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Assessment of nutrients and heavy metals content in soil and some vegetables cultivated in agricultural land around El-Khashab canal (Helwan-El Saff area)

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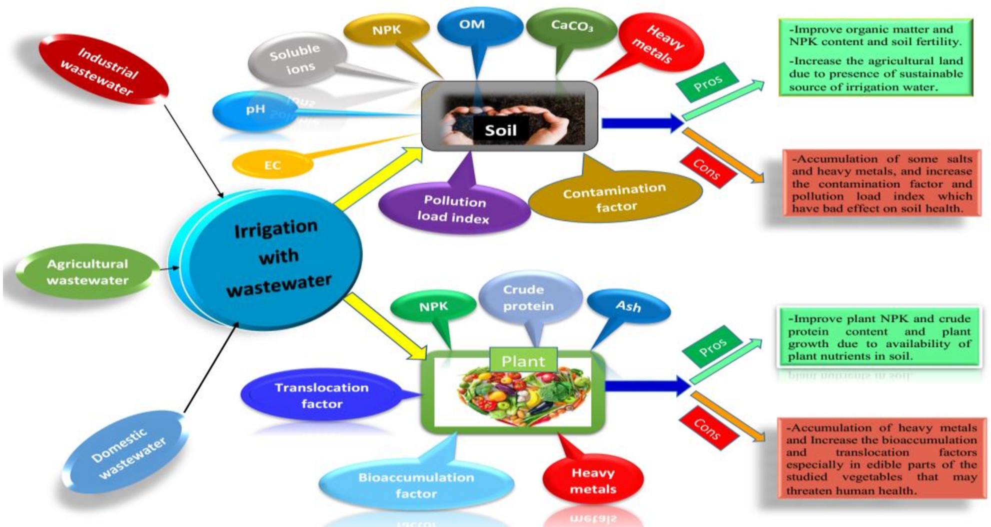
ABSTRACT

This investigation was conducted on nine sites at Helwan–El Saff area, Cairo, and Giza governorates (polluted area), and on three sites, in Metrabeaa village, Monofia governorate (control). This study aimed to assess the impact of wastewater irrigation on soil and plants. Water, soil, and plants samples were collected from El-Khashab canal (polluted water) and from Al-Bagoria canal (Nile water) and from the cultivated land sites adjacent to them. The values of EC, SAR, available N, OM and most of heavy metals (Fe, Mn, Zn, Cu, Co, Cr, and Pb) were significantly higher, in wastewater samples and soil under wastewater irrigation than control. There were significant differences regarding shoot and / or root content of N, P, K, crude protein, ash, heavy metals in all studied plants grown in the different sites. Garlic and onion accumulated most of studied heavy metals in their roots, while cabbage, lettuce and turnip accumulated high concentration of metals in their different organs, especially in their shoot; so, they could be used as phytoextractors. The heavy metals concentration in most of the studied plants exceeded the permissible level. This research declared that wastewater of El-Khashab canal improved soil fertility and OM content, but with risks as heavy metals may threaten sustainable agriculture. The agricultural lands in this area are not suitable for growing vegetables, especially leafy ones, due to their high ability to absorb, translocate and accumulate high concentrations of heavy metals in their edible parts. However, other plants might be cultivated in this area.

Graphical abstract



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Supplementary materials

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1. Introduction

The rapid growth of the world's urban population has not only caused an increase in the demand for the limited available freshwater but has also caused an increase in the volume of wastewater generated year by year [1]. The untreated wastewater generated can find its way into water systems such as rivers, lakes, groundwater and coastal waters with the potential to cause serious pollution. Wastewater may contain undesirable chemical constituents and pathogens that pose negative environmental and health impacts [2]. The rapid increase in domestic, agricultural, municipal and industrial wastewater in developing world under the effects of increasing population, industries and urbanization has been reported by various researchers [3] and [4]. They all remarked that developing countries suffer from problems arising from effluent discharge into river courses which lead to water and agricultural pollution [5].

In many developing countries, farmers are irrigating their crops with wastewater due to the non-availability of an alternative source. This often contains high levels of macro and micronutrients and heavy metals [6]. Contamination of soil in cultivated fields by wastewater loaded with salts and toxic heavy metals has emerged as a new threat to agriculture. The percolations of these surface pollutants through the soil cause salts and heavy metals accumulation over time in the soil pores, especially in the crop root zone, with possible harmful impacts on soil health and crop yield. Prolonged use of saline and sodium- rich wastewater causes soil structural degradation and loss of productivity [7]. Most of wastewater contain heavy metals in an amount sufficient enough to cause soil contamination and toxicity to crop plants. Soil contaminated with heavy metals is a primary route of human exposure to toxic element. [8]. It is estimated that at least 7 % of the world's irrigated land (i.e., 20 million ha) in 50 countries is irrigated with raw or partially treated wastewater, either directly or indirectly for some cities, up to 80% of the vegetables consumed locally are produced using wastewater [9].

The effects of wastewater on soil based on several elements, such as the sources and quality of the wastewater, soil characteristics and crops to be irrigated. There are encouraging and undesirable effects on the soil under wastewater irrigation. It is, therefore, necessary to evaluate the impacts of wastewater on soil health before planning wastewater irrigation in the long-term, and there is a need for soil periodic monitoring, to avoid any imbalance in the nutrient supplies or level of heavy metals contamination [6] and [10].

The present study aimed to assess the content of some heavy metals, chemical constituents (nutrients) in irrigation water, soil and vegetables grown in agricultural land around El-Khashab canal (Helwan – El Saff area).

2. Materials and Methods

2.1. Study area

The investigated area (Helwan-El Saff) is located east of the river Nile and south Cairo between long. 31° 17' 48.91146" and 31° 18' 16.38112" E and Lat. 29° 36' 40.19216" and 29° 48' 33.32128" N. Cairo and Giza governorates [11] (Fig.1)

Helwan is an industrial area at the southern of Cairo and it is nearby the Nile River. It contains nearly 16.5% of the total industrial activities in great Cairo as iron and steel, coke, fertilizers and chemicals, cement, blocks and other industries which are scattered in the study area [11]. Some of these industries discharge their wastes to the nearest wastewater treatment plant, on the other hand, most of them are not linked with the sanitation service of the city. Therefore, the wastewater of these units are discharged into the nearest stream, except iron and steel unit, which discharge their effluents into special pipe to treat it with evaporation. Some farmers use this pipe for irrigation of their fields. The sewage water treatment unit of Helwan also discharge its wastes (after primary treatment) into El-Khashab and El-Saff canals, which is used for irrigation. Most of vegetables which supply markets in the city were cultivated in this area and were irrigated with this polluted water [12].

Helwan- El Saff area can be classified into three regions, domestic region, industrial region and agricultural farms. The area comprises a few small villages (Ezabs) connected to the old and worn-out sewage network. Some of the scattered communities and houses are not connected to the formal sewage network. They dispose their domestic wastes either in private septic tanks (latrines) or directly to the water canals. Besides industrial wastes, the study area might exhibit some inputs from agricultural activities [13].

2.2. Samples and analysis

Water sample were collected from nine sites (Fig.1 and Table 1) in El-Khashab canal in Helwan – El Saff area and from three sites in Al-Bagoria canal in Metrabeaa village, Monof, El Monofia. Surface soil samples (0 -30 cm) were collected from each of the nine sites in the cultivated lands adjacent to El-Khashab canal and from each of the three sites in the cultivated lands adjacent to Al-Bagoria in Metrabeaa village canal as control. In each of the nine sites, cabbage, lettuce, garlic, onion, and turnip were collected during two seasons (Dec. 2018 and Dec. 2019).

The soil samples were air-dried, ground and sieved through a 2 mm sieve for analyses. All plants for each season were chosen at random and were grouped into three replicates then the plants were separated into root and shoot. Plant parts were dried in an electric oven at 65 ^{o}C till constant weight, were grind, then were wet digested using sulphuric and precholric acids mixture (1:1). The soil texture, OM and $CaCO_3$ were determined [14 -16]. The saturated soil paste was prepared according to [17]. Electrical conductivity (EC) was measured according to [17]. Sodium adsorption ratio (SAR) was calculated in water according to [18]. Soluble CO_3^{-2} and HCO_3^- were determined in soil and water according to [19]. The hydrogen ion concentration (pH), Cl^-, Ca^{++}, Mg^{++}, Na^+ and K^+ were estimated in soil and water according to [20]. Sulphates were calculated in soil and water as the difference between the total measured soluble cations and the total measured soluble anions. Available N, P, and K were determined in water, soil and plant according to [21], [20] and [22], respectively. The trace elements (Fe, Mn, Zn, Cu, Co, Cr, and Pb) were determined in water, soil and plant samples according to [23] and [24]. Ash content and crude protein were determined in plant samples according to [25] and [26], respectively.

The contamination factor (CF) for soil is the ratio obtained by dividing the concentration of each heavy metal in the soil by the background concentration of metal (either from literature or directly determined from a geologically similar and uncontaminated area) [27].

CF = C soil / C background

According to [27] **"**the values of Cf < 1 indicate low contamination, 1< Cf < 3 indicate moderate contamination, 3< Cf < 6 indicate considerable contamination and Cf > 6 indicate very high contamination".

The pollution load index (PLI) is "an easy way to prove the deterioration of the soil conditions as a result of the accumulation of heavy metals" [28] and was calculated as the following formula:

$$\text{"PLI} = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \ldots\ldots\ldots\ldots CF_n}\text{"}$$

where n is "the number of metals" and CF is "the contamination factor value".

The bioaccumulation factor (BAF) "is an index of the ability of the plant to accumulate a particular metal with respect to its concentration in the soil substrate" [29]. BAF was calculated as follow:

"BAF_{root} = C plant root / C soil"

"BAF_{shoot} = C plant shoot / C soil"

"BAF_{grains} = C plant grains / C soil"

"Where C plant root, C plant shoot, C plant grains and C soil represent the heavy metal concentrations in the plant root, plant shoot, plant grains and soils, respectively".

The translocation factor (TF) or mobilization ratio "was assessed to determine the relative translocation of metals from below ground root to the aboveground shoot of the plant" [30].

"TF = C shoot / C root"

"Where C shoot and C root represent the heavy metal concentrations in the plant shoot and root, respectively".

All obtained data were subjected to statistical analyses. Analyses of variance was done using ANOVA through computer costat package to get the significance according to [31], where mean values were compared using L.S.D at 5% level.

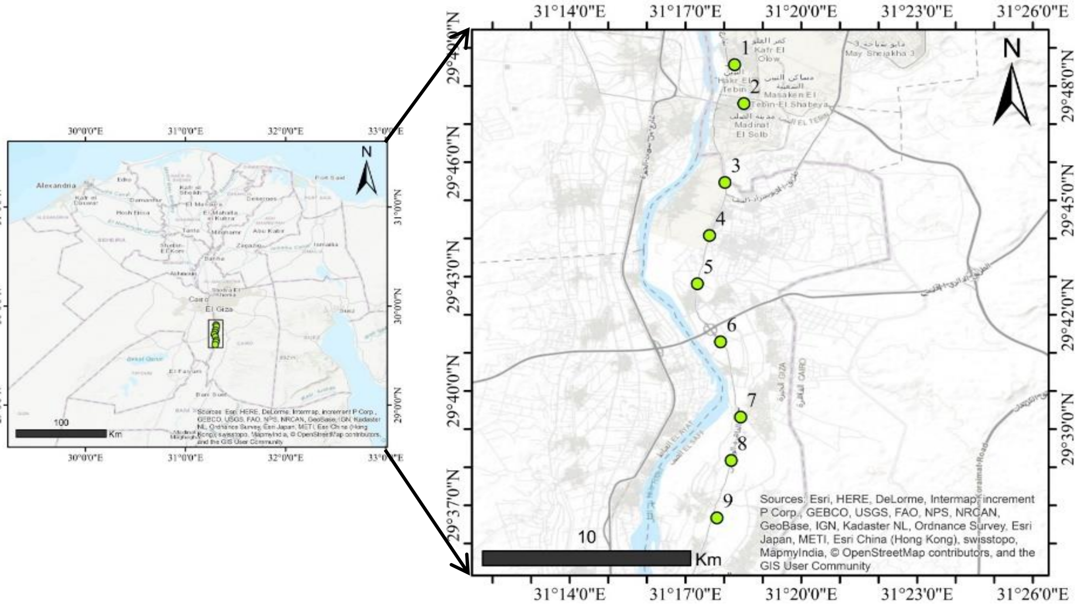

Figure 1. Helwan-El Saff main cities.

Table 1. Name, locality, Global Positioning System (GPS) coordinates, and altitude above sea level of the selected 9 sites within the study area in Helwan-El Saff

Site Number	Site name	Latitude (N)	Longitude (E)	Altitude (meter)
1	Kafr Al-Olow	29° 48' 33.32128"	31° 18' 16.38112"	38
2	Al-Hakr Al-Qibly	29° 47' 32.20652"	31° 18' 30.9253"	52
3	Al-Shoubak Al-Sharqi	29° 45' 28.06934"	31° 18' 1.39432"	67
4	Al-Oteyat	29° 44' 4.48728"	31° 17' 37.41472"	89
5	Al-Ikhsas	29° 42' 48.6243"	31° 17' 18.56681"	61
6	Al-Marj	29° 41' 17.15377"	31° 17' 54.49448"	63
7	Ghammazh Al-Sughra	29° 39' 18.70643"	31° 18' 25.73928"	70
8	Ezbet Al-Gmmal	29° 38' 10.43981"	31° 18' 11.13419"	47
9	Tal Hammad	29° 36' 40.19216"	31° 17' 48.91146"	77

3. Results and Discussion

All the data presented in the results are the mean of two seasons (Dec. 2018 and Dec. 2019).

3.1. Irrigation water

The data presented in S1 show some chemical characteristics of water samples collected from the selected nine sites and water samples of Nile water (control). The measured parameters were EC, SAR, pH, the soluble cations (Ca^{++}, Mg^{++}, Na^+ and K^+), the soluble anions (HCO_3^-, Cl^- and SO_4^{--}) and available N, P and K.

3.1.1. Electric conductivity (EC)

The values of EC of wastwater samples collected from the different nine sites ranged from 0.58 dS m^{-1} in site 8 to 1.23 dS m^{-1} in site 5, with significant differences between the highest value of site 5 and those of all other sites. The mean value of EC was significantly higher in wastewater (WW) samples than the mean value of EC of Nile water samples (S1). The increasing in EC values of El-Khashab canal water due to the disposal of industrial and domestic effluents [32].

3.1.2. Sodium adsorption ratio (SAR)

The values of SAR in the nine collected water samples varied significantly from 1.34 in sites 2 and 8 to 2.76 in site 5. The mean value of SAR increased significantly in wastewater (WW) samples than the mean value of SAR of Nile water samples. This agreed with [33] who reported that the values of SAR of water in irrigation canals at El-Saff and El-Khashab canals ranged from 1.39 to 3.10, while the values of SAR of Nile water was 0.92 (S1).

3.1.3. Hydrogen ion concentration (pH)

The pH of irrigation wastewater samples of the nine sites ranged between 6.95 to 7.1 without significant difference according to the guidelines of [18] and [34] all pH values of irrigation water of the present investigation fall in the normal range (6.5-8.5).The mean value of pH decreased significantly in wastewater (WW) samples as compared with the mean value of pH of Nile water samples (S1).

3.1.4. Soluble ions

3.1.4.1. Soluble cations

Values of the soluble cations Ca^{++}, Mg^{++}, Na^+ and K^+ in irrigation water samples varied significantly from the maximum values recorded in site 4 (K^+), site 5 (Ca^{++} and Na^+) and site 6 (Mg^{++}) to minimum values recorded in site 2 (Mg^{++}), site 8 (Ca^{++} and K^+) and site 9 (Na^+ and K^+). The mean values of the soluble cations in the nine irrigation water samples collected from the nine different sites followed the order: $Ca^{++} > Na^{++} > Mg^{++} > K^+$. The mean values of all cations increased significantly in wastewater (WW) samples as compared with the mean values of Nile water samples (S1).

3.1.4.2. Soluble anions

The soluble anions (HCO_3^-, Cl^- and SO_4^{--}) varied significantly from the maximum values in irrigation water samples collected from site 4 (HCO_3^-), site 5 (Cl^-) and site 6 (SO_4^{--}) to minimum values recorded for samples collected from site 1 (HCO_3^-), site 8 (Cl^-) and site 9 (SO_4^{--}). The mean values of the soluble anions in the nine irrigation water samples collected from the nine different sites followed the order: $SO_4^{--} > Cl^- > HCO_3^-$. The mean values of HCO_3^-, Cl^- and SO_4^{--} were significantly higher in samples of wastewater (WW) than in samples of Nile water.

The water samples that collected from El-Khashab canal (Helwan- El Saff area) were characterized by high pH, EC, TDS, Ca^{++}, Mg^{++}, Na^+, K^+, Cl^-, HCO_3^-, SO_4^{--}, suspended solids and acids. Moreover, the heavy metals (Fe, Mn, Zn, Cd, Ni, Pb, Cu and Cr) were present with negligible concentrations, except Co which was present with high concentrations [13].

3.1.5. Macronutrients (available N, P and K)

The N, P and K values varied significantly from the maximum values in samples of site 4 (for N and K) and site 5 (for P) to the minimum values in samples of sites 8 & 9 for N, P and K. The mean values of N, P and K for the nine water samples follow the order: N > K > P. The maximum values of N, P and K were recorded in sites 4 and 5 (adjacent to the industrial complex) and these values decreased with increasing the distance from the pollution point either upstream or downstream (S1). The mean values of available N and P were significantly lower in wastewater (WW) samples than in samples of Nile water (control); meanwhile, the opposite was true for K. Some factory wastewater are treated before disposal, however many nutrients and organic chemicals remain in significant concentrations in the treated wastewater. The nutrients contained in these wastewater, e.g. N, P, K and OM make it suitable for irrigation, [32].

3.1.6. Heavy metals

The results of heavy metals (Fe, Mn, Zn, Cu, Co, Cr, and Pb) content of water samples collected from the different nine sites are presented in S2.Generaly, the content of all the studied heavy metals, except Co, in water samples collected from the nine sites was lower than the permissible level in irrigation water [35]. The maximum and minimum values of Fe were recorded in water sample of sites 1and 7, respectively. The Mn value in water sample of site 7 varied significantly than the Mn values recorded in all other eight sites.

The maximum value of Zn was recorded in water sample of site 8 and the value decreased significantly until it reached to the minimum values in water sample of sites 4. The water samples of sites 5 and 8 recorded the highest and lowest values of Cu, respectively. The concentration of Co in water samples of all sites was higher than the permissible level, with non-significant difference among the sites, but the water samples of site 7 has the highest value of Co. The highest value of Cr was that of site 8, but the Cr content did not differ significantly among the nine sites. There was no significant difference among the values of Pb in all water samples of all sites. The mean values of all studied heavy metals (except Cu) were significantly higher in water samples of Helwan- El Saff area than in samples of Nile water (S2).

The use of polluted water in irrigation of agricultural land around the big cities in most countries for growing of vegetables is a common practice. Although this contaminated water is rich with OM and plant nutrients, it is also rich with soluble salts and heavy metals such as

Fe, Cu, Zn, Pb, Ni, Sn, Hg, Cr, As, and Al. When this water is used for irrigation of crops for a long period, these heavy metals may accumulate in soil, may cause plant toxicity and soil degradation [5].

3.2. Soil characteristics

The data presented in S3 show some chemical characteristics of soil samples collected from the selected nine sites under wastewater irrigation from El-Khashab canal and the three sites under Nile water irrigation as control. The measured parameters were EC, pH, the soluble cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}), the soluble anions (HCO_3^-, Cl^- and SO_4^{--}) and available N, P and K.

3.2.1. Electric conductivity (EC)

The values of EC of soil samples collected from the different nine sites ranged from 0.84 dSm^{-1} in site 2 to 12.56 dSm^{-1} in site 5 with significant differences between the highest value and the EC values of all other sites. The mean value of EC increased in soil samples under wastewater irrigation (WW) as compared with the mean value of EC of soil samples under Nile water irrigation (control). The EC values of soil sample collected from cultivated sites under wastewater irrigation from El-Khashab canal were approximately twice those collected from Nile Delta sites [36]. The author attributed that to addition of soluble salts as a result of irrigation with mixed water.

3.2.2. Hydrogen ion concentration (pH)

Data presented in S3 declare that the pH of soil samples of the nine sites ranged between 7.87 to 8.06 without significant difference. The mean value of pH increased non-significantly in soil samples under wastewater irrigation (WW) as compared with the mean value of pH of soil samples under Nile water irrigation. The soil that irrigated by contaminated water from Zefta drain and drain no. 5 showed an increase of soil pH as compared with soils irrigated by water from Baher El Mlah (fresh water) [37].

3.2.3. Soluble ions (cations and anions)

Site 5 recorded the highest soil content of Ca^{++}, Mg^{++}, Na^{+}, K^{+}, HCO_3^- , Cl^- and SO_4^{--}. The mean values of all studied soluble cations and anions increased in soil samples under WW irrigation as compared with the mean values of soluble anions of soil samples under Nile water irrigation (S3). In this regard, at El-Saff area the prolonged irrigation with WW increased the accumulation of Cl, N, P, Na and K in soil **[12].** The cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) and anion (Cl^-, SO_4^{--}, and HCO_3^-) content was higher in soil under wastewater irrigation (treated domestic wastewater form Bahr El Baqar drain at The Old Haggagia village, Fakous, El Sharkia Governorate) as compared with that under Nile water irrigation. The authors attributed that to addition of soluble salts as a result of irrigation with wastewater [38].

3.2.4. Macronutrients (available N, P and K)

The content of available N, P and K in the studied soil samples of the nine sites ranged from 257.83 mg $kg^{-}1$, 4.21 mg kg^{-1} and 1104.23 mg kg^{-1}, respectively in site 5 to 99.17 mg kg^{-1}, 0.83 mg kg^{-1} and 170.08 mg kg^{-1}, respectively in site 9 (for N and P) and site 4 (for K). The mean value of N increased non-significantly, P decreased significantly and K decreased non-significantly in soil samples under WW irrigation as compared with the mean values of N, P and K of soil samples under Nile water irrigation (S3). The content of N, P and K in soil irrigated with WW were significantly higher than their corresponding contents in soil irrigated with fresh water. This result might be attributed directly to the contents of the nutrients (N, P and K) in the WW applied [39].

3.2.5. Calcium carbonate

The values of $CaCO_3$ in the nine collected soil samples varied significantly from 6.45% in site 5 to 15.7% in site 2.The mean value of $CaCO_3$ increased significantly in soil samples under WW irrigation as compared with the mean value of $CaCO_3$ of soil samples under Nile water irrigation (S4).

3.2.6. Organic matter

Data presented in S4 declare that OM content in soil samples of the nine sites of the current study varied non-significant from 4 % to 2.49 %. The mean value of OM was significantly higher in soil samples under WW irrigation than in soil samples under Nile water irrigation. Many authors reported similar finding and attributed that directly to the contents of organic compound in the WW applied [39].

3.2.7. Soil texture

S4 revealed that all soil texture classes of the nine sites are clayey, while soil texture classes of control sites are silt loam and loam. These data are in full agreement with El-Motaium and Badawy [40] who reported that the clay content in soils irrigated with WW increased as the irrigation period increased due to the accumulation of clay particles from WW effluent. While Abd El-Hady [33] reported a slight variation in texture and calcium carbonate content of surface soil samples collected from two sites irrigated from El-Khashab canal and Nile water.

3.2.8. Heavy metals

The content of all studied heavy metals (Fe, Mn, Zn, Co, Cr, and Pb except Cu) in most of soil samples exceeded the permissible level [35]. However, there is no general trend that indicates certain site to be always associated with the highest or with the lowest value of all studied heavy metals at once. The mean values of Fe, Mn, Zn and Co increased significantly, but Cu and Cr increased non-significantly in soil samples under WW irrigation as compared with the mean values of these metals of soil samples under Nile water irrigation. The mean value of Pb decreased non-significantly in soil samples under WW irrigation as compared with the mean value of this metal in soil samples under Nile water irrigation (S4).

Wastewater may contain low concentration of heavy metals but, long-term use of this WW could accumulate significant amounts of heavy metals in soil. Moreover, long-standing irrigation of clay soil with WW increased its available Cu, Cd, Pb, Cr, Ni and Zn compared with fresh water irrigated field [41-43]. Soil texture plays a key role in the mobility of metals in soil as affected by the content of fine particles like clay. This clay is important adsorption medium for heavy metals in soils. The clayey soils hold a high amount of metals when compared to sandy one [44].

From the previous data it could be observed that irrigation water and soils in sites around the industrial complex or adjacent to it have the highest values of N, P, K, and OM which improve the soil quality and soil fertility, but at the same time they also have high concentration of soluble salts and heavy metals which led to several soil problems that increase with time. This means that these sites receive large amounts of pollutants (domestic and industrial) which are discharged in El-Khashab canal. Also, the gradual decrease in values of most of the studied parameters from the highest values recorded at sites close to the source point pollution (sites around the industrial complex or adjacent to it) towards either the upstream or the downstream of the irrigation canal. Thus, it could be stated that generally, as the distance increases away from the source point of the industrial discharge effluent the values decrease significantly.

3.3. Plant chemical composition

The plants content of some minerals, heavy metals, ash and crude protein of vegetables grown on the nine chosen sites (farmlands) of the present study are given in S 5-10. The cultivated plants during winter seasons were cabbage (*Brassica oleracea* var.*capitata*), garlic (*Allium sativum* L.), onion (*Allium cepa* L.), turnip (*Brassica rapa* L.), lettuce (*Lactuca sativa* L.). The partitioning of the tested mineral and heavy metals between blow-ground (root system) and above-ground (shoot system) was determined.

3.3.1. Plant content of N, P, K, crude protein and ash

Supplementary materials (S5-7) show several significant differences regarding shoot and / or root content of N, P, K, crude protein and ash in all studied plants grown in the different sites. However, there is no general trend that indicates certain site to be always associated with the highest or with the lowest value of all the above mentioned parameters at once. The content of N, K and crude protein was higher in shoot than in root of cabbage and lettuce plants grown in the studied sites and the opposite was true for P and ash content. The content of N, P, K and crude protein was higher in shoot than in root of garlic plants while, ash content was higher in root than in shoot. Meanwhile, the content of N and crude protein was higher in shoot than in root of onion plants and the opposite was true for the P, K and ash content. Also, the content of N, ash and crude protein was higher in shoot than in root of turnip plants grown in the studied sites and the P and K content was higher in root than in shoot.

The changes in nutrient contents (NPK) of soils (southwestern USA) were reflected in uptake by winter (wheat, berseem) and summer (rice, sorghum) crops growing at these sites from fields irrigated was WW (domestic WW). They reported that higher content of N, P, K and Na were monitored in plant shoots when grown on soils irrigated with WW, probably due to high OM and macro nutrients content of irrigation water which lead to increase fertility of soil [45].

The effect of irrigation with WW (treated domestic WW form Bahr El Baqar drain at The Old Haggagia village, Fakous, El Sharkia Governorate) on ash and protein content of canola, jojoba, jatropha and castor bean plants. The authors concluded that the total protein and ash content exhibited significant reduction in plants under WW irrigation as compared with those under Nile water irrigation [46].

The crude protein contents of different leafy vegetables vary greatly from species to species and this may be due to climatic factors and structural and physiological features [47]. The plants that grown on metal-contaminated soil have low protein due to the high content of heavy metals in their tissues [48]. There are physiological changes take place in plants due to presence of heavy metals that can reduce protein synthesis [49]. High metal concentration may hamper protein metabolism by altering physiological functions and synthetic activities [50]. Heavy metals have the ability to react with proteins and DNA which produces oxidative damages in plant molecules [51].

3.3.2. Plant content of heavy metals

The concentration of all tested heavy metals, except Cu, in root and shoot of all studied plants grown in all sites, exceeded the permissible level.

3.3.2.1. Cabbage

Based on the mean value of each heavy metal in plant (average of root and shoot values), the permissible level of Fe, Mn, Zn and Pb was exceeded by 930.82 %, 28.19 %, 30.42 % and 3414.20 %, respectively [35]. The pattern of the tested heavy metals accumulation, followed the order Fe > Mn > Cr > Pb > Co > Zn > Cu being 4638.71, 384.58, 255.81, 175.71, 85.82, 78.25 and 3.47 mg kg^{-1}, respectively. Comparing the content of heavy metals in root and shoot of cabbage plant, Zn, Cu, Co, Cr and Pb content was higher in shoots (the edible part of the plant) than in roots, while Fe and Mn content was higher in roots than in shoots.

3.3.2.2. Lettuce

According to the mean value of each heavy metal in plant (average of root and shoot values), the permissible level of Fe, Mn, Zn and Pb was exceeded by 907.69 %, 16.18 %, 32.68 % and 3506.00 %, respectively.The pattern of the tested heavy metals accumulation, followed the order Fe > Mn > Cr > Pb > Co > Zn > Cu, being 4534.59, 348.55, 327.85, 180.30, 88.99, 79.61 and 4.85 mg kg^{-1}, respectively. Comparing the content of heavy metals in root and shoot of lettuce plant, Fe, Zn, Cu, Co, Cr and Pb content was higher in shoots (the edible part of the plant) than in roots, while Mn content was higher in roots than in shoots.

3.3.2.3. Garlic

Based on the mean value of each heavy metal in plant (average of root and shoot values), the permissible level of Fe, Mn, Zn and Pb was exceeded by 884.26 %, 20.27 %, 0.58 % and 3029.80%, respectively. The pattern of the tested heavy metals accumulation, followed the order

Fe > Mn > Cr > Pb > Zn > Co > Cu, being 4429.19, 360.81, 163.01, 156.49, 60.35, 51.64 and 3.87 mg kg $^{-1}$, respectively. Comparing the content of heavy metals in root and shoot of garlic plant, Mn and Zn content was higher in shoots (the edible part of the plant) than in roots, while Fe, Co, Cr and Pb content was higher in roots than in shoots.

3.3.2.4. Onion

According to the mean value of each heavy metal in plant (average of root and shoot values), the permissible level of Fe, Mn, Zn and Pb was exceeded by 747.74 %, 3.40 %, 31.47 % and 2789.80 %, respectively [35]. The pattern of the tested heavy metals accumulation, followed the order Fe > Mn > Cr > Pb > Zn > Co > Cu, being 3814.82, 310.21, 210.16, 144.49, 78.88, 31.17 and 3.81mg kg $^{-1}$, respectively. Comparing the content of heavy metals in root and shoot of onion plant, Mn, Cu and Cr content was higher in shoots (the edible part of the pant) than in roots, while Fe, Zn, Co and Pb content was higher in roots than in shoots.

3.3.2.5. Turnip

Based on the mean value of each heavy metal in plant (average root and shoot values), the permissible level of Fe, Mn, Zn and Pb was exceeded by 773.40 %, 10.01 %, 17.60 % and 3065.60 %, respectively. The pattern of the tested heavy metals accumulation, followed the order Fe > Mn > Cr > Pb > Zn > Co > Cu, being 3930.31, 330.02, 286.34, 158.28, 70.56, 33.50 and 3.49 mg kg $^{-1}$, respectively. Comparing the content of heavy metals in root and shoot of turnip plant, Mn, Co, Cr and Pb content was higher in shoots than in roots, while Fe and Zn content was higher in roots (the edible part of the plant) than in shoots.

The uptake of heavy metals by plants varied from species to species, some have high metal contents in their tissues compared to a very low soil metal concentration, while other species have a low uptake of the metal at high soil concentrations [52]. The irrigation with WW led to accumulation of heavy metals in soil and consequently into the cultivated plants ([53], [54] and [55]). They added that the variation in heavy metals concentration in vegetables / cereals of the same site may be ascribed to the difference in their morphology and physiology for heavy metal uptake, exclusion, accumulation and retention. In this concern, many authors as [56] stated that absorption and accumulation of heavy metals in plant tissue depend upon many factors, which include temperature, moisture, OM, pH and nutrient availability. Soil properties influencing heavy metals availability varied significantly between the sites.

The use of industrial effluents and WW for irrigation of vegetables has serious effects in contamination of soils by heavy metals and subsequent accumulation of metals by vegetables. Many of research have been carried out on the heavy metals content of certain crops ([57], [58] and [59]), but none have considered a leafy vegetable. There have been some earlier reports that leafy vegetables have greater ability to accumulate heavy metals in their edible parts than cereals and fruit crops, due to their higher transpiration rate [60 and 5].

Leafy vegetables like lettuce are hyperaccumulators for heavy metals [61]. Green leafy vegetable can accumulate heavy metals in their tissues without showing any toxicity symptoms [62]. The concentrations of heavy metals in lettuce roots and shoots increased with increasing exposure duration [63]. The plants grown under wastewater-irrigated soil have high concentrations of metals in their vegetative and non-vegetative organs [64].

3.4. Pollution quantification

3.4.1. contamination factor (CF)

The soil contamination factor of the nine sites during winter seasons (average of two winter seasons; Dec. 2018 and Dec. 2019) are shown in S11. From the CF mean values of the seven heavy metals, they could be arranged in the order of: Co > Cr > Zn > Mn > Fe > Cu > Pb. According to [27] classification, Mn, Zn, Co and Cr may cause very high contamination; Fe may cause considerable contamination; Cu may cause moderate contamination. Meanwhile, Pb may cause low contamination. From the previous data it could be observed that Co was the most metal which caused contamination in soil of the study area (CF ranged from 5090 to 1760 and mean of 3205.56). On the other hand, Pb was the least metal which caused contamination in all sits (CF ranged from 0.70 to 1.13 and mean of 0.84).

The high level of soil contamination in the study area with these heavy metals is associated with the spread of many industries in which these metals are used. Fe, Mn, Zn and Cu are used in the iron and steel industry, meanwhile, Pb, Mn and Cr are used in the manufacture of glass. As for the paint industry, Pb, Cr, Zn and Mn are one of its main components. Cr is also used in the textile industry, as well as the clay brick industry. Zn is used in the soap and plastic industries. Most of the elements are used in the manufacture of mineral fertilizers [65]. This is in addition to the presence of these heavy metals in sewage and agricultural wastewater, which are randomly disposed of in El-Khashab Canal.

Some authors as [12] studied the spreading of different heavy metals in different particle size fractions of soils under polluted water irrigation in El- Saff area. For all tested metals, the clay fraction had the highest values, while the sand fraction had the lowest. All fractions of soils under industrial wastewater irrigation had the highest amounts of Fe and Mn, while fractions of soils under sewage wastes irrigation had the highest amounts of Zn, Cu, Pb and Cd. Data showed that the amount of heavy metals in the clay fraction was 33, 24, 14, 13, 12 and 10 times that of the sand fraction for Mn, Cu, Fe, Cd, Zn and Pb, respectively. Similar finding was reported by [36].

3.4.2. Pollution load index (PLI)

S11 shows the PLI values for the soil samples collected from the nine sites of the study area during winter seasons. The PLI of soil samples ranged from 26.26 (site 1) to 12.88 (site 9). The use of wastewater in irrigation of agricultural land presents environmental, health and economic challenges as well as benefits. While some benefits and cons are localized and complicated, others can easily be characterized. For example, the risk associated with exposure to pathogens and heavy metals and salinity of soil are easily classified as cons. Meanwhile, Nutrients source, water resources protection and savings, and farm profitability are benefits. Using of wastewater for irrigation has increased over the years due to these benefits especially in regions that suffer from water scarcity problem [66]. The type and severity of effect of wastewater irrigation on public health, water resources and soil are not only dependent on the wastewater quality but also on properties of soil morphology and physiology of plant, climate, type of irrigation and agricultural management applied. Irrigation with wastewater could support both agriculture and water sustainability. It could be concluded that wastewater surely has a great possibility of being a viable alternative water source for irrigation, but risk prevention barriers should be adopted to decrease the undesirable effects [67].

3.5. Phytoremediation parameters

3.5.1. Translocation factor (TF)

The values of the TF of Fe, Mn, Zn, Cu, Co, Cr and Pb in the studied plant species of the present study in the nine sites are presented in S12. The TF values varied among the nine sites, among the metals or among the plant species. The difference in TF of metals may be related to concentration of metal in soil, mobility of heavy metal, or age and nature of plant species [68]. Cabbage, lettuce and turnip plants can translocate most of tested heavy metals to their aerial parts meanwhile, garlic and onion plants accumulated most of tested heavy metals in its root in most of sites. This mean that, cabbage, lettuce and turnip plants could be suitable for phytoextracting most of the studied heavy metals from the contaminated soil (TF > 1). Meanwhile, garlic and onion plants have the potential for phytostabilization (BCF >1 and TF < 1) [69].

3.5.2. Bioaccumulation factor (BAF)

The data given in S13 present the value of BAF of Fe, Mn, Zn, Cu, Co, Cr and Pb in the five plant species of the present investigation. Cabbage, lettuce and turnip plants accumulated high concentration of most studied heavy metals in their shoot, while, garlic and onion plants accumulated the most studied heavy metals in their root. Some plants that belong to genus *Brassica,* have been used in remediation of metal-contaminated sites. *Brassica* species, namely *B. napus* and *B. rapa* accumulate moderate level of heavy metals, *Brassica* crop species may be suitable as phytoremediators due to their highly biomass [70].

4. Conclusion

From the previous data it could be observed that irrigation water and soils in sites around the industrial complex or adjacent to it have the highest values of N, P, K, and OM which improve the soil quality. But at the same time, they also have high concentration of salts and heavy metals which led to several soil problems that increase with the time. There were several significant differences regarding shoot and / or root content of N, P, K, crude protein and ash in all studied plants (cabbage, lettuce, garlic, onion and turnip) grown in the different sites. The concentration of heavy metals in the different parts of the studied plants varied from plant to another at the same site and in the same plant at different sites. Garlic and onion accumulated most of studied heavy metals in their roots, while lettuce, cabbage and turnip accumulated most of studied heavy metals in their shoot. The concentration of studied heavy metals (except Cu) in most of studied plants exceeded the permissible level.

One can conclude that the agricultural land in the study area (Helwan-El Saff) is contaminated with many heavy metals as a result of the aforementioned practices, whether from factories (industrial WW), individuals (municipal WW) or farmers (agricultural drains WW), which poses a very great danger to the fertility of the agricultural land and its suitability for agriculture. As for the vegetables grown in this area, it was noted that they have a high ability to accumulate heavy metals in their various parts, especially the edible ones, which poses a danger to human health directly by eating these plants or indirectly through the food chains. Therefore, the data of the present research revealed that wastewater of El-Khashab canal could effectively be used as fertility source for soil, but there are some risks as heavy metals may threaten sustainable agriculture in the study area. On the other hand, the agricultural lands in this area are not suitable for growing vegetables, especially leafy ones, due to their high ability to absorb, translocate and accumulate heavy metals in their edible parts sometimes with very high concentration. Therefore, the authors recommend close and periodic monitoring for soluble salts, and heavy metals content of both WW irrigation canals and soil of agricultural land under WW irrigation. Besides, only crops that do not uptake, translocate nor should bioaccumulate high levels of heavy metals should be selected to be cultivated in such marginal sites.

From the agroecological point of view, using WW for irrigation in areas suffering lack of fresh water in developing countries with high rate of population growth can fulfill many of principles elements of agroecology aiming at reaching sustainable agriculture and productivity. For instance, using WW fulfill the following principle elements of agroecology: minimize the use of non-renewable resources, avoid the unnecessary use of agrochemical and other technology that adversely affect the environment and human health, costless environment friendly method for wastewater disposal, offer an alternative of fresh water use in irrigation, leading to the increase of cultivated land area, considered a reliable sustainable source for irrigation, wastewater effluents as rich in many plant nutrients and OM, thus increase soil health and fertility level, Save a lot of money, by substituting (completely free) the cost that would be paid for buying fertilizers and it protects the physical and chemical soil properties from degradation that are usually occurred under continues addition of mineral fertilizers.

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