International Journal of Environmental Studies and Researches (2023), 2 (2):67-75

Application of Water Quality Indices Measurements to Study the Suitability of Drain Water Quality for Irrigation in Egypt

Reda Abd El Hamed[1], Ezat Ahmed[1], Ibrahim El-Sayed[2], Salah El Sayed[1] and Mohamed Gad[1]

[1]Evaluation of Natural Resources Department, Environmental Studies and Research Institute, University of Sadat City, Egypt

[2]- Environmental Biotechnology Department, Genetic Engineering and Biotechnology Research Institute, University of Sadat City, Egypt

Abstract

Irrigation water quality indices (IWQIs), geochemical facies, and controlling mechanisms were used in an integrated manner to measure the optimum use of drain water for irrigation under sustainable development conditions. During the summer of 2021, 50 samples of drain water were collected around Rosette Branch. The principal ion concentrations have been obtained in the following order, according to their physicochemical properties: HCO_3^- > Cl^- > SO_4^{2-} > CO_3^{2-} and Na^+ > Ca^{2+} > Mg^{2+} > K^+. Due to evaporation and rock-water interaction, the surface water facies reflect calcium and magnesium bicarbonate type and the calcium and magnesium sulfate type. According to IWQI results, about 4% of samples had high restrictions for irrigation use, 30% had moderate restrictions, and 18% of the samples were subject to restrictions for irrigation use. In accordance with the sodium percentage (Na %) readings, 50% of the drains were acceptable for irrigation, while the other were permissible use for irrigation. All drain water samples scored acceptable for irrigation, according to sodium absorption ratio (SAR) and residual sodium carbonate (RSC).

Keywords: Physicochemical data, Irrigation water quality indices, Sodium percentage and Sodium absorption ratio.

Introduction

Surface water is one of the most vital components of life, as well as one of the substances that make up the majority of the Earth's surface and interior. The majority of Egypt's agricultural advancements depend on irrigation water supplied by irrigation canals. According to the geochemical classification of natural waters and the analysis of chemical data, imitative approaches such as the Piper diagram (**Piper, 1944**) and the Chadha diagram (**Chadha, 1999**) are frequently used to better comprehend the hydrogeochemical characteristics of water. The geochemical regulations that establish the chemical content of water can also be specified using these techniques (**Gad et al., 2020**). The drains are a result of physical, chemical, and biological processes interacting in the aquatic environment (**Rakib et al., 2021**). Because these drain networks are the only source of irrigation in the northern part of the Nile, farmers are significantly use this water to irrigate their land. Basic information on water composition, various geological and chemical processes, and water properties for draining can be found in the chemical properties of the water in relation to geochemical standards. The irrigation water quality indices (IWQIs), which are based on the major cations (K^+, Ca^{2+}, and Mg^{2+}) and anions (Na^+, Cl^-, and SO_4^{2-}), are routinely used to assess water quality for irrigation. These indices include sodium percent (Na%), sodium absorption ratio (SAR), and residual sodium carbonate (RSC). With the help of hydrogeochemical characteristics and water quality indices, this study will evaluate the water quality and estimate the quality of draining water for irrigation.

Materials with methods

Study area

The area of the study representing the southern part of the Nile Delta is situated between $30^{O}\ 05^{/}\ 96^{//}$ and $30^{O}\ 39/\ 61''$ N latitudes $30^{O}\ 51^{/}\ 19^{//}$ and $31^{O}\ 06^{/}\ 99^{//}$ E longitudes (Fig. 1).

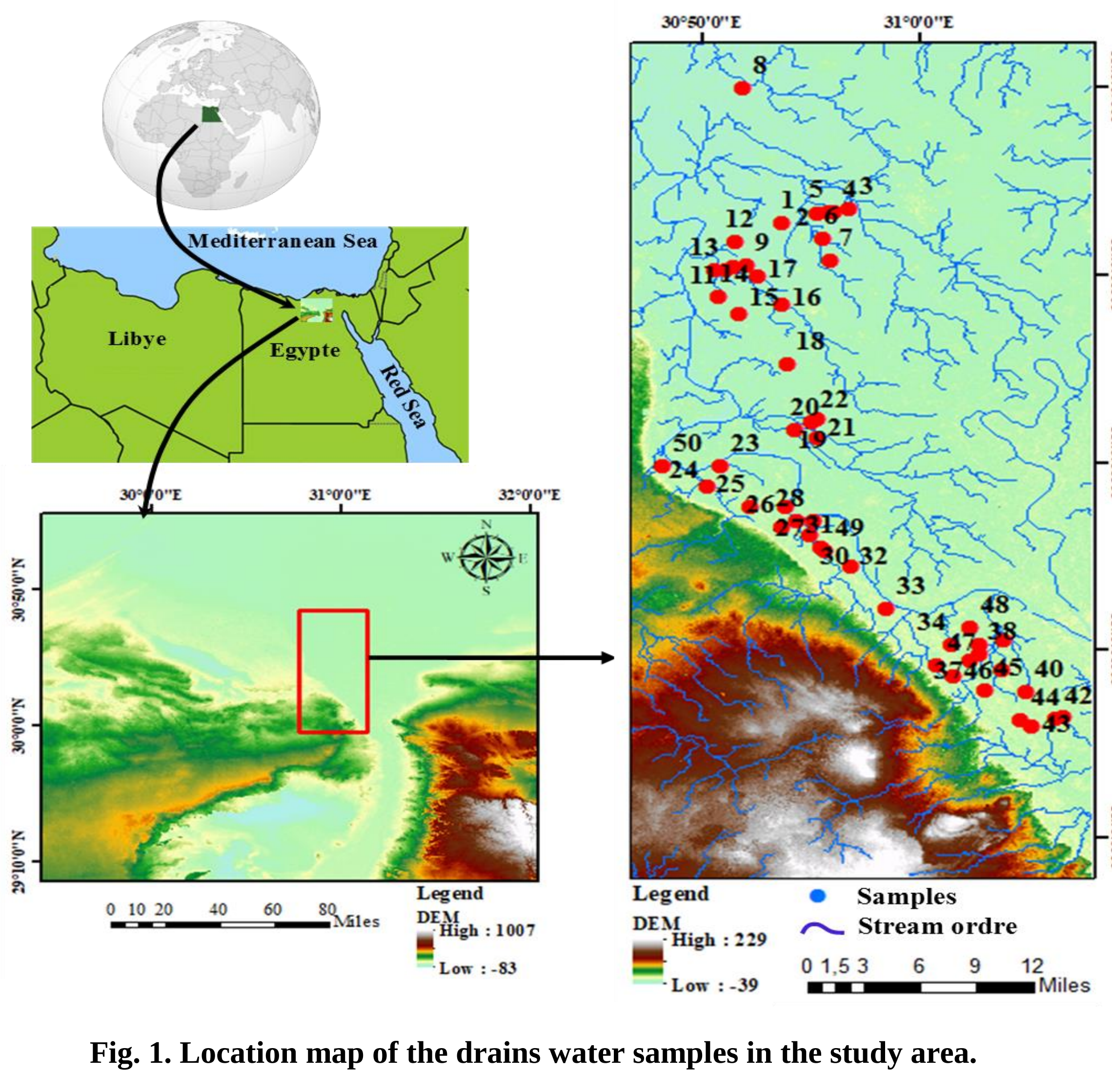

Fig. 1. Location map of the drains water samples in the study area.

Sample collection and analysis

Fifty samples of drain water were collected for this study in year 2021. The samples were kept in a 4 °C refrigerator in 1000 mg polyethylene vials. With the help of conventional analytical methods, physicochemical measurements of the samples were analyzed. To reduce the chance of contamination, the sampling bottles were rinsed twice or three times with the sample water. After calibration, several physicochemical parameters, including pH, temperature, electrical conductivity (EC), and total dissolved solids (TDS), were measured in situ using a portable calibrated salinity multi-parameter instrument (Hanna HI 9811-5, Hanna Instruments Italia Srl, 35030 Sarmeola di Rubano-PD, Italy). In wastewater samples, a number of hydrochemical elements have been evaluated including calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^{-}). The American Public Health Association (APHA) was used to analyze the samples that were obtained according to standard analytical procedures. Na^{+} and K^{+} concentrations were measured by flame spectrometry, $Ca^{2+,}$ and Mg^{2+} through EDTA titration, HCO_3^{-} and CO_3^{-2} by acid titration, Cl^{-} by AgNO3 titration, and SO_4^{2-} by $BaCl_2$ titration.

Imitative techniques

Using the Geochemist's Workbench Student Edition 12.0 software, the imitative approaches, such as the Piper diagram, Chadha diagram, Gibb's diagram, and HFE diagram, were used to determine water composition and hydrochemical properties. The analytical values of the collected water samples including anions and cations were used to study the geochemical characteristics of water and to determine water type (**Piper, 1944**). According to Piper trainer diagram, one triangle for cations and another triangle for anions, as well as a diamond-shaped area that marks a combined cation and anion position, which allows for the differentiation of various types of water. A norther diagram was used to study the chemical data and the geochemical classification of natural waters (**Chadha, 1999**). In this chart, the % difference between weakly acid anions (CO_3^{2-} + HCO_3^{2-}) and high acid anions (Cl^{-} + SO_4^{2-}) is displayed on the vertical axis in mill equivalent percentages, while the percentage difference between alkaline earth (Ca^{2+} + Mg^{2+}) and alkaline ions (Na^{+} + K^{+}) is represent on the horizontal axis. Plotting hydrochemical data on the Gibbs diagram was used to study the regulatory mechanism of drains water chemistry (**Gibbs, 1970**).

Indices of water quality

Water quality indicators, such as IWQI, Na% SAR, and RSC were used to assess drain water quality for irrigation (Table 1).

Results and Discussion

Physical and chemical parameter

Physicochemical parameters are a useful tool for determining water quality on the basics of the chemistry of water and its controlling mechanisms. Water quality ratings and indices are used in irrigation. Table 2 displays the analytical findings for the physicochemical characteristics of the drainage water (pH, TDS, Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}, Cl^{-}, SO_4^{2-} and HCO_3^{-}) in the research region. According to statistical analyses of the physicochemical characteristics, the average temperature of the drain water was around 28.192 ^{O}C, with temperatures ranging from 23.3 to 32.4 ^{O}C. The drains' water was slight alkaline, according to the pH measurements, which ranged from 6.51 to 8.71 and had a mean of 7.64. The EC readings revealed mean of 848.52 µS/cm, which ranged from 330 to 1591 µS/cm. The mean TDS value was 547.5 mg/L, which showed fresh to low brackish water. The TDS values varied from 211.2 to 1034 mg/L, which suitable for irrigation. According to Table 2, the mean ionic contents of K^{+}, Na^{+}, Mg^{2+}, Ca^{2+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, and CO_3^{2-} were 16.615262, 64.80154, 20.400446, 58.87338, 112.5832, 41.4, and 232.092 mg/L, respectively. As a result, the average ion values showed the following

Table 1. Indices of water quality and classification of drain water for irrigation.

Irrigation indices	Range	Water classification	Reference
$IWQI = \sum_{i=1}^{n} Q_i W_i$	85–100	No restriction for use	(**Brown et al. 1970**)
	70–85	Low restriction for use	
	55–70	Moderate restriction for use	
	40–55	High restriction for use	
	0–40	Serve restriction for use	
$Na\% = \frac{Na+k}{Ca+Mg+k} \times 100$	<20	Excellent	(**Todd, 1959**)
	20–40	Good	
	40–60	Permissible	
	60–80	Doubtful	
	>80	Unsuitable	
$SAR = \frac{Na}{\sqrt{\frac{(Ca+Mg)}{2}}}$	<10	Excellent	(**Todd, 1980**)
	10-18	Good	
	18-26	Doubtful	
	>26	Unsuitable	
$RSC = (CO_3 + HCO_3) - (Ca+Mg)$	<1.25	Good	(**Guan et a1., 999**)
	1.25–2.5	Doubtful	
	>2.5	Unsuitable	
	<1	Suitable	

Table 2. Statistical analysis of the physical and chemical parameters for the collected water Samples in the Study Area.

Parameter	Min	Max	Mean
Temp.	23.3	32.4	28.198
pH	6.51	8.71	7.6438
EC	330	1591	848.52
TDS	211.2	1034.15	547.4826
K^+	4.468	37.759	16.615262
Na^+	16.047	150.027	64.80154
Mg^{2+}	4.871	39.493	20.400446
Ca^{2+}	25.494	95.633	58.87338
Cl^-	41	243.1	112.5832
SO_4^{2-}	10	95	41.4
HCO_3^-	86.2	422.8	232.092
CO_3^{2-}	0	0	0

ions in order $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, and $HCO3^- > Cl^- > SO4^{2-} > CO3^{2-}$. These values showed that Na^+ was the predominant cation, while HCO_3^- was the predominant anion in obtained water samples.

Geochemical Facies and Controlling Mechanisms

To accept and comprehend various hydrogeochemical variables that regulate the draining water quality in the examined area, hydrogeochemical data analysis was applied using illustrative approaches, such as Piper and Gibbs diagrams. The geochemical water types were Ca-HCO_3, Na- HCO_3, Ca-Mg-Cl-SO_4, and Na-Ca-HCO_3 based on the chemical characteristics of the tested water samples (Figure 2). According to Piper diagram, two types of water including Ca-Mg-HCO_3 and Ca-Mg-SO_4 were presented based on the chemical analysis of water samples. By graphing the ratios of Na/(Na+Ca) and Cl/(Cl+HCO_3) vs TDS on Gibb's diagram, evaporation and rock-dominated processes were the most important mechanism that effect on the chemical composition of drain water (Fig. 2 a, b).

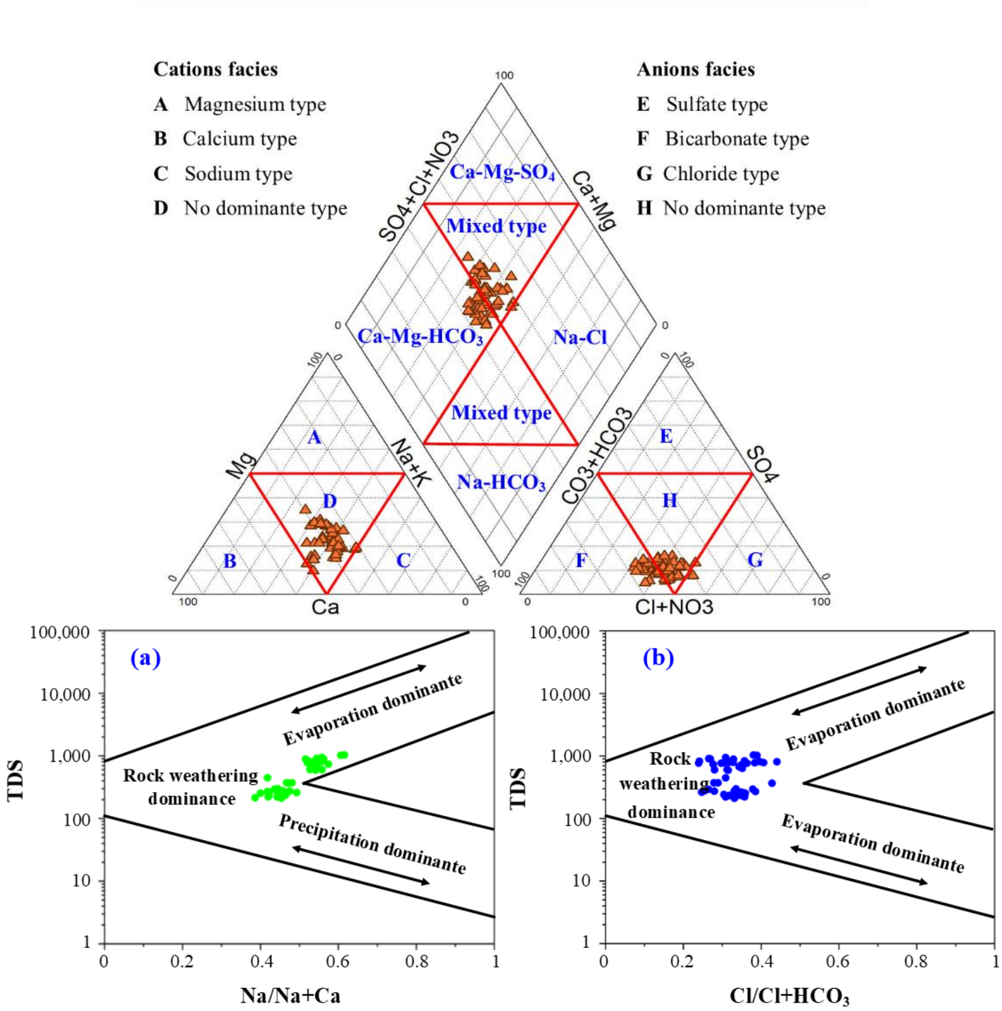

Fig. 2. Distribution of samples result according Piper and Gibbs diagram in the study area.

To determine the hydrogeochemical processes and drain water facies, Chadha's categorization was applied to the samples of collected drain water (Fig. 3). In the field (A, D), drain water samples indicated mixing with alkaline soil exceeds alkaline types (Ca- Mg- HCO_3 and Na-HCO_3 water facies) under the impact of rock-water interaction.

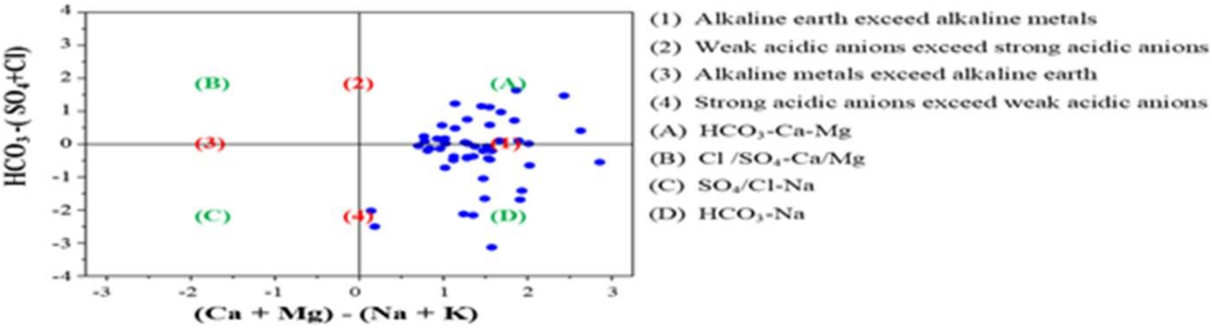

Fig. 3. Illustration of Water facies and geochemical control mechanisms according to Chadha, 1999.

Water quality assessment

The IWQIs such as IWQI, SAR, %Na, and RSC are based on several physiochemical variables of water. The IWQIs were calculated according to arithmetical formulas of selected physiochemical parameters such as Cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (HCO_3^- , Cl^-, SO_4^{-2}).

Irrigation Water Quality Index (IWQI)

The IWQI is a calculated index with no dimensions that reflects all the parameters affecting overall water quality. It creates a single value from several chemical parameters of water samples, providing a detailed evaluation of the overall quality of the water and its suitability for irrigation uses (**Meirelles et al., 2010; Sener et al., 2017; Kachroud et al., 2019**). According to the calculated IWQI values, the IWQI varied from 44.98 to 99.89 with an average of 81.36 (Table 3 and Figure 4a). About 4% of drain water samples have high restrictions for irrigation use, 30% of samples have moderate restrictions, and 18% of samples have low restrictions. The overall index map illustrates the acceptability of the water for irrigation according physical and chemical characteristic. The maps can be used to evaluating the overall effectiveness of drainage systems and determining the suitability of water quality for irrigation.

Table 3. Summary of the descriptive statistics of the determined IWQIs.

Parameter	Min	Max	Mean
IWQI	44.98	99.89	81.36
Na %	25.41	49.53	39.17
SAR	0.64	3.35	1.74
RSC	-2.37	0.03	-0.82

Sodium percentage (Na %)

Water's sodium content reacts with the soil to decrease its permeability, which has an impact on irrigation. The Na% is frequently used to determine the surface water suitability for

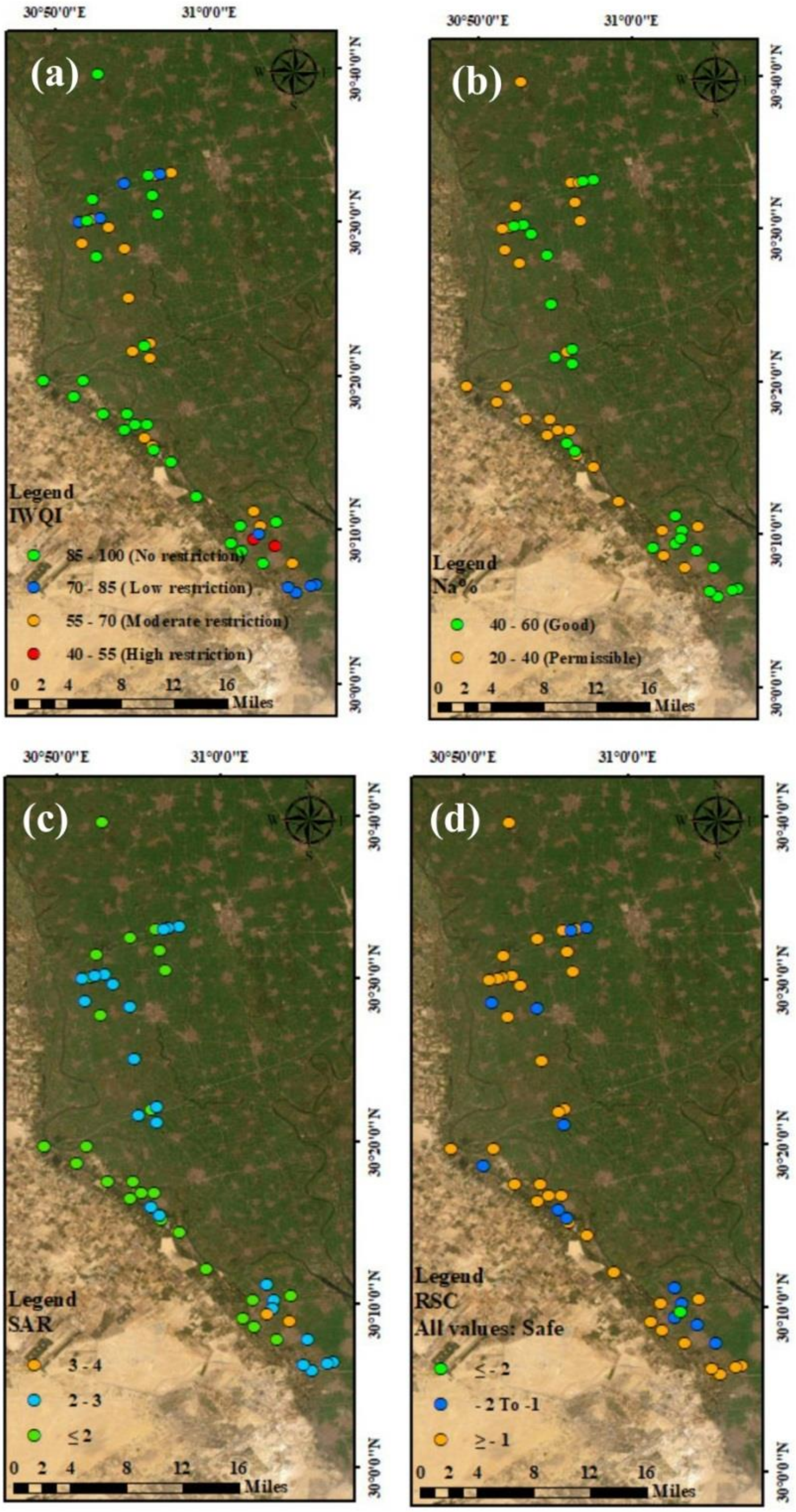

Fig.4. Irrigation water quality index (IWQI) variation maps in the research area.

agricultural use. When compared to Ca^{2+} and Mg^{2+} concentrations, the surface water with high content of Na^{+} reacts with the soil and reduces its permeability, which weakens the soil's structure and leads to an increase in reduced plants. The permeability of agricultural soil is drastically diminished because of the exchange process between sodium in water and calcium and magnesium in soil. The obtained Na% values ranged between 25.41 and 49.53, with a mean of 39.17 (Table 3). According to Na% readings, most water samples (50%) was in good condition, and the remaining percentage was permissible for use in irrigation **(Todd, 1959)** (Table 1 and Fig. 4b).

Sodium Adsorption Ratio (SAR)

According to (**Suarez et al., 2006)**, the SAR is a useful index for determining the suitability of water for irrigation. According to the SAR categorization (Table 1), all drain samples were excellent for irrigation with a SAR less than 10, and the SAR values varied from 0.64 to 3.35 with an average value of 1.74 (Table 3). Since it is a sign of an alkali or salt threat to crops, sodium concentration is a crucial factor in classifying water for irrigation. Planting is impossible because salt reacts with the soil and decreases its permeability. The quality of water in the research around the Rosetta Branch has declined, as seen by the SAR distribution map (Fig. 4c).

Residual Sodium Carbonate (RSC)

The RSC has estimated the risk that carbonates and bicarbonates pose to agricultural water's consistency. According to the United States Environmental Protection Agency (**USEPA, 2012**), water is considered good for irrigation when the RSC value is less than 1.25 and unsuitable when it rises to >2.5. RSC is produced when the alkalinity concentration is above that of the alkaline earth ions (Ca^{2+} and Mg^{2+}). The RSC values revealed a mean value of -0.82, which ranged from -2.37 to 0.03. All drain water samples were classified as excellent (100%) by the RSC results. The RSC results showed that all drain water samples were satisfactory (100%) and suitable for irrigation (Table 3, Figure 4d). More than the sum of the Ca^{2+} and Mg^{2+} concentrations in water, surface water suitability is determined by the effects of excess alkalinity. Concerning the alkaline earth elements, the amount of Na^{+} concentration and excess alkalinity determine the suitability of water for irrigation (**Sudhakar et al., 2013**).

Conclusion

An integrated approaches were used for determining drain water quality for irrigation purposes, with respect physicochemical parameters and indexing. The obtained drain water samples revealed $Ca\text{-}Mg\text{-}HCO_3$ and $Ca\text{-}Mg\text{-}SO_4$ water type. In addition, the evaporation and rock-water interaction mechanisms were identified as the major controlling processes that drive water geochemistry. The IWQI, SAR, RSC, and Na% values were calculated to assess the drainage water quality for irrigation. According to the computed IWQI appropriateness for irrigation, approximately 4% of drain water samples had high restrictions, 30% had moderate restrictions, and 18% had low restrictions for irrigation. Additionally, the SAR results showed that all water samples were suitable for irrigation. Moreover, the RSC and Na% measurements also showed that drain water samples were suitable for irrigation.

References

Brown, R.M , Clelland, N.I, Deininger, R.A., Tozer, R.G and Water, A. 1970. Quality index: Do we dare? Water Sewage Works197, 117, 339–343.

Chadha, D. K. 1999 . A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data. Hydrogeol J 7:431–439.

Gad, M., Elsayed, S., Moghanm, F.S., Almarshadi, M.H., Alshammari, A.S., Khedher, K.M., Eid, E.M.and Hussein, H. 2020. Combining Water Quality Indices and Multivariate Modeling to Assess Surface Water Quality in the Northern Nile Delta, Egypt. Water 12, 2142.

Gibbs, R.J. 1970. Mechanisms controlling world water chemistry. Science. 170:10881.

Guan, W., Chamberlain, R. H., Sabol, B. M. and Doering, P. H. 1999. Mapping Submerged Aquatic Vegetation in the Caloosahatchee Estuary: Evaluation of Different Interpolation Methods", Marine Geodesy, 22, 69 - 91.

Kachroud, M., Trolard, F., Kefi, M., Jebari, S. and Bourrié, G. 2019 .Water quality indices: Challenges and application limits in the literature. Water, 11, 361.

Meireles, A.C.M., Andrade, E.M., Chaves, L.C.G, Frischkorn, H and Crisóstomo, L.A. A. 2010 . New proposal of the classification of irrigation water. Rev. Cienc. Agron., 41, 349–357.

Piper A.M. 1944. A graphic procedure in the geochemical interpretation of water-analyses. EOS Trans Am Geophys Union 25(6):914–928.

Rakib, M.R.J., Jolly, Y.N, Begum, B.A., Choudhury, T.R., Fatema, K.J., Islam, M.S, Ali, M.M.and Idris, A.M. 2021. Assessment of trace element toxicity in surface water of a fish breeding river in Bangladesh: A novel approach for ecological and health risk evaluation.Toxin Rev.

Sener, S, Sener, E and Davraz, A. 2017. Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (Sw-turkey). Sci. Total Environ., 584, 131–144.

Suarez, D.L, Wood, J.D and Lesch, S.M. 2006. Effect of SAR on water infiltration under a sequential rain-irrigation management system. Agric. Water Manag. 86, 150–164.

Sudhakar, A and Narsimha, A. 2013. Suitability and assessment of groundwater for irrigation purpose: A case study of Kushaiguda area, Ranga Reddy district, Andhra Pradesh, India. Adv. Appl. Sci. Res. 4, 75–81.

Todd, D. K. 1959. “Groundwater hydrology” John Willy and Sons, Inc., NewYork, p.334.

Todd, D .1980. "Groundwater hydrology (2^{nd} ed.)", New York: Wiley.