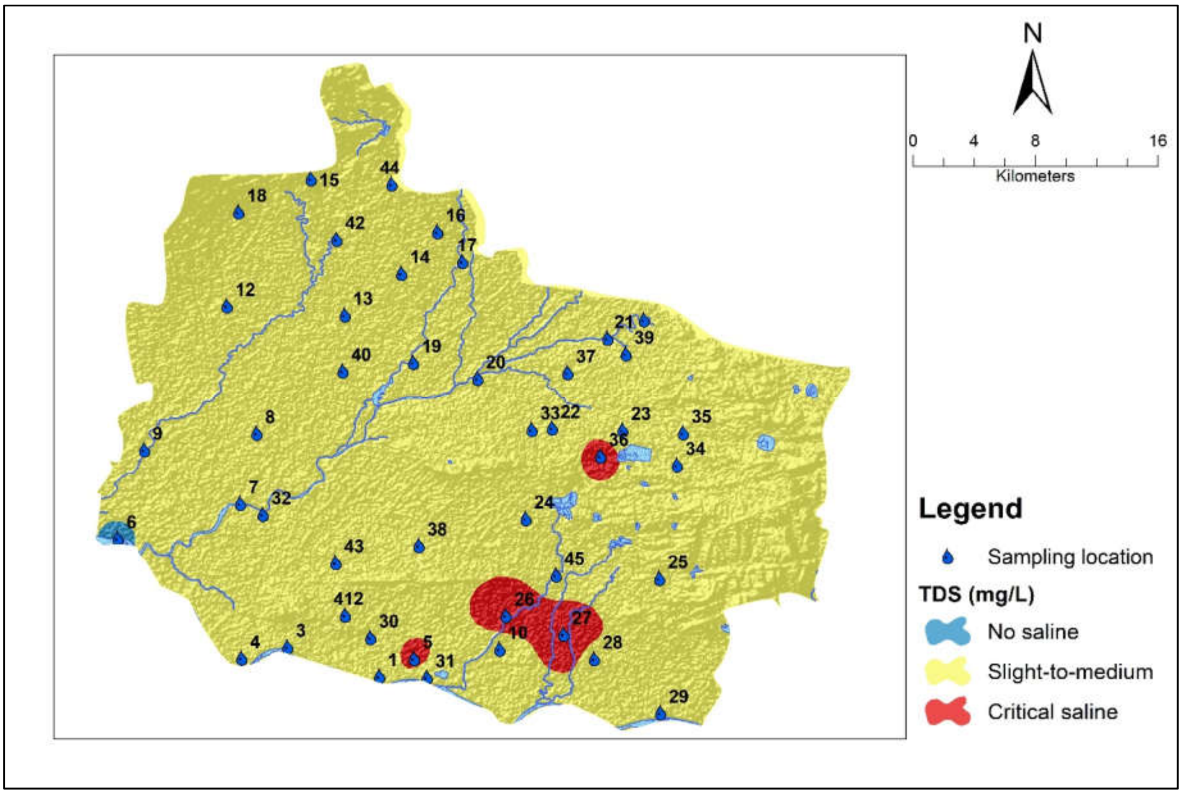

Figure 3: Distribution of TDS in the research region

NO3:
Nitrate is an important nutrient for plants that is generally found in the terrestrial environment. High nitrate value in subsurface water can be detected as a result of numerous cultivation and allied activities, including excessive use of inorganic nitrogenous fertilizers and manures, as well as wastewater discharge by specialized businesses (Dandge et., al., 2022; Madhav et., al., 2018). The Fig. 4 depict the Nitrate concentration ranging between 4.7 to 91 mg/l with mean value 58 mg/l in study region. The WHO 2011 limit for nitrate in water for consumption is 45 mg/l. The assessment discovered that 78% of the subsurface water sources in the studied region had nitrate levels that exceeded the maximum permitted limit.

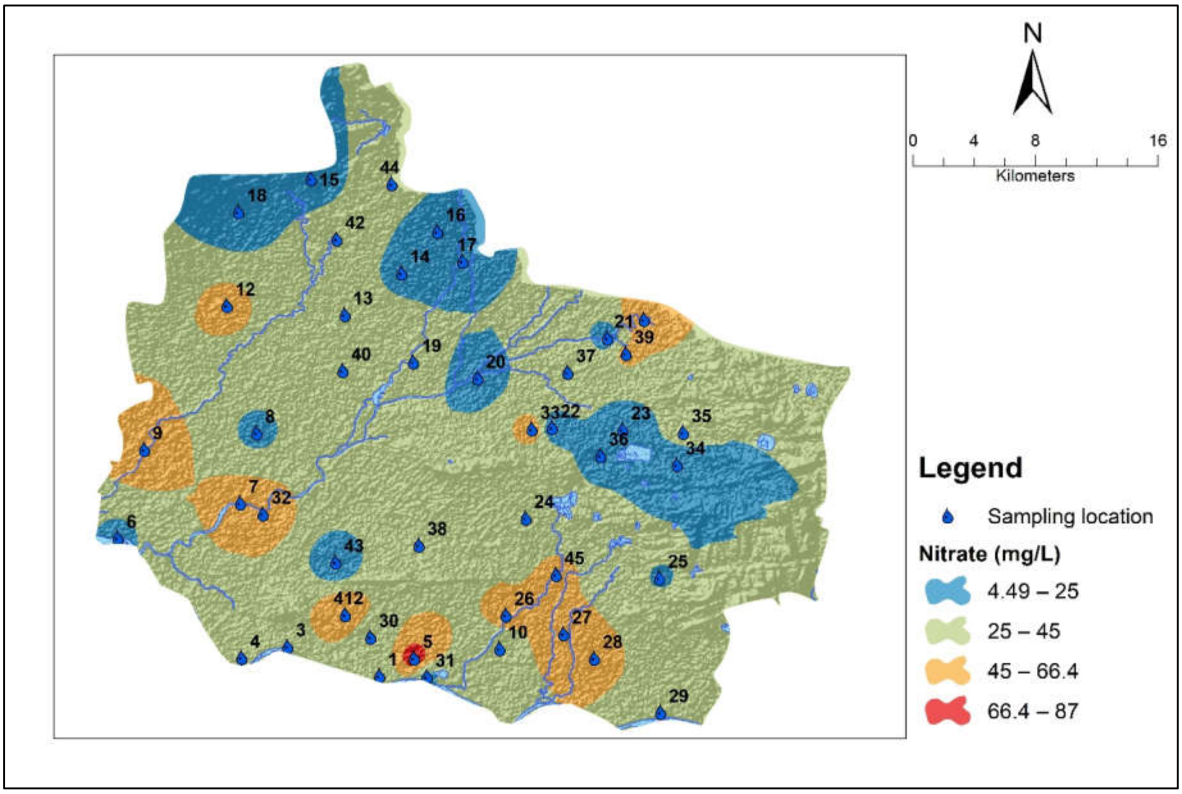

Figure 4: Distribution of NO3 in the research region

SAR:

Freshwater as well as wastewater contains sodium from several sources and sodium carbonate plays key role in higher pH of water (Zaki et., al., 2018). Surplus sodium replaces the quantity of calcium and magnesium present in soil matrix, resulting in an increase in particle size and decreased soil permeability (Ravi et., al., 2020; Kadam et., al., 2021). The sodium absorption ratio is a useful index value for determining sodium concentrations and their impact on subsurface water quality in the research area. In terms of salt content, the figure demonstrated the appropriateness of water for agricultural purposes. If the content of sodium in water surpasses 50 mg/l, It may have a harmful influence on plants. The sodium adsorption ratio (SAR) is a metric used to quantify the amounts of Na, Ca, and Mg in irrigation water, which indicates the potential for harm to soil structure and permeability (Kumar et., al., 2018). If the SAR is less than 2.0, it is safe for plants (Balamurugan et., al., 2016). SAR demonstrates that water for cultivation is categorized into four groups. SAR values <10 is considered as excellent but between 10 and 18 are deemed as good, while values between 18 and 26 are considered as suspect, and values more than 26 are considered as undesirable for cultivation needs. According to Figure 5, the SAR values for the research region are typically low. It ranges from 0.74 to 2.78 with an average of 1.36, indicating a minimal sodium hazard. The findings show that sodium ion concentration has a significant impact on subsurface water quality in the studied area.

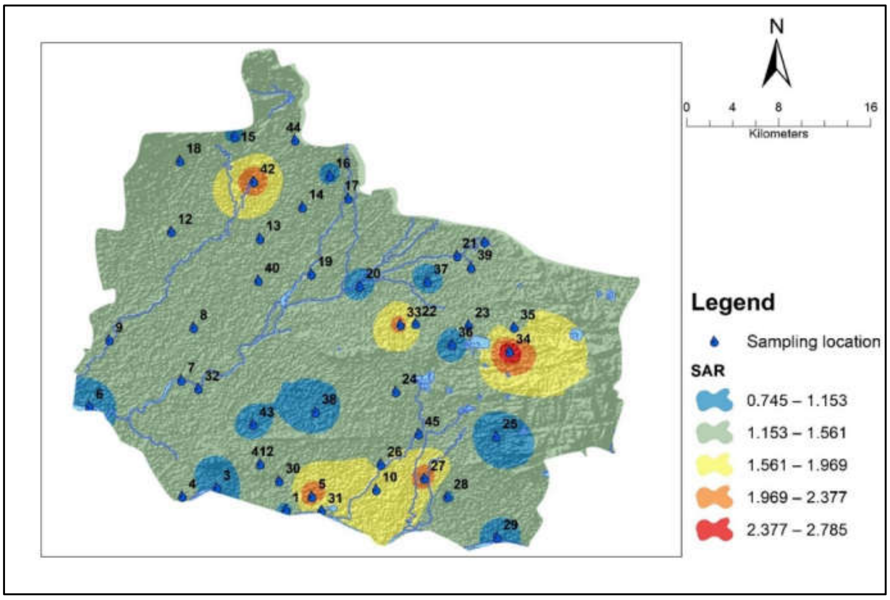

Figure 5: Distribution of SAR in the research region

USSL diagram:
The link between SAR and EC has been described and shown in a US Salinity Laboratory figure (USSL, 1954). The Fig. 6 display the relationship between electric conductivity and sodium adsorption ratio. Almost 93% of subsurface samples (no. of samples = 42) fall into the high saline with less alkaline cluster (C3S1), whereas 7% of groundwater samples (no. of samples = 3) fall into the very high saline with less alkaline cluster (C4S1).

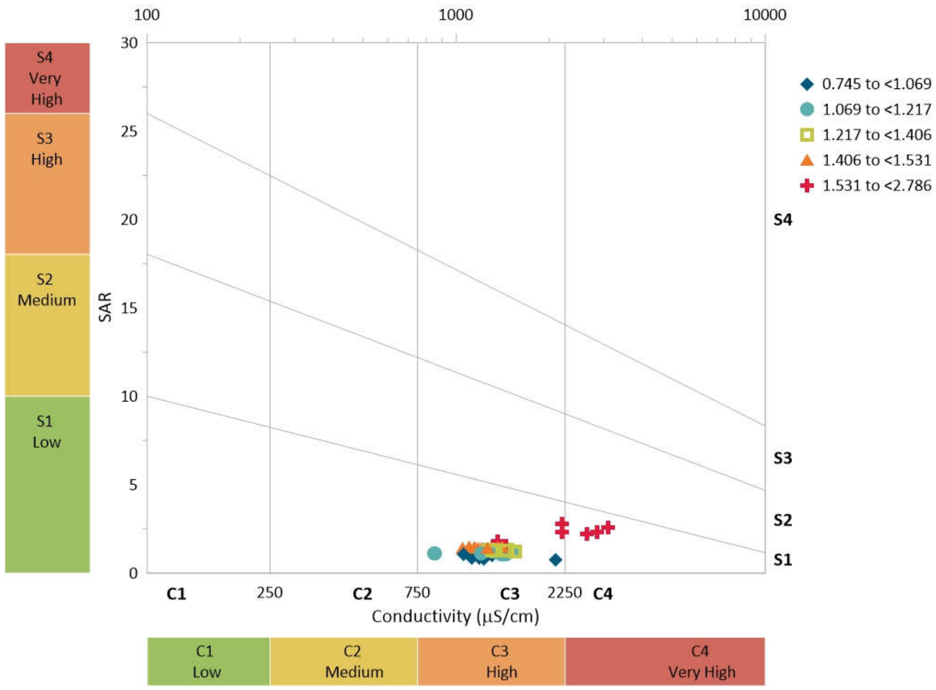

Figure 6: USSL sorting of subsurface water samples in the research region

Na%:

The most important indicator for determining whether subsurface water is suitable for irrigation purposes is the sodium percentage. The amount of sodium in groundwater may be determined by dividing the total of sodium and potassium by the sum of calcium, magnesium, sodium, and potassium. It has been discovered that irrigation water that contains more than 60% salt will cause sodium to build up in the soil, eventually destroying the physical qualities of the soil. A higher salt content in farming water reduces soil permeability, which causes the soil to become drier. The sodium percentage lies between 15.44 to 39.64 with average value 24 in subsurface water samples of the research region. The variation in Na% values has been denoted in Fig. 7. The outcomes indicates, all water samples contain Na% within limit.

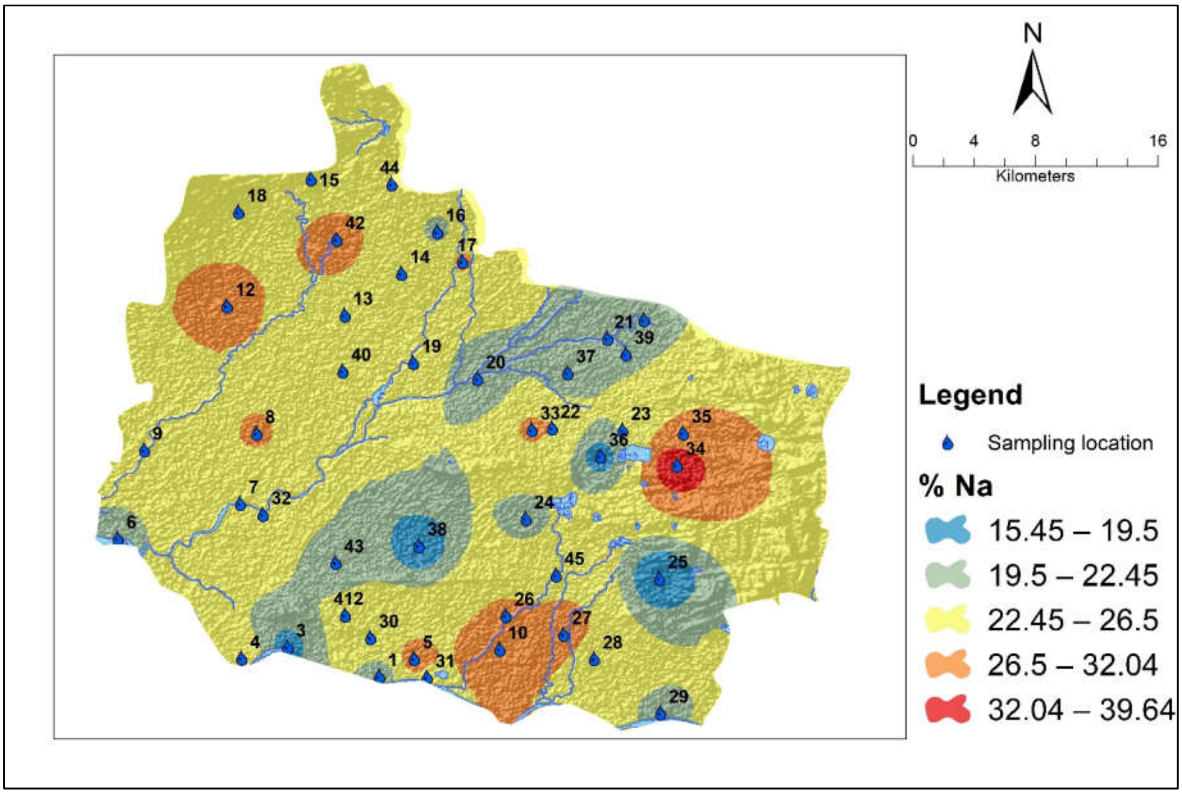

Figure 7: Distribution of Na% in the research region

Wilcox plot:

Wilcox diagram (Wilcox, 1955) has been used to depict the connection between the percentage sodium and electrical conductivity. The Fig. 8 showing the relationship between electric conductivity and sodium percentage. The existing study found that around 2% of samples (no. of samples = 1) have 'excellent' quality water for cultivation purposes. Approximately 89% of samples are classified as 'good' (no. of samples = 40). According to the study, 9% of samples are 'doubtful' (no of samples = 4).

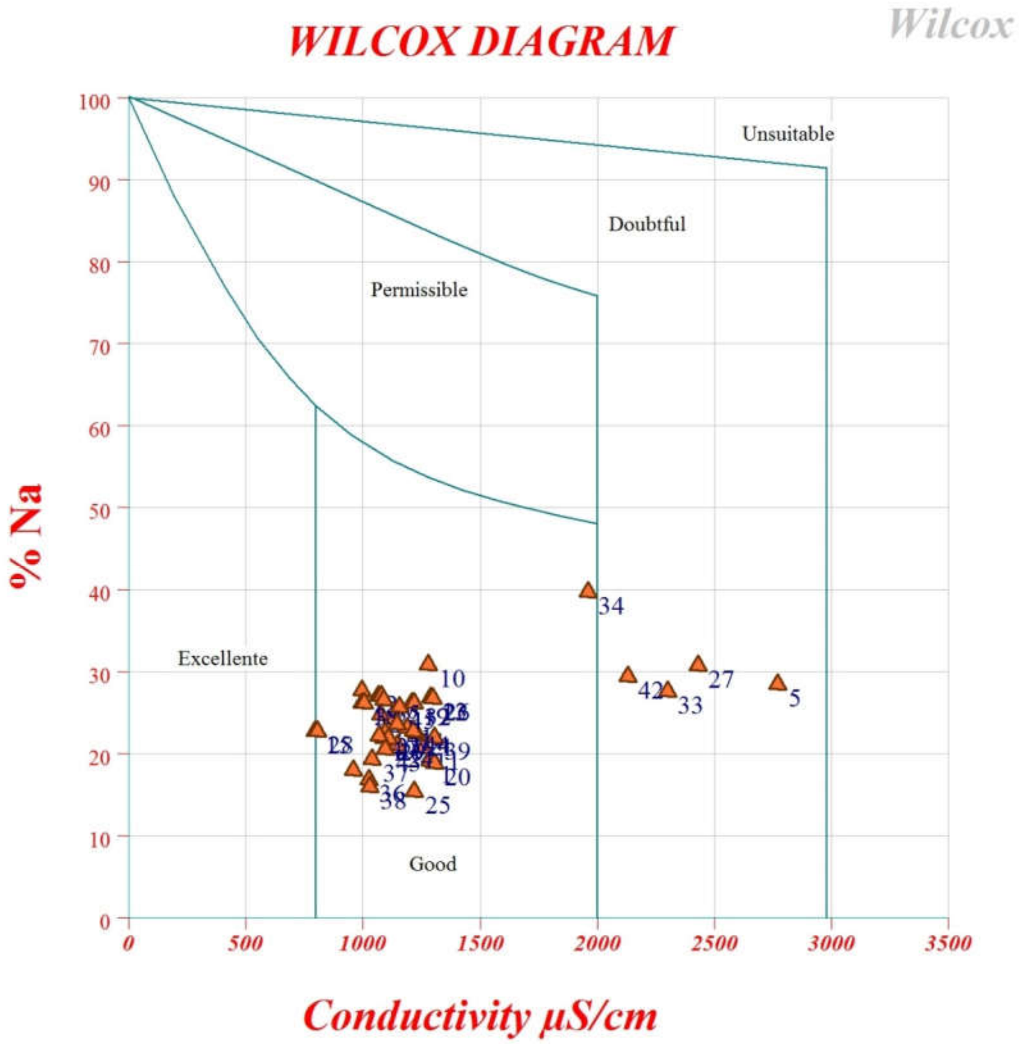

Figure 8: Wilcox diagram for groundwater in the research region

RSC:
Alkali hazard to the soil is caused by sodium carbonate leftover in irrigation water. The clay soil swells and disperses when dissolved salt levels are higher than dissolved calcium and magnesium concentrations, which lowers the soil's ability to infiltrate water. For cultivation purposes, RSC lies below 1.25 meq/l is regarded as safe, while RSC ranging from 1.25 to 2.5 meq/l is considered to be marginal appropriate for cultivation. The RSC values more than 2.5 meq/l are not acceptable for cultivation utilization. In the research region, 18% of the samples that were examined fell into the safe category, whereas 82% (n=37) fell into the zone that is not safe for irrigation activities (Table no.5). The Fig. 9 depicts the variation in the RSC values. The unappropriated practice of synthetic fertilisers in the farming along with discharge of waste from the inhabited region are the key factors for contamination of subsurface water samples in the study area.

Table 5: **RSC sorting of groundwater**

RSC	Class	No. of respective samples	% Samples
<1.5 meq/l	Safe	8	18
1.5 - 2.5 meq/l	Permissible	Nil	Nil
> 2.5 meq/l	Not safe	37	82

Table 6: Subsurface water classification as per Doneen's diagram

Classes	No. of respective samples	% Samples
> 75%	Nil	Nil
25 to 75%	44	98
<25%	1	2

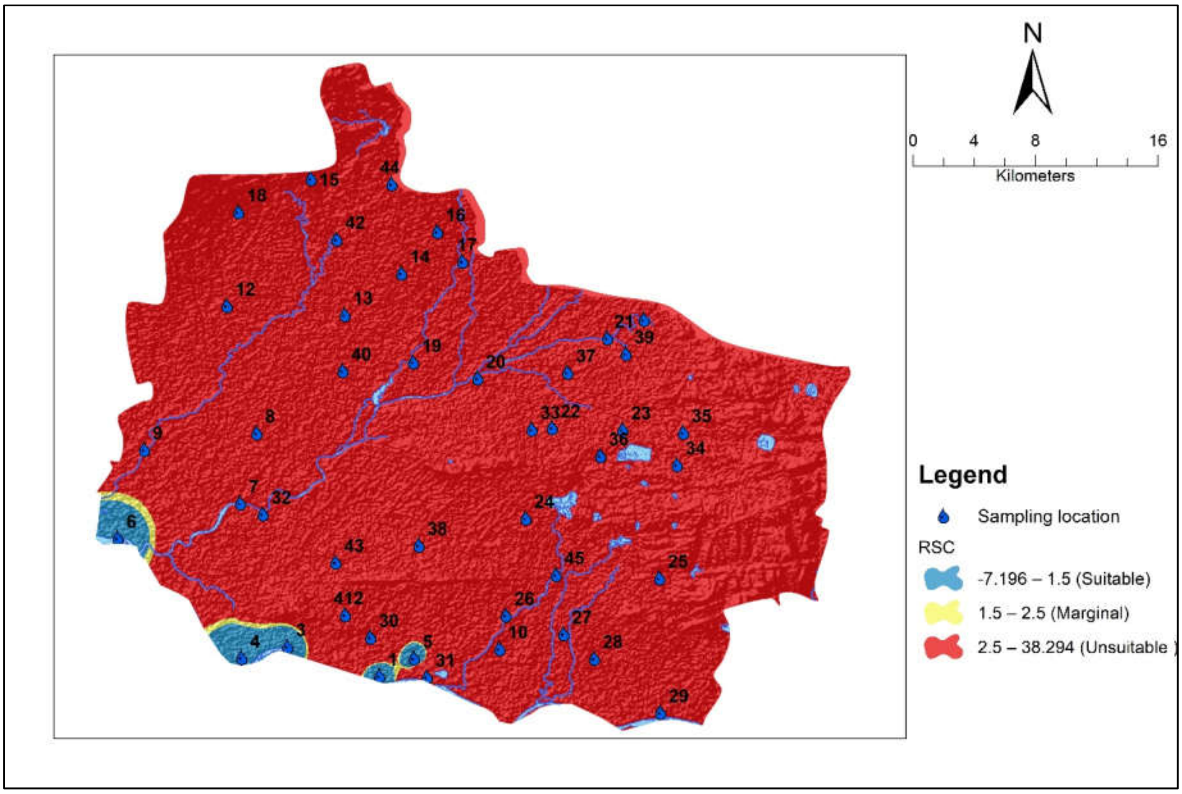

Figure 9: Distribution of RSC in the research region

MAR:

The stability equilibrium of groundwater depends critically on the concentration of calcium and magnesium ions. Because more Mg2+ ions degrade soil quality and make it more alkaline, an increase in magnesium concentration in groundwater reduces agricultural output. Fig. 10 shows a representation of the variance in MAR values. The value of the magnesium absorption ratio ranged from 25.93 to 55.40%, with a mean of 40.68%. The majority of the samples obtained from the research region (n=43, or 96% of them) are deemed suitable for irrigation since they lie under the acceptable level of 50%. In addition, the two samples in surpass the allowable limit. The samples were obtained at a municipal garbage disposal site, demonstrating that geogenic and anthropological actions are the chief components of contamination in the research region.

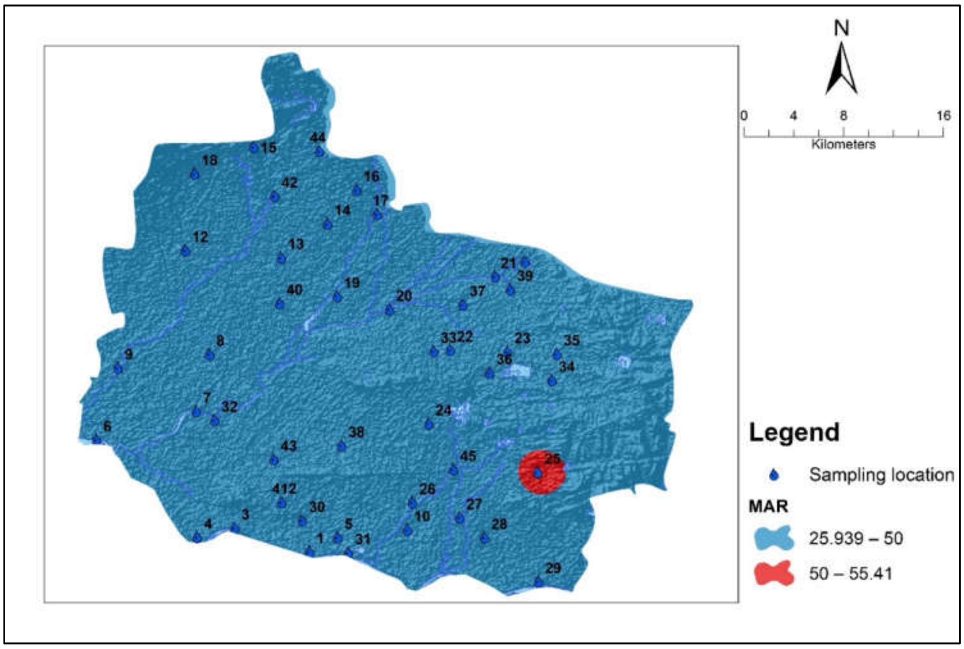

Figure 10: Distribution of MAR in the research region

KR:
Kelly (1963) suggested a Kelly's ratio to identify the presence of salt in irrigation water. Fig. 11 depicts the variance in KR values. The water is classified as appropriate for irrigation when KR < 1 and as unsuitable when KR > 1. The KI values ranging from 0.15 to 0.55 in the research region, with a mean value of 0.30, indicates that the area's water is acceptable for cultivation purpose. All samples from the research region are confirmed to be appropriate for irrigation based on Kelly's ratio.

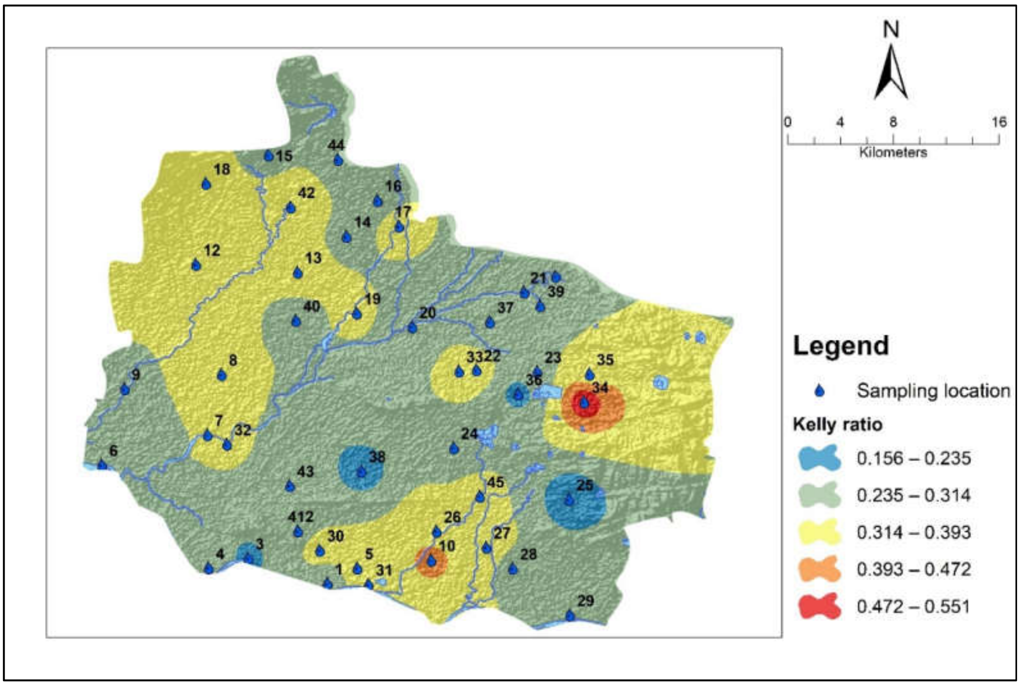

Figure 11: Distribution of KR in the research region

PI:

Doneen's (1964) permeability index is used to grade irrigation water quality into classes I, II, and III. Class I suggests permeability value > 75%, which is excellent for irrigation; Class II implies permeability of 25 to 75%, which is good; and Class III implies permeability of < 25%, which is inappropriate for irrigation. The Fig. 12 depicts the PI value in the research region varied from 47.24 to 24.31%, with a mean of 36.15%. About 98% of the sample fits into the good class group, while 2% falls into the inappropriate for irrigation (Table 6).

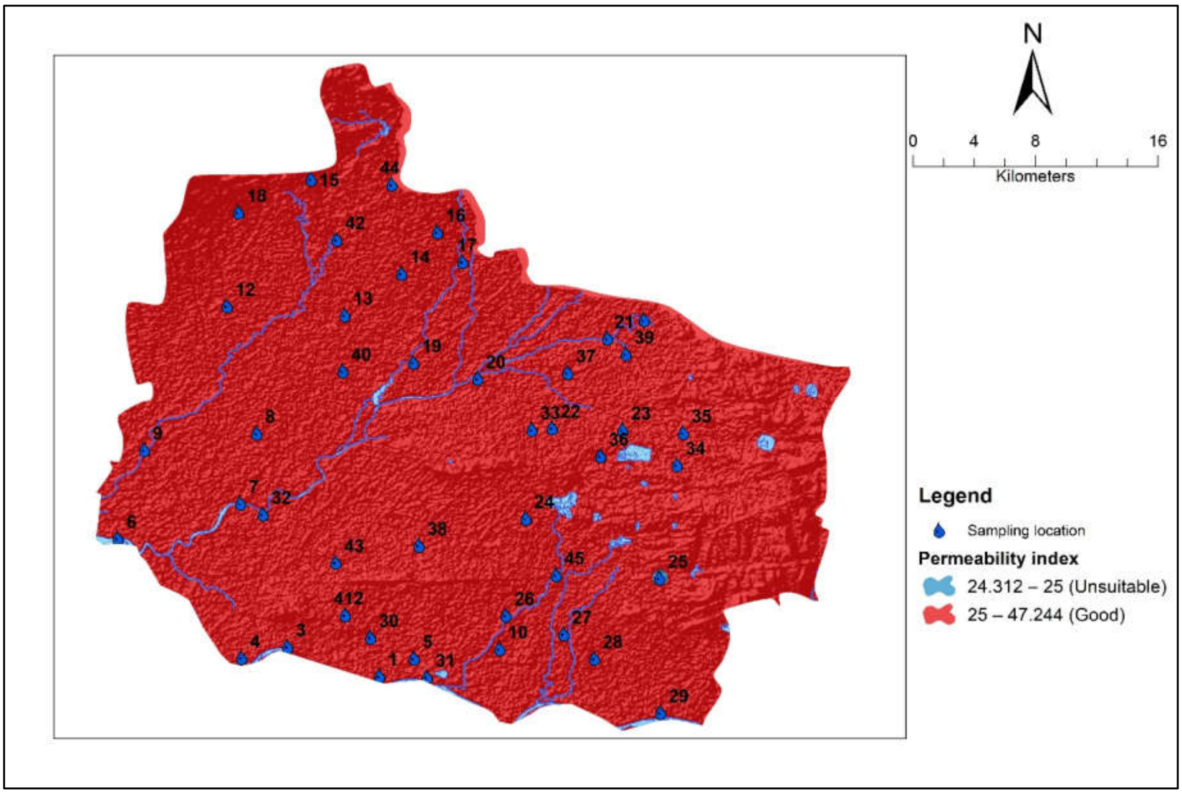

Figure 12: Distribution of PI in the research region

LSI:

The LSI represents the saturation of $CaCO_3$ in terms of calcite formation to some extent, and LSI values between 0.5 and 2 designate the aquatic source as "scale forming but non-corrosive" (Ozair et., al., 2012; Kumar et., al., 2008; Cortes et., al., 2016). The LSI readings range from -0.41 to 1.5, with an average of 0.26 during the assessment period (Fig. 13). According to the categorization above, the LSI < 0 indicating that the water can generate $CaCO_3$ scale and corrosion. Spatial distribution maps reveal LSI less than zero across more than 93% of the whole study region (Table no.7). The observed lime scaling development is caused by basalt lithology, which delivers $CaCO_3$ in groundwater. During the research location, high rock-water residence contact time occurs.

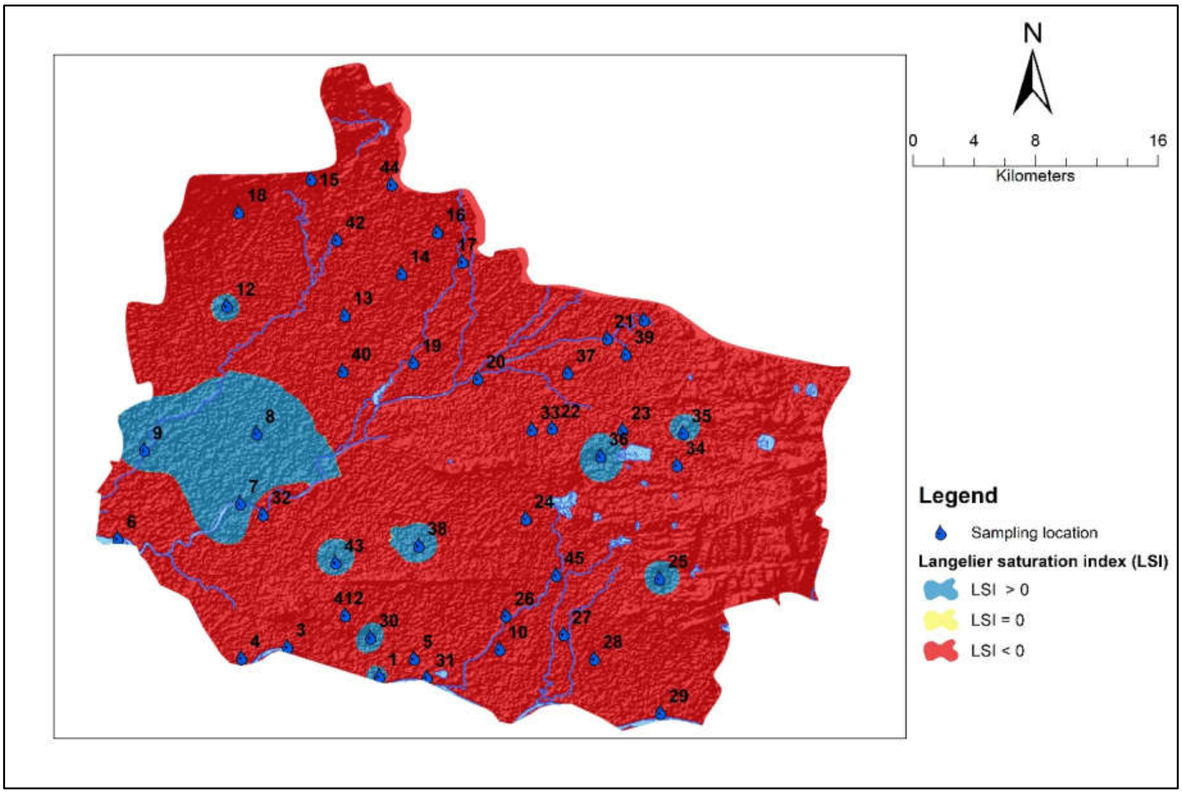

Figure 13: Distribution of LSI in the research region

RSI:

Tchobanoglous in year 2003 proposed that RSI simply indicates water's aggressive tendency towards corrosive and scaling qualities. RSI readings lies between 5.2 to 7.6, with mean of 6.8 during the assessment period. The water little to no scaling or corrosive capacity if the RSI value is 6.8. The RSI range from 6.8 to 8.5 discloses the moderate corrosive tendency while RSI value more than 8.5 denotes rigorous corrosive tendency of the water. The findings at research region indicate, 62% subsurface water samples (Table no.8) might have a detrimental impact on water pumps, pipelines made up of metallic material for cultivation purpose and water transportation gear and amenities in industries (Fig. 14).

Table 7: Langelier saturation index (LSI) as per Tchobanoglous, et al, 2003

LSI value	Classification	No. of respective samples	% of samples
LSI < 0	Undersaturated	42	93
LSI = 0	Neutral	Nil	Nil
LSI > 0	Supersaturated	3	7

Table 8: Ryznar stability index (RSI) as per Tchobanoglous, et al, 2003

RSI value	Classification	No. of respective samples	% of samples
RSI < 5.5	Heavy scaling tendency	3	7
5.5 <RI < 6.2	Moderate scaling tendency	2	4
6.2 <RI < 6.8	Neutral	12	27
6.8 <RI < 8.5	Aggressive tendency	28	62
RI > 8.5	Very Aggressive tendency	Nil	Nil

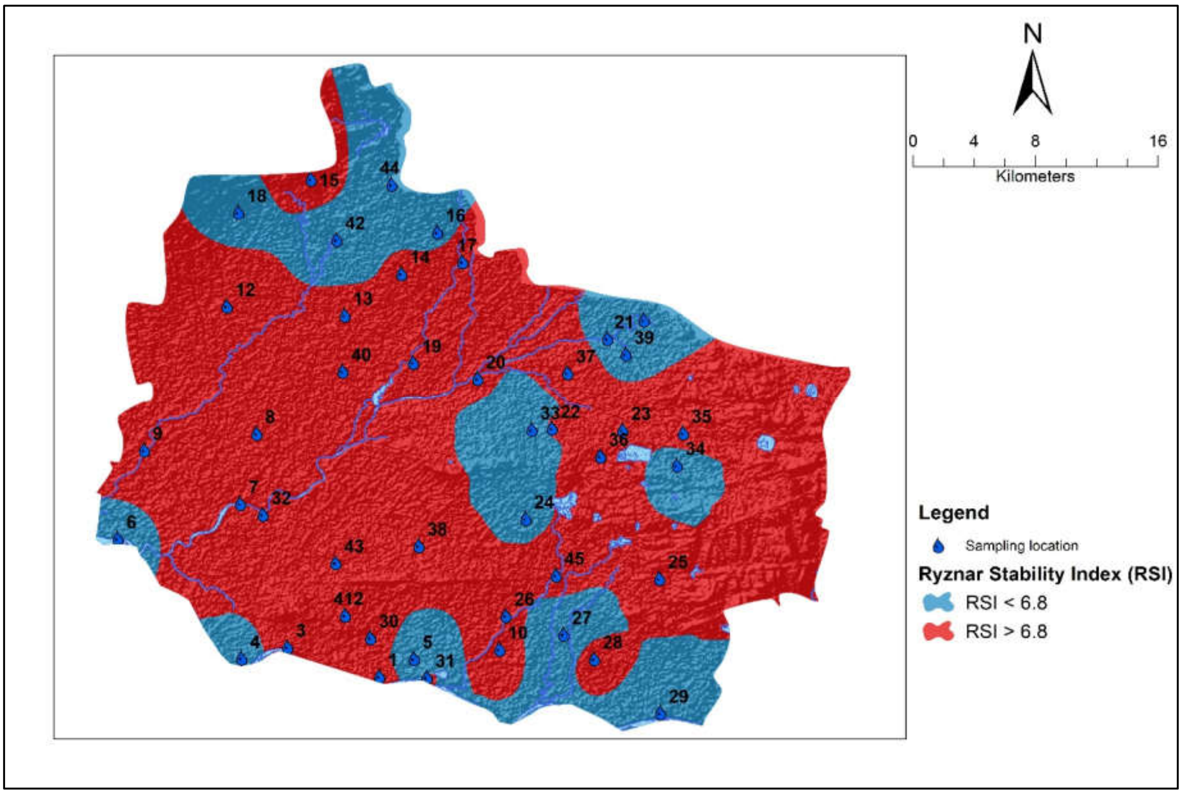

Figure 14: Distribution of RSI in the research region

LSkI:

The Larson-Skold index (LS) regulates the inclination of water to corrosion of the steel and cast-iron pipes (Kalyani et., al., 2017; Kumar et., al., 2022; Shah et., al., 2019; Abbasnia et., al., 2019). The Larson-Skold index readings ranges 0.20 to 1.11, with mean value 0.58 during the assessment period in research area (Table no.9). According to Tchobanoglous, et al, 2003, LSkI < 0.8 discloses chloride and sulphate concentrations will not harm natural film establishment but LSkI value superior than 1.2 reflects the corrosion possibilities. The findings in the research region indicate that 78% groundwater samples have a low corrosive capacity (Fig. 15).

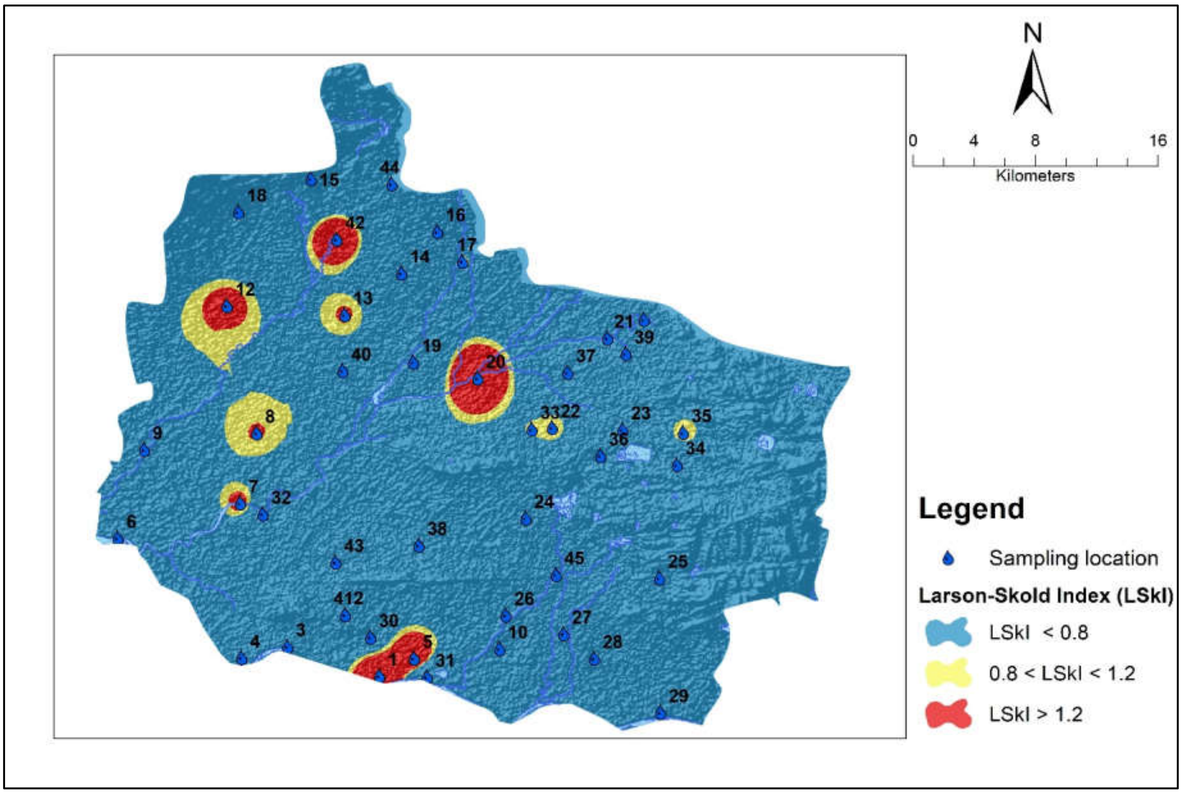

Figure 15: Distribution of LSkI in the research region

Table 9: Larson-Skold index (LSkI) as per Tchobanoglous, et al, 2003

LSkI value	Classification	No. of respective samples	% of samples
< 0.8	Low corrosion tendency	35	78
0.8 < LSkI < 1.2	Moderated corrosion tendency	10	22
> 1.2	High corrosion tendency	Nil	Nil

CONCLUSION

Shahada tehsil is hub for many renowned organisations working in economical, industrial and educational sectors in the North Maharashtra region. The study of subsurface water quality to evaluate its aptness for agricultural and industrial practice has become essential due to the variability in rainfall intensity and uncertainty in its distribution. In direction to investigate the suitability of subsurface water quality for irrigation and industry practice, 45 subsurface water samples were analysed. According to Handa's classification 93% of samples lies within high saline cluster and about 7% of samples listed in very high saline cluster for cultivation. As per the TDS values, all samples in study region listed in 'slight-to-medium' category for the irrigation purposes. The appraisal discovered that, 78% of subsurface water sources in research region displayed nitrate level outside permissible limit. The SAR values lies between 0.74 to 2.78 with mean value 1.36 revealed a low sodium hazard risk. The USSL diagram reveal that, 93% of groundwater samples listed in high saline with less alkaline cluster. The Wilcox diagram highlighted that 89% of samples come lies in 'good' category. The RSC value indicated that 82% of the subsurface water samples comes under inappropriate zone for cultivation purpose. The MAR value showcase that 96% of samples placed within the safe boundary from the study area. As per the Kelly's ratio, all samples from study area lies in suitable category for farming practice. The PI value highlighted that 98% of samples come under suitable irrigation category. The industrial water quality indices highlighted the major variation in suitability of water. The spatial distribution maps reveal LSI value less than zero across more than 93% of the whole study region. The findings in the research region indicate that according to RI values, 62% subsurface water samples might have a detrimental impact on water pumps that include metal due to high corrosive tendency. LSkI value showcase that 78% groundwater samples have a low corrosive capacity. The comprehensive technique of suitability evaluation indicates that subsurface water in the research region is ideal for cultivation. Also, spatial variation maps of LSI, RSI and LSkI illustrations that most pre-monsoon period samples were largely unaffected by minor scaling and corrosive potentials. The study's findings are intended to assist government officials, water managers in developing groundwater management strategies for enhancement of water quality in study region. Hence study indicates that, continuous monitoring of quality groundwater resources can play major role for achieving the goal of sustainable development of the region.

Conflict of interest:
The authors confirm that there are no known conflicts of interest associated with this publication.

Data availability: All data generated or analysed during this study are included in this article.

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