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Soil Quality Indicators in Al-Qalyubia Governorate as Affected by Long-term Wastewater Irrigation

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THE SUSTAINABLE irrigated agriculture in Egypt is threatened by water stress that made the reuse of wastewater an alternative option not only in the sandy desert soils but also in the alluvial soils. To assess the impacts of long-term wastewater irrigation on soil quality, soils have been irrigated with the effluents of Al-Qalyubia drain beside adjacent Nile fresh water-irrigated soils (reference) , sampled and analyzed. The wastewater irrigation improved fertility status, causing significant increases ($P < 0.05$) in total N and AB-DTPA extractable P, Fe and Mn compared to the reference soils. However, there was a significant ($P < 0.05$) build-up in soil salinity and total heavy metals; Cd, Cr, Co, Cu, Ni, Pb and Zn in the wastewater-irrigated soils over the reference soils. The Dutch model indicated that the Nile fresh water remained safe for agricultural production, while the wastewater-irrigated soils could be used under certain precautions. Focal measures are recommended to alleviate heavy metal contaminants to avoid potential environmental risks including mixing the wastewater with the fresh water before use and implementation of proper on-farm treatments.

Introduction

Egypt is water stressed due to aridity, limited natural water resources and increased demand for industrial, domestic and agricultural sectors (Abdel Meguid, 2017). The Nile River is the major source for water supply in Egypt. It provides 55.5 billion m^3 $year^{-1}$ that accounts for more than 90% of the water budget, while the remaining 10% comes from renewable and fossil groundwater beside a few showers of rainfall (ICARDA, 2011). The agriculture sector is the main consumer of fresh water, which consumes 80-85% of water resources (Mahmoud and El-Bably, 2017). The present water supplies are not adequate to maintain sustainable irrigated agricultural, and hence unconventional wastewater resources provide an alternative supply to fulfill the increased demand (Soliman, 2015). Using such waters helps to diminish the gap between supply and demand, prevent contamination of freshwater supplies and provide a solution to water shortage and climate change (Loutfy, 2011 and Ali *et al.*, 2013). Soil quality indicators are a combination of measurable physical,chemical and biological soil properties used to monitor changes in the soil capacity to function within natural or managed ecosystem boundaries (Yao *et al.*, 2013). The physical indicators are related to the retention and transport of water, air, and nutrients. Examples include texture, bulk density, and water holding capacity. The chemical indicators determine soil-plant relations, including pH, EC, organic carbon, plant nutrients and potential contaminants. The biological indicators include microbial biomass C and N, potentially mineralized N and soil respiration (Wienhold *et al.*, 2004). These indicators are affected by agricultural management practices, as the latter cause modifications in soil properties as well as in soil biotic community (Marzaioli *et al.*, 2010).

Attention has been paid to wastewater irrigation which has a notable effect on soil quality under different conditions (Masto *et al.*, 2009 and Rezapour & Samadi, 2011). With the beginning of adopting wastewater irrigation in Nile Delta region since the mid-nineties of the last century (Rashed *et al.*, 1995), positive and negative effects on soil quality have been reported. Benefits were enriching the soil with organic carbon, macro, and micro nutrients, but harmful effects were involved, particularly toxic heavy metal accumulation (Galal, 2015 and Mahmoud & Ghoneim, 2016). Thus, the effective and safe use of wastewater for irrigation requires careful applications of wastewater (Zidan and Dawoud,

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2013). In addition, periodic monitoring and evaluation for soil quality should be conducted (Yadav *et al.*, 2015). In this concern, the current study aimed at monitoring the changes of the physicochemical properties and heavy metals accumulation in alluvial soils in Al-Qalyubia Governorate which have been subjected to long-term wastewater irrigation in comparison to soils irrigated with the Nile fresh water.

Materials and Methods

The area of study

The studied area is located at Tokh District, Al-Qalyubia Governorate between 30° 23’ 40.918” to 30°18’ 42.242” N and 31° 14’ 21.667” to 31°14’ 49.795” E (Fig. 1), covering agricultural fields along the banks of Al-Qalyubia drain. The drain conveys treated and untreated mixes of agricultural, industrial and domestic effluents to Bahr El-Baqar drain that extends northward to Lake Manzala. Farmers have applied these effluents directly to the soil seasonally during water shortage, especially in the summer season for more than 25 years in a furrow application. The area is characterized by hot arid summer and mild rainy winter. The mean annual temperature is 20.3 °C and the highest temperature (36.7 °C) occurs in July, while the lowest (6.4 °C) occurs in January. The annual precipitation is 65.6 mm. The soils are classified according to Soil Survey Staff (2014) as Typic Haplotorrerts with Thermic temperature and Torric moisture regimes.

Samples collections

Nine soil samples were collected from the wastewater-irrigated farms (S1:S9) along the banks of the drain covering a distance of 10.30 km during 2016 summer season. A nearby area irrigated with the Nile fresh water through KamBattin Canal (R1:R9) was selected for nine reference soil samples (Fig. 2). At each crop farm, five surface soil samples (0-30 cm) were collected using a stainless-steel auger and well-mixed in a preventative composite sample. Along with soil samples, three water samples were collected from the drain and another three from the fresh water canal using plastic bottles.

Soil and water analysis

Soil samples were air-dried, crushed and passed through a 2-mm mesh. Soil chemical properties; pH, EC, organic matter (OM), total N were determined following the standard methods of Sparks *et al.* (1996). Available P, K, and micronutrients were extracted using the AB-DTPA (ammonium bicarbonate-diethylene triaminepentaacetic acid) solution at pH 7.6 (Soltanpour and Schwab, 1977).

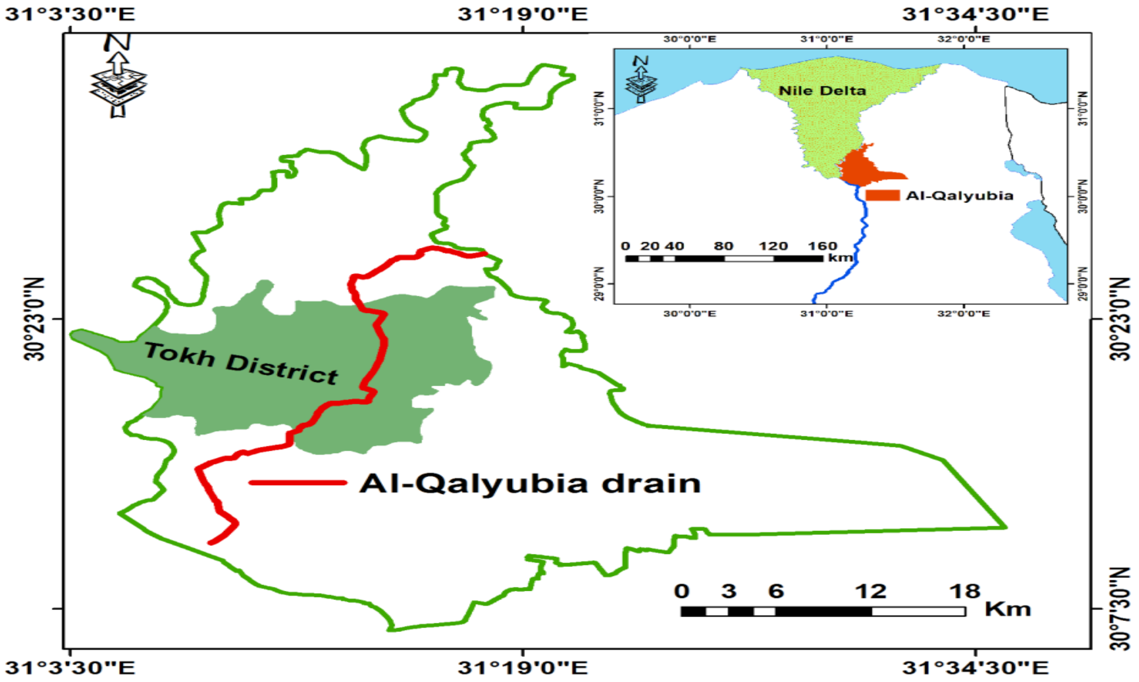

Fig. 1. Location map of the studied area

Soil physical properties; particle size distribution, water holding capacity and bulk density were determined according to Klute (1986). The total forms of heavy metals were extracted using the Aqua regia digestion (Peña-Icart *et al.*, 2011) and the metals were measured in the filtrate using ICP-OES. Water analyses were performed according to APHA (2005). Water pH and EC were measured in-situ using pH and EC meters, respectively while other constituents were determined in the lab.

Heavy metals status in the soil

The Dutch model (from Dutch standard-1988, quoted by Lacatusu, 1998) was used for interpreting the heavy metal contamination/ pollution (C/P) in soils.This system takes into account the clay and organic matter to estimate the limits between classes since these two macro-constituents directly affect other soil physicochemical properties, determining the maximum soil capacity for metals (Lacatusu, 1998). The system uses three standard levels; the natural background level (A), which is calculated from the clay and organic matter; the maximum allowable limits for agricultural purposes (B) and the levels calling immediate soil decontamination measures (C). The C/P index was calculated as the ratio between the total metal content in soil and the reference level. Soil contamination occurs at C/P value lower than 1.0 and involves five intervals; very slight (<0.1), slight (0.1–0.25), moderate (0.26–0.50), severe (0.51–0.75) and very severe (0.76–1.00), On the other hand, the higher values are distinguishing soil pollution which house five intervals; slight (1.1–2.0), moderate (2.1–4.0), severe (4.1–8.0), very severe (8.1–16.0) and excessive (>16.0). The multiple pollution index (Nunes *et al.*, 2003), the summation of the single pollution indexes of metals, was also calculated to estimate the overall pollution.

Statistical analysis

The analysis of variance (ANOVA) was executed to test the differences among soil properties ($P < 0.05$) using statistical package SPSS version 19.0 (SPSS, Chicago, IL, USA).

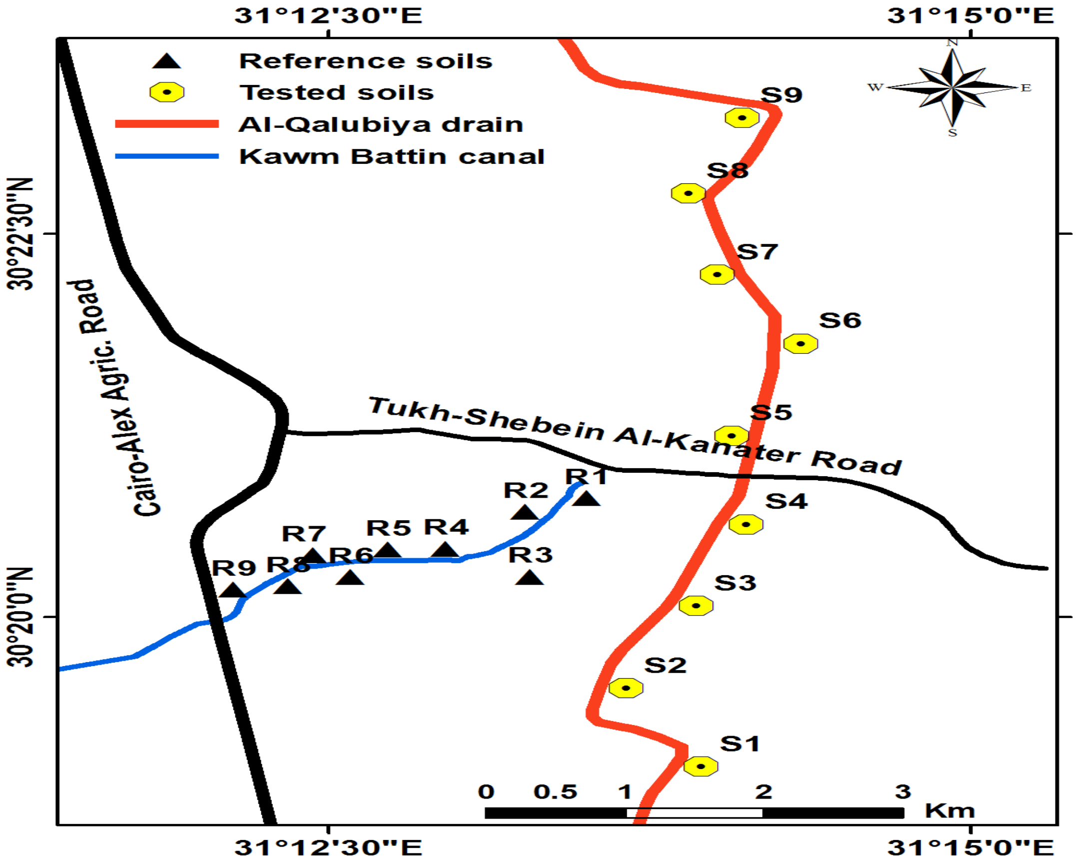

Fig. 2. Locations of soil samples

Results and Discussions

Water quality for irrigation

Results in Table 1 indicate that the Nile fresh water showed safe limits for irrigation since all the studied parameters were below the permissible levels. The means of the parameters for the wastewater were significantly ($P < 0.05$) higher than those of the Nile fresh water, except the Mg-ratio, as an insignificant difference was observed between the two sources. The wastewater had a pH increase of 0.29 units compared to the Nile fresh water; however, it remained within the normal range (6.5-8.4) for irrigation set by FAO (1994). The higher pH is attributed to the higher content of HCO_3 ions in the wastewater compared to the fresh water (Maskooni *et al.*, 2017).The EC and total dissolved solids (TDS) were 3.18 and 3.15 folds, respectively higher than those of the Nile fresh water due to the continuous discharge of brackish effluents along the drain. According to FAO (1994), the wastewater warranted slight to moderate salinity hazards(EC,0.7-3.0 dSm^{-1}; TDS, 450-2000 mg L^{-1}). Although the sodium adsorption ratio (SAR) of the wastewater was higher than the Nile fresh water by 10.42 folds, nopotential infiltration hazard was observed since values of EC and SAR that determine the hazards (FAO, 1994) remained within the safe limit. According to FAO (1992), the Nile fresh water had low suspended solids (< 100 mg L^{-1}), while the wastewater had medium solids (200-350 mg L^{-1}). Also, an entire absence of the $BOD_5$was in the Nile fresh water, while medium value (100-200 mg L^{-1}) was in the wastewater. Slight to moderate toxicity hazards related to Na (SAR 3-9) and Cl(4-10 mmolc L^{-1}) for surface irrigation (FAO, 1994). The contents of NH_4, NO_3, PO_4, SO_4, and K were 2.68, 4.90, 7.33, 8.21, and 2.49 folds, respectively higher than those of the Nile fresh water. Such values indicated higher contents of NH_4, NO_3, PO_4, and K than the permissible limits (FAO, 1994). However, PO_4 according to the Egyptian code for the long-term reuse of treated wastewater in agriculture (ECP-501, 2015) remained within the safe limits, as its content did not exceed 30 mg L^{-1}.Usually, wastewater contains reasonable amounts of plant nutrients than the fresh water, and thus it provides an alternative source for saving inorganic fertilizers (Ghosh *et al.*, 2012).

EC, electrical conductivity; TDS, total dissolved solids; TSS, total suspended solids; BOD, biological oxygen demand; SAR, sodium adsorption ratio; RSC, residual sodium carbonate; TH, total hardness; values of water quality are means± standards error; [a, b] means followed by different superscripts in the row represent significant different ($P < 0.05$); recommended limit according to * Egyptian code for reuse of the treated wastewater in agriculture for long-term; [1] FAO (1994), [2] FAO (1992), [3] USDA (1954), [4]Twort *et al.* (2000) and [5] FAO/UNESCO (1973).

Slight amounts of Cu, Ni and Pb were detected in the Nile fresh water, while Cd, Cr, Co, Fe, Mn, and Zn were below the detection limit. On the other hand, metals content in the wastewater weresignificantly ($P < 0.05$) higher than the Nile fresh water. For the wastewater, Cd, Cr, Co, Cu, Fe, Mn, Ni, and Zn would pose a pollution problem, as their contents exceeded the safe limit for use according to FAO (1994), while Pb remained within the safe limit. On the other hand, Zn remained below the Egyptian environmental standards (ECP-501, 2015) since its content did not exceed the maximum recommended value (5.0 mg L^{-1}).The continuous discharge of industrial effluents along the drain affected negatively the drain-water quality and led to the accumulation of toxic metals. The total hardness (TH) of the wastewater was 2.13 folds higher than the Nile fresh water, and the former was very hard, while the latter was moderately hard (Twort *et al.*, 2000). The significance of TH in waters goes beyond the fact that it determines the toxicity of trace metals; Cu and Zn, as the higher TH, the lower the toxicity of both metals (Chapman, 1996). Concerning the hazardous effect of HCO_3 ions, the Nile fresh water showed negative values of residual sodium carbonate (RSC), indicating a safe use (USDA, 1954), while the wastewater was marginally suitable (1.25-2.5 mmolc L^{-1}). No Mg hazards related to the two sources since Mg-ratio was less than 50%(FAO/UNESCO, 1973).

Impact of water quality on the soil physicochemical properties

Results shown in Table 2 reveal an insignificant ($P < 0.05$) pH increase of 0.09 units in the wastewater-irrigated soils over the reference soils. However, the pH changed according to Soil Science Division Staff (2017) from slightly alkaline (7.4-7.8) in the reference soils to moderately alkaline (7.9-8.4) in the wastewater-irrigated soils. Normally, soils with high clay and organic matter content are susceptible to little pH changes over an extended period due to the strong buffering capacity (Wang *et al.*, 2015). The mean value of EC in the wastewater-irrigated soils was significantly ($P < 0.05$) 2.38-folds higher than the reference soils due to the high soluble salts in the wastewater. As a result, the soils changed according to Soil Science Division Staff (2017)from non-saline (<2 dS m^{-1}) to very slightly saline (2-4 dS m^{-1}).

ESP, exchangeable sodium percentage; OM, organic matter; WHC, water holding capacity; BD, Bulk density; SE, standard error; $^{a, b}$ means followed by different superscripts in the row represent significant different ($P < 0.05$)

TABLE 1. Water quality parameters for irrigation water.

Parameter	Unit	Nile fresh water	Wastewater	Recommended maximumlimit	
				Egypt*	World
Physicochemical					
pH	---	7.18 ± 0.04^{b}	7.47 ± 0.03^{a}	---	6.5 – 8.4 ^{1}
EC	dS m^{-1}	0.39 ± 0.01^{b}	1.24 ± 0.05^{a}	--	0.7 - 3.0 ^{1}
TDS	mg L^{-1}	246.71 ± 7.30^{b}	777.86 ± 14.32^{a}	2000^{2}	450 - 2000 ^{1}
TSS	mg L^{-1}	49.81 ± 0.76^{b}	120.15 ± 5.77^{a}	---	350^{2}
BOD_5	mg L^{-1}	0.00 ± 0.00^{b}	135.33 ± 2.60^{a}	---	300^{2}
Cation and anions					
Na^+	mg L^{-1}	8.74 ± 0.21^{b}	133.40 ± 1.26^{a}	230	920
Ca^{2+}	mg L^{-1}	33.4 ± 1.76^{b}	72.01 ± 1.15^{a}	230	400
Mg^{2+}	mg L^{-1}	16.44 ± 0.41^{b}	34.20 ± 0.35^{a}	100	60
Cl^-	mg L^{-1}	39.05 ± 2.05^{b}	152.64 ± 4.10^{a}	---	350^{1}
HCO_3^-	mg L^{-1}	125.86 ± 4.17^{b}	530.09 ± 10.61^{a}	400	610
Nutrients					
NH_4-N	mg L^{-1}	4.33 ± 0.16^{b}	11.61 ± 0.21^{a}	---	5^{1}
NO_3-N	mg L^{-1}	3.87 ± 0.09^{b}	18.97 ± 0.28^{a}	---	10^{1}
PO_4	mg L^{-1}	0.51 ± 0.05^{b}	3.74 ± 0.06^{a}	30	2^{1}
K	mg L^{-1}	1.41 ± 0.26^{b}	11.57 ± 0.34^{a}	---	2^{1}
SO_4	mg L^{-1}	7.20 ± 0.28^{b}	17.92 ± 0.58^{a}	500	960
Heavy metals					
Cd	mg L^{-1}	< 0.001	0.05±0.01	0.01	0.01^{1}
Cr	mg L^{-1}	< 0.001	0.43±0.03	0.10	0.10^{1}
Co	mg L^{-1}	< 0.001	0.25±0.01	0.05	0.05^{1}
Cu	mg L^{-1}	0.03 ± 0.01^{b}	2.93 ± 0.09^{a}	0.20	0.20^{1}
Fe	mg L^{-1}	< 0.008	6.66±0.27	5.0	5.0^{1}
Mn	mg L^{-1}	< 0.005	0.96±0.09	0.20	0.20^{1}
Ni	mg L^{-1}	0.04 ± 0.01^{b}	0.88 ± 0.04^{a}	0.20	0.20^{1}
Pb	mg L^{-1}	0.06 ± 0.01^{b}	0.82 ± 0.18^{a}	5.0	5.0^{1}
Zn	mg L^{-1}	< 0.001	3.50±0.03	5.0	2.0^{1}
Miscellaneous					
SAR	---	0.31 ± 0.01^{b}	3.23 ± 0.01^{a}	6 - 9	9
RSC	mmolc L^{-1}	-0.97 ± 0.19^{b}	2.24 ± 0.16^{a}	---	2.5^{3}
TH	mg L^{-1}	151.67 ± 6.01^{b}	322.50 ± 4.33^{a}	---	300^{4}
Mg-ratio	---	45.11 ± 0.77^{a}	44.19 ± 0.15^{a}	---	50^{5}

EC, electrical conductivity; TDS, total dissolved solids; TSS, total suspended solids; BOD, biological oxygen demand; SAR, sodium adsorption ratio; RSC, residual sodium carbonate; TH, total hardness; values of water quality are means± standards error; a, b means followed by different superscripts in the row represent significant different ($P < 0.05$); recommended limit according to * Egyptian code for reuse of the treated wastewater in agriculture for long-term; 1 FAO (1994), 2 FAO (1992), 3 USDA (1954), 4Twort et al. (2000) and .(5 FAO/UNESCO (19973

TABLE 2. Physicochemical properties of the studied soils

Properties	**Fresh water-irrigated soils**			**Wastewater-irrigated soils**		
	Min	Max	Mean±SE	Min	Max	Mean±SE
pH (1:2.5 H_2O)	7.41	7.80	7.58±0.07^{a}	7.45	7.99	7.67±0.04^{a}
EC, dS m^{-1} (Soil paste)	0.64	1.75	0.87±0.12^{b}	0.92	5.77	2.07±0.55^{a}
ESP	0.35	0.46	0.48±0.04^{a}	0.43	2.15	0.84±0.18^{a}
OM, g kg^{-1}	17.59	29.32	24.76±1.16^{a}	24.23	35.88	28.09±1.24^{a}
Sand, %	24.82	37.13	29.58±1.55^{a}	23.27	35.68	28.06±1.36^{a}
Silt, %	12.27	25.16	19.65±1.80^{a}	13.89	27.07	21.09±1.83^{a}
Clay, %	44.82	57.28	50.99±1.25^{a}	47.78	58.39	51.08±1.16^{a}
Texture		Clay			Clay	
WHC, %	33.70	36.76	35.44±0.25^{a}	34.33	38.11	36.19±0.43^{a}
BD, Mg m^{-3}	1.18	1.34	1.25±0.02^{a}	1.11	1.28	1.21±0.02^{a}
Total N, g kg^{-1}	2.81	4.21	3.39±0.24^{b}	4.21	6.80	4.98±0.28^{a}
Available P, mg kg^{-1}	1.42	9.94	3.77±0.87^{b}	3.25	13.19	8.24±1.13^{a}
Available K, mg kg^{-1}	197.43	679.83	452.78±53.01^{a}	298.01	862.92	549.32±56.63^{a}
Available Fe, mg kg^{-1}	8.22	11.90	9.99±2.10^{b}	14.80	30.40	20.62±0.48^{a}
Available Mn, mg kg^{-1}	2.14	4.10	2.90±0.23^{b}	5.16	8.20	6.33±0.43^{a}

ESP, exchangeable sodium percentage; OM, organic matter; WHC, water holding capacity; BD, Bulk density; SE, standard error; a, b (means followed by different superscripts in the row represent significant different (P < 0.05

An insignificant difference ($P < 0.05$) in the exchangeable sodium percentage (ESP) occurred between the soils that remained within the safe domain of less than 15 (USDA, 1954). The low ESP could be attributed to the low SAR in the irrigation water (Jalali and Merrikhpour, 2008). Similarly, there was an insignificant difference ($P < 0.05$) in soil organic matter (OM) between the soils that had an adequate (>12.9 g kg^{-1}) OM content (Estefan *et al.*, 2013). Consequently, the effect of wastewater irrigation on soil physical properties; bulk density (BD) and water holding capacity (WHC) has been masked, as insignificant differences ($P < 0.05$) in the two parameters were observed between the soils. Bassouny and Abuzaid (2017) indicated that the changes in soil BD are directly related to changing OM content, while Masto *et al.* (2009) attributed the variation of WHC in soils to the organic matter or clay content in soils or their combinations. Regarding plant nutrients, the wastewater irrigation caused significant increases ($P < 0.05$) in total N by 1.47 folds and the AB-DTPA extractable P by 2.19 folds, Fe by 2.06, and Mn by 2.18 folds over the reference soils due to the high nutrient load in the wastewater.On the other hand, wastewater irrigation did not significantly ($P< 0.05$) affect the available K due to the similar clay content in the soils. Rezapour *et al.* (2010) indicated that type and abundance of clay minerals have a significant role on K availability, especially under arid and semi-arid conditions.

Heavy metals content in soils

Results in Table 3 indicate that the wastewater irrigation resulted in a significant build-up ($P < 0.05$) in heavy metals content compared to the reference soils. The mean values of Cd, Cr, Co, Cu, Ni, Pb and Zn 6.29, 8.62, 49.0, 5.56, 14.24, 13.88, and 3.03 folds, respectively higher than those of the reference soils. The accumulation of heavy metals in the wastewater irrigated soils could be arranged as follows: Zn > Cr > Cu > Ni > Pb > Co > Cd. Studies demonstrated higher heavy metals accumulation in soils of the Nile Delta region which have been irrigated with the wastewater for long periods than those irrigated with the Nile fresh water (Galal, 2015 and Mahmoud & Ghoneim, 2016)

Heavy metals contamination/pollution in soil

Soil contamination points to metal content in soil linked to clay and organic matter content and might not have immediate negative impacts on plant growth or the environment, while soil pollution indicates further limits induce negative environmental risks (Lacatusu, 1998). The mean values of heavy metals in the reference soils did not exceed A value (Table 4), indicating a safe use for agricultural production. Very slight contamination degree was related to Co, Cr, Ni, and Pb, slight to Cd, while Cu and Zn posed moderate contamination (Table 5). In the wastewater-irrigated soils, the mean values of Cd, Cr, Pb, and Zn were below A values, while Co, Cu, and Ni surpassed A values. Severe contamination degrees were associated with Cd, Cr, and Pb and very severe for Zn, while Co, Cu and Ni warranted slight pollution, as the C/P was greater than 1.0.However, Co, Cu, and Ni in soils were higher than level A, they did not exceed level B value (the maximum acceptable limit), which means that the soils could be used for agricultural production under certain precautions. Once the contaminant surpassed level B, land use is mainly directed towards the commercial or industrial use, while exceeding level C indicates that the land is not proper for any agricultural, commercial or industrial use (Abdel-Rahman, 2014). Concerning the overall pollution, a multiple pollution index (MPI) of 0.85 for the reference soils indicates that the soils remained within the safe domain (< 1.0), while the corresponding value for the wastewater-irrigated soils was 6.74, indicating a pollution problem (Nunes *et al.*, 2003).

To avoid the potential environmental risks and to achieve sustainable agricultural production in the studied area, preventive measures are required. The first step is to upgrade water quality and alleviate toxic metals load by 1). controlling the unofficial discharge of industrial as well as domestic effluent along the drain (Elbana *et al.*, 2017); 2). mixing the wastewater with the fresh water before the reuse (Myszograj *et al.*, 2014); 3). application of constructed wetland system (Stottmeister *et al.*, 2006) at small scale; 4). using biological filtration through water plants (Purakayastha and Chhonkar, 2009); and 5). implementing effective media filter through irrigation (Haynes, 2015). The second step is to apply an appropriate on-farm treatment for the in-situ soil remediation to clean-up the contaminants by means of phytoremediation and to minimizing metal uptake and accumulation in foods and forage crops using physical, chemical and biological techniques (Surriya *et al.*, 2015).

Conclusion

Low-quality water with high levels of heavy metals had adverse effects on soil qualities. Long-term wastewater irrigation resulted in a significant ($P < 0.05$) build-up in salinity, total N, available P, Fe and Mn and total heavy metals compared with the reference soils, while insignificant differences were observed concerning pH, ESP, organic matter, claycontent, water holding capacity, bulk density and available K. Heavy metals accumulation in soils followed the decreasing order of Zn > Cr > Cu > Ni > Pb > Co > Cd. The Dutch model and multiple pollution index (MPI) indicated a safe use for reference soils, but a pollution problem for the wastewater-irrigated soils.

TABLE 3. Total heavy metals content, mg kg^{-1} in the studied soils

Heavy metals, mg kg^{-1}	Fresh water-irrigated soils			Wastewater-irrigated soils		
	Min	Max	Mean±SE	Min	Max	Mean±SE
Cd	0.01	0.20	0.08±0.03^b	0.32	1.04	0.50±0.07^a
Cr	6.35	13.40	9.12±0.73^b	36.92	125.96	78.65±9.08^a
Co	0.02	1.21	0.69±0.16^b	25.11	48.46	33.76±2.38^a
Cu	10.26	15.69	12.95±0.66^b	55.96	101.73	73.18±5.04^a
Ni	2.18	7.88	4.43±0.61^b	32.50	90.58	63.08±6.13^a
Pb	2.58	5.38	4.05±0.38^b	23.27	112.88	56.26±11.88^a
Zn	45.96	66.35	56.31±2.61^b	143.85	213.46	170.49±7.76^a

SE, standard error; $^{a, b}$ means followed by different superscripts in row represent significant different ($P < 0.05$).

TABLE 4. The Dutch model used for evaluating heavy metals contamination /pollution

Metals	A values, mg kg^{-1}	B values, mg kg^{-1}	C values, mg kg^{-1}	The current study, mg kg^{-1}			
				Reference soils		Wastewater-irrigated soils	
				A	Mean	A	Mean
Cd	0.4 + 0.007 (Clay + 3OM)	5	20	0.81	0.08	0.82	0.50
Co	20	50	300	20	0.69	20	33.76
Cr	50 + 2Caly	250	800	151.79	9.12	152.84	78.65
Cu	15 + 0.6 (Clay + OM)	100	500	47.08	12.95	47.54	73.18
Ni	10 + Clay	100	500	60.99	4.43	61.42	63.08
Pb	50 + Clay + OM	150	600	103.46	4.05	104.23	56.26
Zn	50 + 1.5 (2Clay + OM)	500	3000	206.76	56.31	208.47	170.49

A, normal level in good soils; B, maximum acceptable limit of the contamination for the agricultural purposes; C, needs immediate soil clean-up measures.

TABLE 5. Levels of soil contamination/pollution of the investigated soils

	Contamination (C)					Pollution (P)					MPI
	Vs	S	M	Sv	Vsv	S	M	Sv	Vsv	E	
Reference soils	Co 0.03 Cr 0.06 Ni 0.07 Pb 0.04	Cd 0.10	Cu 0.28 Zn 0.27								0.85
Wastewater-irrigated soils				Cd 0.61 Cr 0.51 Pb 0.54	Zn 0.82	Co 1.69 Cu 1.54 Ni 1.03					6.74

Vs, very slight; S, slight; M, moderate; Sv, severe; Vsv, very severe; E, excessive pollution; MPI, multiple pollution index

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مؤشرات جودة التربة بمحافظة القليوبية المتأثرة بالري طويل الأمد بمياه الصرف الصحي

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تهدف هذه الدراسة إلى تتبع التغيرات في الخواص الكيميائية والفيزيائية المحددة لجودة الأراضي الرسوبية بمحافظة القليوبية تحت تأثير الري طويل الأمد بمياه الصرف الصحي. تم تجميع ٩ عينات تربة من الحقول الزراعية التي تروى من مصرف القليوبية و٩ عينات أخرى من الأراضي التي تروى بمياه النيل. أظهرت النتائج زيادة معنوية في كل من الأملاح الذائبة، النيتروجين الكلي – الصورة الميسرة من كل من الفسفور، الحديد، المنجنيز – الفلزات الثقيلة في الأراضي المروية بمياه الصرف الصحي مقارنة بالأراضي المروية بمياه النيل. تم إستخدام النظام الهولندي لتحديد مستويات تلوث التربة بالفلزات الثقيلة والذي أظهر أن الأراضي المروية بمياه النيل آمنة من حيث الإستخدام الزراعي بينما ظهرت مستويات للكوبلت والنحاس والنيكل في الأراضي المروية بمياه الصرف الصحي أعلى من الحدود الآمنة، ولكنها لم تتجاوز الحدود القصوى المسموح بها، الأمر الذي يؤكد أن إستخدام هذه الأراضي في إنتاج المحاصيل الغذائية والأعلاف يجب أن يتم بشرط إتخاذ الإجراءات المناسبة لتقليل مستويات الفلزات الثقيلة في مياه المصرف والتربة.