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# Water Quality and Dissolved Organic Carbon Content in Agricultural Streams: Northern Nile Delta Region, Egypt

**Noura Bakr** · **Sahar A. Shahin** · **E. F. Essa** ·
**Tamer A. Elbana**

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**Abstract** Sustainable development goals (SDGs) 2 (zero hunger), 6 (clean water and sanitation), and 15 (life on land) are related to the human-water-soil nexus. Soil organic carbon and nutrients can be removed and transported to waterways through runoff and drainage. The main goals of this study are to quantify the water quality for irrigation and assess the dissolved organic carbon (DOC) contents in streams in the northern Nile Delta, Egypt. A 4-year water quality monitoring program is accomplished by collecting 35 irrigation and drainage water samples per year from the study area. The measured water quality parameters are as follows: salinity, pH, Na, SAR, Cl, and $NO_3$–N. In addition, the DOC content is accessed. The salinity hazard ranged from moderate, for most irrigation samples, to high and very high for drainage samples. All collected water samples have low to medium sodium hazards. Results indicate that average DOC contents in irrigation canals are 2.32 and 2.93 mg $L^{-1}$ for the summer and winter, respectively. The respective means of DOC concentration in drainage canals for the summer and winter seasons are around 3.96 and 5.09 mg $L^{-1}$. This study revealed significant differences in EC, pH, Na, Cl, and SAR, as water quality parameters, between irrigation and drainage canals. Additionally, the studied agroecosystem has seasonal variability in DOC concentration in irrigation and drainage canals between summer and winter. Overall, reusing drainage water for irrigation in the study area requires the selection of suitable crops and site-specific management.

**Keywords** Arid region · Carbon stock · Dissolved organic carbon · Drainage canals · Irrigation canals · Water quality

## 1 Introduction

Water scarcity is one of the most increasing threats to humans, and it worsens with the negative environmental impacts of climate change (Tang, 2020; Liu et al., 2022). Mismanagement of irrigation water can affect agriculture production and threaten food security (Pastor et al., 2019; Liu et al., 2022). Due to water scarcity, especially in the Middle East and North Africa (MENA) region, efficient use of unconventional water sources, including treated wastewater, is essential (Elbana et al., 2017). In the MENA

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N. Bakr (✉) · S. A. Shahin · E. F. Essa · T. A. Elbana
Soils and Water Use Department, Agricultural and Biological Research Institute, National Research Centre, Postal Code, El-Buhouth St, DokkiCairo 12622, Egypt
e-mail: nourabakr@yahoo.com; ne.bakr@nrc.sci.eg

S. A. Shahin
e-mail: saharselim98@yahoo.com; sa.selim@nrc.sci.eg

E. F. Essa
e-mail: abdelsalam_ef@yahoo.com; ef.essa@nrc.sci.eg

T. A. Elbana
e-mail: tamerelbana@yahoo.com; ta.elhammed@nrc.sci.eg

region, agriculture utilizes > 83% of the processed wastewater for most cultivated crops and agricultural production (Maftouh et al., 2022). The negative impacts of climate change will negatively affect the agricultural sector in North Africa, as they may cause a significant decrease in agricultural land and a decline in crop growth. The North African region is already struggling with food and water security. With less precipitation and increasing temperature, water scarcity and food production will be increasingly challenging (Rayan et al., 2022). The most notable climate change risks in North Africa are increasing temperature, drought, sea level rise, and decreasing precipitation (Desmidt, 2021).

Water quality is highly correlated with plant growth and crop yield. Thus, assessing the quality of surface water utilized for irrigation is essential (Salem et al., 2019; Singh et al., 2004; Abdel Meguid, 2019). Different parameters are measured to assess the water quality for irrigation, with the Food and Agriculture Organization (FAO)-29 guidelines “Water Quality for Agriculture” (Ayers & Westcot, 1985) being a widely accepted guideline for determining the quality of irrigation water (Jahin et al., 2020). Furthermore, irrigated cultivated soils with saline water, especially alkali soil with high sodium adsorption ratio (SAR), can cause land degradation and decrease crop yield (U.S. Salinity Laboratory Staff., 1954; Pascale et al., 2005; Liang et al., 2017). Accordingly, Ayers and Westcot (1985) considered those two factors important water quality parameters for irrigated soils. Additionally, the water pH, soluble sodium (Na) and chloride (Cl), and nitrate ($NO_3$) are also considered vital parameters to assess the water quality for irrigation in various international and national standards besides research studies (Ayers & Westcot, 1985; WHO 2006; U.S. Environmental Protection Agency., 2012; ECP 501, 2015, JICA, 2016; Eltarabily et al., 2018; Abuzaid & Jahin, 2021).

The Nile River is the primary source of irrigation in Egypt. The cultivated lands in the Nile Valley and Delta are irrigated from the intensive irrigation canal network directly from the River Nile. Due to the population and water demand increases, a non-conventional source of water irrigation (from drainage canals) was also utilized as a regular irrigation practice during the water shortage season (Elbana et al., 2017; Khafagy et al., 2018). Like other suburban areas, treated wastewater (including industrial and municipal) is commonly utilized for irrigation in various places worldwide (Singh et al., 2004). Due to the negative impacts of climate change, a significant decrease in the Nile River’s flow in Egypt is predicted (Abdelhaleem & Helal, 2015). This decrease will significantly threaten water security (Rayan et al., 2022).

Dissolved organic carbon (DOC) plays a crucial role in the dynamics of stream ecosystems, as it affects acidity, nutrient uptake, and bioavailability of toxic compounds since the DOC affects the transport of metals and trace organic contaminants (Cole et al., 2007; Aiken et al., 2011; Barron & Duarte, 2015). The DOC comprises the largest C pool (680–700 Pg C, Petagrams of $C = 10^{15}$ g of C) of reduced C in the hydrosphere (Calleja et al., 2019; Hung et al., 2022); it is the primary OC pool in most aquatic ecosystems (Wetzel, 2001). The DOC is an essential component of the global carbon cycle (Dittmar & Stubbins, 2014). Additionally, DOC concentrations and flux are mainly governed by the quantity and quality of soil organic carbon (SOC) (Huang et al., 2013).

The DOC flux is a mechanism of transferring soil carbon (C) from aboveground organic litter to groundwater or adjacent streams (Evans et al., 2020). The DOC flux, with high mobility and reactivity (Van Gaelen et al., 2014), from an ecosystem, is a significant component of carbon (C) budgets and regulates the global C cycle (Jardine et al., 2006; Li et al., 2017). Globally, the annual flux of OC from terrestrial ecosystems to oceans is approximately 0.4–0.5 Pg C (Aitkenhead & Mcdowell, 2000), from which around 0.2 Pg C is DOC (Ciais et al., 2013). Fabre et al. (2020) also stated that the global riverine DOC flux is around 131.6 Tg C year$^{-1}$ (teragrams $C = 10^{12}$ g of C). Generally, the DOC concentrations in water streams are high where water moves directly from being in contact with the plant or organic material into the streams, especially through low adsorption capacity soils with low clay content (Nelson et al., 1990, 1992).

Based on a seasonal monitoring program in the Nile River Damietta Branch, Badr (2016) reported that the average DOC concentration in the summer and winter seasons was $3.85 \pm 0.67$ and $5.52 \pm 0.95$ mg L$^{-1}$, respectively. The author explained that the phytoplankton growth and autotrophic bacteria produce DOC in the summer, which may accumulate in the system in the fall and winter seasons causing higher DOC concentrations.

However, Ribas-Ribas et al. (2011) attributed the seasonal variation of DOC concentrations in June and November 2006 in the Gulf of Cádiz, Iberian Peninsula, to different nutrient inputs. In Mediterranean rivers, the DOC concentration ranged between 1.61 and 2.62 mg $L^{-1}$ (Santinelli 2015), whereas the global average concentration in rivers is around 5 mg $L^{-1}$ (Dai et al. 2012).

The DOC pools reflect terrestrial OC that accumulates, transfers to adjacent stream networks, and affects the aquatic environments in open lakes, seas, or oceans. The DOC could express the organic load from wastewater (including sewage, industrial effluent, and agricultural runoff) and their effect on aquatic environments (Badr et al., 2013 and Badr, 2016). Both land use/land cover (LULC) and climate change substantially affect the DOC concentrations in water streams (Butman et al., 2015; Duan et al., 2017; Dubois et al., 2010; Huntington & Shanley, 2022; Schramm et al., 2009; Stanley et al., 2012; Vaughn et al., 2021; Xenopoulos et al., 2021).

Intensive agricultural practices can increase nutrient load (such as nitrogen and phosphorus) in surface waters (Smith & Schindler, 2009). Enriching such nutrients could lead to eutrophication, accordingly, more significant inputs of DOC (Hilton et al., 2006) and, eventually, water quality deterioration (Li et al., 2020). Therefore, the assessment of DOC concentration in agroecosystems under conventional cultivation, cropped with regular full irrigation and drainage, is highly concerning (Guo et al., 2011). Besides the consequences of global warming on carbon cycling, other environmental drivers influence DOC, such as land degradation and soil salinization (Stanley et al., 2012). Additionally, agriculture (as one of the main LULC) and cultivation practices, such as artificial irrigation and drainage, affect the DOC concentration and flux from field to water channel (Stanley et al., 2012). The role of agricultural practices on agricultural stream DOC dynamics is still unclear, where intensive irrigation practices could significantly affect the production and transport of DOC to surface waters and downstream ecosystems (Oh et al., 2013). In the Nile Delta region, there are increases in wastewater drainage due to population increases and the intensification of economic activities (Elbana et al., 2017; Abdelrazek, 2019) which leads to high water scarcity levels. Accordingly, the Ministry of Water Resources and Irrigation adapts a strategy to reuse wastewater in irrigation (Abdallah et al., 2019; Salman et al., 2019). So, it is crucial to investigate the water quality in irrigation and drainage canals as they are both utilized for irrigation in the Nile Delta region. Therefore, the main purposes of this research are to (1) assess the streams-water quality for irrigation and the difference between irrigation and drainage canals in the study area and (2) quantify the temporal variation in DOC concentration in irrigation and drainage canals during summer and winter seasons in the northern Nile Delta region and its importance as water quality factor. The main hypothesis of the current research is that the DOC content will vary due to seasonal variation (summer and winter) and the type of streams (irrigation and drainage canals).

## 2 Materials and Methods

### 2.1 Site Description

The area under investigation geographically belongs to the northern Nile Delta region, Kafr El-Sheikh governorate, Egypt (Fig. 1). Kafr El-Sheikh governorate shares administrative boundaries with Dakahlia and Behaira governorates from the east and west, respectively. Additionally, the Mediterranean shoreline bounds the northern coastal area of the governorate (Fig. 1).

The study area includes the Burullus Lake and the surrounding terrestrial area between longitudes 30° 20′ and 31° 10′ E and latitudes 31° 15′ and 31° 37′ N and covers approximately 1480 $km^2$. The monthly meteorological data of temperature (°C) and wind speed ($m\ s^{-1}$) at 2 m, precipitation, and relative humidity (%) were downloaded from the National Aeronautics and Space Administration Prediction of Worldwide Energy Resources (NASA POWER) website (https://power.larc.nasa.gov). Over 40 years (1981–2020), the raw data were statistically analyzed and presented in Table 1. The meteorological data reveals that the investigated area has an arid climate with average annual precipitation of approximately 120 mm, and mean temperature varied from 15° to 30 °C in January and July, respectively. Agricultural land and fish farms are the main LULC in this area. Likewise, in other areas in the Nile Delta region, the study area involves fertile agricultural lands intensively covered with water streams of approximately

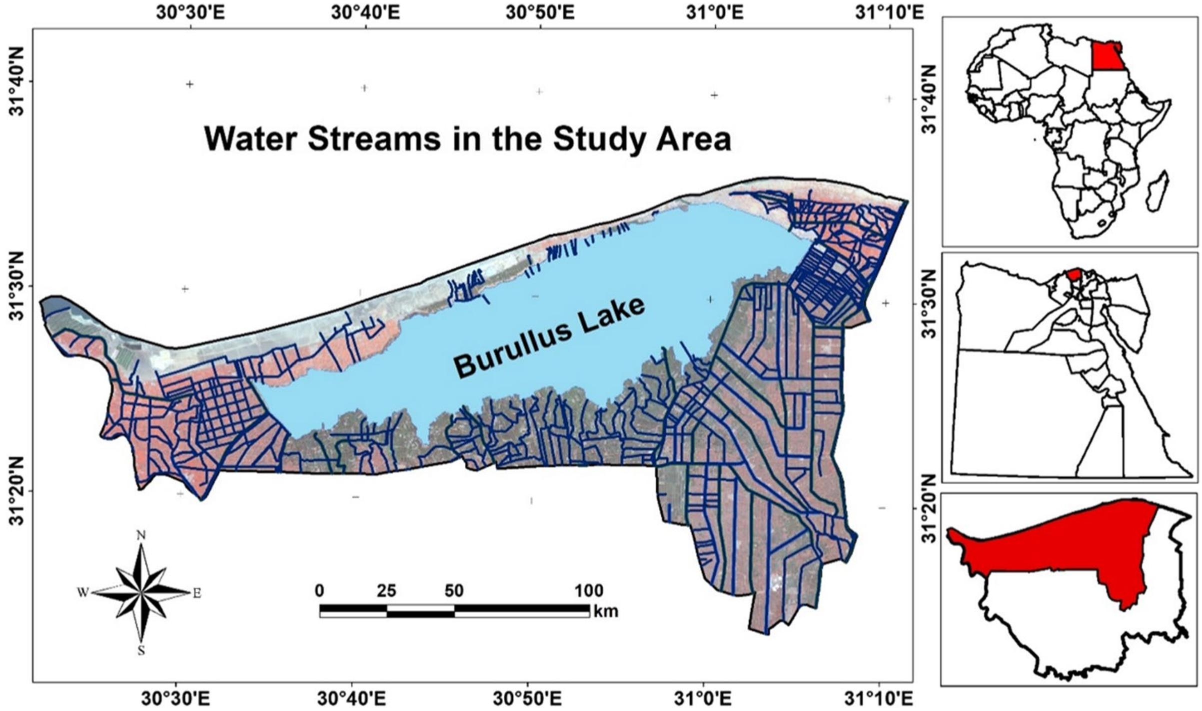

**Fig. 1** The water streams and general location of the study area, northern Nile Delta, Kafr El-Sheikh governorate, Egypt

**Table 1** The descriptive statistics parameters of the collected meteorological data between 1981 and 2020 for the study area in Egypt

| Parameter | | Maximum | Minimum | Median | Mean | Variance | C.I. of mean |
|---|---|---|---|---|---|---|---|
| Temperature (°C) | Maximum | 34.17 | 21.19 | 31.52 | 29.54 | 22.79 | 3.03 |
| | Minimum | 23.59 | 9.79 | 15.83 | 16.23 | 26.10 | 3.25 |
| | Mean | 27.55 | 14.85 | 21.25 | 21.20 | 23.02 | 3.05 |
| Wind speed (m $s^{-1}$) | Maximum | 11.09 | 7.33 | 9.10 | 9.16 | 1.87 | 0.87 |
| | Minimum | 0.75 | 0.29 | 0.35 | 0.42 | 0.03 | 0.10 |
| | Mean | 4.38 | 3.77 | 4.11 | 4.11 | 0.04 | 0.13 |
| Precipitation | mm $day^{-1}$ | 1.01 | 0.00 | 0.24 | 0.33 | 0.13 | 0.23 |
| | Sum (mm) | 31.22 | 0.01 | 7.19 | 10.09 | 121.37 | 7.00 |
| Relative humidity (%) | | 68.70 | 64.77 | 66.70 | 66.64 | 1.63 | 0.81 |

1380 km total length (Fig. 1) that were created and calculated based on the hydrology tool in ArcMap 10.4.

## 2.2 Water Samples: Analyses and Water Quality Assessment

Collecting samples from irrigation and drainage canals was necessary since reusing the drainage water in irrigation is a common agricultural practice in this area (Elbana et al., 2017). Therefore, 35 georeferenced surface water samples were collected annually from the exact locations for 4 years (2018 to 2021). Fifteen water samples were collected from irrigation canals, and 20 samples from drainage canals (Fig. 2). The samples were collected during the summer (July and August) and winter (January and February).

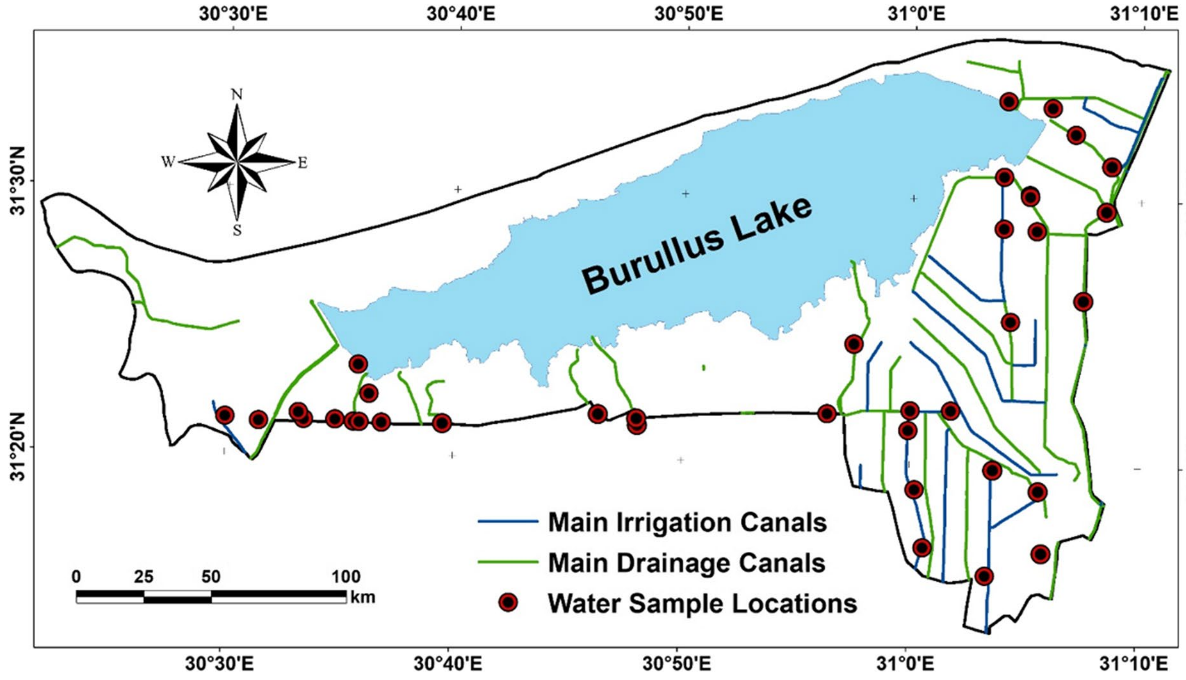

**Fig. 2** The main irrigation and drainage canals with the water sample locations in the study area, northern Nile Delta, Kafr El-Sheikh governorate, Egypt

During the field visit, a portable electric conductivity (EC) meter (Adwa, AD310 Standard Professional Conductivity-TEMP Portable Meter) and pH meter (Adwa, AD111 Standard Professional pH-ORP-TEMP Portable Meter) were utilized to record the simultaneous and actual values of EC and pH. Additionally, a 1-l water sample was manually collected in a clean plastic bottle. The collected water samples were kept in an icebox immediately, then shipped to the laboratory and refrigerated at 4 °C for further analyses. In the laboratory, the soluble ions of calcium (Ca) and magnesium (Mg) by EDTA titrimetric method, sodium (Na) and potassium (K) using a flame photometer (Janway PFP7 flame photometer, Cole-Parmer Ltd, Stone, Staffs, UK), and chloride (Cl) by silver nitrate titrant, besides ammonium ($NH_4$) and nitrate ($NO_3$) by Kjeldahl method, and phosphate (P) using a spectrophotometer (Jasco V-730 UV–Visible Spectrophotometer) were analyzed based on Baird and Bridgewater (2017).

The Egyptian Code for reusing treated wastewater in agriculture (ECP 501, 2015) was considered for water quality assessment. This code is mainly based on the FAO-29 guidelines (Ayers & Westcot, 1985). The FAO guidelines are the basis of national and international standards for assessing water quality for irrigation (WHO 2006; U.S. Environmental Protection Agency., 2012).

Furthermore, the diagram for the classification of irrigation waters (U.S. Salinity Laboratory Staff., 1954) was applied to evaluate the salinity and sodium hazards based on the waters' EC and SAR values, respectively. The high saline water can deteriorate irrigated soils and decrease crop productivity. Moreover, the excessive sodium content and corresponding SAR can degrade soil structure and cause sodicity hazards to irrigated soils (El-Bana, 2003).

For the DOC analysis, measurements were achieved within 48 h of collecting water samples. The samples for DOC analysis were filtered (0.7 µm, Whatman GF/F), transferred to quartz cell, and then placed in a spectrometer instrument (Jasco V-730 UV–Visible Spectrophotometer) to measure DOC at 254 nm UV absorbance and reported in $cm^{-1}$. The final DOC concentration (mg $L^{-1}$) was calculated according to EPA Method 415.3 (Potter & Wimsatt, 2005).

### 2.3 Statistical Analysis

A descriptive statistical analysis of the water chemical analysis results was performed. Additionally, an analysis of variance (ANOVA) was conducted to investigate the significant statistical differences between the irrigation and drainage canals. First, the normality test via Shapiro–Wilk was carried out, and then the significance of the means of the irrigation and drainage canals results were tested. The SPSS 26 software (IBM SPSS 2019) was utilized to perform the statistical analysis at a 95% confidence interval (significance level of $\alpha = 0.05$).

## 3 Results and Discussions

### 3.1 Water Quality for Irrigation

The chemical analyses for the collected water samples from the irrigation and drainage canals in the study area include EC, pH, Ca, Mg, Na, K, Cl, SAR, $NH_3$, $NO_3$, and P. The results reveal that almost all values of the studied parameters were higher for drainage canals than for irrigation canals. The descriptive statistical parameters of the chemical analysis results are presented in Table 2.

The EC values range from 0.29 to 1.89 dS $m^{-1}$ for irrigation canals and from 1.13 to 5.58 dS $m^{-1}$ for drainage canals. However, positive skewness was

**Table 2** The descriptive statistical parameters for the chemical characteristics of the collected water samples from the irrigation and drainage canals in the study area in Egypt

| Parameters | EC | pH | Ca | Mg | Na | K | Cl | SAR | $NH_4$ | $NO_3$ | P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **dS $m^{-1}$** | | **meq $L^{-1}$** | | | | | | **mg $L^{-1}$** | | |
| | **Irrigation canals** | | | | | | | | | | |
| Minimum | 0.29 | 7.57 | 1.50 | 0.50 | 1.23 | 0.13 | 0.60 | 1.04 | 0.39 | 0.12 | 1.52 |
| Maximum | 1.89 | 7.87 | 7.00 | 4.70 | 23.12 | 0.72 | 7.00 | 15.86 | 6.59 | 7.45 | 5.75 |
| Mean | 0.80 | 7.72 | 2.45 | 2.54 | 7.67 | 0.31 | 2.51 | 4.96 | 2.28 | 2.53 | 3.79 |
| Std. error[†] | 0.18 | 0.03 | 0.49 | 0.44 | 2.28 | 0.06 | 0.63 | 1.58 | 0.62 | 0.73 | 0.45 |
| Std. dev[††] | 0.60 | 0.10 | 1.63 | 1.46 | 7.55 | 0.19 | 2.07 | 5.23 | 2.05 | 2.43 | 1.34 |
| Variance | 0.36 | 0.01 | 2.67 | 2.13 | 57.05 | 0.04 | 4.30 | 27.37 | 4.18 | 5.90 | 1.81 |
| Skewness | 1.24 | -0.32 | 2.55 | -0.03 | 1.08 | 1.26 | 1.18 | 1.46 | 1.21 | 1.12 | -0.53 |
| Percentiles 25 | 0.39 | 7.64 | 1.50 | 1.20 | 1.69 | 0.18 | 1.00 | 1.38 | 0.78 | 0.79 | 2.50 |
| Percentiles 50 | 0.54 | 7.73 | 1.80 | 2.70 | 2.92 | 0.23 | 1.70 | 1.69 | 1.76 | 1.96 | 4.23 |
| Percentiles 75 | 1.35 | 7.80 | 2.80 | 3.60 | 12.40 | 0.42 | 4.00 | 5.93 | 4.12 | 4.94 | 4.59 |
| SWilk Prob[†††] | 0.00 | 0.78 | $<0.001$ | 0.62 | 0.02 | 0.05 | 0.03 | 0.00 | 0.03 | 0.04 | 0.46 |
| | **Drainage canals** | | | | | | | | | | |
| Minimum | 1.13 | 7.64 | 1.50 | 2.50 | 7.10 | 0.38 | 5.33 | 5.02 | 0.39 | 0.19 | 1.38 |
| Maximum | 5.58 | 9.30 | 6.25 | 10.00 | 37.28 | 0.90 | 23.20 | 18.45 | 9.06 | 7.41 | 7.61 |
| Mean | 3.01 | 8.21 | 2.45 | 5.85 | 23.74 | 0.58 | 8.76 | 11.56 | 2.56 | 2.35 | 4.25 |
| Std. error[†] | 0.38 | 0.13 | 0.29 | 0.62 | 2.56 | 0.04 | 1.14 | 1.16 | 0.63 | 0.58 | 0.47 |
| Std. dev[††] | 1.46 | 0.49 | 1.13 | 2.41 | 9.91 | 0.16 | 4.40 | 4.47 | 2.45 | 2.24 | 1.69 |
| Variance | 2.14 | 0.24 | 1.27 | 5.80 | 98.28 | 0.03 | 19.36 | 20.02 | 6.02 | 5.01 | 2.87 |
| Skewness | 0.42 | 0.83 | 3.01 | 0.13 | -0.77 | 0.58 | 2.86 | -0.03 | 1.71 | 1.36 | 0.13 |
| Percentiles 25 | 1.55 | 7.68 | 2.00 | 3.50 | 10.58 | 0.41 | 6.67 | 6.69 | 1.17 | 0.82 | 2.94 |
| Percentiles 50 | 3.07 | 8.12 | 2.25 | 6.17 | 27.92 | 0.58 | 7.50 | 11.64 | 1.37 | 1.56 | 4.35 |
| Percentiles 75 | 4.01 | 8.42 | 2.60 | 8.00 | 29.57 | 0.65 | 8.83 | 13.94 | 3.53 | 3.33 | 5.33 |
| SWilk Prob[†††] | 0.29 | 0.15 | $<0.001$ | 0.37 | 0.02 | 0.19 | $<0.001$ | 0.21 | 0.00 | 0.01 | 0.99 |

[†] Standard error of the mean

[††] Standard deviation

[†††] Shapiro–Wilk normality tests

observed, and 75% of the irrigation and drainage samples exhibited salinity less than 1.35 and 4.01 dS m$^{-1}$, respectively. Based on Ayers and Westcot (1985) in Table 3, the EC values for irrigation canals varied from *no restriction* to *slight restriction* for irrigation. However, the EC values for drainage canals varied from *moderate restriction* to *severe restriction* for irrigation. The pH values range between 7.6–7.9 and 7.6–9.3 for irrigation and drainage canals, respectively. The pH values of irrigation canal-water samples are within the normal range for irrigation. However, the drainage canals-water samples exhibited higher pH, and 25% of the samples were higher than the normal pH range for agricultural irrigation (Table 2 and 3).

As shown in Table 2, Na concentrations vary from 1.23 to 23.12 and 7.1 to 37.28 meq L$^{-1}$ for water samples of irrigation and drainage canals, respectively. However, 50% of samples contain less than 2.92 and 27.92 meq L$^{-1}$ for irrigation and drainage canals, respectively. Such high Na concentration in drainage water samples is ascribed to Na being the dominant cation in the study area soils (El-Bana, 2003).

Moreover, the SAR values range from 1.04 to 15.86 and 5.02 to 18.45 for irrigation and drainage canals, respectively. The respective means are 5 and 11.6 (Table 2). Based on salinity level and SAR value, samples from irrigation canals can cause slight to moderate infiltration problems in irrigated soils (Table 3). Water with SAR of > 9 has a severe restriction for irrigation because of Na toxicity problems; thus, such water sources should only be used for Na-tolerant crops (Ayers & Westcot, 1985).

The maximum Cl concentrations varied from < 7 meq L$^{-1}$ for irrigation canals to 23 meq L$^{-1}$ for drainage canals. Although Cl is an essential micronutrient for plants, elevated concentration of Cl represents a growth-limiting factor for most crops. Suarez and Grieve (2013) emphasized the significant reduction of fruit yield due to high Cl concentration in soil, which is hard to mitigate its adverse impacts on plant growth compared with Na ions. Results indicate that > 75% of irrigation canal samples were classified with no Cl restriction use for irrigation. Conversely, < 25% of drainage water samples can be irrigated without Cl restriction (Table 2 and 3). The Mg concentrations for irrigation canals range from 0.5 to 4.7 meq L$^{-1}$, whereas they range from 2.5 to 10 meq L$^{-1}$ for drainage canals. Limited variability of Ca and K concentrations in irrigation and drainage canals was observed (Table 2).

Nitrogen and phosphorus are essential macronutrients for plant growth. Two forms ($NH_4$–N and $NO_3$–N) of nitrogen were analyzed. The concentration

**Table 3** Guidelines of water quality parameters for irrigation (modified: Ayers & Westcot, 1985)

| Irrigation problem | | | | Unit | Degree of restriction on use | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Ayers and Westcot (1985) | | | **Current study (based on mean value)** | |
| | | | | | **None** | **Slight to moderate** | **Severe** | **Irrigation** | **Drainage** |
| Salinity | $EC_w$ | | | dS m$^{-1}$ | < 0.7 | 0.7–3.0 | > 3.0 | Slight to moderate | Severe |
| Infiltration | SAR | 0–3 | & $EC_w$ = | | > 0.7 | 0.7–0.2 | < 0.2 | Slight to moderate | None |
| | | 3–6 | | | > 1.2 | 1.2–0.3 | < 0.3 | | |
| | | 6–12 | | | > 1.9 | 1.9–0.5 | < 0.5 | | |
| | | 12–20 | | | > 2.9 | 2.9–1.3 | < 1.3 | | |
| | | 20–40 | | | > 5.0 | 5.0–2.9 | < 2.9 | | |
| Specific ion toxicity | Na | | | SAR | < 3 | 3–9 | > 9 | Slight to moderate | Severe |
| | Cl | | | meq L$^{-1}$ | < 4 | 4–10 | > 10 | None | Slight to moderate |
| Miscellaneous effect | $NO_3$–N | | | mg L$^{-1}$ | < 5 | 5–30 | > 30 | None | None |
| | pH | | | | 6.5–8.4 | | | Within normal range | Within normal range |

of $NH_4$ varied between 0.39 and 6.59 mg $L^{-1}$ with a mean value of 2.28 mg $L^{-1}$ for irrigation canals. However, the respective $NH_4$ values for drainage canals were 0.4, 9.1, and 2.6 mg $L^{-1}$. The concentration of $NO_3$ varied between 0.12, −7.45, and 0.2–7.4 mg $L^{-1}$ with mean values of 2.53 and 2.35 mg $L^{-1}$ for irrigation and drainage canals, respectively (Table 2 and 3). However, > 75% of irrigation and drainage water samples were less than the recommended threshold value of 5 mg $L^{-1}$ for $NO_3$ concentration (Table 3). In agreement with our results, El-Bana et al. (2006) found no restriction on reusing drainage water in the northwestern delta due to nitrate or boron concentrations.

The results revealed an acceptable phosphorus concentration level in the collected water samples, where 75% contained < 4.59 and 5.33 mg $L^{-1}$ for irrigation and drainage samples, respectively. The means of P concentrations were 3.8 and 4.3 mg $L^{-1}$ for irrigation and drainage canals, respectively, where the maximum measured P (7.61 mg $L^{-1}$) was reported for drainage water samples (Table 2 and 3). According to World Health Organization (WHO) guidelines, phosphorus concentration of < 20 mg $L^{-1}$ in wastewater increases crop productivity without reducing the availability of micronutrients (WHO 2006).

Based on the Shapiro–Wilk normality test results, almost all variables for the irrigation canals did not pass the normality test with a *p-value* < 0.05, except the pH, Mg, and P. For the drainage canals, six variables (EC, pH, Mg, K, SAR, P) passed the normality test with a *p-value* > 0.05. Conversely, the remaining variables (Ca, Na, Cl, $NH_4$, and $NO_3$) did not pass the normality test (Table 2). These findings indicate that most variables are generally not normally distributed, which is consistent with skewness results.

The ANOVA model was performed to test the effects of canal type (irrigation and drainage) on the assigned water quality parameters in Table 3 (EC, pH, Na, Cl, $NO_3$–N, and SAR). The ANOVA results revealed statistically significant differences between the water quality parameters for irrigation and drainage canals with *p*-value < 0.05 except $NO_3$–N. Specifically, strong statistical significant differences are observed for EC, Na, and Cl with a *p*-value of < 0.001. The *p*-values of 0.002 and 0.013 are assigned for SAR and pH, respectively. The studied water quality parameters passed the ANOVA normality test for residuals except $NO_3$–N, in which the normality failed due to unequal variance between the studied groups. Accordingly, Kruskal–Wallis ANOVA on Ranks was conducted for $NO_3$–N. The $NO_3$–N is not significantly different between irrigation and drainage canals with a *p*-value of 0.876 which is greater than a confidence interval of 0.05.

Furthermore, the results of water analyses were utilized to assess the water quality for irrigation and drainage canals according to the diagram for the classification of irrigation waters (U.S. Salinity Laboratory Staff., 1954). Figure 3 shows the evaluation of water sources for irrigation based on the salinity value and SAR. Figure 3 modifies the original diagram using EC units of dS $m^{-1}$ that equals 0.001 μmhos $cm^{-1}$. Table 4 shows the levels of salinity and SAR to indicate the quality of water used in irrigation.

According to U.S. Salinity Laboratory Staff. (1954), the irrigation water samples are dominantly medium saline (C2) with low and medium sodium hazards (S1 and S2, respectively). However, the drainage water samples are classified as high to very high saline water (C3 and C4, respectively) with low to medium sodium hazards (Fig. 3). Such results are compatible with evaluating water quality based on the FAO guidelines (Ayers & Westcot, 1985). The final results of salinity and sodium hazard are consistent with Khafagy et al. (2018), who reported that C2-class is dominant in irrigation canals, whereas C3 and C4 classes dominate in various drains in the northern Nile Delta region.

## 3.2 Variation in DOC Concentration

Seasonal variations in DOC concentrations in irrigation and drainage canals are presented in Table 5. For summer water samples, the DOC in irrigation canals varied between 1.56 and 2.89 mg $L^{-1}$ with a mean value of 2.32 mg $L^{-1}$, whereas the respective values of 3.70, 4.27, and 3.96 mg $L^{-1}$ were reported for drainage canals. For winter water samples, the DOC in irrigation canals varied between 2.45 and 3.51 mg $L^{-1}$ with a mean value of 2.93 mg $L^{-1}$, whereas the respective values of 4.60, 5.41, and 5.09 mg $L^{-1}$ were observed for drainage water samples. In the Nile Damietta Branch, Badr (2016) reported an average DOC of 5.15 mg $L^{-1}$, ranging between 2.23 and 11.3 mg $L^{-1}$. Data in Table 5 revealed higher DOC concentrations were observed in drainage canals compared to irrigation canals. That can be ascribed

**Fig. 3** Diagram for the classification of irrigation (blue) and drainage (green) waters in the study area

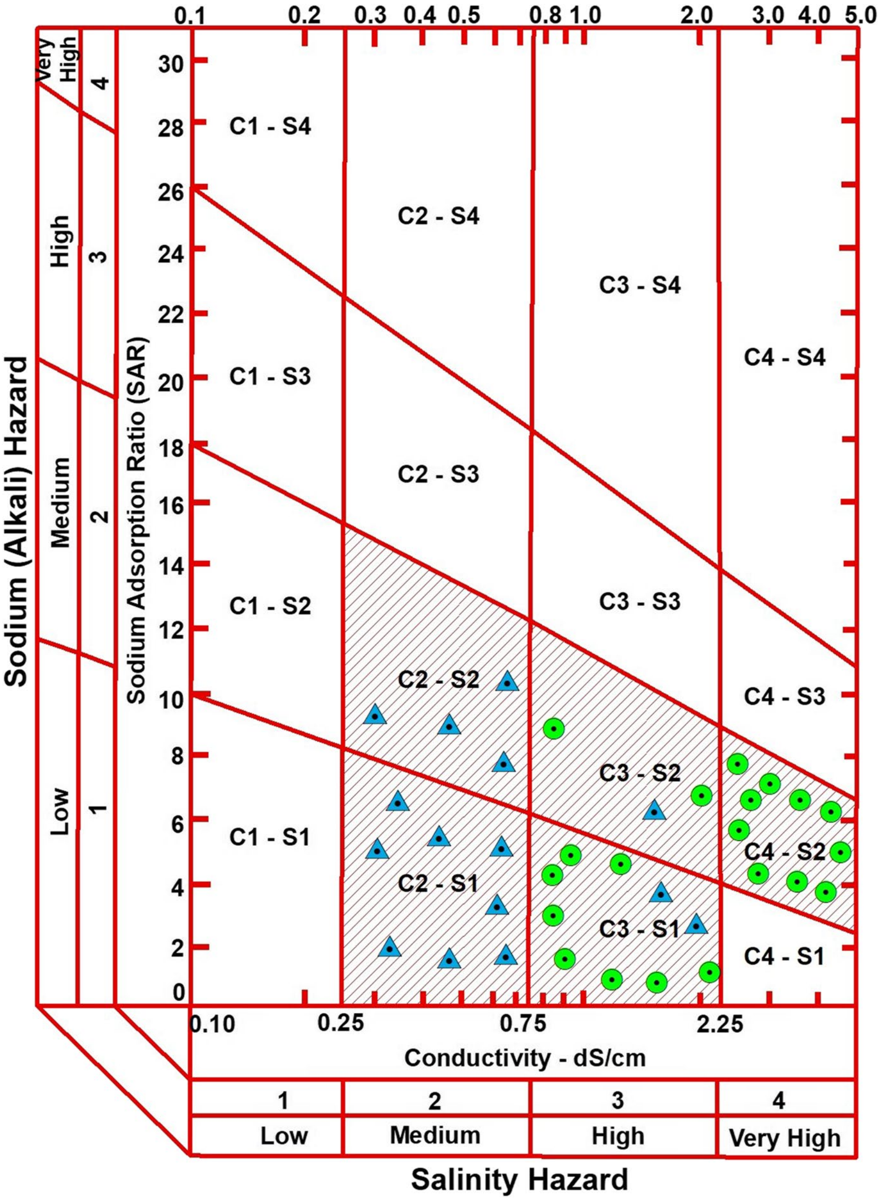

**Table 4** The classification of water used in irrigation based on U.S. Salinity Laboratory Staff. (1954)

| Salinity | | | Sodium | | |
|---|---|---|---|---|---|
| Degree | **Value (dS m$^{-1}$)** | **Class** | **Degree** | **SAR** | **Class** |
| Low | $<0.250$ | C1 | **Low** | 0–10 | S1 |
| Medium | 0.250–0.750 | C2 | **Medium** | 10–18 | S2 |
| High | 0.750–2.250 | C3 | **High** | 18–26 | S3 |
| Very high | $>2.250$ | C4 | **Very high** | 26–30 | S4 |

to the leaching of DOC from soil and plant residues via drainage and water seepages into agricultural streams. A similar trend was observed for N and P nutrients, with higher contents of Mg, $NH_4$, $NO_3$, and P observed for drainage water samples than irrigation water samples (see Table 2). A significant positive correlation between Co, Ni, Se, Fe, Mn, and $SO_4$ with DOC in soils was reported by Shaheen et al. (2014) for fluvial and lacustrine Nile delta soils.

Moreover, the concentrations of DOC were generally higher in the collected winter samples

**Table 5** The descriptive statistical parameters for the water samples from the irrigation and drainage canals in the study area in Egypt

| | **Dissolved organic carbon (DOC) mg $L^{-1}$** | | | |
|---|---|---|---|---|
| **Season** | **Summer** | | **Winter** | |
| **Canals type** | **Irrigation** | **Drainage** | **Irrigation** | **Drainage** |
| Minimum | 1.56 | 3.70 | 2.45 | 4.60 |
| Maximum | 2.98 | 4.27 | 3.51 | 5.41 |
| Mean | 2.32 | 3.96 | 2.93 | 5.09 |
| Std. error† | 0.41 | 0.17 | 0.25 | 0.13 |
| Std. dev†† | 0.72 | 0.29 | 0.50 | 0.33 |
| Variance | 0.52 | 0.08 | 0.25 | 0.11 |
| Skewness | − 0.64 | 0.79 | 0.34 | − 0.72 |
| Percentiles 25 | 1.56 | 3.70 | 2.48 | 4.75 |
| 50 | 2.43 | 3.91 | 2.88 | 5.19 |
| 75 | 2.89 | 4.19 | 3.42 | 5.36 |
| SWilk Prob††† | < 0.001 | 0.02 | 0.01 | < 0.001 |

†Standard error of the mean

††Standard deviation

†††Shapiro–Wilk normality tests

compared with summer samples (Table 5). Results herein are in agreement with Badr (2016) who reported a higher DOC for winter (5.52 mg $L^{-1}$) than summer (3.85 mg $L^{-1}$) water samples. The increase in DOC concentrations in winter could be attributed to runoff influence. Winter precipitation in the Nile Delta can increase DOC transport from the adjacent soils to waterways. This justification is consistent with Aitkenhead et al. (1999), Tranvik and Jansson (2002), Erlandsson et al. (2008), Stanley et al. (2012), and Nisha et al. (2022). However, Hernes et al. (2008) reported a higher DOC in summer (5.0 to 7.2 mg $L^{-1}$) than in winter (2.0 to 3.0 mg $L^{-1}$) in the Sacramento River valley in California; they attributed the high DOC in summer to the effect of occasional storms and additional irrigation supplies in summer.

Two-way ANOVA analysis (Table 6) shows that season variation (summer and winter) was more affected by DOC concentrations than the type of canals (irrigation and drainage canals). Additionally, the two examined factors (season and canal type) significantly affected DOC concentrations since the *p*-values for both factors were less than the significance level of 0.05. Conversely, the interaction between these two factors (S X C) was not statistically significant, as a *p-value* of 0.325 is greater than 0.05 (Table 6).

In summary, water quality results indicated low water salinity in irrigation canals. Conversely, the salinity of drainage canals is significantly high and should be used under high precaution. There is a significant seasonal variation in DOC contents for irrigation and drainage canals during summer and winter. Generally, the DOC content was consistently higher in drainage canals during winter compared to summer irrigation canals.

## 4 Conclusions

Irrigation and drainage water samples were collected and analyzed in summer and winter from the northern Nile Delta region, Egypt, for four consecutive years. The results of the water quality assessment revealed that water in irrigation canals exhibited no to slight salinity and infiltration restrictions as agricultural irrigation. The high salinity of the drainage water represents a severe salinity restriction to reusing this water resource for irrigation. In addition, slight to moderate and severe specific Na toxicity restrictions were assigned to irrigation and drainage water samples, respectively. However, over 75% of the collected irrigation and drainage water samples had acceptable nitrogen and phosphorus levels. The specific Cl toxicity represented a slight to moderate restriction on reusing drainage water for irrigation. Temporal variation in DOC contents in irrigation and drainage

**Table 6** Two way ANOVA for the effects of season (summer and winter) and canal type (irrigation and drainage) on DOC in the study area in Egypt

| Source of variation | Type III sum of squares | *df* | Mean square | *F* | *p*-value |
|---|---|---|---|---|---|
| Season (S) | 2.906 | 1 | 2.906 | 14.692 | 0.002 |
| Canals type (C) | 12.078 | 1 | 12.075 | 61.072 | < 0.0001 |
| S X C | 0.209 | 1 | 0.209 | 1.055 | 0.325 |

canals during summer and winter was evaluated. The concentrations of DOC were higher in winter than in summer water samples. Besides, elevated DOC contents were observed in drainage canals compared to irrigation canals. Therefore, site-specific management and proper crop selection should be considered whenever the drainage water is reused for irrigation.

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**Data Availability** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Declarations**

**Conflict of Interest** The authors declare no competing interests.

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