Assessment of agricultural drainage water reuse for irrigation in El-Behira Governorate, Egypt

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ABSTRACT

Agriculture sector and food security of Egypt are under stresses due to the shortage of freshwater budget. Agricultural drainage water reuse can be considered as the most appropriate solution to overcome the irrigation water shortage. Quality of the reused drainage water is of concern, particularly in arid regions, such as Egypt, due to salinity problems. Therefore, water quality assessment for reuse projects is essential. The objective of this work is to assess three different drainage water reuse projects in El-Behira Governorate, Egypt, based on experimental records and water quality index approach. Thirty-six water samples were seasonally collected from three different projects during 2017. Drainage water, freshwater and blended water were evaluated according to the Egyptian and international (FAO) guidelines for drainage and irrigation water. Moreover, CCME-WQI and NSF-WQI were applied to assess the drainage and irrigation water according to the Egyptian standards. Most of the recorded parameters for drainage and irrigation water exceeded the permissible limits. The results confirmed the “Poor” and “Marginal” water quality status of all studied drains (drainage water) according to the Egyptian standards. The water quality status of all studied canals (blended water) was classified as “Bad” according to NSF-WQI. These results confirm that current drainage and blended water in the study area shouldn’t be used. To avoid deterioration of the soil, crops, food security elements and health protection, treatment systems for drainage water are urgently recommended. Drainage water reuse projects should be carefully installed, and water quality assessment should be accompanied with these projects. This study is the base for an ongoing pilot project of using a low-cost drainage water improvement technology which can be considered as a supplemented tool to drainage water reuse.

Introduction

The strategy of agricultural drainage water reuse is the most appropriate solution to overcome the irrigation water shortage (Elshemy, 2017). It is considered as the fastest effective and economical method to provide accepted water characteristics for irrigation purpose. Especially with the high cost of other methods such as the use of treated sewage water or sea-water desalination. Water reuse was defined by Tripathi, Bisen, and Tiwari (2019) as: “water which is used twice or more time before it returns back to the natural water cycle.” Recently, wastewater was widespread used as a low-quality water resource for compensating the irrigation water shortage all over the world (Tabatabaei et al., 2020). Sherov and Urinboev (2020) estimated the collector-drainage water in the world by about 300 Km³/year, which is considered as a great quantity which should be reused. However, reuse without an accurate management can severely cause adverse environmental outcomes, such as soil salinization and degradation and reducing crops yields (Tripathi et al., 2019). Angelakis, Asano, Bahri, Jimenez, and Tchobanoglous (2018) presented an overview of wastewater reuse evolution over the last 5,000 years. Three phases were discussed, the first from the Bronze Age (3200–1100 BC), where domestic wastewater was used for irrigation by some civilizations including China, Egypt, the Indus Valley, Mesopotamia and Crete. Then, the second phase for the period (1000 BC–330 AD) where the Greek and Roman used it for irrigation. In the modern time, wastewater application for agriculture was utilized in Europe and USA. Water resource in the Mediterranean region are subjected to some stresses, such as climate change, growing population and irrigation development, which affect their quantity and quality (Ait-Mouheb, Mayaux, Mateo-Sagasta, Hartani, & Molle, 2020). Some studies discussed applying of reuse strategy in the Mediterranean environment (Ait-Mouheb et al., 2020; Bortolini, Maucieri, & Borin, 2018; Lavrnić, Zapater-Pereyra, & Mancini, 2017; Saliba, Callieris, D’Agostino, Roma, & Scardigno, 2018; Sezen, Yazar, Tekin, & Yildiz, 2016). Bortolini et al. (2018) developed an irrigation water quality tool to evaluate the low-quality water for reuse for irrigation in the Mediterranean arid and semi-arid regions. This tool considers three categories of the water quality...
parameters; crop yield and soil fertility indicators, hygiene and health quality indicators and irrigation systems indicators. A lot of studies assessed the reuse strategy according to regional standards (Beard, Bierkens, & Bartholomeus, 2019; Cakir, 2016; Haldar et al., 2020; Khan et al., 2019; Lavrińčik et al., 2017; Müller & Cornel, 2017; Tripathi et al., 2019) or by developing management tools (Al-Mamoori & Al-Maliki, 2016; Ansari, Alavi, & Ghafoori, 2018; Ashu & Lee, 2019; Hatcho, Kurihara, Matsuno, & Horino, 2018; Jiao, Yu, & Xu, 2018; Sharifipour et al., 2020; Tan, Shao, & Gu, 2018).

Egypt is considered as one of the leader countries which applied the wastewater reuse approach, historically and in the present time. For the present, it was started as early as the 1920s (Saad, Marwa, Bayoumi, Zoghodan, & El-Dissoky, 2015). Drainage water of the Upper Egypt is completely returned to the Nile River which increase its salinity by about 100 ppm in Cairo than that in Aswan, this volume is estimated by about 2.3 BCM annually (INECO, 2009). The country annually receives about 55.5 BCM through the Nile River, in addition to about 2.4 and 6.5 BCM from nonrenewable deep groundwater and shallow groundwater, respectively, and about 1.6 BCM through the rains. The total freshwater budget reached to about 66 BCM, while the total water demands were about 79.5 BCM in 2017 (Mohie El Din & Moussa, 2016). According to Mohie El Din and Moussa (2016), in 2025 the total water shortage would be about 26 BCM, including about 18.3 BCM for agriculture. Moreover, it is expected that, by 2050, the country would require at least 50% more of freshwater (Parkes, 2013). Since nineties, Egypt has already been below the “international water poverty” index of 1000 m³/person/year. The average water per capita has significantly declined, especially in the recent years in conjunction with the rapid increase in population growth (MWRI, 2014). The freshwater shortage should be accomplished through non-conventional water resources such as waste and drainage water reuse (Gabr, 2018). Drainage water is recycled officially by the Ministry of Water Resources and Irrigation (MWRI) and unofficially by farmers. Official drainage water reuse by pumping drainage water back into the Nile River, irrigation canals, and to recharge the shallow groundwater in the Nile Delta (Wolters et al., 2016). Unofficial drainage water reuse was observed, especially along Bahr El-Baqr, Bahr Hadous, Gharbia, Edko, Mouheet and Umoum drains (Gabr, 2018; Sallam, El Shewy, & Dawoud, 2014), its amount ranges from 2.8 BCM to 4 BCM per year (Tanji & Kielen, 2002). Drainage water reuse increased the freshwater budget of Egypt by about 20% (Wolters et al., 2016).

A lot of studies were addressed in the literature which discuss the drainage water suitability for agriculture, a prior drainage water treatment before reuse was the main conclusion for most of the studied cases (Gabr, 2018). Some of these studies will be discussed in the following section.

Allam and Negm (2013) discussed the possibility of using drainage water for irrigation in the northern of the Nile Delta (Kafr El-Sheikh Governorate). Nine water quality parameters were recorded for Nahshart drain include BOD, COD, TSS, TDS, NO₃, NH₄, TP, pH and salinity. According to the Egyptian standards, the authors concluded that the drainage water was not suitable for direct reuse for irrigation. In the same governorate, Saad et al. (2015) carried out some field experiments in the Nile Delta (Kafr El-Sheikh Governorate) to investigate the effects of reusing of agricultural drainage water, treated wastewater and mixed drainage or wastewater with freshwater on the crops’ productivity (Maize and Cotton). The authors used split-plot design, where main plots were assigned to different irrigation water sources. The results revealed that reusing of low-quality water could save freshwater and increase the farmer income. In 2019, El-Agha et al. investigated the drainage system of the Meet Yazid Canal catchment area, which is located in the upper central part of the Nile Delta, by measuring and comparing four parameters (EC, DO, pH and temperature) to the standards. The results showed that the main drains water did not meet the standards for reuse in agriculture (El-Agha, Molle, Rap, El Bialy, & Abou El-Hassan, 2020). In the Nile Delta too, Shaban (2020) investigated the trend variability of drainage water reuse in terms of the discharge and salinity, using statistical assessment tools and based on data sets since 1984. The results showed that both parameters had increasing trends except for the western Nile Delta region which had an insignificant salinity trend. For the future, the author revealed that based on prediction statistical tool, the mean reuse discharge has a potential for increasing for this region. Utilizing of WQI, Elsokkary (2012) used CCME-WQI to evaluate the drainage water of selected drains in the Upper Egypt and the Nile Delta. The author reported that the most drains of the Upper Egypt are categorized between very poor and very good, while those the Nile Delta were between very poor and good. In 2019, El-Sayed and Shaban developed a new proposed WQI for reusing of drainage water in Egypt, based on collected water quality data set (2000–2015). The index was applied for the drainage water in the Nile Delta region as a benchmarking (El-Sayed & Shaban, 2019). Developing of water quality models to manage the reuse process were addressed in limited publications. In 2009, El-Gammal et al. applied DUFLOW model to assess drainage water reuse of the Gharbia drain in the Nile Delta (Kafr El-Sheikh Governorate). Based on recorded water quality parameters (BOD, COD, TSS, TN and TP), the authors reported that the drainage water is not suitable for direct irrigation. Some scenarios were simulated, and the results indicated that primary and secondary treatment for the wastewater, which represents about
25% of the drain discharge, can greatly improve the drain water quality (El-Gamal, Hatem, & El-Bahrawy, 2009). Allam, Tawfik, Yoshimura, and Fleifle (2016) coupled QAUL2Kw model and a genetic algorithm to investigate different scenarios of the drainage water discharge for the Gharbia drain in the Nile Delta (Kafr El-Sheikh Governorate). The main objective was to investigate the drainage water reuse for agriculture based on the Egyptian standards. In 2017, Wahba applied DRAINMOD-S model to simulate different irrigation water scenarios include freshwater and/or drainage water in the Nile Delta region. Better results obtained for the following scenarios: deficit irrigation combined with controlled drainage, cyclic and inter-seasonal cycling use of drainage water with freshwater (Wahba, 2017). Treatment technologies for drainage water were discussed in limited publications, a full review for these technologies can be found in Elshemy (2017). Elkassar and El-Ganzori (2016) tested the “Controlled Drainage” technology at farm level in two pilot areas in the Nile Delta (Samatay area, El-Gharbiya Governorate and Lawiya area, El-Behira Governorate). The used technology depends on storing drainage water to be reused during plant growing periods. CROP_WAT model was used to estimate required water requirements. The authors expect that the proposed system could present a clear farm water management improvement.

The objective of this work is to assess three different drainage water reuse projects in El-Behira Governorate, Egypt. Regional and international guidelines, in addition to two different water quality indices were utilized, based on experimental records. As a result of the lack of freshwater quantity at most times of the year, especially in the summer season, farmers in the study area are forced to reuse the drainage water. Either lifting drainage water, unofficially, directly from drains by small diesels pumps. Or mixing drainage water with fresh canal water, which is lifted by pumping projects that established by MWRI as a solution for the water shortage. But, agricultural drains in the study area suffer from lot of pollutants such as domestic, sewage and agricultural wastes. Especially for being located at the end of the Nile River, what makes it more vulnerable to water shortage and deteriorating water quality (GIZ, 2017) and may make its water unsafe to be reused. So, three different drainage water reuse projects were chosen to be assessed for this research.

**Study area**

The study area of this work is located in the western Delta region, western to the Rosetta Branch (the Nile River western branch) in El-Behira governorate, Egypt, as shown in Figure 1. El-Behira Governorate is one of the largest agricultural governorates in Egypt with a total arable area of 1.7 Million Feddan (Mahmoud, 2014). Which makes it as the second largest governorate in water consumption with an annual amount of about 4 BCM/year (Meguid, 2017). Agricultural areas in El-Behira governorate represent more than two thirds of the total agricultural areas in the western Delta region (El-Nahrawy, 2011). It contributes alone by about 65% of the country’s apple and 40% of Banana production with more than 43% of population works in agricultural (Mahmoud, 2014).

Farmers in El-Behira Governorate suffer from the lack of irrigation water. Therefore, MWRI has established a number of local drainage water reuse projects to help in solving the irrigation water shortage problem. Three of these projects were chosen to be assessed in this study. The three selected projects are Mostanad, El-Gorn and El-Ginia projects that located in Shubrakhit, El-Rahmaniya and Damanhur districts, where their principal irrigation water sources

*Figure 1. Location of the study area.*
are Sahel Markas and El-Khandak El-Sharki main canals, respectively. The three projects are described in the following sections.

**Project no. 1 (Mostanad project)**

Mostanad pumping project is located at Shobrakhit district. It was constructed on the end of Mostanad canal to feed Emtdad Mostanad and Emry canals from Shobrakhit drain, as shown in Figure 2, with an average discharge of 5 m$^3$/s. The characteristics of Mostanad canal and Shobrakhit drain are as following:

**Mostanad canal characteristics**
- Mostanad canal is a branch canal that receives irrigation water from the left side of Sahel Markas main canal at (23.420) Km. Then, it distributes water on Emtdad Mostanad and Emry canals.
- Its total length is about 3.550 km, feeding an area of about 3350 Feddan.
- The bed width of the canal where the pumping station was constructed is 2 m.
- Emtdad Mostanad Canal is a distributive canal begins from the end of Mostanad Canal with a total length of 2.980 km serving an area of 1000 Feddan.
- Emry canal takes its water from the end of Emtdad Mostanad Canal with a total length of 2.5 km and bed width of 1 m.
- It serves an area of about 350 Feddan.

**Shobrakhit drain characteristics**
- Its total length is about 40.260 Km with a bed width of 3 m at the pumping project location.
- It serves an area of 90 Feddan.
- The maximum discharge is about 15.80 m$^3$/s, while the minimum discharge is about 5.30 m$^3$/s.
- The bed level in its outlet is (-2.30 m). Its drainage water is lifted to higher levels through Shobrakhit pump station until water reaches Lake Edko.
- More than seven pumping projects were constructed on its branches to feed the near branch canals.

**Project no. 2 (El-Gorn project)**

El-Gorn pumping project was implemented in El-Rahmaneia district. It was constructed at (6.000) Km of El-Gorn canal to feed its end from Etay/Shobrakhit drain, as shown in Figure 3, with a discharge of about 1 m$^3$/s. The characteristics of the receiving canal and the feeding drain are described in the following sections.

**El-Gorn canal characteristics**
- El-Gorn canal is a distributive canal that receives irrigation water from the end of a branch canal (El-Dahri El-Gharbi canal) at (21.000) Km.
- Its total length is 7.000 Km. The bed width of the canal at its end where the pumping project was constructed is 2 m.

**Etay/Shobrakhit drain characteristics**
- It’s a third-degree drain which is serving an area of 23.160 Feddan.
- Its total length is 20 Km with bed width of 2.50 m at the pumping project place.
- The maximum discharge is 5.68 m$^3$/s, while the minimum discharge is 1.89 m$^3$/s.
- The bed level in its outlet is (-1.30 m), where it delivers its water to Shobrakhit drain.

**Project no. 3 (El-Ginina project)**

El-Ginina pumping project was implemented at Damanhur district. It was constructed at the end of El-Ginina canal to feed its end from Etay/Educo drain with a discharge of 0.5 m$^3$/s as shown in Figure 4.

![Figure 2](image-url) Location of the Project No.1 (Mostanad pumping station) in El-Behira Governorate (modified after Google Earth).
El-Ginina canal characteristics
- El-Ginina canal is a distributive canal that receives irrigation water from a main canal (El-Khandak El-Sharki canal) at (35.320) Km.
- Its total length is 5.9 Km and is serving an area of 571 feddan. The bed width of the canal at its end where the pumping project was constructed is 1 m.

Etay/Educo drain characteristics
- It's a second degree drain with a total length of 5.0 Km.
- It is a water conveyor drain that delivers drainage water to Edko drain at (43.500) Km.
- Its bed width at the pumping project place is 5.0 m.
- The maximum allowable discharge is 5.06 m$^3$/s, while the minimum allowable discharge is 2.53 m$^3$/s.

Methodology
A water quality monitoring program was designed and performed to seasonally cover the considered drainage water sources (drains) and the irrigation water sources (canals) before and after the mixing process for the three projects. The physical, chemical and biological analyzed parameters for each sample were compared to the local and international guidelines and water quality standards for drainage water and irrigation water. Then, two water quality indices were applied to assess the projects water quality situations, the first index is the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI), while the other index is the National Sanitation Foundation Water Quality Index (NSF-WQI). The applied methodology can be summarized in the following steps:

1. Designing of a water quality monitoring program which covers the three investigated projects water ways (drain & canals) all over the considered study period.
2. Experimental work includes collecting of seasonal water quality samples from investigated drainage and irrigation channels (before and after mixing).
3. Laboratory analysis (physical, chemical and biological) is conducted for the collected samples (36 samples).
(4) Egyptian water quality standards for irrigation water and international water quality standards for irrigation water were considered to assess the physical, chemical and biological parameters of the collected samples.

(5) WQIs (CCME & NSF) were applied to assess the seasonal water quality status for the investigated drainage and irrigation channels.

The monitoring system, the considered guidelines and the applied water quality indices are presented in the following sections.

**Experimental work**

The discharge of the three considered irrigation canals of the three projects are recorded during the study period as can be seen in Figure 5. Thirty-six water samples were collected from the three considered projects according to the following plan:

- The samples were seasonally collected, starting from the winter of 2017 to the autumn of 2017.
- Samples were collected from the drains, from the irrigation canals before the mixing point and then from the irrigation canals after the mixing by drainage water (from drains).
- The samples were transported to the Laboratory of Soil Research, West Delta Region at El-Behira Governorate for lab analysis.

The recorded and analyzed parameters were as following:

- Three physical parameters: water temperature, turbidity and total dissolved solids (TDS).
- Twenty-three chemical parameters: pH, total alkalinity, EC, total hardness, COD, BOD, DO, NO₃, NH₄, PO₄, Fe, Cu, Zn, Mn, Pb and Major ions (Na⁺, Ca²⁺, K⁺, Mg²⁺, HCO₃⁻, CO₃⁻, Cl⁻ and SO₄²⁻).
- One biological parameter: fecal coliform.

The statistical characteristics of the recorded parameters (maximum, minimum and average) of the drainage water, irrigation water from canals before mixing and irrigation water from canals after mixing are listed in Tables 1, 2 and 3, respectively.

**Guidelines and water quality standards**

Two guidelines groups were considered to assess the water quality status of irrigation water before and after mixing process. These guidelines are the Egyptian standards and the international standards.

**Egyptian water quality standards for irrigation water**

Egyptian water quality standards for drainage water and treated wastewater (TWW) which are used for irrigation are controlled through some laws as following:

- Law 12/1984 for irrigation water (Table 4).
- Law 48/1982 (decree No. 51/2013 – modified with decision No. 208/2018) for drainage water (Table 5).
- Egyptian Wastewater Reuse Code 2015 for irrigation [ECP-501/2015] (Tables 6 and 7)

**International water quality standards for irrigation water**

The limits for irrigation of the Food and Agriculture Organization (FAO limits) (Ayers & Westcot, 1985) are considered for this study (Table 8).

**Water quality index approach**

**CCME-WQI**

The Canadian Council of Ministers of the Environment developed the CCME-WQI as a flexible index which can assemble unspecific number of water quality parameters according to available records and

![Figure 5. Temporal variation of the irrigation canals discharge during the study period.](image-url)
their corresponding standards (objectives). This index can be calculated according to the following equation (Cash and Wright, 2001):

$$ \text{CCME} - \text{WQI} = 100 - \left[ \left( F_1^2 + F_2^2 + F_3^2 \right)^{1/2} / 1.732 \right] $$

Eq.(1)

Where factors $F_1$, $F_2$ and $F_3$ are defined as scope, frequency and amplitude, respectively, where are described in detail in the CCME guide (Cash and Wright, 2001). The water quality status according to this index is classified into five categories as shown in Table 9. For this work, 12 water quality parameters were selected to calculate the CCME-WQIs for the three investigated drains (DO, COD, BOD, TDS, NO$_3$, SO$_4$, Fe, Mn, FC, pH, water Temp., turbidity). The index objectives are the Egyptian water quality standards for drainage water reuse [Law No. 48/1982 – Article No. 51 amended in 2013].

NSF-WQI

In 1970, the National Sanitation Foundation developed one of the earliest WQI, NSF-WQI (Brown, McClelland, Deninger, & Tozer, 1970). The index assembles nine water quality parameters (with specific weights): DO (17%), FC (16%), BOD (11%), pH (11%), nitrate (10%), phosphate (10%), temperature

### Table 1. Statistical characteristics of drainage water parameters.

| No. | Project No. 1 | Project No. 2 | Project No. 3 |
|-----|---------------|---------------|---------------|
|     | WQ Par. (mg/l) | Max | Min | Av  | Max | Min | Av  | Max | Min | Av  |
| 1   | FC (N /100 ml) | 1.1 | 2.0 | 3.1 | 2.4 | 2.0 | 1.1 | 9.3 | 1.5 | 3.3 |
| 2   | BOD           | 45.00 | 25.00 | 33.75 | 55.00 | 15.00 | 33.75 | 75.00 | 15.00 | 35.00 |
| 3   | COD           | 134.0 | 86.00 | 109.8 | 115.0 | 88.00 | 105.3 | 121.0 | 88.00 | 103.3 |
| 4   | DO            | 5.10 | 2.88 | 4.05 | 4.50 | 1.03 | 2.71 | 4.50 | 3.80 | 4.17 |
| 5   | NH$_4$        | 4.45 | 3.00 | 3.43 | 3.92 | 0.83 | 1.67 | 5.60 | 1.00 | 3.28 |
| 6   | NO$_2$        | 85.50 | 31.33 | 52.03 | 22.77 | 15.20 | 20.01 | 89.50 | 24.78 | 61.00 |
| 7   | PO$_4$        | 3.49 | 1.06 | 1.87 | 1.20 | 0.59 | 0.87 | 1.48 | 0.76 | 1.17 |
| 8   | pH            | 7.67 | 7.06 | 7.44 | 7.45 | 7.26 | 7.35 | 7.71 | 7.22 | 7.52 |
| 9   | TDS           | 1018 | 541 | 799 | 832 | 573 | 726 | 1050 | 653 | 897 |
| 10  | Mn            | 0.94 | 0.18 | 0.37 | 0.16 | 0.14 | 0.16 | 0.35 | 0.11 | 0.25 |
| 11  | Pb            | 0.82 | 0.00 | 0.32 | 0.43 | 0.00 | 0.11 | 0.27 | 0.00 | 0.07 |
| 12  | Fe            | 1.93 | 0.62 | 1.70 | 0.59 | 0.29 | 0.43 | 1.54 | 0.38 | 0.85 |
| 13  | Cu            | 1.35 | 0.00 | 0.34 | 1.88 | 0.00 | 0.47 | 2.01 | 0.00 | 0.51 |
| 14  | Zn            | 0.17 | 0.02 | 0.13 | 0.63 | 0.02 | 0.26 | 0.47 | 0.02 | 0.24 |

### Table 2. Water quality statistical characteristics of irrigation water from canals before mixing.

| No. | Project No. 1 | Project No. 2 | Project No. 3 |
|-----|---------------|---------------|---------------|
|     | WQ Par. (mg/l) | Max | Min | Av  | Max | Min | Av  | Max | Min | Av  |
| 1   | FC (N /100 ml) | 4.5 | 2.3 | 1.3 | 9.3 | 4.3 | 6.8 | 2.4 | 4.0 | 9.8 |
| 2   | BOD           | 25.00 | 15.00 | 33.75 | 15.50 | 7.00 | 8.8 | 10.05 | 5.0 | 6.3 |
| 3   | COD           | 95.0 | 15.0 | 67.5 | 86.0 | 70.0 | 80.3 | 98.05 | 59.0 | 74.8 |
| 4   | DO            | 5.4 | 4.3 | 4.9 | 5.4 | 4.4 | 4.8 | 5.2 | 5.0 | 5.1 |
| 5   | NH$_4$        | 0.3 | 0.2 | 0.2 | 0.9 | 0.4 | 0.6 | 0.6 | 0.2 | 0.4 |
| 6   | NO$_2$        | 27.7 | 7.6 | 14.7 | 8.2 | 1.9 | 5.3 | 8.1 | 1.7 | 4.9 |
| 7   | NO$_3$        | 1.9 | 0.2 | 0.8 | 0.4 | 0.2 | 0.3 | 0.3 | 0.2 | 0.2 |
| 8   | pH            | 7.5 | 7.3 | 7.4 | 7.6 | 7.2 | 7.4 | 7.9 | 7.2 | 7.5 |
| 9   | TDS           | 768 | 224 | 440 | 608 | 190 | 396 | 346 | 205 | 272 |
| 10  | Mn            | 0.3 | 0.0 | 0.2 | 0.2 | 0.1 | 0.2 | 3.2 | 0.3 | 1.3 |
| 11  | Pb            | 0.4 | 0.0 | 0.1 | 0.4 | 0.0 | 0.1 | 0.3 | 0.0 | 0.1 |
| 12  | Fe            | 1.2 | 0.0 | 0.4 | 0.4 | 0.3 | 0.4 | 0.6 | 0.0 | 0.2 |
| 13  | Cu            | 0.1 | 0.0 | 0.0 | 0.9 | 0.0 | 0.2 | 0.4 | 0.0 | 0.1 |
| 14  | Zn            | 0.2 | 0.0 | 0.1 | 0.2 | 0.0 | 0.1 | 0.4 | 0.0 | 0.2 |
| 15  | SAR           | 6.6 | 1.7 | 4.2 | 6.1 | 1.8 | 3.8 | 4.9 | 1.5 | 2.9 |
| 16  | T. Alk.       | 255 | 50 | 154 | 190 | 64 | 110 | 126 | 60 | 82 |
| 17  | T. Hard       | 15.7 | 4.5 | 10.4 | 12.5 | 6.8 | 9.4 | 7.0 | 4.9 | 6.0 |
| 18  | SO$_4$        | 23.5 | 2.4 | 10.2 | 21.1 | 1.0 | 11.5 | 24.0 | 1.0 | 9.8 |
| 19  | HCO$_3$       | 5.1 | 1.0 | 3.1 | 3.8 | 1.3 | 2.2 | 2.5 | 1.2 | 1.7 |
| 20  | Cl             | 7.0 | 1.2 | 3.4 | 7.0 | 1.5 | 3.5 | 3.1 | 1.0 | 1.8 |
| 21  | Mg            | 2.6 | 0.7 | 1.6 | 1.8 | 1.0 | 1.3 | 1.1 | 0.4 | 0.7 |
| 22  | Ca            | 2.0 | 0.6 | 1.5 | 2.3 | 1.0 | 1.6 | 1.8 | 0.8 | 1.2 |
| 23  | K             | 2.0 | 0.2 | 0.8 | 1.1 | 0.2 | 0.5 | 0.9 | 0.2 | 0.4 |
| 24  | Na            | 5.0 | 1.2 | 3.1 | 4.9 | 1.3 | 2.8 | 2.3 | 1.1 | 1.7 |
| 25  | EC (dS/m)     | 1.2 | 0.4 | 0.7 | 1.0 | 0.3 | 0.6 | 0.5 | 0.3 | 0.4 |
| 26  | Tur. (NTU)    | 13.0 | 5.2 | 8.4 | 16.8 | 2.8 | 11.5 | 11.5 | 4.3 | 6.8 |
Table 3. Water quality statistical characteristics of irrigation water from canals after mixing.

| Irrigation Water after Mixing | Project No. 1 | Project No. 2 | Project No. 3 |
|------------------------------|---------------|---------------|---------------|
| No.  | FC (N/100 ml) | Max | Min | Av | Max | Min | Av | Max | Min | Av |
| 1    | 9.3           | 9.3 | 3.1 |    | 4.3 | 1.5 | 2.9 | 2.1 | 7.0 | 1.1 |
| 2    | 25.0          | 15.0 | 20.0 |    | 30.0 | 15.0 | 21.3 | 30.0 | 10.0 | 16.3 |
| 3    | 130.0         | 18.0 | 90.0 |    | 100.0 | 88.0 | 94.8 | 105.0 | 80.0 | 87.7 |
| 4    | 5.3           | 3.9 | 4.5 |    | 5.2 | 2.0 | 3.7 | 4.6 | 4.0 | 4.3 |
| 5    | 0.9           | 0.2 | 0.4 |    | 1.9 | 0.8 | 1.1 | 3.2 | 0.3 | 1.3 |
| 6    | 30.0          | 15.2 | 22.9 |    | 18.2 | 5.6 | 10.0 | 10.5 | 1.8 | 7.3 |
| 7    | 2.6           | 0.8 | 1.4 |    | 0.8 | 0.5 | 0.7 | 1.2 | 0.3 | 0.7 |
| 8    | 7.4           | 7.0 | 7.5 |    | 7.5 | 7.2 | 7.4 | 7.7 | 7.3 | 7.5 |
| 9    | 1005          | 264 | 708 |    | 736 | 272 | 559 | 1018 | 550 | 826 |
| 10   | 0.7           | 0.1 | 0.3 |    | 0.1 | 0.0 | 0.1 | NA* | NA* | NA* |
| 11   | 0.6           | 0.0 | 0.2 |    | 0.4 | 0.0 | 0.1 | 0.2 | 0.0 | 0.1 |
| 12   | 1.9           | 0.1 | 0.8 |    | 0.3 | 0.0 | 0.2 | 1.1 | 0.0 | 0.5 |
| 13   | 1.2           | 0.0 | 0.3 |    | 0.3 | 0.0 | 0.1 | 1.8 | 0.0 | 0.9 |
| 14   | 0.2           | 0.0 | 0.1 |    | 0.2 | 0.0 | 0.1 | 0.3 | 0.0 | 0.1 |
| 15   | 10.2          | 1.9 | 6.6 |    | 7.9 | 3.0 | 5.9 | 12.3 | 5.3 | 8.6 |
| 16   | T. Alk.       | 444 | 60  | 214 |    | 306 | 94  | 159 | 340 | 78  | 227 |
| 17   | T. Hard       | 21.8 | 9.6 | 15.8 |    | 15.6 | 8.2 | 12.0 | 21.1 | 7.5 | 13.9 |
| 18   | SO4         | 43.2 | 5.3 | 16.0 |    | 28.8 | 1.9 | 16.3 | 26.4 | 4.3 | 20.5 |
| 19   | HCO3       | 8.9 | 1.2 | 4.3 |    | 6.1 | 1.9 | 3.2 | 6.8 | 1.6 | 4.5 |
| 20   | Cl           | 8.5 | 2.2 | 6.0 |    | 8.2 | 1.9 | 4.9 | 9.7 | 5.8 | 6.8 |
| 21   | Mg           | 3.0 | 1.6 | 2.3 |    | 2.2 | 1.1 | 1.8 | 3.0 | 1.0 | 1.9 |
| 22   | Ca           | 3.8 | 1.2 | 2.6 |    | 2.6 | 1.3 | 1.9 | 3.5 | 1.2 | 2.4 |
| 23   | K            | 2.6 | 0.3 | 1.1 |    | 1.3 | 0.3 | 0.9 | 2.3 | 0.5 | 1.2 |
| 24   | Na           | 7.5 | 1.4 | 5.1 |    | 6.0 | 2.0 | 4.3 | 7.4 | 4.0 | 6.1 |
| 25   | EC (mg/S)    | 1.6 | 0.4 | 1.1 |    | 1.2 | 0.4 | 0.9 | 1.6 | 0.9 | 1.3 |
| 26   | EC (mg/S)    | 124.0 | 12.6 | 49.0 |    | 51.3 | 3.1 | 25.3 | 125.0 | 6.9 | 67.0 |

Change (10%), turbidity (8%) and total solids (7%). NSF-WQI can be calculated using the following Equation WQI (Brown et al. 1970):

$$\text{NSF - WQI} = \left[ \sum W_i * Q_i / \sum W_i \right]_{i=1:n}$$

Eq (2)

Where, $W_i$ = weight unit of each parameter, $n$ = number of selected parameters and $Q_i$ is the sub-index quality value for the $i^{th}$ parameter, can be obtained from the appropriate sub-index rating graph, in Brown et al. (1970). The water quality status can be classified into five categories according to this index, as can be seen in Table 9. For this study, six water quality parameters, out of nine, were used to calculate NSF-WQI. TP, TSS and temperature change were not available.

Results and discussions

Thirty-six water samples were seasonally collected from the three projects from the canals and the drains before mixing and from the canal after mixing during the period from February 2017 to November 2017. The physical, chemical and biological analyzed parameters for each sample were compared to the Egyptian and international guidelines and water quality standards for drainage water and irrigation water. Moreover, two water quality indices were applied to assess the drainage and irrigation water quality status.

Assessment of drainage water

Law 48/1982 (decree No. 51/2013 – modified with decision No. 208/2018) is concerning the drainage water guidelines before mixing with freshwater for irrigation purposes, Table 5. Some of the recorded
Table 6. Egyptian code for the reuse of TWW in agriculture (MWRI, 1998) according to the degree of treatment.

| Degree of treatment/ objectives | Degree A | Degree B | Degree C | Degree D |
|--------------------------------|----------|----------|----------|----------|
| Turbidity (NTU)                | 5        | Not defined | Not defined | Not defined |
| BOD 5 mg/l                    | 80       | 30       | 80       | 350      |
| E. coli/100 ml                | 20       | 100      | 1000     | Not defined |

Table 7. Egyptian code for the reuse of TWW in agriculture (MWRI, 1998) (for the chemical elements of wastewater treated and reused for irrigation purposes).

| Parameter | Maximum concentration for long-term use |
|-----------|----------------------------------------|
| PO₄ (mg/l) | 30                                     |
| SO₄ (mg/l) | 500                                    |

parameters, such as: pH, temperature, TDS, Zn, Mn and Fe, were within the permissible limits. While, other parameters such as: FC, BOD, COD, DO, Pb and Cu values exceeded the permissible limits during some seasons as shown in Figure 6 and Figure 7. NO₃ and PO₄ of the drainage water are also presented in Figure 7 due to their effect on the quality of drainage water. Moreover, TDS values ranged from minimum concentration of 541 ppm at the first project to the maximum concentration of 1050 ppm at the third project (see Table 1), which ensure that these drainage water shouldn’t be used for irrigation without mixing with freshwater (1:1) according to the Egyptian standards.

- For FC: all records for the three drains were far above the maximum permissible limit (5000 N/100 ml) for all seasons. Where the maximum value was at project No.1 during autumn in Shobrakhit drain (11000000 N/100 ml). And the lowest value was at project No. 3 in Etya /Edco drain during spring (15000 N/100 ml). For BOD: The highest values of BOD that were far above the standard limits (30 mg/l) within the study period were recorded at: project No.1 by 45 and 35 mg/l during summer and autumn seasons, respectively, at project No.2 by 35 and 55 mg/l during winter, and autumn seasons, respectively and at project No. 3 by 75 mg/l during the summer season. These results indicate that all drains suffer from severe sewage pollution.
- For COD: all the recorded values for the 3 drains during the study period were higher than the maximum permissible limit (50 mg/l) for all seasons. The highest value was monitored during autumn (134 mg/l) at project No. 1. While, the lowest one was recorded at the same project during summer (86 mg/l). For Pb: for the three projects Pb showed very small values that were within the permissible limits (0.1 mg/l) during winter and spring. While for project No.1 during summer and the three projects during autumn, Pb exceeded the limits with the highest one during autumn at project No. 1 (0.822 mg/l). These results confirm the industrial pollution of these drains.
- For DO: the majority of the recorded DO values of drainage water were below standards (5 mg/l) during the study period. As, the highest DO values that hardly exceeded the limits (5 mg/l) were recorded at Project No.1 during winter and summer by 5.1 and 5 mg/l, respectively. These records are expected due to the high amounts of received organic matters in the drains which consumes DO in the degradation process.
- For Cu: the recorded values of Cu for the three drains exceeded the permissible limits (1 mg/l) only during summer (1.3468, 1.8806, 2.0143) mg/l for projects No. 1, 2 and 3, respectively. And were within the permissible limits during the other seasons. These values of Cu in the summer season may return to used pesticides for summer crops in the around agricultural lands.

Table 8. FAO guidelines of water quality for irrigation (Ayers & Westcot, 1985).

| Water Quality Parameter | Degree of problem |
|-------------------------|-------------------|
|                         | No Problem | increasing problem | Severe problem |
| EC (dS/m)               | < 0.70      | 0.70–3.0            | >3.0          |
| For salinity problem    | > 0.7       | 0.7–0.2             | < 0.2         |
| For permeability problem| < 0.4       | 0.4–1.0             | >1.0          |
| Adj SAR                 | < 6.0       | 6–12                | >12           |
| NO₃–N (mg/l)            | < 5         | 5–30                | >30           |
| NH₄–N (mg/l)            | 10          | 5–50                | >50           |

Table 9. Ranking of the water quality status of water bodies according to the CCME-WQI & NSF-WQI score.

| CCME-WQI Rank | CCME-WQI Score | NSF – WQI Rank | NSF – WQI Score |
|---------------|----------------|----------------|----------------|
| Poor (P)      | 0–44           | Very bad (VB)  | 0–25           |
| Marginal (M)  | 45–64          | Bad (B)        | 25–50          |
| Fair (F)      | 65–79          | Medium (M)     | 50–70          |
| Good (G)      | 80–94          | Good (G)       | 70–90          |
| Excellent (E) | 95–100         | Excellent (EX) | 90–100         |
For NO₃ and PO₄, it can be noticed the high concentrations of both components in the drainage water due to the used fertilizers, particularly for projects No.1 and No. 3.

According to the previous evaluation, the drainage water for the three project is not valid to be used for irrigation, according to the Egyptian standards. A pre-treatment should be firstly done to improve the drainage water quality before mixing with freshwater. Treatment process should focus on parameters such as BOD, COD, FC and Cu, which have exceeded the permissible limits.

Assessment of irrigation water

According to Egyptian standards (Law 12/1984)

Egyptian standards for irrigation water (Law 12/1984 – Table 4) is mainly focusing on two water quality parameters which cause salinity and permeability problems for the agricultural lands. These parameters are salinity, which is presented by EC or TDS, and Adjusted sodium adsorption ratio (Adj. SAR). Figure 8 presents the records of EC and TDS and the calculated values of Adj. SAR (based on the concentrations of Na, Ca and Mg) of the canals in the three projects, before and after mixing with drainage water.

For salinity, before mixing, as can be seen, the salinity records (EC and TDS) of the irrigation water are already high in winter and autumn seasons due to the decrease in water discharge, check Figure 5, in these two seasons. For project No.1, the freshwater salinity exceeded the permissible limits of Egyptian standards in both seasons, while project No. 2 exceeded the permissible limits only in the summer season. The three projects have minimum salinity values in the spring season, where the freshwater discharges are maximum during this season (Figure 5). Project No. 3 has the minimum salinity values among the three projects (average TDS is about 272 ppm). After mixing between both freshwater and drainage water, the salinity of the irrigation water of the three projects exceeded the permissible limits for all seasons, except for the first two projects in the spring season.
Although project No. 3 had the minimum salinity records before mixing, its salinity records after mixing are the highest due to the drainage water salinity of this project which had the highest salinity records (average TDS is about 900 ppm, Table 1).

For Adj SAR, before mixing, the three projects didn’t exceed the permissible limit of Adj SAR. While after mixing, the first and third projects exceeded the permissible limits of Adj SAR in the winter and the spring, respectively, and close to the permissible limits in the autumn and the summer, respectively. The bad status of the drainage water quality of the project No. 3 lead to a bad water quality status of the blended water.

According to the Egyptian standards of irrigation water, the blended irrigation water of the three projects causes salinity and permeability problems due to its high salinity and risky levels of Adj SAR.

**According to Egyptian standards (ECP-501/2015)**

Egyptian Standards (ECP-501/2015 – Tables 6 and 7) are mainly for the reuse of treated wastewater in agriculture. So, these standards were considered to evaluate the irrigation water of the three before and after mixing, assuming the highest degree of treatment (degree A). The considered parameters were turbidity, BOD, FC (as indicator of E. Coli), PO4 and SO4.

Figure 9 shows the records of these parameters for the three projects during the study period. For PO4 and SO4, both parameters didn’t exceed the permissible limits before and after the mixing. While for turbidity and FC, both parameters exceeded the permissible limits before and after the mixing for the three projects. For BOD, high concentrations were experienced before and after the mixing, the records of BOD after mixing exceeded the permissible limits for the three projects, except for project No. 3 in the winter and autumn seasons.

These records are clearly stated the municipal pollution of the canals and drains in the study area, which made the water quality status of freshwater and blended irrigation water are worse than treated wastewater. A simple wastewater treatment plant, mainly for BOD, COD and FC, should be applied on the drains of the study area to improve the water quality of blended irrigation water.

**According to the FAO guidelines**

The limits for irrigation of the Food and Agriculture Organization (FAO limits) (Ayers & Westcot, 1985) were considered for this study (Table 8). FAO limits classify the degree of problem due to using irrigation...
water to three classes: no problem, increasing problem or severe problem, according to the records of some water quality parameters (EC, Adj SAR, NO₃, NH₄ and pH). Moreover, these limits include standards for some heavy metals (Zn, Pb, Fe, Mn and Cu). The records of the considered parameters for the irrigation water, before and after mixing, for the three projects are shown in Figure 10 and Figure 11. For EC, the projects No. 1 and No.2 already exceeded the permissible limit, in the winter and autumn seasons for the first project and in the summer for the second one. While after mixing, the three projects exceeded the permissible limit, particularly project No. 3 which had high records of salinity all seasons. According to FAO classification, using of this irrigation water will cause an “increasing problem,” which confirms the salinity problems which attained according to the Egyptian standards. For Adj SAR, where the FAO limit (6) is less than the Egyptian...
Figure 9. Variation of some water quality parameters of irrigation water in the three projects before (to the left) and after (to the right) the mixing process during the study period [Egy-ECP Guidelines].

standard of (9), two projects of the three (1 & 2) hardly exceeded the permissible limit before mixing. While after mixing, the three projects exceeded the permissible limit, except for one season for each project. The first two projects are classified as “increasing problem,” while project No. 3 is classified as “severe problem” which can cause permeability problems for the soil. For the nitrate, the three projects already before mixing have risky concentrations of NO₃ for most seasons, particularly project No. 1 which can be classified as “increasing problem.” So, after mixing, the three projects can be classified according to FAO limits as “increasing problem” (5–30 mg/l). Some parameters didn’t exceed the permissible limits before and after the mixing, such as NH₄, pH, Zn, Pb and Fe. While two heavy metals, Mn and Cu, have critical values. For Mn, unfortunately the records of the project No. 3 after mixing were not available, which for sure would be
dangerous concentrations due to the high records of the drain (the maximum is 0.35 mg/l and the average is 0.25 mg/l, Table 1) and the canal before mixing (the maximum is 3.2 mg/l and the average is 1.3 mg/l, Table 2) in this project. Project No. 1 exceeded the permissible limit (before and after mixing) in the autumn season, while it was less than the limit in other seasons, while the project No. 2 records were less than the limit in all seasons. For Cu, it was found only in the summer season for the three projects, before and after mixing, in addition to the project No. 3 in the spring season after mixing. All the measured values exceeded the permissible limit, except for the first project before mixing.

According to the international guidelines, FAO limits, the irrigation water of the three projects can be classified as “increasing problem,” which reveals the bad status of the water quality. These results confirm the other result which were based on the Egyptian standards. Improvement of the drains and canals water quality of the three projects are essential.

**Water quality index**

Two water quality indices were used to practically facilitate having an overall water quality statue for drainage water (CCME-WQI) and irrigation water (NSF-WQI) in the study area. Using of WQI approach is essential for presenting results to decision makers as a single estimation, instead of details of a lot of water quality parameters. The results of the WQIs are presented in the following sections.

**CCME-WQI (drainage water assessment)**

CCME-WQI was used to evaluate the water quality status of the drainage water in the three considered projects. The records of 12 water quality parameters were used, in addition to the Egyptian drainage water standards (Table 5). Figure 12 and Table 10 show the temporal distribution of CCME-WQI for the three selected drains for the three projects for the studied period. For the first project, the water quality status of drainage water (Shobrakhit drain) was ranked as “Poor,” according to the Egyptian standards for drainage water, except in the spring season which was hardly ranked as “Marginal.” Similar to this project, the drainage water of project No. 2 (Etay/Shobrakhit drain) was ranked too as “Poor” except in the winter season which was hardly ranked as “Marginal.” While project No. 3 (Etay/Educo drain) was ranked between “Poor,” in the summer and autumn seasons, and “Marginal” in the winter. Its highest CCME-WQI was calculated in the spring season as “Fair,” due to

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**Figure 10.** Variation of some water quality parameters of irrigation water in the three projects before (to the left) and after (to the right) the mixing process during the study period [FAO Guidelines].
the increase in water discharge (Figure 8). Generally, CCME-WQI confirms that the water quality status of drainage water for projects No. 1 and No. 2 is ranked as “Poor,” average CCME-WQI were 41.7 and 41.6, respectively. While for the third project, it can be classified as “Marginal,” an average value of 50.9, due to this drain has the minimum municipal pollution among the three drains, minimum FC (an average of 3.3E+05 N/100 ml) and maximum DO (an average of 4.17 mg/l), see Table 1.

So, according to these results and based on the Egyptian standards for drainage water, the three drains should have treatment plants to improve the quality of drainage water before using for agriculture.

| Project | Before Mixing | After Mixing |
|---------|---------------|--------------|
| Zn (mg/l) | Jan-17 | Mar-17 | Apr-17 | Jun-17 | Aug-17 | Sep-17 | Nov-17 | Dec-17 |
| Pb (mg/l) | Jan-17 | Mar-17 | Apr-17 | Jun-17 | Aug-17 | Sep-17 | Nov-17 | Dec-17 |
| Fe (mg/l) | Jan-17 | Mar-17 | Apr-17 | Jun-17 | Aug-17 | Sep-17 | Nov-17 | Dec-17 |
| Mn (mg/l) | Jan-17 | Mar-17 | Apr-17 | Jun-17 | Aug-17 | Sep-17 | Nov-17 | Dec-17 |
| Cu (mg/l) | Jan-17 | Mar-17 | Apr-17 | Jun-17 | Aug-17 | Sep-17 | Nov-17 | Dec-17 |

Figure 11. Variation of some water quality parameters of irrigation water in the three projects before (to the left) and after (to the right) the mixing process during the study period [FAO Guidelines].
NSF-WQI was used, based on nine water quality parameters, to evaluate the water quality status of the three canals of irrigation water (after mixing) of the three considered projects during the study period. Figure 13 and Table 10 show the temporal distribution of NSF-WQI for the three canals after the mixing process for the three projects for the studied period. According to the NSF-WQI ranking, the three canals water quality were ranked as “Poor.” Small differences can be noticed between the three canals due to the differences in the water quality records of each season. Generally, the average NSF-WQI values for Mostanad canal, El-Gorn canal and El-Ginina canal, were 38.2, 40.5 and 39.1, respectively, which are ranked as “Poor” water quality status. These results confirm the previous results of CCME-WQI, which can be simply stated that the “Bad” water quality status of drainage water will cause a “Bad” water quality status for the blended irrigation water, which shouldn’t be used for irrigation without treatment.

**NSF-WQI (blended irrigation water assessment)**

NSF-WQI was used, based on nine water quality parameters, to evaluate the water quality status of the three canals of irrigation water (after mixing) of the three considered projects during the study period. Figure 13 and Table 10 show the temporal distribution of NSF-WQI for the three canals after the mixing process for the three projects for the studied period. According to the NSF-WQI ranking, the three canals water quality were ranked as “Poor.” Small differences can be noticed between the three canals due to the differences in the water quality records of each season. Generally, the average NSF-WQI values for Mostanad canal, El-Gorn canal and El-Ginina canal, were 38.2, 40.5 and 39.1, respectively, which are ranked as “Poor” water quality status. These results confirm the previous results of CCME-WQI, which can be simply stated that the “Bad” water quality status of drainage water will cause a “Bad” water quality status for the blended irrigation water, which shouldn’t be used for irrigation without treatment.

**Conclusion and recommendations**

Agricultural drainage water re-use is the main, and sole, water resource for Egypt to fulfill its increasing freshwater requirements due to the shortage of
its freshwater quota. The drainage water reuse is mainly considered, officially and non-officially, for agriculture through mixing with freshwater or without mixing (in case of the depletion of irrigation waters in canals). So, water quality assessment for drainage water and blended irrigation water is essential for food security and health protection as the agricultural drains receive industrial and municipal wastes, in addition to agricultural pollution.

Three different drainage reuse projects in El-Behira governorate, a coastal governorate lies to the west of the Nile Delta, were selected to assess the water quality status of the irrigation water. Each project has an irrigation system which consists of an agricultural drain and an irrigation canal. Drainage water are pumped to the canal from the drain to complete the required irrigation water for agriculture. So, water quality samples were collected from the drain (drainage water), the canal before mixing (irrigation water) and the canal after mixing (blended irrigation water). Fourteen water quality parameters were recorded for the drain and 26 parameters were recorded for the canal (before and after mixing), in addition to the water discharge in canals. The water quality records were statistically analyzed and then compared to Egyptian (for drainage and irrigation water) and international guidelines (for irrigation water). Moreover, two water quality indices were applied to assess the drainage and irrigation water.

The results revealed the critical situation of the three projects where most of the water quality parameters of drainage and irrigation water exceeded the permissible limits (national and international) to ensure that the drainage water shouldn’t be reused for agriculture and the blended irrigation water shouldn’t be used for irrigation. The applied water quality indices confirmed the previous results and ranked the drains as “Poor” to “Marginal,” based on the Egyptian standards for drainage water, and ranked the canals as “Bad,” based on NSF-WQI.

This study showed a severe deterioration in water quality of water channels in the study area. Particularly, high rates of fecal coliform contamination that confirms the presence of sewage pollution. A process of water treatment should be done before using blended water for irrigation, particularly with small quantities of freshwater in the mixing process. Using of a low-cost drainage water improvement technology which can be considered as a supplemented tool to drainage water reuse, at least on drains, is essential. This study is the base for an ongoing pilot project of using a low-cost drainage water improvement technology in one of the considered projects.

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