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RESEARCH ARTICLE

Groundwater Quality Assessment Using GIS for Agricultural Propose in Molakalmur Taluk, Karnataka

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Abstract

Objectives: To assess the carbonate concentration in relation to calcium and magnesium concentrations and to determine TDS and sodium concentration in relation to other cations. The study's overall goal is to examine the suitability of groundwater for irrigation/agricultural purposes in Molakalmur Taluk of Chitradurga District, Karnataka, India. **Methods:** The current study was carried out to analyze the water quality and spatial distribution of physicochemical parameters of groundwater in study area. A total of 92 groundwater samples were collected during the pre-monsoon period; ArcGIS 9.2 was used to create a spatial distribution map based on a geographic information system. The concentrations of various ions like Ca^{+2}, K^{+1}, Cl^{-1}, Mg^{+2}, HCO_3^{-1}, Na^{+1}, CO_3^{-2}, and SO_4^{-2} were evaluated as per BIS 3025 (2014) and compared to various irrigation standards like Sodium Adsorption Ratio (SAR), Percentage of Sodium (%Na), Magnesium Adsorption Ratio (MAR), Kelley's Ratio/Kelly's Index (KI), Permeability Index (PI) Electrical Conductivity (EC), Total Hardness (TH), Total Salt Concentration, Chloride in irrigation water and integrated standards such as USSL and Wilcox diagram. **Findings:** During the pre-monsoon period, the majority of the samples in the study area fell into the hard to very hard water category. According to Evaluated water quality indices like SAR, MAR, PI, KI, SSP, CI and total salt concentration around 5 to 15 percent water samples are not good for agricultural purpose and as per the integrated parameters like USSL and Wilcox the percentage samples that are unsuitable for irrigation is going up to 30 percentage due to presence of higher Electrical conductivity. **Novelty:** In the study region, there is no perennial river and the main ion chemistry of Molakalmur Taluk's groundwater has never been investigated before. The present work attempts to study the suitability of water for agricultural purpose. The findings of the study will aid in the collecting of crucial data on groundwater quality in Molakalmur Taluk. The findings of the study could also help groundwater managers and urban planners to restore and improve groundwater quality.

Keywords: Physicochemical parameters; Irrigational water quality; Salinity hazard; Alkalinity hazard; Geographic Information System

1 Introduction

Groundwater, as a complex resource that is recharged annually with the help of rainfall and is vulnerable to various activities which will degrade the quality of the water[1–3].Groundwater is an important source of water for domestic uses such as irrigation, drinking and manufacturing processes. One of the most critical aspects of groundwater research is water quality. The hydro chemical investigation shows weather the water quality that is ideal for agriculture, change in the water quality will be mainly due to oxidation–reduction reactions and rock-water interaction. In the studied area, groundwater is the predominant source of agriculture. The suitability of irrigation water is determined by the water quality, the soil type, soil's drainage characteristics, the plants' ability to absorb salt and the atmosphere groundwater quality has deteriorated as a result of excessive use of groundwater for various purposes. In the study region, there is no perennial river and the main ion chemistry of Molakalmur Taluk's groundwater has never been investigated before. During the pre-monsoon period, water samples were obtained from 92 stations and analyzed for chemical characteristics, chemical characteristics of groundwater play a crucial part in classifying and determining water quality. The seven major constituents present in water quality are Ca^{+2}, Mg^{+2}, Cl^{-1}, HCO_3^{-1} Na^{+1}, K^{+1}, and SO_4^{-2}, A number of methodologies and approaches have been established to evaluate chemical data; chemical classification reveals the major cations, anions, and their interrelationships. Understanding water quality parameters is easier when they are represented graphically. The purpose of this research is to look at the suitability of groundwater for irrigation in Molakalmur Taluk. To assess the water quality various standards have been measured like Sodium adsorption ratio (SAR). Percentage Sodium (%Na), Kelley's Ratio, Permeability index (PI), Magnesium Ratio (MAR), soluble sodium percentage (SSP), Electrical conductivity (EC), and Chloride classification[4–8].M^{i}n^{i}m^{u}m, maximum and mean values of the standards are represented in Table 1 .

1.1 Study Area

Molakalmur Taluk is situated in Chitradurga district of Karnataka, India, between 14º 30'00" to 15º 00' 00" North Latitude and 76º 40' 00" to 76º 51' 00" East Longitude. According to 2011 census, the taluk has an area of 739 km^2 including 695.94 km^2 rural area and 43.06 km^2 urban area, with a total population of 141,284 people. Figure 1 represents the study area. Agriculture, horticulture, and animal husbandry are the main sources of employment, employing nearly 80% of the workforce. In Molakalmur Taluk, Gneiss & Granites are the key water bearing formations. The thickness, and structure of rock formations influence the occurrence, transport, and storage of groundwater. Groundwater in the study area occurs in weathered and fractured granite, gneisses. The people in this region are frequently facing water shortage and poor water quality problems.

1.2 Significance of Study

In the study region, there is no perennial river and the main ion chemistry of Molakalmur Taluk's groundwater has never been investigated before. The present work attempts to study the suitability of water for agricultural purpose. The findings of the study will aid in the collecting of crucial data on groundwater quality in Molakalmur Taluk. The findings of the study could also help groundwater managers and urban planners to restore and improve groundwater quality.

2 Methodology

In total, 92 groundwater samples were obtained from the study region for investigation during the pre-monsoon period, the location of sample collection is as shown in Figure 2. They were gathered from their individual bore wells in cleaned 1L polyethylene bottles. Each bottle was cleaned with distilled water to prevent contamination. In the laboratory, the analysis was carried out as per BIS 3025 (2014) and with the help of standard instruments. Concentrations are stated in mg/l and then converted to mEq/L for computations except pH, TDS and EC.

The hydrogen ion concentration, temperature, conductivity, and TDS in water samples were determined using a portable standard meter. For the analysis of sodium and potassium, a flame-photometer was utilized. Total Alkalinity (TA), Calcium Hardness (CH) and Total Hardness (TH) as $CaCO_3$ were assessed volumetrically. Sulphate by turbidity method and Fluoride, Copper, Iron was determined for drinking purpose using portable checkers from Hanna Equipment's India Pvt. Ltd. The correctness of analysis has been verified with the help of Equation 1 and Equation 2. The following indicators were calculated to assess the suitability of water for agricultural purpose like Sodium adsorption ratio (SAR), Percentage Sodium (%Na), Kelley's Ratio, Permeability index (PI), Magnesium Ratio (MAR), soluble sodium percentage (SSP), Electrical conductivity (EC), and Chloride classification. ArcGIS 9.2 was used to create a spatial distribution map based on a geographic information system and the flow chart for the analysis is represented in Figure 3.

$$1.0 < \frac{Measured\ TDS}{Calculated\ TDS} < 1.2 \quad (1)$$

$$\%\ \text{Difference} = 100\ X\ \frac{\sum cations - \sum anions}{\sum cations + \sum anions} < 5\% \quad (2)$$

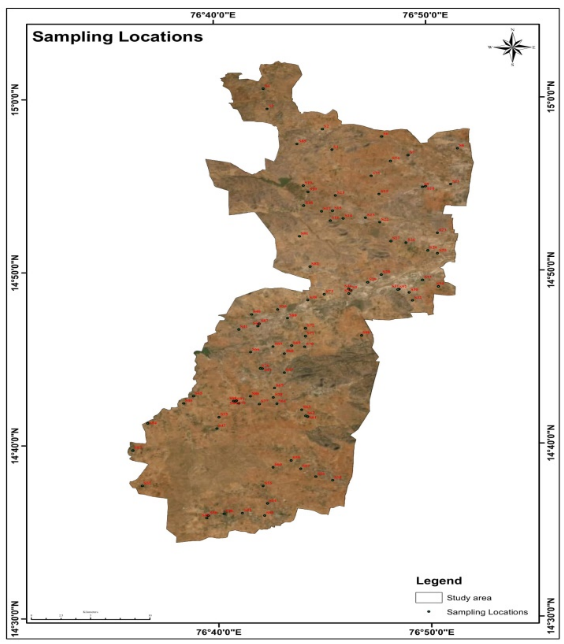


Fig 1. Location map of study area

3 Result and Discussion

Excessive amounts of dissolved ions like sodium, bicarbonate, and carbonates in irrigation water have a physical and chemical effect on plants and agricultural soil by decreasing soil productivity. These ions have a physical effect on plant's cell structure by reducing the osmotic pressure. As a result, water cannot enter the leaves and branches. The chemical effects of these ions are to disrupt plant metabolism. The plant growth is mainly influenced by the concentration of sodium and boron than the total concentration of other ions[9].The plants absorb salts and nutrients from the soil based on osmotic pressure in plants. The higher salinity lessens the osmotic activity in plants there by intervene in the process of absorption of nutrients and water from the soil. To assess the quality of water, various irrigation water quality standards are adopted for determination of water quality that is suitable for irrigation. Table 1 shows the water quality standard outcome with maximum and minimum and mean

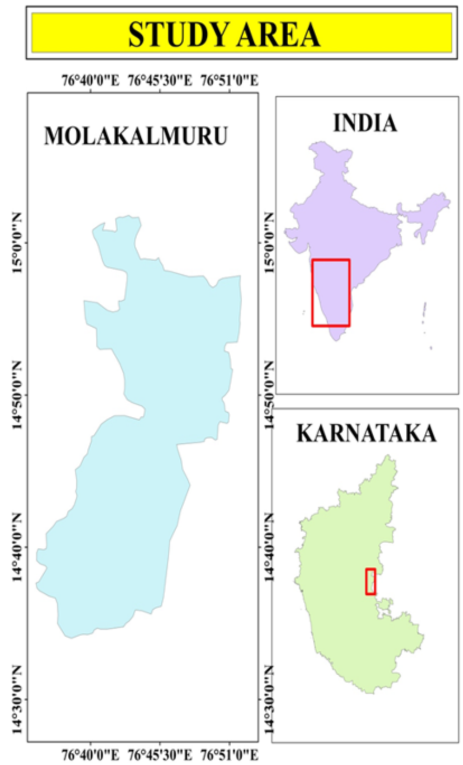


Fig 2. Samples from various locations

concentrations.

Table 1. Irrigation standards with minimum, maximum and mean values

S.No	Irrigation standard	Unit	Min	Max	Mean
1	Sodium Adsorption Ratio (SAR)	mg/l	1.31	28.34	9.20
2	Percentage Sodium (%Na)	mg/l	8.31	58.59	29.61
3	Magnesium Ratio MAR (%)	mg/l	4.55	66.47	34.50
4	Kelley's Ratio (KR)	mg/l	0.06	1.21	0.34
5	Permeability index (PI)	mg/l	10.90	58.11	26.66
6	Electrical Conductivity (EC)	μS/cm	674	5114	1778.09
7	Total Salt Concentration	μS/cm	674	5114	1778.09
8	Total Hardness (TH)	mg/l	136	864	405.21
9	Chloride Content	meq/l	0.42	10.92	2.76

3.1 Sodium adsorption ratio (SAR)

Richards proposed this ratio in 1954 as a measure of sodium adsorption by soil and soil structure damage, higher sodium levels affect soil permeability and add to overall water salinity, which can be hazardous to sensitive crops [10]. This is one of the most significant criteria in determining groundwater for irrigation. The SAR values are computed using Equation 3 and ranging from 1.31 to 28.34 as we can observed in Table 1. SAR values indicated in Table 2 shows that 58.70% of water was of excellent quality, 36.96% was good quality, 3.26% was doubtful for irrigation and 1.09% of water is not suitable for irrigation [11], The spatial distribution of SAR is shown in Figure 4.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+} + Mg^{2+}}{2}}}$$

3.2 Percentage of sodium (%Na)

In natural waters, Percentage of sodium (%Na) is a widely used parameter to indicate suitable use of water for agriculture, and the value of %Na is derived using Equation 4. Irrigation water with a high sodium content inhibits crop growth and reacts with the soil, lowering its permeability[12]. The %Na values are ranging from 8.31 to 58.59 as we can observed in Tables 1 and 2 shows the classification of samples and number of samples. Based on classification 16.30% of the water samples fall in excellent condition, 71.74% of water falls in good condition, 11.96% of water falls in permissible condition and not even one percent of water is under doubtful or unsuitable condition. Figure 5 depicts the spatial distribution of %Na.

$$\%Na^{+} = \frac{(Na^{+} + K^{+})X\,100}{(Ca^{+2} + Mg^{+2} + Na^{+} + K^{+})} \quad (4)$$

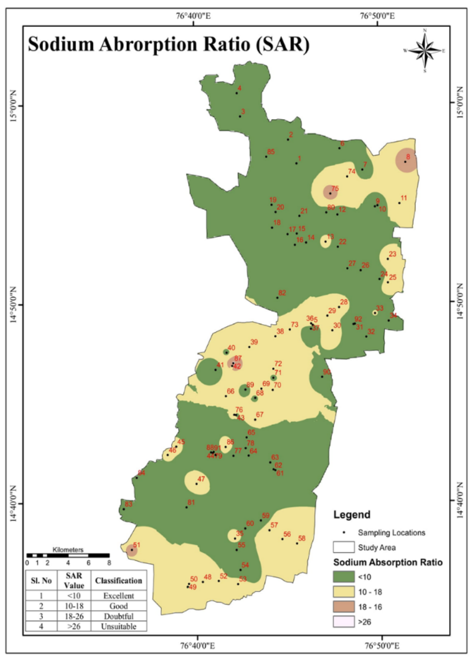


Fig 3. Flow chart for analysis

3.3 Magnesium Adsorption Ratio (MAR)

One of the most significant indicators for measuring irrigation water quality is the magnesium concentration in the water. As the soil becomes more saline, excessive magnesium concentrations affect crops, and detrimental impact on soils are expected when water MAR values exceed 50[3,13]. TheMAR values for groundwater is calculated using Equation 5. In Table 1 it is seen that MAR values in Molakalmur Taluk varies from 4.55 to 66.47 and Table 2 shows that 90.22% of the water is appropriate for irrigation and 9.78% is not suitable for irrigation purpose.

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

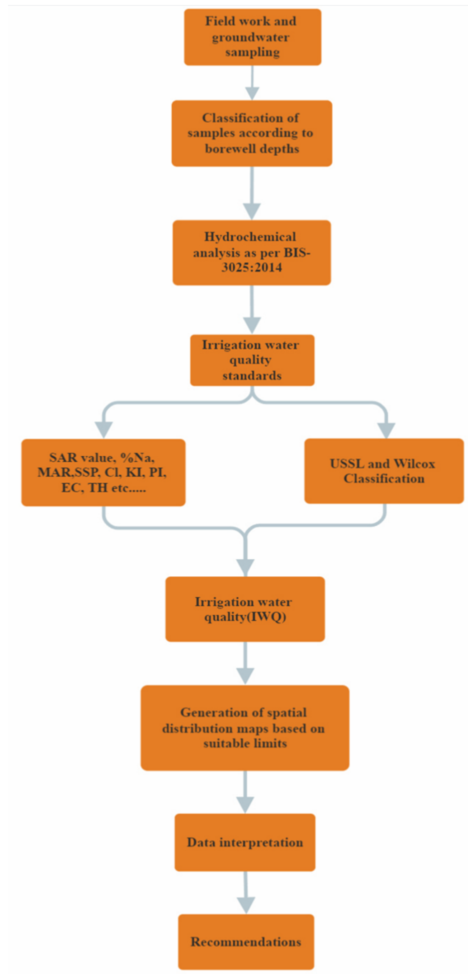


Fig 4. Spatial distribution of SAR in Molakalmur Taluk

3.4 Kelley's Ratio/ Kelley's Index

Calcium serves an important part in plant mineral nutrition. Ca^{2+} ions are frequently replaced by Na^{+} ions and is based on the ratio of Na^{+} to Ca^{2+} and Mg^{2+} as shown in Equation 6 [11]. Water with a Kelley's index of less than one is appropriate for irrigation, whereas water with a Kelley's index of greater than one indicates that the water contains far too much sodium [14]. The value of Kelley's ratio in Table 1 varies from 0.06 to 1.21 and in Table 2 It is observed that 97.83% of water samples are suitable for irrigation and 2.17% is unsuitable for irrigation according to Kelley ratio, showing a good balance of sodium, calcium and magnesium ions.

$$KR = \frac{Na^{+}}{(Ca^{+2} + Mg^{+2})} \quad (6)$$

3.5 Permeability index (PI)

Long-term usage of groundwater for irrigation purpose affects soil permeability, depending on the soil type and quality of irrigation water used [15]. This index is calculated using Equation 7 based on Na^{+}, Ca^{+2}, Mg^{+2} and HCO_3^{-2} content of water. Doneen proposed a permeability index that considers dissolved solids to quantify soil susceptibility to permeability loss in connection to water quality. The Permeability index (PI) values in Table 1 suggests that the values vary from 10.90 to 58.11 and Table 2 indicates about 26.09% of water is excellent, 64.13% is good, 9.78% is injurious and there is no such water which falls in a category of unsatisfactory. The spatial distribution of %PI is shown in Figure 6.

$$PI = \frac{\left(Na^{+} + \sqrt{HCO_3^{-}}\right)\ x\ 100}{Ca^{+2} + Mg^{+2} + Na^{+}}$$

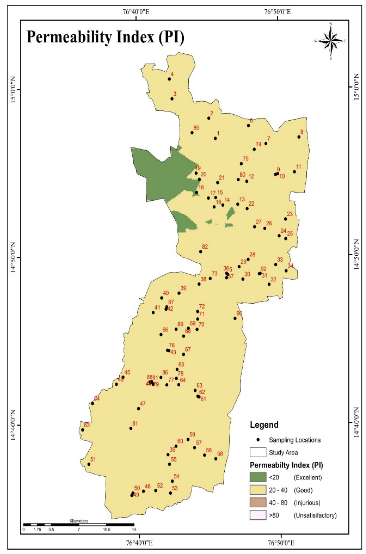
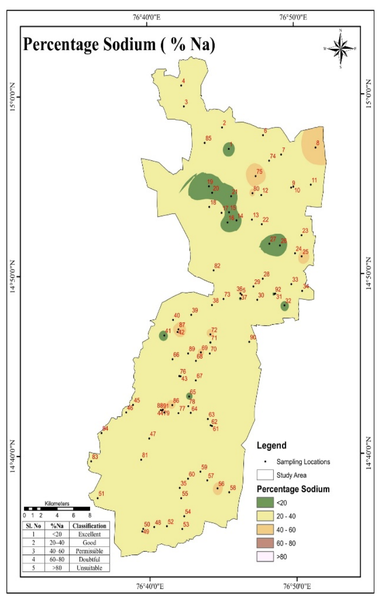


Fig 5. Spatial distribution of %Na in Molakalmur Taluk



Sl. No	%Na	Classification
1	<20	Excellent
2	20–40	Good
3	40–60	Permissible
4	60–80	Doubtful
5	>80	Unsuitable

Fig 6. Spatial distribution of PI in Molakalmur Taluk

3.6 Electrical conductivity

Electrical conductivity, which represents TDS in groundwater, is a strong indicator of salinity hazard to crops. The plant's inability to compete for water with ions in the soil solution is the main effect of high EC water on crop yield[16]. Plants will have less water available when EC is high, the values of EC vary from 674 μS/cm to 5114 μS/cm as shown in Table 1. The groundwater quality based on EC is shown in Table 2, it represents that various limit of EC in which 2.17% samples falls in good condition, 65.22% samples fall in permissible condition, 17.39% samples fall in doubtful condition and 15.22% samples falls under unsuitable condition. The spatial distribution of EC in several ground water samples is depicted in Figure 7. The values are expressed in μS/cm.

3.7 Total salt concentration

The suitability of irrigation water is determined by numerous factors, such as water quality, soil type, plant characteristics, irrigation method, drainage, climate and local condition[17]. The consistency of irrigation water should be assessed in terms of the degree of harm it causes to soil properties as well as crop yield, when soluble salts are present in various concentrations. BIS 11624-1986 is adopted to evaluate the quality of irrigation water, as per Table 2, 48.91% samples fall in low salt concentration region, 35.87% of water fall in medium salt concentration region, 15.22% of water present in high salt concentration region and there are no samples that are in very high salt concentration. Spatial distribution of EC in Molakalmur Taluk as per BIS 11624 is shown in Figure 8.

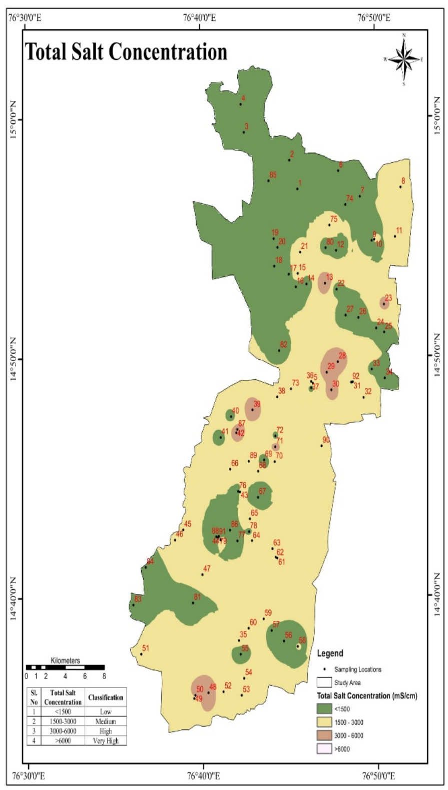


Fig 7. Spatial distribution of EC in Molakalmur Taluk

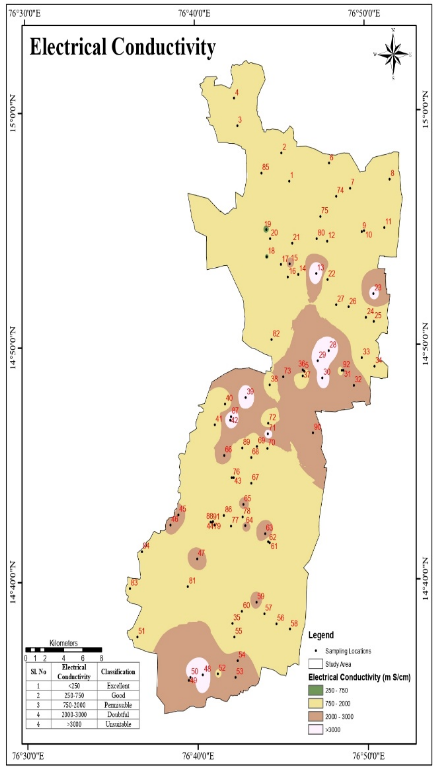


Fig 8. Spatial distribution of of groundwater quality based ontotal salt concentration as per BIS 11624-1986

3.8 Total Hardness

The amount of calcium and magnesium in the water is measured by hardness. Depending on the hardness of the water and the type of plants, calcium and magnesium are required for plant growth. During the pre-monsoon season, the Total Hardness (TH) ranges from 136 to 864 mg/l, with an average of 405.21 mg/l in Molakalmur Taluk. The overall permitted limit of TH for drinking, according to WHO guidelines, is 600 mg/l, with 300 mg/l being the most desirable limit. As a result, the groundwater in the study area was classified based on hardness, as described by Sawyer and McCarthy in 1967, and the results are presented in Table 2. The majority of the samples in the study area fell into the hard to very hard water category, according to the TH classification of groundwater. During the pre-monsoon ground water quality analysis in Molakalmur Taluk, 3 samples were classified as moderately hard, 32 samples are hard and 57 samples were classified as very hard. This indicates the study area is having very hard water during pre-monsoon. Hardness levels exceeding a specific threshold might affect the water supply system and plants can display signs of distress, such as pale or yellow leaves. Spatial distribution of Total Hardness in Molakalmur Taluk as per Sawyer and McCarthy is shown in Figure 9.

3.9 Chloride in irrigation water

Chloride is neither absorbed or held back by soils, according to reports, rather it travels freely with the soil–water into the crop. As a result, too much chloride in the soil can cause necrosis in plants, which is commonly followed by early leaf drop or defoliation [18].

The ranges of chloride vary from 0.42 to 10.92 mEq/L in Molakalmur Taluk as shown in Table 1 and classification of chloride is shown in Table 2, in which, 45 samples are safe for all plants, 23 samples show some injury in sensitive plants, 22 samples are moderately safe and remaining 2 samples can cause severe problems. Spatial distribution Chloride in irrigation water of Molakalmur Taluk is shown in Figure 10.

3.9.1 Stuyfzand (1989 classification of chloride

Water was categorized by Stuyfzand 1989 based on the concentration of Cl ions. The measurements are in mEq/L. According to this classification, the area's groundwater is 9.78% very fresh, 66.12% fresh, 18.57% Fresh brackish and 5.53% Brackish.

3.10 Soluble sodium percentage (SSP)

The value of SSP varies from 6.47 to 57.31 as shown in Table 1 and Soluble sodium percentage (SSP) represented in Table 2 shows that 5.5% of water is unsuitable for irrigation and 94.5% is good for irrigation. The SSP is calculated using Equation 8.

$$SSP\% = \frac{Na^{+} x\, 100}{Ca^{+2}+Mg^{+2}+Na^{+}} \quad (8)$$

Groundwater quality based on SAR (BIS: 11624– 1986)

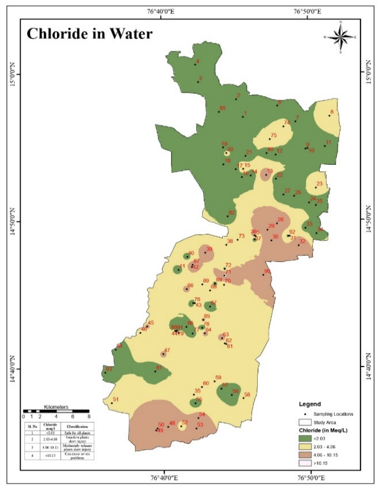


Fig 9. Spatial distribution of Total Hardness in Molakalmur Taluk

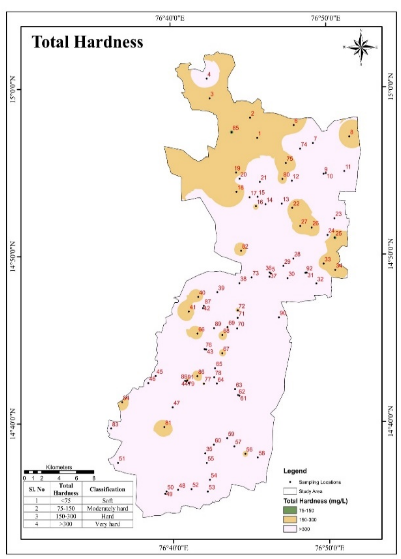


Fig 10. Spatial distribution Chloride in irrigation water of Molakalmur Taluk

Table 2. Groundwater quality based on SAR (BIS: 11624 – 1986)

Water Quality Index	Range	Water class	No. of samples	Percentage of samples
SAR Value	<10	Excellent	54	58.70
	10-18	Good	34	36.96
	18-26	Doubtful	3	3.26
	>26	Unsuitable	1	1.09
Percentage of Na (Na%)	<20	Excellent	15	16.30
	20–40	Good	66	71.74
	40–60	Permissible	11	11.96
	60–80	Doubtful	0	0
	>80	Unsuitable	0	0
Magnesium Ratio MAR (%)	<50	Suitable	83	90.22
	>50	Unsuitable.	9	9.78
Kelley's Ratio (KR)	<1	Good	90	97.83
	>1	Bad	2	2.17
Permeability Index (PI)	<20	Excellent	24	26.09
	20-40	Good	59	64.13
	40-80	Injurious	9	9.78
	>80	Unsatisfactory	0	0
Electrical Conductivity (EC)	<250	Excellent	0	0.00
	250-750	Good	2	2.17
	750-2000	Permissible	60	65.22
	2000-3000	Doubtful	16	17.39
	>3000	Unsuitable	14	15.22
Electrical Conductivity (BIS- 11624)	<1500	Low	45	48.91
	1500-3000	Medium	33	35.87
	3000-6000	High	14	15.22
	>6000	Very high	0	0.00
Total Hardness	<75	Soft	0	0.00
	75-150	Moderately hard	3	3.26
	150-300	Hard	32	34.78
	>300	Very hard	57	61.96
Chloride concentration (Mass 1990)	<2.03	Safe for all plants	45	48.91
	2.03-4.06	Sensitive plants show injury	23	25.00
	4.06-10.15	Moderately tolerant plants show injury	22	23.91
	>10.15	Can cause severe problems	2	2.17

3.11 Wilcox's Classification

Wilcox 1955 created a graphical relationship between sodium percentage and total dissolved salt to highlight the quality of water for irrigation purposes and the graph is subdivided into five zones to determine water that is suitable for irrigation. Figure 11 displays Wilcox's diagram with the collected water samples plotted on it. Table 3 summarizes the suitability of water for irrigation purposes. According to the plot around 1 sample is present in excellent to good condition and 67.39% samples are in good to permissible condition, 2.17% samples are in permissible to doubtful condition, 15.21% samples are in doubtful to unsuitable condition, 14.13% of sample are in unsuitable condition.

Table 3. Wilcox classification of groundwater

S.No	Classification	No. of samples	Percentage of samples
1	Excellent to good	1	1.08
2	Good to permissible	62	67.39
3	Permissible to doubtful	02	2.17
4	Doubtful to unsuitable	14	15.21
5	Unsuitable	13	14.13

3.12 The US Salinity Laboratory Staff Classification

The effects of sodium on soil and plants make it one of the governing ions. The lowering of soil permeability and the hardness of the soil are the two primary effects of sodium. Both effects result from the soil's sodium ions replacing calcium and magnesium ions. The relationship between SAR and EC is represented in the graph prepared by the US Salinity Laboratory staff. The classes C1 to C4 represent a steady increase in hazard from total concentration of salt, whereas the classes from S1 to S4 represent a major increase in hazard from exchangeable sodium. The various water types have really been categorized into sixteen categories, each with its own set of characteristics and a certain level of irrigation suitability based on the combined hazard of Na/(Ca + Mg) and TDS indicated as EC. These 16 categories were indicated in Figure 12 and these are then divided into three main groups (I, II and III). C1–S1 and C2– S1 belong to Group I, which is suitable for irrigation. C1–S2, C2–S2, C3–S1, and C3–S2 belong to Group II, which is conditionally suitable and C1–S3, C1–S4, C2–S3, C2–S4, C3–S3, C3–S4, C4–S1, C4–S2, C4–S3, and C4–S4 are in Group III that are unsuitable for irrigation(19,20). According to Tables 4 and 5 and Figure 12, the samples are distributed widely in C2–S1, C3–S1, C3–S2, C3–S3, C3–S4, C4–S2, C4–S3 and C4–S4 classes by covering eight of the sixteen classes. The highest number of salinity and sodium hazard samples are found in the C3 category, with EC between 750 and 2250 μS/cm, and almost 65% samples are conditionally suitable and 30% samples are unsuitable for irrigation since they were distributed in group III.

Table 4. Salinity hazard class as per USSL

S.No	EC Class	Water quality	Range (μS/cm)	No. of samples	Percentage of samples
1	C1	Low salinity	100-250	0	0
2	C2	Medium salinity	250-750	2	2.17
3	C3	High salinity	750-2250	68	73.92
4	C4	Very high salinity	>2250	22	23.91

Table 5. Sodium Hazard class based on USSL

S.No	SAR Class	SAR Value	Quality	No. of samples	Percentage of samples
1	S1	<10	Excellent	54	58.70
2	S2	10-18	Good	34	36.96
3	S3	18-26	Doubtful	3	3.26
4	S4	>26	Unsuitable	1	1.09

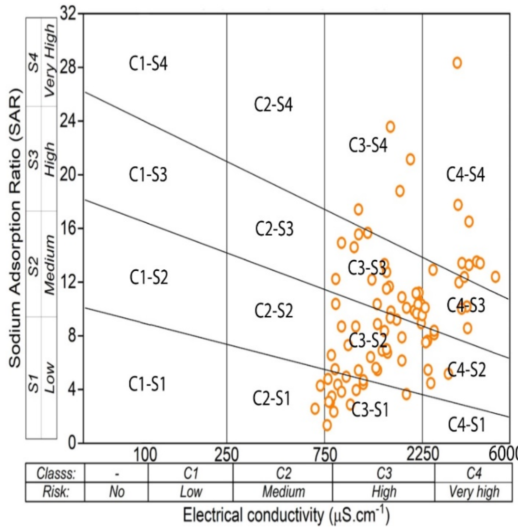


Fig 11. Plot between Na% against EC for study area (Wilcox classification)

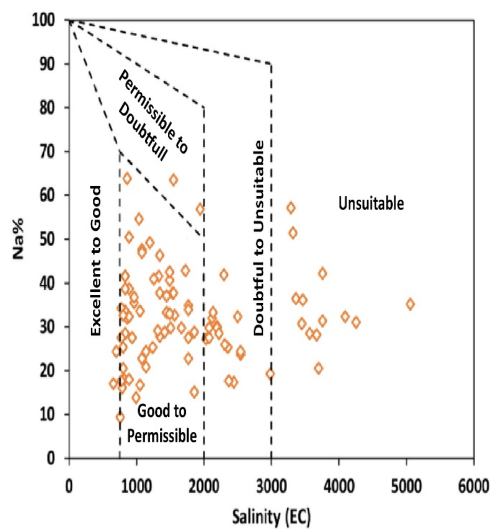


Fig 12. Plot between SAR and EC for study area (USSL classification)

4 Conclusion

The present study evaluated the suitability of groundwater for irrigation/agricultural purpose in Molakalmur Taluk. According to evaluated water quality indices like SAR, MAR, PI and total salt concentration around 5 to 15 percent water samples are not good for agricultural purpose. As per the integrated parameters like USSL and Wilcox the percentage samples that are unsuitable for irrigation is going up to 30 percentage due to presence of higher Electrical conductivity.

To ensure that water is suitable for agriculture, a continual monitoring programme of water quality is essential. Most of the borewells are privately owned by the farmers. Appropriate groundwater recharge methods, limited groundwater usage, measures to avoid groundwater pollution, and awareness of the importance of water quality have to be suggested for all users.

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