



# Hydrochemical Characterization And Irrigation Suitability Of Groundwater In Akola Tehsil, Maharashtra

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**Abstract:** This study assesses the hydrochemical characteristics and irrigation suitability of groundwater in Akola Tehsil, Maharashtra. A total of 20 groundwater samples were analyzed for 19 physico-chemical parameters using standard analytical methods. Hydrogeochemical tools such as Piper and Gibbs diagrams were used to interpret water types and geochemical processes, while Wilcox and USSL diagrams evaluated the water's suitability for irrigation. Most samples fall within the “good to permissible” range, with a few showing elevated salinity and sodium hazards. The results highlight the influence of rock–water interaction and agricultural activities on groundwater quality, providing a basis for sustainable irrigation planning in the region.

**Keywords** – Groundwater Irrigation suitability, hydrogeochemistry.

## 1. INTRODUCTION

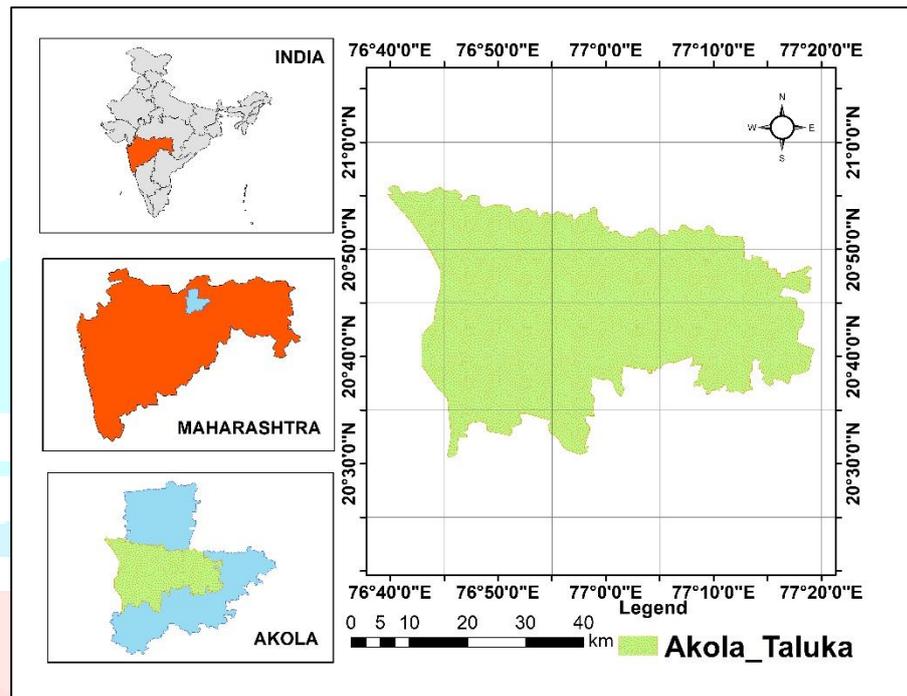
Groundwater plays a crucial role in supporting agricultural activities in semi-arid regions like Vidarbha, where surface water resources are often scarce and unreliable. Akola Tehsil, located in the Vidarbha region of Maharashtra, lies within the basaltic terrain of the Deccan Traps and largely depends on groundwater for irrigation. However, due to increasing pressure from population growth, intensive farming, and climatic variability, the quality of groundwater in this region has significantly deteriorated (CGWB, 2013). One of the primary challenges affecting groundwater use for irrigation in Akola Tehsil is the elevated level of Total Dissolved Solids (TDS). High TDS levels, often resulting from geogenic processes such as rock-water interaction, ion exchange, and evaporation, can adversely impact soil structure, reduce crop yield, and limit water infiltration (Ayers et al, 1985; Ghoto, et al., 2025). As a result, a significant portion of the groundwater in Akola Tehsil is deemed unsuitable for agricultural use, particularly in areas with poor drainage and intensive use of fertilizers. To evaluate the hydrochemical processes influencing water quality and determine its suitability for irrigation, hydrogeochemical tools such as Piper and Gibbs diagrams are commonly used to classify groundwater types and understand geochemical evolution. In addition, Wilcox and USSL diagrams are widely applied to assess irrigation water quality by examining salinity and sodicity hazards, primarily based on parameters like Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), and sodium percentage (Todd & Mays, 2005; Hem, 1985). This study focuses on the hydrochemical characterization and irrigation suitability of groundwater in Akola Tehsil through the analysis of 20 groundwater samples, assessed for 19 physico-chemical parameters. The key objectives are: (i) to identify the major geochemical processes affecting groundwater chemistry using Piper and Gibbs plots, and (ii) to evaluate irrigation water quality using Wilcox and USSL classifications. The findings aim

to provide a scientific basis for sustainable groundwater management in agriculture and support future policy development in water-stressed regions of Maharashtra.

## 2. Materials and Methods:

### 2.1 Study Area:

Akola Tehsil, located in the Vidarbha region of Maharashtra, is underlain by Deccan Trap basalt, a hard rock formation influencing the region's hydrogeology. The area experiences semi-arid climatic conditions with an average annual rainfall of 800-900 mm. Due to seasonal variability and limited surface water availability, the region depends heavily on groundwater for both drinking and irrigation. However, salinity and high total dissolved solids (TDS) levels often render groundwater unsuitable for agricultural use in several parts of the tehsil (CGWB, 2013; GSDA, 2019).



**Figure 2.1:** Showing study area of Akola Taluka of Akola District of Maharashtra, India.

### 2.2 Sample Collection:

A total of 20 groundwater samples were collected from borewells, dug wells, and handpumps across Akola Tehsil during the pre-monsoon and post-monsoon periods 2020. Sampling was conducted using clean, high-density polyethylene bottles following the standard guidelines by APHA (2005). Bottles were filled without air bubbles, sealed, and kept preserve sample integrity during transportation.

### 2.3 In-Situ Water Quality Analysis:

Field measurements for pH, electrical conductivity (EC), total dissolved solids (TDS), temperature, salinity, dissolved oxygen (DO) and oxidation-reduction potential (ORP) were carried out at sampling sites using a HANNA HI-9829 portable multiparameter water quality meter. This instrument is widely used in hydrogeological studies due to its reliability and field accuracy (HANNA Instruments, 2017).

### 2.4 Laboratory Analytical Methods:

A total of 19 physico-chemical parameters were analyzed using standard procedures. Major cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ) were determined using EDTA titrimetric and flame photometric methods, while major anions ( $\text{Cl}^-$ ,  $\text{F}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{PO}_4^{3-}$ ) were analyzed using a double-beam UV-Visible spectrophotometer (Shimadzu UV-1900) and ion-selective electrode probes. Bicarbonate ( $\text{HCO}_3^-$ ) and carbonate ( $\text{CO}_3^{2-}$ ) were estimated through acid titration methods following Hem (1985). Salinity was computed from EC, and Sodium Adsorption Ratio (SAR) and Percent Sodium (%Na) were calculated using standard equations to assess irrigation suitability (Ayers & Westcot, 1985).

## 2.5 Hydrogeochemical Interpretation:

To classify groundwater into chemical facies and understand controlling geochemical processes, several hydrogeochemical tools were used. Piper diagrams, originally proposed by (Piper, 1944), were used to identify the dominant hydrochemical facies based on the major cation-anion composition. Gibbs diagrams (Gibbs, 1970) were employed to evaluate the influence of rock-water interaction, precipitation dominance, or evaporation dominance on groundwater chemistry. These plots are particularly useful in basaltic terrains where geogenic sources often dictate solute concentrations (Todd & Mays, 2005; Jeong, 2001).

## 2.6 Evaluation of Irrigation Suitability:

Groundwater suitability for irrigation was assessed using the Wilcox diagram (Wilcox, 1955), which relates sodium percentage to EC to classify water into categories such as excellent, good, permissible, and unsuitable for irrigation. Additionally, the USSL (United States Salinity Laboratory) diagram (Richards, 1954), plotting SAR against EC, was applied to evaluate the salinity and sodicity hazards associated with irrigation use. These tools are commonly used in Indian hydrogeological assessments and are particularly effective in evaluating groundwater in semi-arid agricultural zones like Akola.

## 2.7 Data Analysis and Software:

Data analysis and plotting were performed using Microsoft Excel, Diagrams, and GW Chart. These software tools provided graphical representations of the hydrogeochemical data through Piper, Gibbs, Wilcox, and USSL plots, aiding in visual and statistical interpretation.

## 3. Results and Discussion:

### 3.1 Descriptive Statistics of Physico-Chemical Parameters:

The statistical summary of groundwater samples collected from Akola Tehsil is presented in table 3.1. The analysis includes minimum, maximum, average, and standard deviation (SD) for 19 physico-chemical parameters. These values were compared with permissible limits as per WHO (2017) and BIS (2012) standards to assess the suitability of groundwater for drinking and irrigation purposes. The pH values ranged from 6.01 to 8.58, with a mean of 7.20 for pre-monsoon and 7.60 for post-monsoon which falls within the permissible limits of 6.5-8.5 prescribed by WHO (2017) and BIS (2012), indicating that the groundwater is generally neutral to slightly alkaline. The Total Dissolved Solids (TDS) varied widely from 348 to 7851 mg/L, with a mean of 2149 mg/L in pre-monsoon and 2179 mg/L in post-monsoon. Notably, over 70% of the samples exceeded the WHO limit of 1000 mg/L, suggesting elevated mineral content due to intensive rock-water interaction and evaporative concentration (Rao et al., 2017). The Electrical Conductivity (EC) showed a strong correlation with TDS, ranging from 696 to 15702  $\mu\text{S}/\text{cm}$  (mean: 4331.5  $\mu\text{S}/\text{cm}$ ), indicating highly mineralized groundwater. According to Wilcox (1955), EC values above 1500  $\mu\text{S}/\text{cm}$  may pose a salinity hazard for irrigation, which applied to nearly half the samples. The Oxidation-Reduction Potential (ORP) ranged from -190.8 to +163.67 mV, reflecting a mix of oxidizing and reducing conditions in the aquifer, which can influence the mobility of redox-sensitive species like iron and uranium (Sharma et al., 2019). Groundwater temperature values ranged between 21.12 °C and 29.87 °C (mean: 27.43 °C), slightly exceeding the desirable limit of 25 °C in some samples. This could be attributed to the semi-arid climate and the geothermal gradient in the Deccan basalt terrain (Subba Rao, 2008). Salinity ranged from 0.34 to 7.93 PSU, with a mean of 2.41 PSU, and several samples exceeded the 0.5 PSU threshold for drinking water, suggesting evaporative enrichment or salt leaching (Todd & Mays, 2005). The Dissolved Oxygen (DO) ranged from 0.5 to 11.54 mg/L (mean: 3.61 mg/L for pre-monsoon and 5.2 mg/L for post-monsoon.), with many samples below the 5 mg/L threshold, indicating suboxic to anoxic conditions that favour the dissolution of elements such as Fe, Mn, and U (APHA, 1998). Fluoride concentrations varied from 0.22 to 1.13 mg/L (mean: 0.7 mg/L), well within the WHO limit of 1.5 mg/L, indicating that fluoride levels in the region are not a health concern (Aoba & Fejerskov, 2002). However, chloride levels were elevated, ranging from 41.7 to 2831 mg/L (mean: 491.83 mg/L), with many samples exceeding the BIS limit of 250 mg/L, suggesting possible contamination from sewage or waste discharge (Rao et al., 2017). Nitrate concentrations were particularly alarming, ranging from 7.30 to 372 mg/L (mean: 56.1 mg/L), far exceeding the WHO limit of 50 mg/L. This indicates significant anthropogenic influence, likely from agricultural fertilizers and septic systems (Kumar et

al., 2023). Sulphate levels ranged between 21.7 and 912.40 mg/L, with a mean of 267.49 mg/L. About half the samples exceeded the WHO limit of 250 mg/L, possibly due to gypsum or anhydrite dissolution (CGWB, 2013). Phosphate concentrations varied from 0.51 to 4.0 mg/L (mean: 1.95 mg/L), indicating anthropogenic inputs such as detergents and fertilizers, despite the absence of a WHO standard (Patil et al., 2020). Uranium levels ranged from 1.19 to 23.29 µg/L (mean: 5.88 µg/L for pre-monsoon and 8.3 µg/L for post-monsoon), remaining within the WHO limit of 30 µg/L, although continuous monitoring is advised due to its nephrotoxic and radiological effects (Balaram et al., 2022). Total hardness ranged from 110 to 3643 mg/L (mean: 1160 mg/L), with most samples far exceeding the BIS standard of 300 mg/L, classifying the water as very hard. This is consistent with the elevated magnesium hardness (34-1678 mg/L) and calcium hardness (76-2175 mg/L), with means of 112 and 696.5 mg/L, respectively, reflecting extensive weathering of basaltic minerals (Alam, 2013). Alkalinity and bicarbonate, both ranging from 120 to 400 mg/L (mean: 246.19 mg/L), suggest a carbonate buffering system derived from rock dissolution, helping to stabilize groundwater pH (Hem, 1985). Sodium (Na<sup>+</sup>) levels varied from 12.41 to 143.05 mg/L (mean: 84.55 mg/L), all within the acceptable limit of 200 mg/L for irrigation (USSL, 1954), although excessive sodium can impair soil structure over time. Finally, potassium (K<sup>+</sup>) exhibited a wide range from 2.14 to 453 mg/L (mean: 26.28 mg/L), exceeding the aesthetic limit of 12 mg/L in several samples. Elevated potassium could be attributed to the leaching of feldspathic minerals or the use of potash fertilizers (Patil et al., 2020).

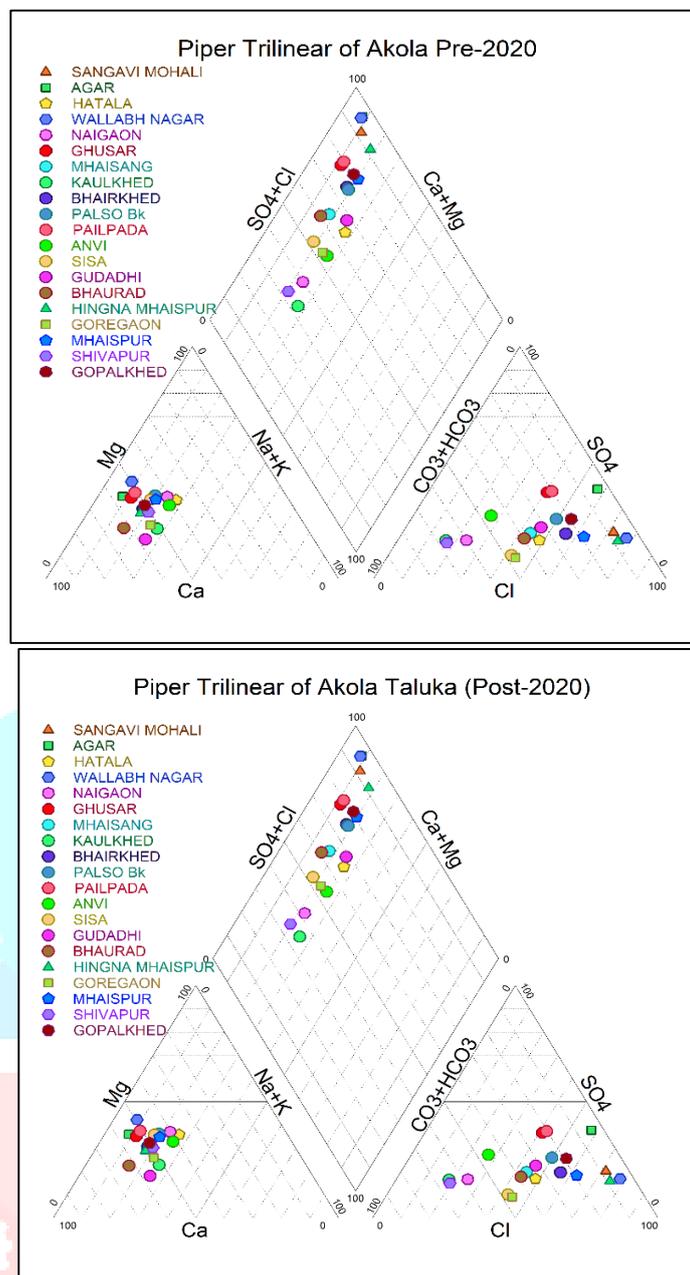
**Table 3.1:** Descriptive statistics of groundwater quality parameters in Akola Tehsil and comparison with WHO/BIS standards.

Parameter	Min	Max	Mean	SD	Pre-monsoon 2020		Post-monsoon 2020		WHO/BIS Permissible Limit	No. of Samples Exceeding Limit
					Min	Max	Mean	SD		
pH	6.01	8.18	7.20	0.44	6.31	8.58	7.6	0.5	6.5–8.5 (BIS)	Nil
TDS (ppm)	348	7810	2149.4	2154.6	366	7851	2179.1	2161.3	1000 (WHO/BIS)	High (Approx. 65%)
EC (µS/cm)	696	15600	4304	4283	732	15702	4358.2	4322.6	1500–3000 (Irrigation)	~67%
ORP (mV)	190.8	154.7	-5.87	77.06	201.8	163.67	-6.2	81.5	--	--
Temperature (°C)	24.53	29.87	28.69	1.09	21.83	26.58	25.5	1.0	--	--
Salinity (ppm)	0.34	7.91	2.34	2.39	0.38	7.93	2.4	2.4	--	--
DO (ppm)	0.5	7.84	3.44	2.28	1.23	11.54	5.2	3.2	--	--
Fluoride (ppm)	0.22	1.13	0.59	0.27	0.26	1.32	0.7	0.3	1.5 (WHO/BIS)	Nil
Chloride (ppm)	41.7	2791	531.56	766.96	53.70	2831	452.1	609.6	250 (BIS)	High (~60%)
Nitrate (mg/L)	7.30	360	54.2	51.3	7.58	372	56.1	6.1	50 (WHO/BIS)	High (Approx. 25%)

<b>Sulphate (mg/L)</b>	21.7	889	227.09	231.73	24.10	912.40	240.4	237.5	500 (WHO)	High (Approx. 10%)
<b>Phosphate (mg/L)</b>	0.51	3.38	1.698	0.68	0.58	4	2.2	0.8	-	-
<b>Uranium (ppb)</b>	1.19	18.69	5.88	4.60	1.97	23.29	8.3	5.5	30 (WHO)	Nil
<b>Total Hardness (mg/L)</b>	110	3570	1140.0	1014.1	123	3643	1180.9	1027.5	300 (BIS)	High (~65%)
<b>Magnesium Hardness (mg/L)</b>	34	1631	452.6	434.31	41	1678	474.9	443.1	--	--
<b>Mg<sup>2+</sup></b>	8.25	396.06	109.90	105.46	10	407.5	115.3	107.6	50	High (~60%)
<b>Calcium Hardness (mg/L)</b>	76	2149	687.45	585.95	82	2175	706.1	590.8	75–200 (desirable)	Very High
<b>Ca<sup>2+</sup></b>	30.43	860.63	275.31	234.66	32.8	871	282.8	236.6	100	High (~70%)
<b>Alkalinity (mg/L)</b>	120	400	246.19	82.31	137	421	260	78.68	300 (BIS)	High (~20%)
<b>Bicarbonate (mg/L)</b>	120	400	246.19	82.31	137	421	260	78.68	-	-
<b>Sodium (Na<sup>+</sup>) (mg/L)</b>	12.41	76.95	31.24	15.26	15.9	143.05	84.5	40.12	200 (irrigation)	Nil
<b>Potassium (K<sup>+</sup>) (mg/L)</b>	2.14	14.53	10.28	5.20	0.76	16.42	10.58	5.43	12 (WHO aesthetic)	High (~45%)

### 3.2. Hydrochemical Facies (Piper Diagram):

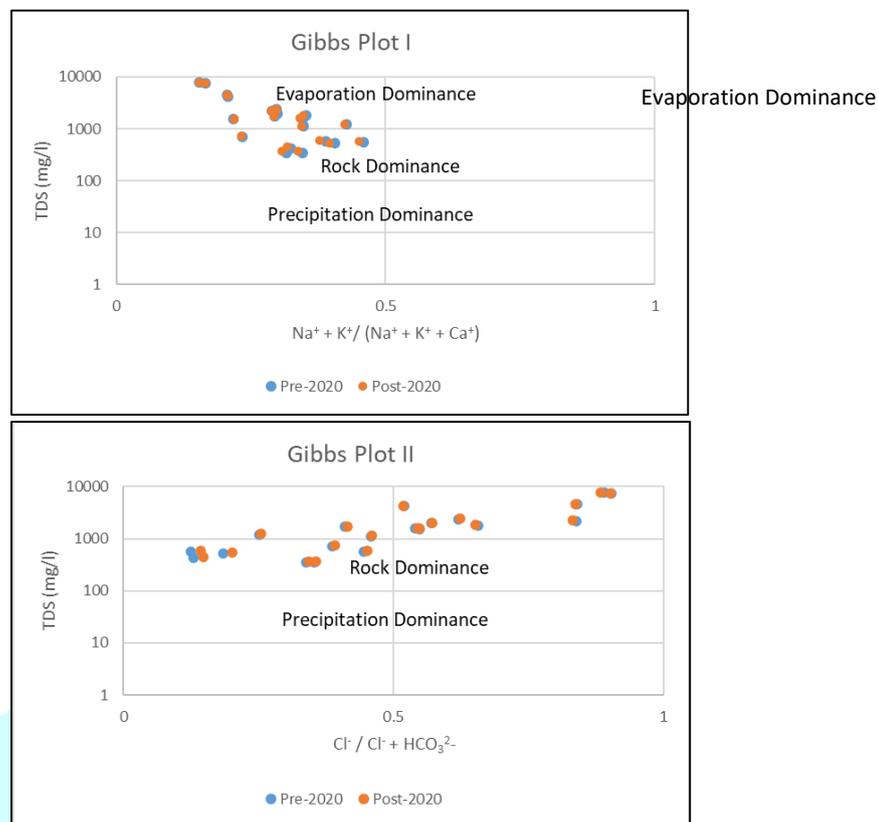
The Piper trilinear diagram (Figure 3.1) was employed to classify groundwater types in Akola Tehsil based on major ion chemistry. The majority of samples plot in the Ca-Mg-HCO<sub>3</sub> facies, indicating freshwater influenced by the weathering of silicate and carbonate minerals from Deccan Trap basalts. This suggests a geogenic origin dominated by rock-water interaction. A few samples trend toward mixed Ca-Na-HCO<sub>3</sub> and Ca-Mg-Cl facies, reflecting possible ion exchange and localized anthropogenic inputs such as fertilizer use or domestic discharge. The absence of Na-Cl type water indicates low salinity and no seawater intrusion, consistent with the inland semi-arid setting. These findings are in line with previous studies in basaltic terrains of Maharashtra and central India, where Ca-Mg-HCO<sub>3</sub> facies are commonly reported (Patil et al., 2020; Alam, 2013). The results confirm that groundwater chemistry in the region is primarily governed by natural geochemical processes with minor anthropogenic influence.



**Figure 3.1 :** Piper trilinear diagram of Akola tehsil groundwater sample

### 3.3. Geochemical Processes (Gibbs Diagrams):

Gibbs diagrams were utilized to identify the dominant geochemical processes influencing groundwater chemistry in Akola Tehsil. Two plots were analyzed: (i) TDS vs.  $(Na^+ + K^+) / (Na^+ + K^+ + Ca^{2+})$  and (ii) TDS vs.  $Cl^- / (Cl^- + HCO_3^-)$ , representing cation and anion controls, respectively shows in figure 3.2a & 3.2b. In the cation plot figure 3a, the majority of groundwater samples cluster within the evaporation dominance, indicating that the groundwater chemistry is largely governed by water-rock interaction, particularly the weathering of basaltic minerals. A few samples fall near the rock dominance zone, suggesting minor evaporative enrichment, especially in regions with shallow water tables and high temperatures. The anion plot shows in figure 3b a similar trend, where most data points lie within the rock dominance and evaporation dominance zones. The absence of samples in the precipitation dominance field implies limited influence from direct rainfall recharge, likely due to the semi-arid climate and low infiltration rates. These patterns confirm that rock-water interaction is the primary geochemical process, with evaporation playing a secondary role. Similar findings have been reported in basaltic aquifers of central India (Alam, 2013; Patil et al., 2020). The dominance of rock-weathering processes is also consistent with the high TDS, hardness, and bicarbonate concentrations observed in the study area.



**Figure 3.2:** (a) Gibbs I diagram: TDS vs.  $(\text{Na}^+ + \text{K}^+) / (\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+})$ . (b) Gibbs II diagram: TDS vs.  $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^{2-})$

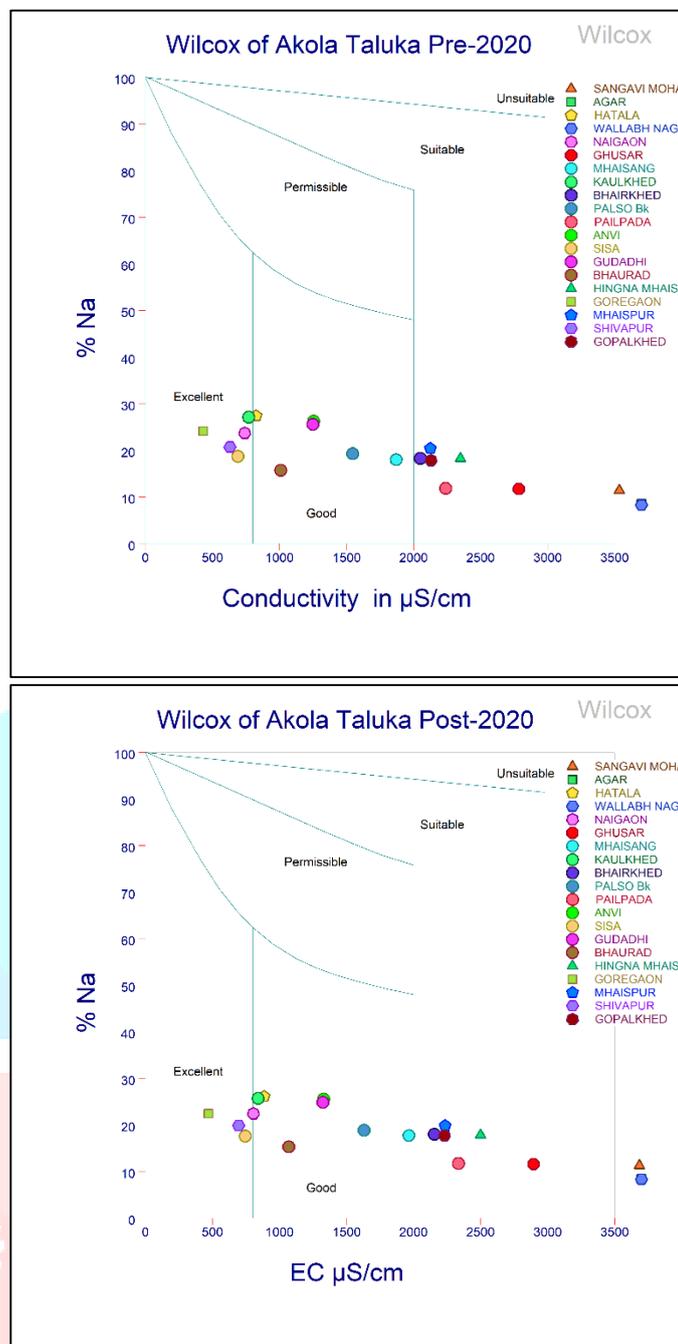
### 3.4. Irrigation Suitability Assessment:

#### 3.4.1 Wilcox Diagram:

The Wilcox diagram, which classifies irrigation water based on conductivity (EC) and sodium percentage (%Na), was employed to evaluate the suitability of groundwater samples from Akola Tehsil for agricultural use (Figure. 3.3). Out of the 20 samples analyzed, the distribution across the irrigation quality zones is as follows:

- 8 samples (S1, S3, S4, S6, S9, S11, S13, S16) fall in the “Good to Permissible” category, indicating low salinity and sodium hazard. These samples are suitable for irrigation across a wide range of soils and crops.
- 7 samples (S2, S5, S7, S10, S12, S15, S18) lie within the “Permissible to Doubtful” category. These may be used for irrigation with moderate salt-tolerant crops, provided proper soil management practices are followed.
- 6 samples (S8, S14, S17, S19, S20) plot in the “Doubtful to Unsuitable” zone, exhibiting high EC and sodium content. Such water poses risks of sodium accumulation in the root zone, leading to soil permeability reduction and adverse crop growth, especially in poorly drained soils (Ayers & Westcot, 1985; Wilcox, 1955).

The presence of high EC in these samples suggests intense water–rock interaction, extended residence time, or anthropogenic influences, such as excessive fertilizer use and return flow from irrigated fields. This trend is also reported in similar basaltic terrains of peninsular India (Patil et al., 2020; Rao et al., 2017). Despite some high-risk zones, the overall results indicate that 66% of samples (14 out of 20) fall within acceptable limits for irrigation, although site-specific soil amendments such as gypsum application and efficient drainage are recommended for the remaining 34% of locations.



**Figure 3.3:** Wilcox diagram showing irrigation water quality based on %Na and EC for groundwater samples (S1–S21) in Akola Tehsil.

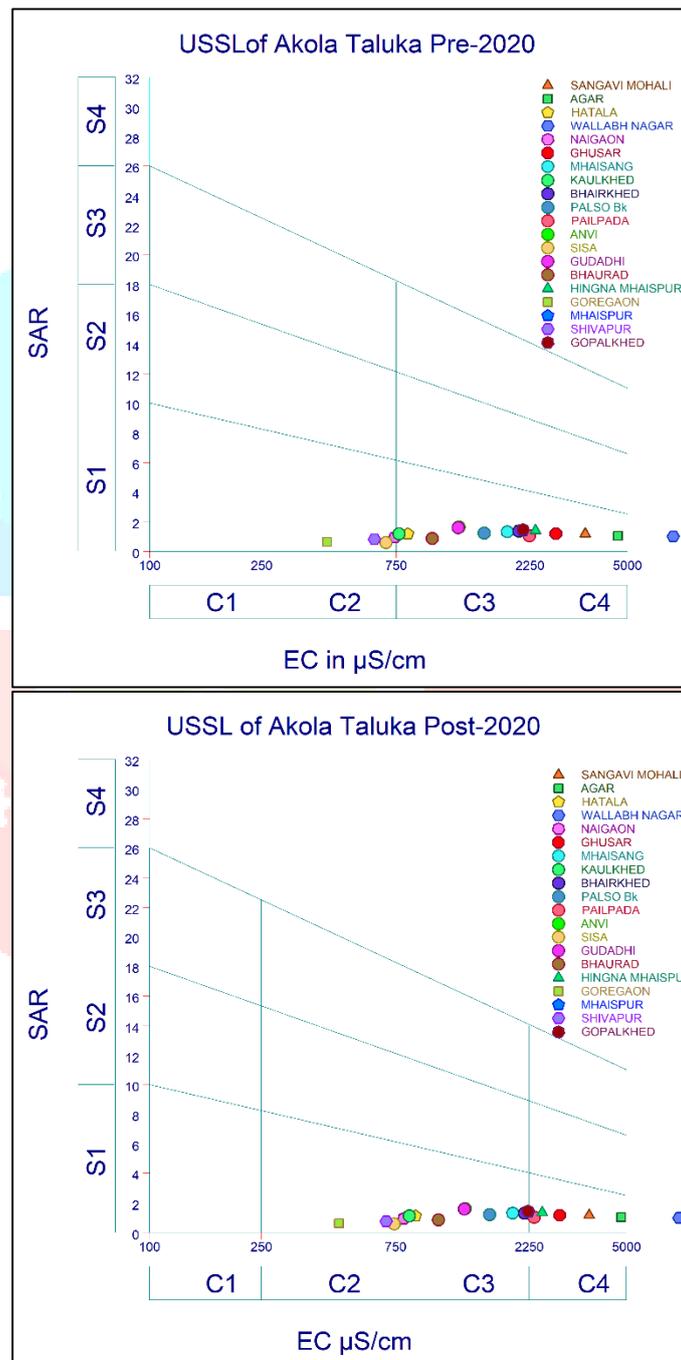
### 3.4.2. USSL Diagram:

The USSL diagram (Figure 3.4) was used to assess the suitability of groundwater for irrigation by plotting Sodium Adsorption Ratio (SAR) against Electrical Conductivity (EC). This classification helps determine the potential salinity and sodium hazards associated with the use of groundwater for agriculture. In this study, groundwater samples from 20 locations in Akola Tehsil were analyzed, and their distribution on the USSL plot is as follows:

- 6 samples (S1, S3, S4, S6, S9, S13) are located in the C3-S1 zone, representing high salinity and low sodium hazard. These waters are generally safe for irrigation if used on well-drained soils and salt-tolerant crops.
- 7 samples (S2, S5, S7, S10, S11, S12, S15) fall in the C3-S2 zone, indicating high salinity and medium sodium hazard. These can be used cautiously with proper soil amendments (e.g., gypsum) and leaching management to avoid sodium accumulation in the root zone.
- 5 samples (S8, S14, S17, S18, S19) are found in the C4-S2 zone, showing very high salinity and medium sodium hazard. The use of these waters is limited, as they may lead to reduced soil permeability and crop stress unless intensive soil management practices are implemented.

- 3 samples (S16, S20) are classified under the C4-S3 zone, representing very high salinity and high sodium hazard. These waters are considered unsuitable for irrigation under normal agricultural conditions and require significant modification, including high-efficiency drainage systems and salt-tolerant crop selection.

The dominance of C3 and C4 classes reflects the semi-arid climate, evaporative concentration, and rock-water interactions typical of basaltic terrains. These findings are consistent with earlier groundwater irrigation suitability studies in Maharashtra (Patil et al., 2020; Rao et al., 2017). Out of 20 samples, 57% (12 samples) fall in the marginal to moderate hazard zones (C3-S1 and C3-S2) and are conditionally suitable for irrigation, while the remaining 43% (8 samples) fall in high-risk zones (C4-S2 and C4-S3) and demand precautionary use or treatment.



**Figure 3.4:** USSL diagram classifying 21 groundwater samples from Akola Tehsil based on SAR and EC for irrigation suitability.

#### 4. Conclusion:

This study evaluated the hydrochemical characteristics and irrigation suitability of groundwater in Akola Tehsil, Maharashtra, using 20 samples analyzed for 19 physico-chemical parameters. The results indicate that many samples exceed WHO/BIS limits for TDS, EC, hardness, chloride, and nitrate, reflecting both natural weathering of basaltic rocks and anthropogenic influences such as agriculture and domestic waste. The Piper diagram revealed Ca-Mg-HCO<sub>3</sub> as the dominant water type, while Gibbs plots confirmed that rock-water interaction is the primary geochemical process, with minor evaporative influence. Irrigation assessments using Wilcox and USSS diagrams showed that 57-66% of the samples are suitable or marginally suitable, while 34-43% fall in high-risk categories due to salinity and sodium hazards. Overall, groundwater in the region is moderately suitable for irrigation, though careful management, periodic monitoring, and use of soil amendments are essential for sustainable use in agriculture.

#### Authors Contribution:

**ALT:** Investigation, Writing-Original Draft, Formal Analysis. **GVK:** Supervision, Reviewing and Editing. **RGK:** Statistical analysis. **NAD:** Help in Sampling.

#### Conflict of Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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