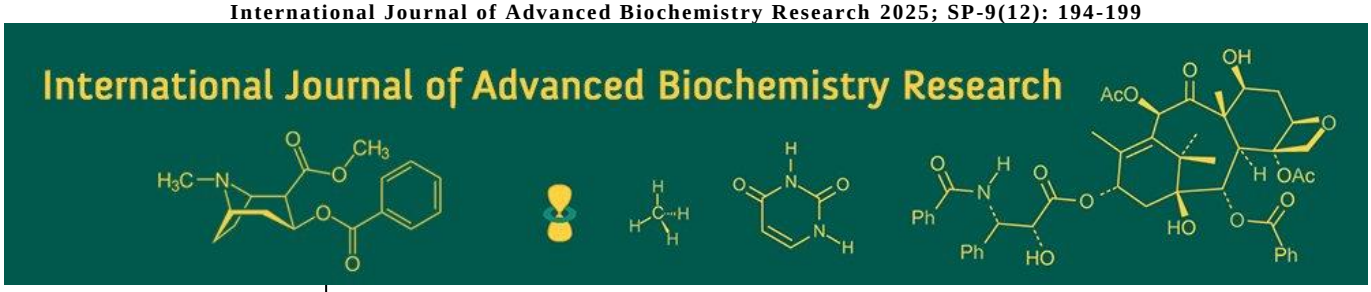

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Assessment of ground water quality for irrigation in Tapi command area of Dhule district: I. cation and anion concentration

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Abstract
The investigation was carried out on 'Assessment of ground water quality for irrigation in Tapi command area of Dhule district' during the year 2024-25 with the objectives to assess the cation and anion concentration in irrigation water from Tapi command area of Dhule district and to classify water for its suitability for irrigation in Tapi command area. A systemic survey was carried out in Tapi river command area and depending upon the variation in physiographic units in the study area. Total 100 irrigation water samples (open well and tube well) were collected during the month of April and May 2024 at grid of 5 km x 5 km with GPS location. The samples were analyzed in the laboratory for cationic and ionic composition using standard procedures. The data thus obtained was interpreted with their relative properties and categorized as per ratings of irrigation water quality. In Tapi command area, about, 17% samples were in moderately high in Ca^{2+} content. Regarding Mg^{2+} content, 36% samples were high and 11% samples were in very high category. Regarding Na^{+} content, 25% samples were moderately high. About 24% samples were moderately high in CO_3^{2-}content. About 53% samples were injurious to unsuitable regarding Cl^{-}content.

Keywords: Tapi command, water quality, cations, anions

Introduction
The most frequent and necessary element for all living is water. It has been crucial in determining how the earth's history has unfolded. It is the most amazing and powerful creature that exists on our planet. Water conservation and use are therefore crucial to human well-being. The fundamental technique for understanding the variance in the quality of contaminated water bodies and, consequently, safeguarding and conserving them is water quality analysis.

Nearly half of India's cultivated land is irrigated by groundwater, according to the Food and Agriculture Organization (FAO). In Maharashtra, canal irrigation makes up about 23% of the net irrigated area, whilst well irrigation makes up about 55%. Although the quality of groundwater used for irrigation varies greatly around the nation, the Indian government encourages the use of groundwater through bore and well wells. According to studies, a significant amount of groundwater utilized for irrigation is of low quality since the total dissolved solids (TDS) in the water can range from 219.88 to 6897.29 mg l^{-1}.

Because there is little rainfall in India's dry and semi-arid regions, crops there mostly depend on irrigation, whereas in sub-humid regions, irrigation enhances natural precipitation. In India, irrigation covers around one-third of all arable land. Compared to other states, states such as Rajasthan, Karnataka, Gujarat, and Maharashtra have fewer water resources (Anand, 2006) [1]. In the future, water will be a vital resource that will limit agricultural output, particularly in the state of Maharashtra.

The Tapi River is the Indian Peninsula's second-largest west-flowing river. At an elevation of roughly 752 meters, the river rises close to Multai in the Betul district of Madhya Pradesh. It travels approximately 724 kilometres before joining the Gulf of Cambay, of which 228 kilometres are in Madhya Pradesh, 228 kilometres are in Maharashtra, 214 kilometres are in Gujarat, and the remaining 54 kilometres serve as the shared border between Madhya

Pradesh and Maharashtra. The river typically flows through the states of Gujarat, Maharashtra, and Madhya Pradesh from east to west (Subbaiah *et al.*, 2020) [12].

The evaluation of ground water encompasses both the quantity and quality of ground water in a specific location. A detailed assessment of ground water in relation to other water resources is necessary for the planning and management of this renewable natural resource for a variety of uses, such as drinking, irrigation, industrial, *etc.* Because of their complexity and site-specific problems, ground water systems must be evaluated and understood using an integrated approach.

In order to maintain soil health and sustained crop production, irrigation water quality assessment is crucial. It entails examining a range of physical, chemical, and biological factors that affect how suitable water is for agricultural use. Salinity, sodicity, pH, and the presence of certain ions like sodium, chloride, bicarbonate, and boron are important variables that can negatively impact soil structure and plant growth. Electrical conductivity (EC), total dissolved solids (TDS), and the ratio of sodium to calcium and magnesium are also frequently assessed to ascertain the likelihood of soil toxicity or degradation. By keeping an eye on these factors, farmers may make better judgements about crop selection, soil additives, and irrigation techniques, increasing agricultural output and averting long-term farmland harm.

Materials and Methods

A systemic survey was carried out in Tapi river command area and depending upon the variation in physiographic units in the study area. The village cadastral maps were used as base maps for delineating boundaries with actual observations throughout the course of traversing. Total 100 irrigation water (open well and tube well) samples were collected during the month of April and May 2024 at grid of 5 km x 5 km with GPS location. Water samples were collected in closed air tight plastic bottles and transported to laboratory for analysis. The sampling was done within 24 hrs of water collection. The samples were analyzed in the laboratory for calcium and magnesium by Versenate method, sodium and potassium by flame photometer, carbonate, bicarbonate and chloride by titration, nitrate by using Devard`s alloy as given by Richards (1954) [11]. Sulphate was determined by turbidimetric method (Jackson, 1973) [3].

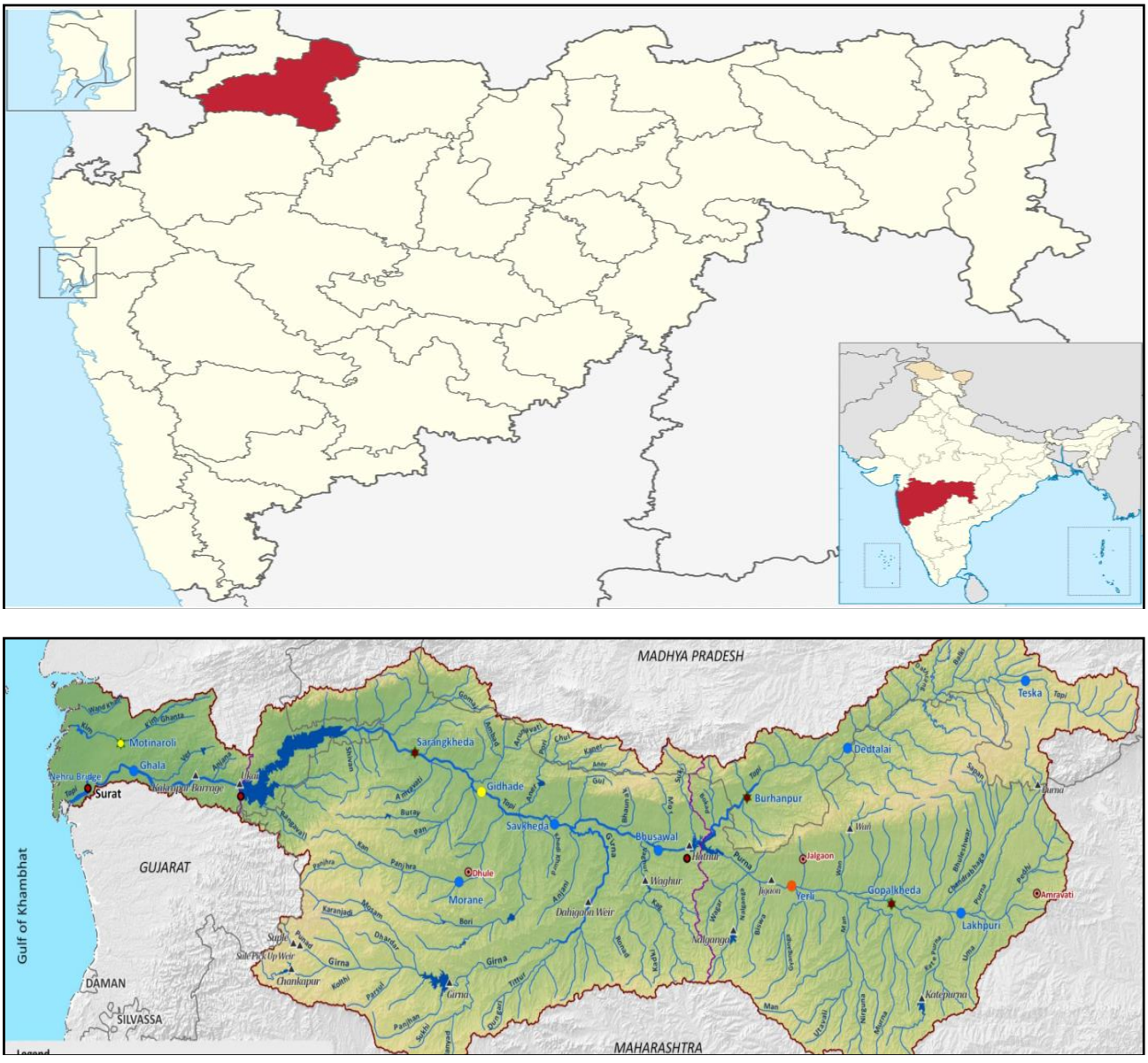

Fig 1: Location Map of Tapi Command Area

Results and Discussion

Major cations

Calcium

A total of 17% irrigation water samples, comprising 5 from Shirpur and 12 from Sindkheda, were categorized as "Low" (1.1 to 2.0 meq L^{-1}), indicating that a small portion of the irrigation water sources had relatively lower calcium concentrations. The majority of the water samples (66%) were under the "Moderate" category (2.1 to 4.0 meq L^{-1}), with 39 samples from Shirpur and 27 from Sindkheda, signifying that most of the irrigation water in the Tapi command area had optimal calcium levels for agricultural use. Additionally, 17% samples (6 from Shirpur and 11 from Sindkheda) were categorized as "Moderately High" (4.1 to 6.0 meq L^{-1}), which, although within permissible limits, might require monitoring in long-term use, especially under poor drainage conditions. The statistical summary of calcium content revealed that the calcium concentration ranged from a minimum of 1.48 meq L^{-1} (Sindkheda) to a maximum of 4.45 meq L^{-1} (Shirpur), indicating a wide but acceptable distribution. The mean calcium concentration was found to be 2.91 meq L^{-1} for both tehsils and the overall Tapi command area, placing it in the "Moderate" category. The standard deviation (SD) values were 0.75 for Shirpur, 0.97 for Sindkheda, and 0.87 for the overall area, suggesting relatively moderate variability in calcium concentration among the samples. These observations align with the findings of Joshi *et al.* (2024) [4], who found that irrigation waters from semi-arid regions of Maharashtra had primarily moderate calcium concentrations, which ensure cationic balance and improve soil health, particularly when sodium levels are high.

Magnesium

As per the categorization, no sample from either tehsil was under the "Very Low" (<1.0 meq L^{-1}) or "Low" (1.01-2.0 meq L^{-1}) categories, indicating that magnesium deficiency is not an issue in the region's irrigation water. A total of 13% samples (3 from Shirpur and 10 from Sindkheda) were categorized under the "Moderate" (2.01 to 4.0 meq L^{-1}) class, suggesting satisfactory magnesium levels for crop health and minimal risk of imbalance. The majority of the 40% water samples (22 from Shirpur and 18 from Sindkheda), were under the "Moderately High" (4.01 to 6.0 meq L^{-1}) category, indicating that still within acceptable limits, these irrigation waters may pose a risk of magnesium accumulation with prolonged use, especially in soils with poor drainage. Furthermore, a considerable portion of the samples (36%) in total (19 from Shirpur and 17 from Sindkheda) were under the "High" (6.01-8.0 meq L^{-1}) category. If such irrigation water is used consistently, it may lead to increased soil exchangeable magnesium levels and compete with calcium uptake, potentially affecting plant nutrient balance. Importantly, 11% samples (6 from Shirpur and 5 from Sindkheda) were found to be in the "Very High" (>8.01 meq L^{-1}) class. Such levels are undesirable for irrigation as they can increase soil hardness and alkalinity, reduce soil permeability, and negatively affect soil structure. For the entire Tapi command area, the overall mean magnesium concentration was 5.83 meq L^{-1}, with a range from 3.19 to 8.48 meq L^{-1} and a standard deviation of 1.50, placing the majority of samples in the "Moderately High" to "High" category. Similar results were showed in the study conducted by Mondal *et al.* (2021) [6].

Sodium

None of the irrigation water samples collected from either Shirpur or Sindkheda tehsils was under the "Very Low" (<2.0 meq L^{-1}) category, indicating a general presence of sodium in measurable amounts across the Tapi command area. Likewise, no samples were categorized as "High" (8.1 to 10.0 meq L^{-1}) or "Very High" (>10.0 meq L^{-1}), which is a positive indication that sodium toxicity is not a threat in the region's irrigation practices. The majority of the samples (52% samples) were found to be in the "Moderate" (4.1-6.0 meq L^{-1}) range, with 26 samples each from Shirpur and Sindkheda tehsils, each, suggesting that most of the irrigation water sources contain sodium within acceptable limits for irrigation use. However, the moderate level indicates that continual use should be monitored to avoid gradual sodium build-up in the soil, especially in poorly drained fields. About, 25% samples (12 from Shirpur and 13 from Sindkheda) were categorized under the "Moderately high" (6.1 to 8.0 meq L^{-1}) class. A total of 23 samples% (12 from Shirpur and 11 from Sindkheda) belonged to the "Low" sodium category (2.1 to 4.0 meq L^{-1}). This group reflects the safest range for irrigation purposes with minimal risk of sodicity, thus being suitable for most crops and soil types. The mean sodium concentration for the entire command area was 5.01 meq L^{-1}, suggesting that, on average, sodium levels were within the moderate range as per standard irrigation water quality classification. Similar results were shown by Joshi *et al.* (2024) [4].

Potassium

Out of 100 samples collected from the Tapi command area, the majority of irrigation water samples (47% samples) were under the "Moderate" category (0.51 to 0.80 meq L^{-1}), followed by 34% samples in the "Low" range (0.21 to 0.50 meq L^{-1}). About, 19% samples were categorized as "Moderately high" (0.80 to 1.00 meq L^{-1}). None of the samples were under the "Very Low (<0.20)", "High (1.01 to 1.50)", or "Very high (>1.51)" categories, indicating no extreme potassium levels in the region's irrigation water. A closer look at tehsil-wise data revealed that in Shirpur tehsil, out of 50 samples, 27 were classified under moderate, 14 under low, and 9 under moderately high potassium categories. In Sindkheda tehsil, 20 samples each belonged to the moderate and low classes, while 10 samples were moderately high. The potassium concentration in irrigation water ranged from 0.21 to 1.00 meq L^{-1} across the Tapi command area. The mean potassium content was recorded as 0.59 meq L^{-1}, which places the overall irrigation water quality under the moderate category. The standard deviation was 0.21, indicating relatively low variability in potassium content across the region. A comprehensive assessment across peninsular India by Ramakrishna *et al.* (2023) [9] reported K^+ levels ranging between 0 to 23 mg L^{-1}, with nearly 19% of groundwater samples exceeding the BIS threshold, highlighting fertilizer application and weathering of feldspathic rocks as primary contributors.

Major anions

Carbonate

Out of 100 irrigation water samples collected from the Tapi command area, the majority, i.e., 38% samples, were categorized under the moderate class (0.31 to 0.60 meq L^{-1}). This was followed by 32% samples under the low class (0.01 to 0.30 meq L^{-1}) and 24% samples in the moderately

high category (0.61 to 0.90 meq L^{-1}). Only 6% samples were in the very low (< 0.0 meq L^{-1}) category. Notably, none of the samples were in the high (>0.90 meq L^{-1}) or very high (>1.21 meq L^{-1}) classes, indicating the absence of severe carbonate hazards in the region. The carbonate concentration across the Tapi command area ranged from 0.00 to 0.80 meq L^{-1}, indicating no extreme or hazardous levels of carbonate in any sample. The mean carbonate content for the entire command area was 0.42 meq L^{-1}, placing it in the moderate category, which is generally acceptable for irrigation. A study by Patil *et al.* (2024) on the distribution of carbonate in Northern Maharashtra's groundwater revealed that high carbonate values were linked to specific lithological zones that were rich in limestone.

Bicarbonate

None of the irrigation water samples collected from the Tapi command area were found in the moderately high (5.01 to 7.00 meq L^{-1}), high (7.01 to 9.00 meq L^{-1}) or very high (> 9.01 meq L^{-1}) classes, indicating no severe bicarbonate hazard. Out of 100 samples, the majority (43% samples) were in the low category (1.51 to 3.00 meq L^{-1}), followed by 36% samples in the moderate range (3.01 to 5.00 meq L^{-1}). Only 21% samples were found in the very low category (<1.50 meq L^{-1}), showing favorable irrigation water quality with minimal bicarbonate risk. The bicarbonate content ranged from 1.03 to 4.61 meq L^{-1}, suggesting no extreme values in the dataset. The mean bicarbonate level for the entire Tapi command area was 2.61 meq L^{-1}, which falls under the low category, indicating that bicarbonate concentration is generally within acceptable limits for irrigation purposes. At the tehsil level, the mean bicarbonate concentration in Shirpur tehsil was slightly higher at 2.66 meq L^{-1} with a standard deviation (SD) of 1.09, while Sindkheda tehsil had a mean of 2.56 meq L^{-1} with an SD of 1.02. The overall SD for the Tapi command area was 1.04, indicating moderate variability in bicarbonate levels. These results are consistent with those of Patel *et al.* (2023), who found that irrigation water from semi-arid regions of Maharashtra had mean bicarbonate levels of 3.5-4.8 meq L^{-1}. They suggested soil amendments and routine monitoring to avoid long-term alkalinity issues.

Chloride

None of the irrigation water samples collected from either Shirpur or Sindkheda tehsil were under the excellent category (<2.0 meq L^{-1}). This indicates the absence of highly desirable irrigation water in terms of chloride content across the Tapi command area. The majority of the samples were classified as either good to injurious (2.0-6.0 meq L^{-1}) or injurious to unsuitable (>6.0 meq L^{-1}). Out of the total samples analyzed, 47% samples were categorized as good to injurious, while the remaining 53% samples were deemed injurious to unsuitable due to their high chloride content. Specifically, Shirpur tehsil had 24 samples in the good to injurious category and 26 samples in the injurious to unsuitable category. Similarly, Sindkheda tehsil recorded 23 samples in the good to injurious class and 27 samples in the injurious to unsuitable class. These figures suggest a significant chloride hazard in more than 50% of the irrigation water samples. The chloride concentration in irrigation water samples from the Tapi command area ranged from 3.03 to 10.43 meq L^{-1}, indicating that all samples exceeded the ideal threshold (<2.0 meq L^{-1}). The mean chloride content for the entire area was 6.53 meq L^{-1}, placing the average in the injurious to unsuitable category, suggesting that irrigation with such irrigation water may pose potential risks to chloride-sensitive crops. Similar results were reported in the studies of Ramakrishna *et al.* (2023) [9].

Sulphate

The sulphate content in all 100% irrigation water samples collected from the Tapi command area were within the acceptable limits, with none exceeding the injurious threshold of 12.0 meq L^{-1}. A total of 53% samples were categorized as excellent (< 4.0 meq L^{-1}), indicating high suitability for irrigation. Among these, Shirpur tehsil contributed 30 samples, while Sindkheda tehsil contributed 23 samples to this category. The remaining 47% samples were classified under the good to injurious category (4.0 to 12.0 meq L^{-1}), suggesting caution may be required for salt-sensitive crops, though they are still generally considered safe for irrigation. Specifically, 20 samples from Shirpur and 27 samples from Sindkheda fell into this class. Notably, no samples across either tehsil were found in the injurious to unsuitable category (>12.0 meq L^{-1}), reflecting the overall safety of irrigation water with respect to sulphate content in the Tapi command region. The sulphate content across the Tapi command area ranged from 1.95 to 5.64 meq L^{-1}, with an overall mean of 3.82 meq L^{-1}, which lies just below the threshold of the excellent category. This average value suggests that, the sulphate content in the region's irrigation water is within acceptable limits for most crops. The results are confirmed with the studies of Elsayed *et al.* (2020) [2] and Rathod *et al.* (2021) [10].

Nitrate

Out of total water samples, 75% samples were categorized under the moderate category (1.1 to 11.3 meq L^{-1}), indicating acceptable concentrations of nitrate suitable for irrigation. Specifically, 38 samples from Shirpur tehsil and 37 samples from Sindkheda tehsil fell under this category. The remaining 25% samples were classified under the low category (<1.1 meq L^{-1}), which although not harmful, may indicate limited nitrate availability for nitrate-demanding crops. This includes 12 samples from Shirpur and 13 from Sindkheda. Notably, no samples from either tehsil were found in the high (11.3 to 22.6 meq L^{-1}) or very high (>22.6 meq L^{-1}) categories, indicating absence of hazardous nitrate levels across the region. The nitrate concentration in the Tapi command area ranged from 0.30 to 3.00 meq L^{-1}, with an overall mean value of 1.59 meq L^{-1}, which is well within the moderate and safe limits for irrigation use. The standard deviation (SD) was recorded at 0.74, suggesting relatively moderate variability in nitrate distribution across the region. Similar results were found by Marghade *et al.* (2021) [5].

Table 1: Categorization of calcium (meq L^{-1}) in irrigation water in Tapi command area

Category Sample No.	Shirpur tehsil	Sindkheda tehsil	Tapi command area
	1-50	51-100	(% samples)
Very low (< 1.0)	0	0	0
Low (1.1-2.0)	5	12	17
Moderate (2.1-4.0)	39	27	66
Moderately high (4.1-6.0)	6	11	17
High (6.1-8.0)	0	0	0
Very high (> 8.1)	0	0	0

Table 2: Categorization of magnesium (meq L^{-1}) in irrigation water in Tapi command area

Category Sample No.	Shirpur tehsil	Sindkheda tehsil	Tapi command area
	1-50	51-100	(% samples)
Very low (< 1.00)	0	0	0
Low (1.01-2.00)	0	0	0
Moderate (2.01-4.00)	3	10	13
Moderately high (4.01-6.00)	22	18	40
High (6.01-8.00)	19	17	36
Very high (> 8.01)	6	5	11

Table 3: Categorization of sodium (meq L^{-1}) in irrigation water in Tapi command area

Category Sample No.	Shirpur tehsil	Sindkheda tehsil	Tapi command area
	1-50	51-100	(% samples)
Very low (< 2.0)	0	0	0
Low (2.1-4.0)	12	11	23
Moderate (4.1-6.0)	26	26	52
Moderately high (6.1-8.0)	12	13	25
High (8.1-10.0)	0	0	0
Very high (> 10.00)	0	0	0

Table 4: Categorization of potassium (meq L^{-1}) in irrigation water in Tapi command area

Category Sample No.	Shirpur tehsil	Sindkheda tehsil	Tapi command area
	1-50	51-100	(% samples)
Very low (< 0.20)	0	0	0
Low (0.21-0.50)	14	20	34
Moderate (0.51-0.80)	27	20	47
Moderately high (0.80-1.00)	9	10	19
High (1.01-1.5)	0	0	0
Very high (> 1.51)	0	0	0

Table 5: Categorization of carbonates (meq L^{-1}) in irrigation water in Tapi command area

Category Sample No.	Shirpur tehsil	Sindkheda tehsil	Tapi command area
	1-50	51-100	(% samples)
Very low (< 0.0)	2	4	6
Low (0.01-0.30)	15	17	32
Moderate (0.31-0.60)	19	19	38
Moderately high (0.61-0.90)	14	10	24
High (0.91-1.20)	0	0	0
Very high (> 1.21)	0	0	0

Table 6: Categorization of bicarbonates (meq L^{-1}) in irrigation water in Tapi command area

Category Sample No.	Shirpur tehsil	Sindkheda tehsil	Tapi command area
	1-50	51-100	(% samples)
Very low (< 1.50)	10	11	21
Low (1.51-3.00)	22	21	43
Moderate (3.01-5.00)	18	18	36
Moderately high (5.01-7.00)	0	0	0
High (7.01-9.00)	0	0	0
Very high (> 9.01)	0	0	0

Table 7: Categorization of chlorides (meq L^{-1}) in irrigation water in Tapi command area

Category Sample No.	Shirpur tehsil	Sindkheda tehsil	Tapi command area
	1-50	51-100	(% samples)
Excellent (< 2)	0	0	0
Good to injurious (2.0-6.0)	24	23	47
Injurious to unsuitable (> 6.0)	26	27	53

Table 8: Categorization of sulphates (meq L^{-1}) in irrigation water in Tapi command area

Category Sample No.	Shirpur tehsil	Sindkheda tehsil	Tapi command area
	1-50	51-100	(% samples)
Excellent (< 4)	30	23	53
Good to injurious (4.0-12.0)	20	27	47
Injurious to unsuitable (> 12.0)	0	0	0

Table 9: Categorization of nitrates (meq L^{-1}) in irrigation water in Tapi command area

Category Sample No.	Shirpur tehsil	Sindkheda tehsil	Tapi command area
	1-50	51-100	(% samples)
Low (< 1.1)	12	13	25
Moderate (1.1-11.3)	38	37	75
High (11.3-22.6)	0	0	0
Very high (> 22.6)	0	0	0

Table 10: Irrigation water quality in Tapi command area

Parameter	Minimum	Maximum	Mean	SD
Calcium (meq L^{-1})	1.48	4.45	2.91	0.87
Magnesium (meq L^{-1})	3.19	8.48	5.83	1.50
Sodiuim (meq L^{-1})	3.05	7.50	5.01	1.21
Potassium (meq L^{-1})	0.21	1.00	0.59	0.21
Carbonates (meq L^{-1})	00	0.80	0.42	0.21
Bicarbonates (meq L^{-1})	1.03	4.61	2.61	1.04
Chlorides (meq L^{-1})	3.03	10.43	6.53	2.29
Sulphates (meq L^{-1})	1.95	5.64	3.82	1.02
Nitrates (meq L^{-1})	0.30	3.00	1.59	0.74

Conclusion

In Tapi command area, about, 17% samples were in moderately high in Ca^{2+} content. Regarding Mg^{2+} content, 36% samples were high and 11% samples were in very high category. Regarding Na^{+} content, 25% samples were moderately high. About 24% samples were moderately high in CO_3^{2-}content. About 53% samples were injurious to unsuitable regarding Cl^{-}content. In general, Shirpur and Sindkheda tehsils irrigation water quality is appropriate for farming. However, Sindkheda needs to pay more attention to the buildup of sodium and chloride, while Shirpur needs to have its bicarbonate and magnesium levels closely

monitored. In susceptible areas, site-specific management techniques like gypsum application, better drainage, and crop rotation with salt-tolerant cultivars are recommended to maintain soil health and crop yields over the long term.

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