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Analysis of the Suitability of Irrigation Water Quality in the Data Makmur Secondary Canal for Agricultural Crops Based on the SAR and RSC Method Classification

Rifa Amanda Raihan*, **Syahrul**, **Purwana Satriyo**

Universitas Syiah Kuala

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ABSTRACT

This study aims to analyze the suitability of irrigation water quality in the Data Makmur Secondary Canal for agricultural crops based on the SAR and RSC method classifications. This study uses a quantitative approach supported by laboratory analysis. Water sampling was carried out with reference to the Indonesian National Standard (SNI) 06-2412-1991 concerning Water Quality Sampling Methods. Irrigation water samples were taken at the observation points of the Data Makmur Secondary Canal, with each sample volume ranging from 200–500 mL. The water samples were then analyzed at the Banda Aceh Industrial Standardization and Services Center and the Environmental Quality Testing Engineering Laboratory of the Chemical Engineering Study Program, Faculty of Engineering, Syiah Kuala University. The results of the irrigation water quality analysis in the Data Makmur Secondary Canal showed that the Sodium Adsorption Ratio (SAR) value for all samples was in the range of 0.3547–0.4471. This value is included in the very good category according to Todd standards (<10 meq/L), thus indicating that the irrigation water does not have the potential to cause sodicity problems and is still safe to use for agricultural activities. However, the Residual Sodium Carbonate (RSC) value showed a relatively high range, namely 1.927–3.629 meq/L. Based on Eaton's classification (>2.50 mEq/L), most samples are classified as unsuitable for irrigation, except for several points in Sample 2. This condition indicates the potential risk of soil structure degradation must be more closely aligned with the material being extracted and decreased soil permeability if water is used continuously. Therefore, regular water quality monitoring and further studies are needed with additional parameters and sampling points to achieve a more comprehensive representation of irrigation water quality.

1. INTRODUCTION

The agricultural sector is a key pillar in supporting food security, particularly in regions with potentially productive land and supporting infrastructure, such as irrigation areas. Aceh Province, with its favorable geographic characteristics and abundant natural resource potential, offers significant opportunities to increase agricultural production, particularly rice, a strategic national food commodity. The Krueng Aceh Irrigation Area *(Daerah Irigasi, D.I.)* is one of the largest and most important irrigation systems in Aceh Province, encompassing productive agricultural areas in Aceh Besar Regency and Banda Aceh City (Wulandari & Basri, 2021) (Ramli et al, 2022) (Wijaya et al, 2025). The Krueng Aceh Irrigation Area serves as the backbone of wetland farming systems, particularly lowland rice cultivation, which relies heavily on a stable and sustainable supply of irrigation water.

Irrigation water plays a vital role in supporting plant growth and productivity, particularly in intensively cultivated rice fields (Nugroho et al, 2018; Tirtalistyani et al,

*Correspondence author.
E-mail: rifaamandaraihan003@gmail.com (Rifa Amanada Raihan)
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2022) (Rejekiningrum et al, 2022) (Arif et al, 2024). However, poor water quality has the potential to reduce soil fertility and significantly inhibit plant growth in the long term (Okorogbona et al, 2018) (Dotaniya et al, 2023) (Haokip et al, 2025). Certain chemical compounds in water, such as sodium, chloride, and carbonate, can degrade the physical and chemical properties of the soil, impacting the efficiency of nutrient uptake by plants (Ayers & Westcot, 1985). Therefore, the success of an irrigation system is not only assessed from the quantitative availability of water, but also from the chemical quality of the water (Zaman et al, 2018) (Bortolini et al, 2018).

Providing water for irrigation without quality standards will not only produce unsatisfactory agricultural yields but also damage agricultural land (Uyttendaele et al, 2015). The suitability of water for irrigation depends heavily on the salt content of the water (Chhabra, 2021a). Good quality water is not excessively polluted by chemicals or minerals (Madhav et al, 2020). The potential for water quality degradation in irrigation canals is becoming increasingly apparent due to increasing environmental pressures (Malakar et al, 2019). Major sources of pollution include domestic wastewater, surface runoff from excessive fertilizer and pesticide use, and excess nutrients that cause eutrophication, the excessive growth of algae that damages other ecosystems in the water, reducing oxygen levels (FAO, 2019).

Furthermore, numerous agricultural activities around rice fields utilize irrigation canals, which can lead to water pollution (Wang et al, 2019). If uncontrolled, this can lead to dangerous long-term contamination and reduce the economic value and productivity of agricultural land. Furthermore, fish farming activities in irrigation canals also have the potential to alter the chemical characteristics of the water (Thaib et al, 2025). One of the main threats to soil and plants resulting from poor irrigation water quality is high levels of sodium (Na^+). High sodium concentrations can cause the soil to become hard and compacted due to the breakdown of the soil aggregate structure. Consequently, water infiltration is drastically reduced, making the soil more prone to waterlogging and making it difficult to absorb water (Manik et al, 2019; Kaur et al, 2020; Zhang et al, 2025). Furthermore, high concentrations of sodium can cause direct toxicity to sensitive plants and inhibit the absorption of essential nutrients such as calcium and magnesium.

To assess the suitability of irrigation water for agricultural land, chemical parameters such as the Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are widely used as primary indicators. SAR reflects the potential for sodium to replace calcium and magnesium in the soil, directly affecting soil structure and water absorption. Meanwhile, RSC measures the potential for carbonate and bicarbonate formation in water, which can reduce the availability of calcium and magnesium in the soil (Murtaza et al, 2021). Carbonate and bicarbonate are not directly included in the SAR formula, but they affect the availability of calcium and magnesium in the SAR formula. Measuring these two parameters is crucial to ensure that water used for irrigation does not harm the soil in the long term.

One of the main canals in the Krueng Aceh River network is the Data Makmur secondary canal, which irrigates thousands of hectares of rice fields in Aceh Besar. Despite its vital role in supporting local rice productivity, there is currently no recent data or in-depth study available on the water quality conditions in this canal, particularly regarding SAR and RSC parameters. The absence of this data is a major urgency for conducting scientific and measurable research on irrigation water quality, to ensure the sustainability of agricultural production and environmental conservation.

2. METHODS

This study uses a quantitative approach supported by laboratory analysis. Water sampling was carried out with reference to the Indonesian National Standard (SNI) 06-2412-1991 concerning Water Quality Sampling Methods. Irrigation water samples were taken at the observation point of the Data Makmur Secondary Canal, with each sample volume ranging from 200–500 mL. Sampling was carried out under two conditions, namely irrigation water before entering the rice fields and water leaving the rice fields in the Krueng Aceh Irrigation Area (DI), to obtain a comprehensive picture of water quality. Then the water samples were analyzed at the Banda Aceh Industrial Standardization and Services Center and the Environmental Quality Testing Technique Laboratory of the Chemical Engineering Study Program, Faculty of Engineering, Syiah Kuala University to obtain data according to the parameters set in this study. These water samples were taken horizontally and the samples were composited for analysis in the laboratory. After the laboratory analysis results are obtained, the next stage is to carry out analytical calculations to convert the laboratory test result units from milligrams per liter (mg/L) to milliequivalents per liter (meq/L), according to the SAR and RSC methods, using the formulations in Equations (4) and (5).

The sampling process involved two separate sampling sessions, one after three days of no rain, to prevent the irrigation water from mixing with rainwater. Furthermore, if the samples were taken on a rainy day, the irrigation water could become contaminated with dissolved soil particles. Rainwater can dilute the concentration of ions such as calcium, sodium, and magnesium in the irrigation water. This can cause the test results to not reflect the true condition of the irrigation water.

Water Quality Analysis Using the SAR Method

Samples taken from locations or fields where the units from laboratory test results are still in milligrams/liter, these units must be converted into units in the SAR method to milliequivalent/liter, namely with Equation (4):

$$\text{Meq} = \frac{mg \times Valence}{atomic\ or\ molecular\ weight} \qquad (4)$$

With the equation in Table 1 (Richards, 1954).

Table 1.
Atomic weight and valence

No	Element	Atomic Weight	Valence
1	Sodium	23	1
2	Potassium	39	1
3	Calcium	40	2
4	Phosphorus	31	3.5
5	Magnesium	24	2

Source: (Richards, 1954)

Based on the test results obtained from the laboratory analysis test, then calculations were carried out using the SAR (Sodium Adsorption Ratio) method based on Equation (2) on the results of the laboratory test. Then, after the calculation has been obtained, it can be entered into the classification by Todd (1980). So that with the results of all these calculations, it can be known whether the groundwater is suitable or not for use in agricultural production.

Water Quality Testing Using the RSC Method

Samples taken from locations or fields where the laboratory test results are still in milligrams/liter must be converted to the RSC method's units of milliequivalents/liter, as shown in Equation (5):

$$Meq=\frac{mg \times Valensi}{BM\ ion/z} \quad ()$$

Description:

Ion MW = Molecular weight of ion (g/mol)

z = Valence of ion

mg/L = milligrams/liter

With the equation in Table 2 (Plaster, 1985).

Table 2.
Conversion factor/ ion

No	Element	Atomic Weight	Valence
1	Sodium	23	1
2	Calcium	40	2
3	Magnesium	24	2
4	Carbonate	60	2
5	Bicarbonate	61	1
6	Potassium	39	1
7	Phosphorus	31	3

Source: (Plaster, 1985)

Based on the test results obtained from the laboratory analysis test, then calculations were carried out using the RSC (Residual Sodium Carbonate) method based on the equation in the laboratory test results. After the calculation process is carried out and the RSC value is obtained, the value can be compared and entered into the classification of irrigation water quality levels based on the standards set by Amoo in 2024 (Amoo et al, 2024). Thus, the results of this entire calculation process will provide clear information regarding whether the groundwater from the location meets the eligibility requirements and is safe for use in agricultural production activities, especially in terms of sustainable and productive agricultural land irrigation.

3. RESULT AND DISCUSSION

Krueng Aceh Irrigation Area (D.I.)

The Krueng Aceh Irrigation Area in Aceh Province lies within the Krueng Aceh River Basin, spanning Aceh Besar Regency and Banda Aceh City. The 145 km river drains a watershed of about 1,400 km² covering ten districts. One of its secondary networks, the Data Makmur Secondary Canal in Montasik District, was selected for irrigation water sampling. Samples were taken from four points: the secondary main canal, right irrigation canal, left irrigation canal, and drainage canal. This canal serves 228.34 ha of farmland, with a width of 0.50 m, discharge of 0.357 m³/s, and water depth of 0.51 m, supporting agriculture. (S. Wijaya et al, 2023).

Figure 1. Data Makmur secondary channel gate

The administrative location of the study is Data Makmur Village, Montasik District, Aceh Besar Regency, Aceh Province. Water sampling was carried out at four observation points at different sampling times, with the aim of obtaining a comprehensive picture of water quality along the irrigation canal. The first observation point is located at the secondary irrigation canal gate of Data Makmur, which functions as the main route for water distribution to agricultural land. The second observation point is located at the Right Data Makmur irrigation canal, while the third observation point is located at the Left Data Makmur irrigation canal. The fourth observation point is determined at the final irrigation discharge channel, namely the location of water output after being used for agricultural activities. The determination of these four observation points is intended to determine changes in water characteristics and quality from the distribution source to the discharge channel.

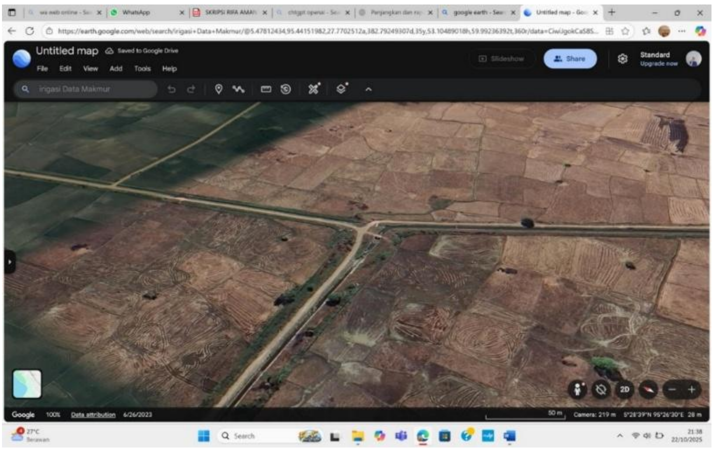

Figure 2. Location of water intake at the Data Makmur irrigation gate on the Secondary Channel with coordinates 5°28'41"N 95°26'29"E.

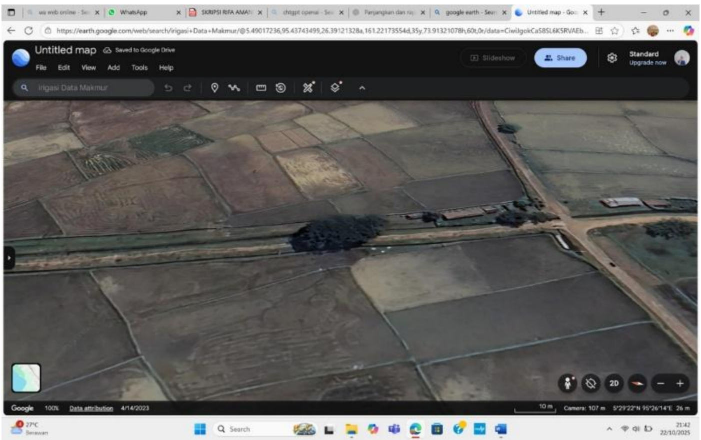

Figure 3. Location of water intake for Data Makmur irrigation on the Right Channel with coordinates 5°29'26"N 95°26'13"E.

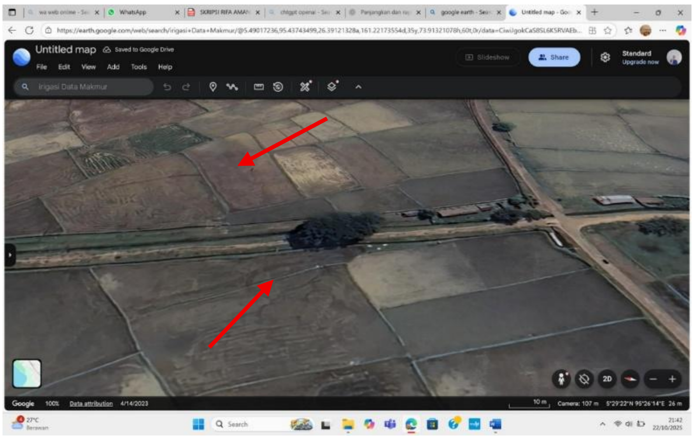

Figure 4. Location of water intake for Data Makmur irrigation in the Left Channel with coordinates 5°29'26"N 95°26'13"E.

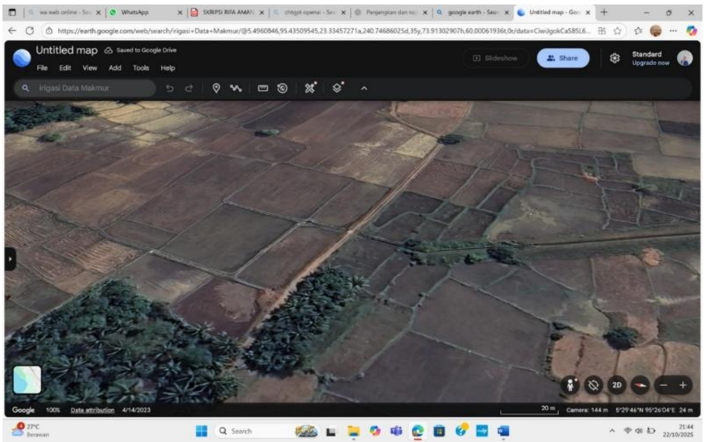

Figure 5. Location of water intake in the drainage channel (drainer) with coordinates 5°29'46"N 95°26'06"E.

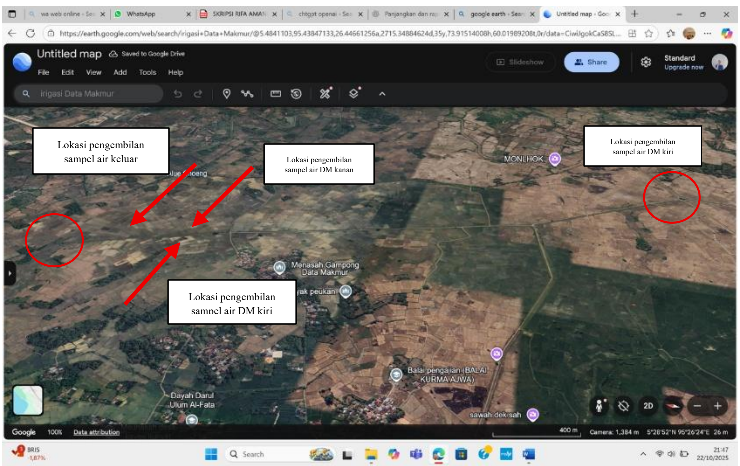

Figure 6. Water sampling points are in the secondary, right, left, and drainage channels.

The distance between the inlet and outlet water sampling points is a measure of the length or difference in space separating the two locations. It can be measured using specific units such as meters or kilometers, depending on the needs and the measurement method used. The distance between the inlet and outlet water sampling points is approximately 2.13 km.

SAR Value Parameter Calculation Results

Based on the analysis of the Sodium Adsorption Ratio (SAR) values in Table 3, all water samples tested showed very low SAR values, ranging from 0.3547 to 0.4471 meq/L. These values are categorized as "Very Good," indicating that the sodium ion content in the water is relatively small compared to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. This condition indicates that the water has a very low risk of causing soil structure degradation when used for irrigation, and does not cause potential sodication in the soil.

Table 3.

Results of the SAR (Sodium Adsorption Ratio) method analysis

No	Sample Code	SAR value (meq/L)	Water Class
1	Sample 1: Water inlet	0.4471	Very Good
2	Sample 1: Water outlet	0.4086	Very Good
3	Sample 1: Water right DM (demineralization)	0.4048	Very Good
4	Sample 1: Water left DM	0.3868	Very Good
5	Sample 2: Water inlet	0.4031	Very Good
6	Sample 2: Water outlet	0.3547	Very Good
7	Sample 2: Water right DM	0.4147	Very Good
8	Sample 2: Water left DM	0.3895	Very Good

Source: Research Data (2025)

The highest SAR value was recorded in Sample 1 inlet water at 0.4471 meq/L, indicating slightly higher sodium content before treatment, though still within safe limits. After treatment, the SAR decreased to 0.4086 meq/L, showing effective sodium reduction. Similar very good results were observed in right DM water (0.4048 meq/L) and left DM water (0.3868 meq/L).

Sample 2 showed a comparable trend, with SAR decreasing from 0.4031 meq/L at the inlet to 0.3547 meq/L at the outlet. Right DM water (0.4147 meq/L) and left DM water (0.3895 meq/L) also maintained stable ion balance.

Overall, all samples had SAR <10, indicating excellent water quality, safe for agricultural and industrial use, with balanced calcium and magnesium levels preventing sodicity risks.

Figure 7. SAR method test graph

Residual Sodium Carbonate (RSC) Value

Based on RSC calculations, several samples were unsuitable for irrigation due to high carbonate and bicarbonate levels. Sample 1 inlet (3.057 meq/L), outlet (2.788 meq/L), right DM (2.905 meq/L), and left DM (3.629 meq/L) exceeded 2.5 meq/L, indicating potential soil alkalinity risks that may reduce nutrient availability and water infiltration.

Sample 2 inlet (2.592 meq/L) was also unsuitable. However, Sample 2 outlet (2.142 meq/L), right DM (1.927 meq/L), and left DM (2.083 meq/L) fell into the doubtful category (1.25–2.5 meq/L). These waters can still be used for irrigation with proper soil management, such as gypsum application, to mitigate alkalinity effects.

Table 4.

Results of the RSC (Residual Sodium Carbonate) method analysis

No	Sample Code	RSC Value (meq/L)	Water Class
1	Sample 1: Water inlet	3.057	Not suitable
2	Sample 1: Water outlet	2.788	Not suitable
3	Sample 1: Water right DM	2.905	Not suitable
4	Sample 1: Water left DM	3.629	Not suitable
5	Sample 2: Water inlet	2.592	Not suitable
6	Sample 2: Water outlet	2142	Doubtful
7	Sample 2: Water right DM	1.927	Doubtful
8	Sample 2: Water left DM	2.083	Not suitable

Source: Research Data (2025)

Overall, these results indicate that the water in Sample 1 (both at the inlet, outlet, and left and right sides of the DM) has a low level of suitability for irrigation due to the dominance of high carbonate and bicarbonate contents. In contrast, the water in Sample 2 showed slightly better conditions, although still within the questionable limits for sustainable use. This indicates differences in water chemistry that may be influenced by agricultural activities, soil conditions, and land management processes at the sampling location.

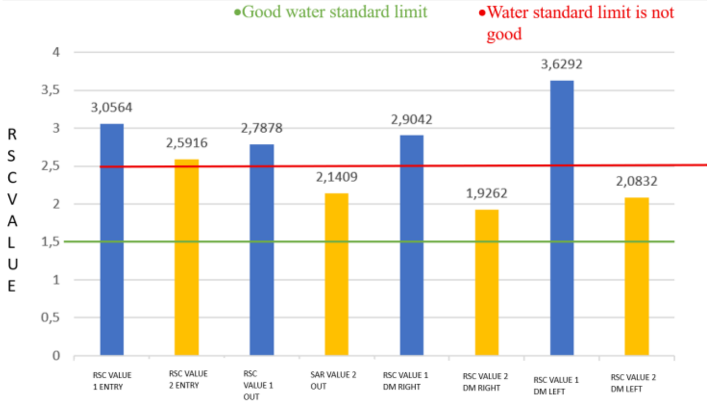

Figure 7. RSC method test graph

Sodium Adsorption Ratio (SAR)

The Sodium Adsorption Ratio (SAR) is a key indicator used to assess sodicity in irrigation water and soil. SAR represents the concentration of sodium (Na^+) relative to calcium (Ca^{2+}) and magnesium (Mg^{2+}), and is used to evaluate potential infiltration problems caused by sodium imbalance (Minhas & Qadir, 2024). High SAR values can degrade soil structure, while low values indicate sufficient calcium and magnesium to maintain stability.

Proper irrigation management must consider SAR alongside pH and EC to prevent soil degradation. Excess sodium can lead to sodicity, causing clay swelling, pore blockage, surface hardening, and reduced infiltration (Öztürk et al, 2023). This condition limits water movement and restricts root access to water despite surface availability.

SAR is widely used to assess irrigation water suitability, as high values indicate sodium dominance that may displace calcium and magnesium in soil, damaging its structure ((Kgopa et al, 2018)) ((Rengasamy, 2018)). Therefore, chemical analysis of Na^+, Ca^{2+}, and Mg^{2+} was conducted to calculate SAR using Equation (2), with results classified based on irrigation suitability standards (Todd, 1980), alongside EC and pH analysis.

Residual Sodium Carbonate (RSC)

RSC is defined as the excess of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions compared to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in irrigation water. It measures the potential of water to raise soil pH and cause precipitation of calcium or magnesium carbonates, which can make the soil hard and less productive. The primary purpose of RSC is to determine whether irrigation water is safe for long-term use without causing soil degradation (Singh et al, 2022), to help farmers or soil scientists design irrigation strategies, such as adding gypsum ($CaSO_4$) to neutralize alkalinity, and to complement SAR (Chhabra, 2021b), as SAR does not consider carbonate and bicarbonate, which are important in alkaline water.

This method was first introduced by Richards (1954) in the context of diagnosing saline and alkaline soils and has become a standard in guidelines from the U.S. Department of Agriculture (USDA) and international organizations such as the Food and Agriculture Organization (FAO). RSC is based on a chemical reaction in which carbonate and bicarbonate ions can react with Ca^{2+} and Mg^{2+} to form insoluble compounds such as $CaCO_3$ or $MgCO_3$. If the concentration of CO_3^{2-} and HCO_3^- is higher than Ca^{2+} and Mg^{2+}, then sodium (Na^+) will remain dissolved and can be adsorbed by soil particles, increasing sodicity. The main factors that affect RSC include high ion concentrations of CO_3^{2-} and HCO_3^- from water sources such as rivers or wells, and the pH of the water. Water with a pH >8.4 tends to have more CO_3^{2-}, as well as temperature and salinity, with high temperatures can increase precipitation, while high salinity (TDS >2000 mg/L) can affect ion balance (Joyce & Coulson, 2020).

RSC differs from SAR in that it only looks at the ratio of Na^+ to Ca^{2+} and Mg^{2+}, without considering carbonate. If SAR is high but RSC is low, the risk of alkalinity is likely low. Conversely, a high RSC indicates a specific alkalinity problem. Limitations and considerations of the RSC method are that RSC does not directly consider other ions, such as Na^+ or K^+, making it less accurate for water with high salinity. This method is better for alkaline water) (for saline water, use SAR or EC. Lab measurement errors can affect results) (use standard methods such as titration for CO_3^{2-} and HCO_3^-. In practice, RSC should be validated by field testing, as local soil conditions vary (Prohaska et al, 2022).

4. CONCLUSION

First, the Sodium Adsorption Ratio (SAR) values in Sample 1 ranged from 0.4471 at the inlet to 0.3868 at the left DM, while in Sample 2 they ranged from 0.4147 at the right DM to 0.3547 at the outlet. All SAR values were significantly below 10 meq/L, indicating low sodium hazard and classifying the water as very good according to Todd's standards. This shows that the irrigation water does not contain harmful salt levels and remains safe for agricultural use. Second, the Residual Sodium Carbonate (RSC) values in Sample 1 ranged from 2.788 to 3.629 meq/L, while in Sample 2 they ranged from 1.927 to 2.592 meq/L. Most samples exceeded 2.50 meq/L, placing them in the unsuitable category based on Eaton's classification, except Sample 2 outlet and DM waters which fell into the doubtful range. High RSC levels may increase soil alkalinity, reduce permeability, and hinder plant growth. Therefore, regular water quality monitoring is recommended, along with further studies including additional parameters and broader sampling to ensure irrigation suitability.

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