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Impact of Longterm Irrigation with Wastewater on Potentially Toxic Elements Accumulation in some Edible Plants: Northern Dakahlia Governorate As A Case Study

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ABSTRACT

The purpose of this study is to investigate the impact of long-term irrigation with low-quality water resources (wastewater) on the accumulation of potentially toxic elements (PTEs) in some edible plants (date palm (*Phoenix dactylifera L*), olive, pomegranate, eggplant, pepper, wheat and clover) as well as casuarina trees and iceplant (*Mesembryanthemum crystallinum L.*). Water, soil and plant were collected from Kalabsho, Dakahlia chemical properties and PTEs concentration. The prevalence of PTEs concentration in wastewater was higher in summer compared to autumn and winter seasons. Concentrations of PTEs in wastewater ranked were: (i) Zn>Fe>Al>Cu>Ni>Mn with, Co, Cd, Pb and Cr not detected (ND) during the autumn, (ii) Mn>Zn>Fe>Al>Ni>Pb>Cu whereas, Co, Cd and Cr were ND during summer, and (iii) Zn>Al>Fe>Mn>Ni while, Co, Cd, Cu, Pb and Cr were ND during winter. Similarly, Mn showed highest concentration in soil. In all cases, the levels of PTEs concentrations in water and soil were within allowable limits of FAO/WHO. Concentrations of PTEs were above maximum allowable limits except Ni and Cu in olive young leaves, casuarina young and old needles as well as pepper leaves. The accumulation characteristics of clover and iceplant has proven their potentiality in phytoremediation of PTEs contaminated soil. General, PTEs concentrations were within the permissible limits in water and soil but above the maximum allowable limit in plants except Ni. The bioaccumulation factor (BCF) was >1.0 in all PTEs under consideration. Findings from this investigation increased our understanding regarding ecotoxicological hazard of PTEs in marginal soils irrigated with low-quality water resources.

Keywords: PTEs, Wastewater, Soil, Plants

INTRODUCTION

The expression "heavy metals" refers to metals/metalloids with densities greater than 5.0 gcm^{-3} (Mosa et al et al., 2022; Mortada et al., 2023; Mosa et al., 2023). Heavy metals naturally occur in soils generated by geological processes such as modification and erosion of geological subsurface materials (Kabata-Pendias and Pendias 2001; Zhao and Kaluarachchi 2002). The majority of heavy metals (such as; Cu, Fe, Ni, Mn, Co, and Zn) are needed in trace amounts for proper growth and functions of animals and plants; however, their excessive amounts can severely harm the biosphere (Hu et al., 2017). Due to the scarcity of fresh water resources, many parts of the world depend upon low-quality water for irrigation and other agricultural purposes (Mukherjee et al., 2022). This practice might contaminate soil, and poses a considerable hazard to all linked complexes in its surroundings causing environmental contamination given their nonbiodegradability in soil matrix (Briggs 2003; Skála et al. 2018). The release of heavy metals into the atmosphere by anthropogenic activities are *via* industrial effluents, agrochemical applications and household discharges (Shaheen et al., 2022; Abidin et al., 2024; Mohankumar et al., 2024). Heavy metals contamination of arable soils has major health consequences, particularly when these soils are utilized for the cultivation of vegetables and/or edible crops leading to heavy metal absorption from the soil and accumulate in their tissues (Unver et al., 2015; Ugulu et al., 2016; Abdullahi et al., 2021). Wastewater, fertilizers and sewage water are the primary causes of heavy metal accumulation in soil matrix (Briffa et al., 2020; Rashid et al., 2023). Several physicochemical parameters, including organic matter, calcium carbonate, pH salinity and moisture content can modulate the solubility of heavy metal in soil (Rakesh and Raju 2013). These soluble substances find their ways into food chain (water-soil-plant-animal-human) through plant uptake (Mortada et al., 2023; Shaapera et al., 2013). Therefore, heavy metal concentrations in consumable food crops must be controlled below certain limits. Despite the intensive research carried out to monitor the ecotoxicological hazard of PTEs in soils irrigated with low-quality water resources, little is known about these hazardous effects in areas surrounding estuaries, in which the study area is located. Therefore, the main objectives of this investigation are to: (i) monitor PTEs concentration in low-quality irrigation water resources in marginal soils of northern Delta, Egypt, (ii) evaluate the potential binding of PTEs onto soil matrix, (iii) quantify PTEs concentration in some plants irrigated with these water resources, and (vi) assess the ecotoxicological hazard of these PTEs on irrigated plants.

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MATERIALS AND METHODS

Study area

Soil, water and plants samples were collected from Kalabsho Agricultural Research Farm, Dakahlia Governorate (31°28'54.63" N, 31°19'29.68" E). Kalabsho is predominantly known to be an agrarian community, cultivating varieties of fruit trees, cereals and vegetables. This area is characterised by inadequate freshwater resources for irrigation resulting in the utilisation of waste and drainage water as an alternative source of fresh water.

Reagents and equipment

For chemical analyses, high quality analytical chemical reagents (Darmstadt, Germany) were used with no further purification processes required. For chemical solution preparations, deionized water (18.2 x 10^{-3} Ω) (Nano pure water, Barnstead) was utilized. Applying the standard approach, fifteen soil samples were collected from the study area. Soil samples were air-dried to achieve a constant weight with a daily weight loss of no more than 5%, and then pre-treated in line with ISO 11464 (ISO, 2004). Fifteen (15) irrigation water samples (100 mL) were taken from wastewater, filtered, stored in an icebox, and transferred to the laboratory. Furthermore, representative young and old leaves were sampled from three randomly chosen trees in the research area. Deionized water was used to properly cleansed the leaves from solid materials and debris before oven-drying at 75 ºC till a constant weight was attained, then milled using a ceramic mortar.

Soil chemical properties

Analytical methods for soil chemical properties were used in accordance with conventional procedures: The Jenway 3505 pH/mV/Temperature Meter was used to measure soil pH in 1:2.5 deionized water suspension (Sparks et al., 2020), and the electrical conductivity (EC) meter (Model HANNA HI9835) was used to measure soil EC in soil-water extract. Water soluble anions and cations were measured in deionized water extract: cations of Na^+, Ca^{2+}, Mg^{2+}, and K^+ using an Inductively Coupled Plasma Spectrophotometer (model ICP/CIROS CCD SOP, Germany) and anions of SO_4^{2-} and Cl^- were determined using ion chromatography (Morales et al., 2000). The available nitrogen, phosphorus and potassium (NPK) concentrations were analysed according to the standard methods (Piper 2017; Spark et el., 2020; Mosa et al., 2023).

Water chemical properties

The pH, EC, main cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+), and anions (Cl^-, SO_4^{2-}) were all measured in water. The Jenway 3505 pH/mV/Temperature Meter was used to measure pH and the electrical conductivity (EC) meter (Model HANNA HI9835) was used to measure water EC. Inductively Coupled Plasma Spectrophotometer (model ICP/CIROS CCD SOP, Germany) was used to measure the cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+), whereas ion chromatography was used to measure the anions (SO_4^{2-} and Cl^-) (Morales et al., 2000). Irrigation coefficients of Na%, sodium adsorption ratio (SAR), Kelly ratio (KR) and magnesium adsorption ratio (MAR) were also calculated using the formulae below (Ogunfowokan et al., 2013):

$$Na\% = (Na^{2+}/Na^{+} + K^{+} + Ca^{2+} + Mg^{2+})x100$$

$$KR = Na^{2+}/Ca^{2+} + Mg^{2+}$$

$$SAR = Na^{+} \Big/ \sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}$$

$$MAR = Mg^{2+}/Ca^{2+} + Mg^{2+}$$

The concentrations of PTEs in wastewater samples were measured using ICP (model ICP/CIROS CCD SOP, Germany) (Mosa et al., 2011).

Chemical properties of plants

Plant materials were collected from Kalabsho Research Farm, Mansoura University, Dakahlia Governorate. Samples were pulverized in a stainless-steel mill and digested in a microwave digestion equipment (MLS GmbH model, Germany; Tüzen 2003) with 6 mL of HNO_3 (65%) and 1 mL of H_2O_2 (30%). ICP was used to analyse the concentration of inorganic elements in plant samples. A spectrophotometer was also used to quantify the total phosphorus (P) concentration in the leaves.

Bioconcentration factor (BCF)

Bioconcentration factor was used to determine the potentiality of PTEs accretion in plant tissues. The content of PTEs in organisms were assessed through the application of bioconcentration factor (Takarina and Tjiong, 2017):

$$BCF = \frac{Heavy\ metal\ concentration\ in\ plant\ tissue}{Heavy\ metal\ concentration\ in\ soil}$$

RESULTS AND DISCUSSION

Water quality characteristics

The pH, EC values, mean values of some anions, cation and irrigation water quality criteria were shown in Table 2. The pH value of irrigation water samples was alkaline ranged from 6.5 to 8.4. This finding was matched with those obtained by Badr et al., (2023) since the alkaline nature often exists in irrigation water resources mixed with wastewater. The pH values recorded were between 7.64 and 8.41. The pH values for wastewater were within the irrigation guidelines except one (Sample, W04), which recorded 8.4. The mean values of major cations were $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ (Table 2). Similarly, Table 3 present the results of some cation concentrations in soil irrigated with wastewater resources and (Table 3) present some elemental values potentially derived from fertilizers applied during those periods. The results in Tables 4 and 5 present some wastewater samples analysis collected from kalabsho used for irrigation in the study area during the periods: Autumn, Summer and Winter season respectively. Whereas for heavy metal in autumn it was (Zn >Fe > Al > Cu > Ni > Mn) with Co, Cd, Pb and Cr not detected (ND) (Table 5). In summer the order in abundance was (Mn > Zn >Fe > Al > Ni > Pb > Cu). However, Co, Cd and Cr were not detected (ND) (Table 6). And in winter it was (Zn > Al > Fe > Mn = Ni whereas, Co Cd, Cu, Pb and Cr were not detected (Table 7). The relatively high value of salinity is as a result of high amounts of soluble ions (Na^+, K^+, Mg^{2+} and Ca^{2+}; $Cl^–$ and $SO_4^{2–}$). The negative consequences of sodium presented as (SAR > %Na > KR > MAR) and range of mean values of the major cations $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ were 22.82-111.09 > 61.27-78.91% > 1.82-4.24 > 0.37-0.80 and 143-1456.26 > 29.76-271.61 > 39.44-98.00 > 9.14-48.63 mg/L, respectively. The SAR value indicated slight-to-moderately degree of constraint for utilisation because of the high amount of Na^+ ions in water (greater than 26%) as was also observed by (Mosa et al., 2023) in all cases except in one sample point that recorded 22.82. However, the promising criteria that showed suitability of utilisation in irrigation is the value of KR and the low value of MAR (less than 50) substantiated the suitability of water for irrigation (Gupta and Gupta, 1987) (Table 1). In ascending order, soil PTEs concentrations were Mn > Fe > Al > Zn > Cu > Cd > Co > Cr = Ni and the range concentration values were 0-1.67, 0.17-0.17, 0-0.91, 0-0.67, 0-0.23, 0-0.03, 0-0.003, 0-0.02 =0.02 mg/kg and Pb not detected (Table 6).

Considering the fertilizer potentially derived elements (Table 4) it can be concluded that, the most commonly applied fertilizers were phosphorus and sulphur based during the seasons (autumn, summer and winter) and in soil results. This may add to eutrophication processes in waterbodies causing algal blooms and murky waters making it unfavourable to aquatic organisms and other inhabitants.

Table 1. Irrigation water quality guidelines

Parameter	Symbols	Units	Range
Electrical conductivity	EC_W	dS/m	0-3.0
Magnesium	Mg^{2+}	cmolc/L	0-5
Sodium	Na^+	cmolc/L	0-40
Calcium	Ca^{2+}	cmolc/L	0-20
Chloride	Cl^-	cmolc/L	0-30
Acid/Base	pH	1-14	6.0-8.5
Sulphate	SO_4^-	meq/L	0-20
Potassium	K	meq/L	0-0.052
Sodium Adsorption Ratio	SAR	-	0-9
Aluminium	Al	meq/L	0-5
Cadmium	Cd	meq/L	0-0.01
Cobalt	Co	meq/L	0-0.05
Chromium	Cr	meq/L	0-0.1
Copper	Cu	meq/L	0-0.2
Iron	Fe	meq/L	0-5
Manganese	Mn	meq/L	0-0.2
Nickel	Ni	meq/L	0-0.2
Lead	Pb	meq/L	0-5
Zinc	Zn	meq/L	0-2

Adopted from Ogunfowokan, et al., (2013)

Table 2. EC, pH, Anions, Cations and Irrigation water quality criteria in wastewater resources

EC dS/m	pH	NO_3^- cmolc/L	Cl^- cmolc/L	SO_4^{2-} cmolc/L	Na^+ cmolc/L	Ca^{2+} cmolc/L	Mg^{2+} cmolc/L	K^+ cmolc/L	%Na	SAR	KR	MAR
0.17	8.0	6.17	2678.5	430.91	245.97	47.26	54.85	13.03	68.12	34.43	2.41	0.54
0.16	7.9	1.45	4843.2	589.72	230.74	79.79	47.01	11.5	62.52	28.98	1.82	0.37
0.13	8.1	3.79	2188.2	381.4	177.74	51.44	40.41	9.88	63.6	26.23	1.94	0.44
0.17	8.4	0.48	3852.6	384.29	249.97	56.77	46	15.75	67.84	34.87	2.43	0.45
0.10	8.1	4.60	2272.5	394.41	143.05	48.85	29.76	11.81	61.27	22.82	1.82	0.38
0.13	7.6	9.63	451.37	165.49	180.7	53.29	37.4	11.76	63.82	26.83	1.99	0.41
0.11	8.1	10.95	458.67	162.38	161.9	39.44	34.52	9.14	66.08	26.62	2.19	0.47
0.14	8.2	11.87	412.89	149.65	217.2	53.14	38.23	12.07	67.74	32.13	2.38	0.42
0.25	8.1	9.26	431.42	151.74	389.53	61.52	73.12	20.17	71.56	47.47	2.89	0.54
0.23	8.1	2.01	565.5	186.33	369.15	61.50	63.05	17.31	72.24	46.78	2.96	0.51
0.89	8.0	8.41	462.13	162.10	1456.26	72.08	271.61	45.5	78.91	111.09	4.24	0.79
0.74	8.1	4.44	1406.7	199.47	1197.62	59.97	236.07	40.33	78.07	98.44	4.05	0.8
0.39	7.8	ND	18018	1360.6	627.83	43.99	123.83	24.31	76.57	68.54	3.74	0.74
0.49	8.1	4.27	2099	269.14	780.84	55.11	147.23	38.27	76.44	77.63	3.86	0.73
0.63	8.0	3.56	1722.1	256.9	1018.58	98.00	182.03	48.63	75.61	86.08	3.64	0.65

Table 3. Cation concentrations in soil irrigated with wastewater resources

Na^+ mg/kg	Ca^{2+} mg/kg	Mg^{2+} mg/kg	K^+ mg/kg
17585.58	13473.26	1682.25	1138.03
953.47	3565.6	313.04	260.23
1710.41	2861.44	312.41	208.63
267.98	2971.02	407.15	174.02
1078.74	4344.68	534.94	460.13
246.97	1312.21	111.63	162.95
297.73	1304.06	97.48	251.17
372.25	1320.88	104.80	311.23
249.72	1429.22	83.53	133.19
334.67	1432.57	135.60	152.52
15290.94	10051.6	2030.14	2607.82
36725.40	7063.42	2063.78	2341.50
12142.10	6076.36	1538.79	709.88
35.69	1779.34	122.61	58.45
37.57	1696.72	121.78	61.00

Table 4. Values of elements potentially derived from fertilizers

Water						Soil	
Autumn		Summer		Winter			
P mg/l	S mg/l	P mg/l	S mg/l	P mg/l	S mg/l	P mg/kg	S mg/kg
0.38	79.55	0.1	11.47	0.09	16.21	4.12	10358.9
0.87	42.33	0.23	3.14	0.08	74.95	3.21	1145.63
0.27	45.1	0.3	13.5	0.17	32.28	3.28	919.3
0.3	55.15	4.69	23.82	0.44	28.04	40.77	81.36
0.32	39.11	0.57	11.49	0.41	29.53	6.03	215.02
0.34	57.49	0.16	10.11	0.88	37.61	25.21	84.99
0.19	37.2	0.27	12.3	0.3	31.29	37.98	101.88
0.19	30.45	2.92	16.26	0.26	68.51	23.23	142.44
0.28	77.17	1.93	29.86	0.38	54.33	4.75	47.26
0.31	60.58	1.04	3.31	0.56	59.03	4.59	74.33
0.13	248.9	0.08	9.22	0.63	62.82	0.58	4164.52
0.12	171.9	0.11	8.35	0.29	79.66	2.75	2446.06
0.22	129.6	0.11	8.97	0.64	17.17	2.43	1339.79
0.22	152.5	7.28	12.72	0.69	26.83	7.18	43.74
0.22	186.3	8.85	13.25	0.53	108.83	8.83	45.57

Table 5. PTEs concentrations in wastewater used for irrigation

Sample	Autumn						Summer							Winter				
	Fe mg/l	Al mg/l	Mn mg/l	Zn mg/l	Cu mg/l	Ni mg/l	Fe mg/l	Al mg/l	Mn mg/l	Zn mg/l	Cu mg/l	Pb mg/l	Ni mg/l	Fe mg/l	Al mg/l	Mn mg/l	Zn mg/l	Ni mg/l
W01	0.08	0.07	0.01	0.08	ND	0.02	ND	0.05	ND	ND	ND	ND	ND	0.01	0.07	ND	0.09	ND
W02	0.01	0.07	0.01	0.13	ND	ND	0.12	0.01	1.05	ND	ND	ND	0.01	ND	0.05	ND	0.12	ND
W03	0.09	0.08	0.01	0.16	ND	0.02	0.01	0.04	ND	ND	ND	ND	0.01	ND	0.04	ND	0.19	ND
W04	0.09	0.07	0.01	0.12	ND	0.02	0.09	0.08	0.02	0.1	0.01	ND	0.01	ND	0.04	ND	0.18	0.01
W05	ND	0.08	ND	0.13	ND	0.01	0.1	0.11	0.3	0.08	ND	0.01	0.01	0.01	0.08	ND	0.08	ND
W06	ND	0.08	ND	0.1	ND	0.01	0.02	0.1	ND	ND	ND	ND	0.01	0.02	0.05	0.01	0.08	ND
W07	ND	0.04	ND	0.04	ND	ND	0.01	0.07	ND	ND	ND	ND	0.03	ND	0.04	ND	0.12	ND
W08	ND	0.07	ND	0.09	ND	0.01	0.04	0.03	0.13	ND	ND	ND	0.01	ND	0.03	ND	0.15	ND
W09	ND	0.06	ND	0.11	ND	ND	0.05	0.04	0.03	ND	ND	ND	0.02	ND	0.02	ND	0.22	ND
W10	ND	0.06	0.01	0.18	ND	ND	0.03	0.07	0.29	ND	ND	ND	0.01	ND	0.02	ND	0.19	ND
W11	ND	0.04	ND	0.12	0.06	ND	0.08	0.08	0.05	0.15	0.02	0.02	0.01	ND	0.03	ND	0.1	ND
W12	ND	0.05	ND	0.16	0.05	0.01	0.01	0.03	0.02	ND	ND	ND	0.02	ND	0.05	0.01	0.09	0.01
W13	0.05	0.06	ND	0.07	0.03	0.01	0.01	0.07	ND	0.09	ND	ND	0.01	ND	0.03	ND	0.18	ND
W14	ND	0.04	ND	0.17	0.02	0.01	0.06	0.04	0.1	ND	ND	ND	0.01	ND	0.04	ND	0.17	ND
W15	0.1	0.05	0.02	0.15	0.02	0.02	0.19	0.08	0.17	0.06	ND	0.01	ND	ND	0.03	ND	0.18	ND
Mean	0.03	0.06	0.01	0.12	0.01	0.01	0.06	0.06	0.14	0.03	0.002	0.003	0.011	0.003	0.041	0.001	0.14	0.001

Table 6. PTEs concentrations in soils (S) irrigated with wastewater resources.

Sample	Fe mg/kg	Mn mg/kg	Al mg/kg	Zn mg/kg	Co mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/kg	Cr mg/kg	Ni mg/kg
S1	0.41	0.51	ND	ND	ND	0.02	0.15	ND	ND	0.02
S2	0.47	ND	0.89	ND	ND	0.02	0.08	ND	0.01	ND
S3	0.28	0.96	0.61	ND	ND	0.02	0.10	ND	ND	ND
S4	0.61	0.90	0.61	0.01	ND	0.02	0.22	ND	ND	ND
S5	0.25	ND	ND	ND	ND	0.02	0.11	ND	0.02	ND
S6	0.78	0.81	0.06	0.43	0.01	ND	0.19	ND	ND	ND
S7	0.98	0.90	0.58	ND	ND	0.01	0.23	ND	ND	ND
S8	0.69	0.62	0.75	0.67	0.03	0.01	0.21	ND	ND	ND
S9	0.37	0.01	0.91	0.53	ND	0.01	0.00	ND	ND	ND
S10	0.33	0.00	0.24	0.18	ND	ND	0.05	ND	ND	ND
S11	0.17	1.15	ND	ND	ND	0.01	0.04	ND	ND	ND
S12	0.21	1.67	ND	ND	ND	0.02	0.03	ND	ND	ND
S13	0.26	1.00	0.89	ND	ND	ND	0.03	ND	ND	ND
S14	0.39	0.37	0.24	ND	ND	0.01	0.06	ND	ND	ND
S15	1.07	0.59	0.82	ND	ND	0.03	0.08	ND	ND	ND
Mean	0.485	0.633	0.440	0.121	0.003	0.013	0.105	0.000	0.002	0.001

Heavy metals concentration in plant samples

Results of PTEs concentrations of edible fruits and vegetables were given in (Table 7). In date palm (*Phoenix dactylifera L.*) the fruits have the highest concentration of Fe, Mn, Cd and Pb with values of 550, 150, 0.31 and 4.2 mg/kg respectively. Young leaves recorded the highest concentrations of Co, Cu and Cr with values of 0.36, 20.01 and 2.1 mg/kg respectively. whereas the old leaves have highest concentration in Al, Zn, and Ni with recorded values of 535, 13.3, and 2.0 mg/kg respectively. This is because date palm has the ability to accumulate PTEs in their tissues according to biomass production, size of plant and growth rate of the plant. According to Aldjain et al., (2011) supported the assertion, date palm fruits are highly susceptible to contamination with PTEs. Hence, they concluded that high metal concentrations in fruits were due to the irrigated wastewater influenced by the different industrial processes, pesticides and fertilizers that contaminate water as well as the soil. Sulaiman et al., (2021) reported that in date palm leaves and fruits, Cd and Cr were observed to significantly increase in the leaves of plant, with Cu concentration been highest in the fruits. Busaidi et al., (2015) also reported that, soils irrigated with wastewater were relatively high in heavy metals and they further observed high concentration of Ni, Fe and Zn in date palm fruits. In olive plants (*Olea europaea*), the concentration of PTEs was more in the old leaves than other parts of the plant. Old leaves were able to accumulate considerably larger amounts of certain metals, particularly Fe, Al, Co, Pb, Ni and Cu, than other portions of the plants, showing that olive plants exploit these less-active metabolic leaves as sinks for PTEs. Fe, Al, Co, Pb, Ni and Cu recorded highest in the old leaves with values 381, 368, 0.57, 2.2, 1.3 and 19.5 mg/kg respectively. Whereas, Mn, Zn, Cd and Cr recorded 25, 18.5, 0.2 and 2.8 mg/kg values respectively in fruits. Habahbeh et al., (2021) reported that, long-term irrigation with wastewater led to high concentration of heavy metals in plant parts when compared to their amounts in soil and irrigation water. Olive fruits accumulated higher levels of Cu, Cd and Zn whereas, the leaves have more Fe, Zn and Mn than other parts. However, only Fe and Cr were identified in greater amounts in the roots and stem bark than in the fruits and leaves. This indicates that olive plants are good PTEs accumulators. In casuarina (*Casuarina*), the lowest values were recorded in the young leaves. Casuarina young needles have the highest concentration of Co, Cd, Cu and Cr with values 0.13, 0.18, 9.6 and 2.8 mg/kg respectively, whereas, the old needles have Fe, Al, Mn, Zn, Pb and Ni in highest quantity with values 596, 677, 136, 20.3, 4.1 and 1.3 mg/kg respectively. In research conducted it was discovered that casuarina needles have the ability to accumulate moderate concentration of Ni in the leaves but high concentration of Pb in the root. Because casuarina is a good phytostabilizer of heavy metals in the soil (Bahnasy, 2018). To corroborate the earlier report Slaimi et al., (2021) reported heavy metal removal efficiency of casuarina in the roots was 92% for Cd, 77% for Pb, 83% for Ni, and 73% for Zn more than in the shoot. It was concluded that long term continuous reuse of wastewater translocates heavy metals to other parts of the plant. Pomegranate (*Punica granatum*) results showed that old leaves of pomegranate have the highest concentration of Al, Co, Cd, Cu, Cr and Ni with values 814, 0.49, 0.29, 17.4, 2.5 and 1.7 mg/kg. Whereas, fruits recorded highest concentration of Fe, Mn, Zn and Pb with values 778.0, 56.0, 26.2 and 4.7 mg/kg, respectively. The metabolically less-active leaves were used by the plants as a storage for PTEs concentration. Eggplant (*Solanum melongena L.*), the leaves have the highest concentration of Mn, Co, Cu, Cr and Ni with recorded values 55.0, 0.35, 20.5, 2.6 and 0.8 mg/kg respectively while the fruits have the highest accumulation of Fe, Al, Zn, Cd and Pb with recorded values of 558, 481,58.0, 0.22 and 4.3 mg/kg respectively. According to Tariq et al., (2023), the degree of heavy metal concentration in fruits of eggplant is determined by the ability of the plant to preferentially translocate heavy metal from contaminated soil. Cadmium recorded highest concentration with Pb as the lowest. In their findings they concluded that irrigation water, particularly wastewater is the main source of heavy metal accumulation in eggplant. The pepper plant (*Capsicum*), have the leaves with highest concentration of Fe, Al, Zn, Cr and Ni with recorded values 258, 172, 37.8, 2.8 and 0.6 mg/kg whereas, in the fruits Mn, Co, Cd, Cu and Pb were highest in concentration with recorded values 152, 0.88, 0.33, 17.5 and 3.8 mg/kg respectively. Ayman et al., (2021) in their findings on the concentration of heavy metals in pepper plant irrigated with wastewater indicated significant changes in heavy metal levels in the plant, soil, and water samples. Heavy metals identified in pepper fruits in high concentrations were Cd, Cr, Ni, Pb, Cu, and Zn with translocation factor less than 1. In wheat plants (*Triticum aestivum L.*), Fe has the highest concentration and Cd as the least with recorded values 458 and 0.25 mg/kg respectively. Concentration of heavy metals in wheat was as a result of deposition of heavy metal sourced from atmosphere and/or in water, which eventually get into the soils, thereby serving as pathway for heavy metal into wheat resulting from long-term reuse of wastewater irrigation (Wu et al., 2013; Xue et al., 2014). Batool et al., (2023) reported that wheat grains have significant content of Zn (3.31 mg/kg) and lowest content of Ni (1.02 mg/kg). The values of bioconcentration factor (BCF) of Cd, Ni, Fe and Mn were less than 1.0 indicating their low content in wheat grains. However, the Pollution load index (PLI) was highest in Cd but lowest in Zn hence greater Health hazard index for Cd and Zn. In clover (*Trifolium alexandrinum L.*), Fe has the highest and the lowest was Cd with recorded values 257 and 0.28 kg/mg respectively. Abuzaid et al., (2021) reported the concentration values of Co, Cu, Ni and Pb to be above the maximum allowable limits in berseem clover shoots irrigated with wastewater for animal feeds. While the translocation factor root-to-shoot for Cr, Co and Ni were < 1.0 but for Cu, Pb, and Zn were > 1.0. It was concluded that berseem clover plant is a good phytofiltrator of Cr, Co and Ni, and good phytoextractor of Cu, Pb and Zn from heavy metal contaminated soils. Regarding iceplant, leaves have Cd as the least concentration whereas Fe have the highest with corresponding values 0.18 and 0.57 mg/kg respectively. Haddad et al., (2023) investigated the impact of nine heavy metal pollutants (Cd, Cr, Cu, Ni, Pb, K, Fe, Mn, and Zn) on irrigation water and soil and discovered that these pollutants find their ways into iceplant roots and shoots through translocation. The results shows that Cd, Fe, Pb, and Zn levels in iceplant roots and shoots were higher than WHO allowable limits, but K had the highest Translocation Factor (TF = 57.8) and Bioconcentration Factor (BCF = 126.8), expressing its efficiency in phytoremediation and function in improving iceplant drought tolerance. Finally, some of the elements under investigation are beneficial to plants at low concentration for a variety of biological functions but because of the continuous reuse of wastewater may have increased the accumulation of heavy metals in the soil and resulting in high concentration in plant through translocation over-time.

Table 7. PTEs concentrations in fruits and vegetables irrigated with wastewater resources

Plants	Fe mg/kg	Al mg/kg	Mn mg/kg	Zn mg/kg	Co mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/kg	Cr mg/kg	Ni mg/kg
Dates young leaves	307	280.1	133	7.6	0.36	0.18	20.01	2.1	2.1	1.1
Dates old leaves	548	535	147	13.3	0.21	0.2	17.9	3.3	1.6	2
Dates fruits	550	288	150	8.7	0.19	0.31	15.1	4.2	1.8	0.7
Olives young leaves	266	298	15	14.1	0.32	0.18	9.7	1.1	2.1	1.1
Olives old leaves	381	368	16	11.2	0.57	0.17	19.5	2.2	2.4	1.3
Olives fruits	274	44	25	18.5	0.47	0.2	12.3	1.8	2.8	1
Casuarina young needles	195	192	99	16.8	0.13	0.18	9.6	2.8	2.8	0.7
Casuarina Old needles	596	677	136	20.3	0.11	0.11	8.4	4.1	1.9	1.3
Pomegranate leaves	248	814	24	15.7	0.49	0.29	17.4	4.3	2.5	1.7
Pomegranate fruits	778	177	56	26.2	0.22	0.26	16.3	4.7	1	1.2
Eggplant leaves	301	248	55	41.9	0.35	0.13	20.5	3	2.6	0.8
Eggplant fruits	558	481	54	58	0.22	0.22	20.4	4.3	2	0.6
Pepper leaves	258	172	26	37.8	0.85	0.28	8	1.9	2.8	0.6
Pepper fruits	106	23	152	22.5	0.88	0.33	17.5	3.8	2.5	0.3
Wheat leaves	458	341	41	29.7	0.39	0.25	16.3	2	2.1	1.1
Clover leaves	257	231	55	34.4	0.67	0.28	21.9	4	2	0.9
Iceplant leaves	244	162	101	27.5	0.57	0.18	12	4.3	2.1	1.2

BCF results of heavy metal concentration in plants.

It was observed that, highest concentration of Fe, Mn, Cu and Ni were found in date palm leaves, and in casuarina needles highest concentration of Cr, Ni and Al were dictated, also in eggplant fruits there was highest concentration of Zn; olive leaves have the highest concentration of Cd; Cr and Ni were highest in both pepper leaves and olive fruits. Similarly, pepper fruits have the highest concentration of Fe, Al and Ni; while, Mn was highest in pomegranate leaves, Zn and Cd recorded highest in date palm fruits; Cu was highest in pepper leaves; Cr have the highest concentration in both olive fruits and pomegranate fruits (Figures 1 - 8). However, from the results obtained BCF values were greater than 1.0, which indicates the plants ability to absorb heavy metals at high concentration in their tissue due to continuos reuse of wastewater.

The concentration of some nutrient elements in plant tissues were presented in Table 8. It was observed that potassium has the highest concentration in all the plants except in olive old leaves and pomegranate leaves that sodium percentage was higher because under salt stress Ca, Mg, K, S and P content decreases, and in casuarina young and old needles as well as pomegranate fruits calcium was observed to be high. The high potassium percentage in the plant tissue may be as a result of uptake from soil rich in potassium resulting from long-term application of wastewater with high potassium levels, which causes the build-up of soil potassium.

Table 8. Percentage concentrations of some elements in plant parts

	Na %	Ca %	Mg %	K %	P %	S %
Dates young leaves	0.08	0.48	0.44	0.67	0.16	0.25
Dates old leaves	0.08	0.61	0.37	0.69	0.17	0.24
Dates fruits	0.03	0.62	0.31	0.95	0.13	0.25
Olives young leaves	0.55	0.41	0.29	0.64	0.14	0.21
Olives old leaves	0.87	0.51	0.33	0.46	0.15	0.28
Olives fruits	0.44	0.68	0.38	0.96	0.15	0.10
Casuarina young needles	0.19	2.20	0.36	0.74	0.10	0.14
Casuarina Old needles	0.38	2.07	0.27	0.54	0.10	0.20
Pomegranate leaves	1.24	0.55	0.34	1.20	0.38	0.14
Pomegranate fruits	0.47	1.93	0.68	0.79	0.22	0.19
Eggplant leaves	0.06	2.18	1.46	2.58	0.54	0.48
Eggplant fruits	0.57	1.57	1.43	3.02	0.54	0.57
Pepper leaves	0.11	2.50	2.52	3.80	0.66	0.65
Pepper fruits	0.09	0.27	0.4	3.93	0.55	0.35
Wheat leaves	1.24	0.32	0.45	3.69	0.54	0.52
Clover leaves	1.58	1.08	0.75	3.42	0.63	0.41
Iceplant leaves	0.17	2.14	1.84	6.28	0.87	0.38

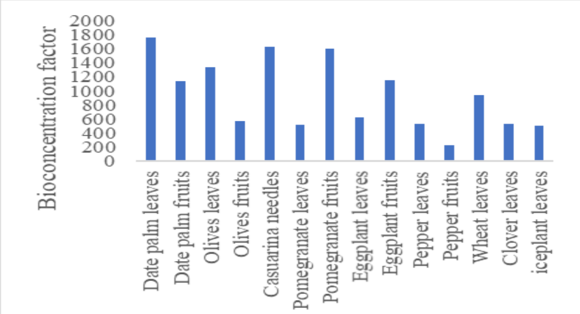

Figure 1: BCF oF Fe in Plants

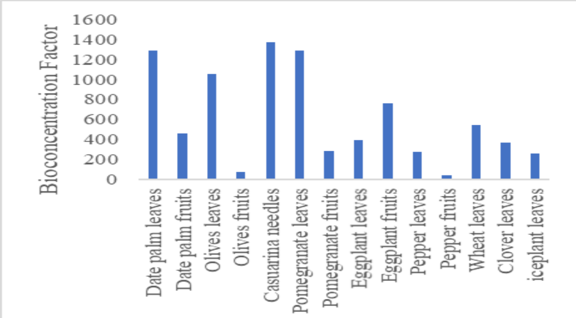

Figure 2: BCF of Al in Plants

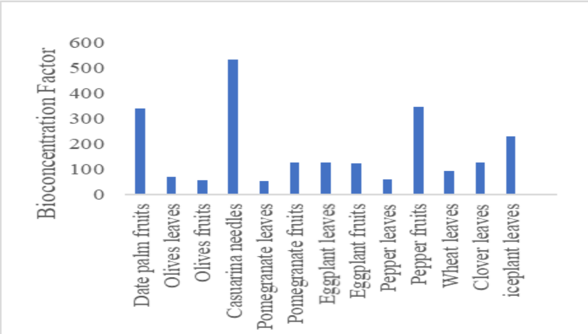

Figure 3: BCF of Mn in Plants

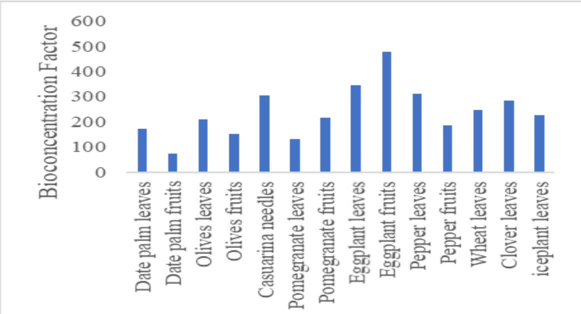

Figure 4: BCF of Zn in Plants

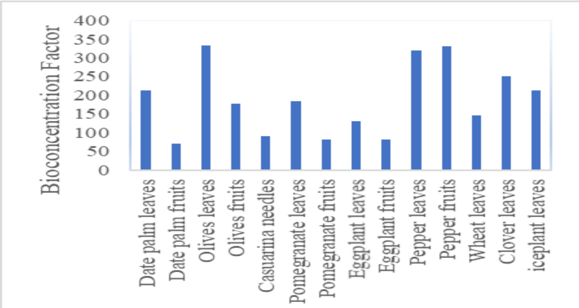

Figure 5: BCF of Cd in Plants

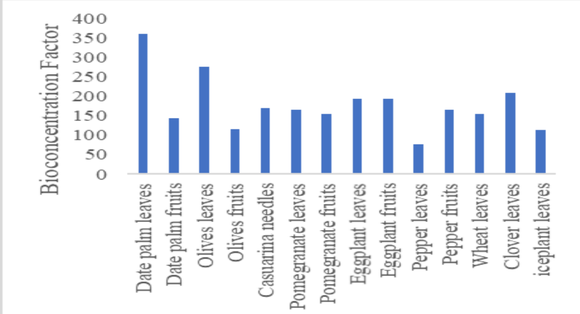

Figure 6: BCF of Cu in Plants

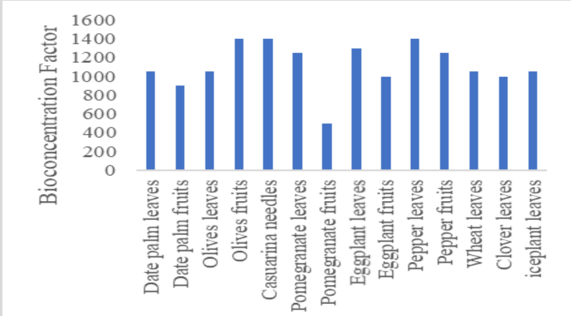

Figure 7: BCF of Cr in Plants

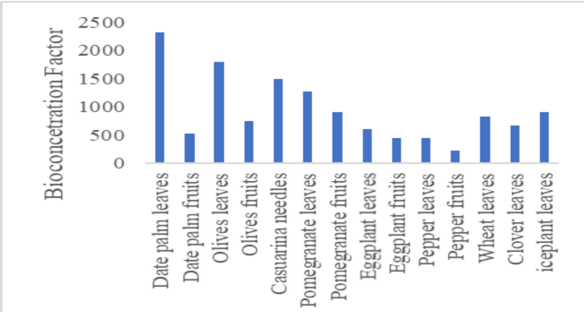

Figure 8: BCF of Ni in Plants

CONCLUSION

The amount of PTEs pollution in soils and plants were determined by the characteristics of wastewater used for irrigation and the impact of long-term reused. In the findings, concentrations of Fe, Al, Mn, Zn, Co, Cd, Cu, Pb, Cr, and Ni in soils and wastewater were found to be within allowable limits of FAO/WHO. On the other hand, the concentrations of Co, Cu and Pb were generally high in plants. Pomegranate fruits recorded low Cr concentration, whereas, Cd was found to be high in date palm fruits, eggplants fruits, pomegranate, pepper, wheat and clover leaves.

RECOMMENDATIONS

i. Regular check on wastewater and soil potentially toxic elements load should be carried out
ii. Industrial effluents should be adequately treated prior to discharge
iii. Landfills should be located away from canals to prevent migration of harmful substances into the water
iv. State of the art technology should be used in landfill areas for the conversion of waste to useful resources

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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تأثير الري طويل الأمد بموارد المياه منخفضة الجودة على تراكم العناصر المحتملة السمية في بعض النباتات الصالحة للأكل: محافظة شمال الدقهلية كدراسة حالة

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الملخص

الغرض من هذه الدراسة هو دراسة تأثير الري طويل الأمد بموارد مائية منخفضة الجودة (مياه الصرف الزراعي) على تراكم العناصر المحتملة السمية في بعض النباتات الصالحة للأكل (نخيل التمر، الزيتون، الرمان، البادنجان، الفلفل، القمح والبرسيم) وكذلك أشجار الكازوارينا ونبات الغسول . تم تقييم عينات المياه والتربة والنباتات التي تم جمعها من منطقة قلابشو – محافظة الدقهلية لمعرفة الخواص الكيميائية وتركيز العناصر المحتملة السمية . كانت تركيزات العناصر المحتملة السمية أعلي في فصل الصيف مقارنة بفصلي الخريف والشتاء. كان تركيز العناصر المحتملة السمية علي النحو التالي:-- الزنك ثم الحديد ثم الألمونيوم ثم النحاس ثم النيكل ثم المنجنيز في فصل الخريف في حين كانت تركيزات عناصر الكوبلت والكادميوم والرصاص والكرم أقل من حد التقدير.- المنجنيز ثم الزنك ثم الحديد ثم الألمونيوم ثم النيكل ثم الرصاص ثم النحاس في فصل الصيف في حين كانت تركيزات عناصر الكوبلت والكادميوم والكروم أقل من حد التقدير.- الزنك ثم الألمونيوم ثم الحديد ثم المنجنيز ثم النيكل في فصل الشتاء في حين كانت تركيزات عناصر الكوبلت والكادميوم والنحاس والرصاص والكروم أقل من حد التقدير. وبالمثل كان تركيز عنصر المنجنيز هو الأعلى في التربة تلاه عناصر الحديد ثم الألمونيوم ثم الزنك ثم النحاس ثم الكادميوم ثم الكوبلت ثم الكروم والنيكل. وفي كل الأحوال كانت تركيزات العناصر محتملة السمية في عينات المياه والتربة في الحدود المسموح بها طبقا لمنظمتي الأغذية والزراعة ومنظمة الصحة العالمية. كانت تركيزات العناصر المحتملة السمية أعلي من الحدود المسموح بها في عينات النبات التي تمت تحليلها فيما عدا النيكل والنحاس في أوراق الزيتون الصغيرة وأوراق الكازورينا (الكبيرة والصغير) وكذلك أوراق الفلفل. أظهرت نباتات البرسيم والغسول قدرة عالية علي تراكم العناصر المحتملة السمية وبالتالي مقدرة عالية علي المعالجة النباتية للأراضي الملوثة . بصفة عامة, كان تركيز العناصر المحتملة السمية في الحدود المسموحة في التربة والمياه ولكن أعلي من الحدود المسموح بها في النبات فيما عدا عنصر النيكل. كان معامل التراكم لكل العناصر المحتملة السمية أكبر من 1 . أدت النتائج المتحصل عليها من هذه الدراسة إلي زيادة الوعي والفهم فيما يتعلق بالضرر السمي للعناصر المحتملة السمية في بعض الأراضي الهامشية المروية بموارد مائية منخفضة الجودة