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Assessment of Non-Conventional Irrigation Water in Greenhouse Cucumber (*Cucumis sativus*) Production

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Abstract: Climate change, urbanization and subsequent environmental changes are depleting freshwater resources around the globe. The reuse of domestic, industrial and agricultural wastewater is an alternative approach to freshwater that can be used for irrigation purposes. However, these wastewaters may contain hazardous and toxic elements, such as heavy metals that are hazardous for human health and the environment. Therefore, an experiment was conducted to evaluate the concentration of macro, micro and heavy metals in cucumber irrigated with different resources (tap water, greywater, dairy water and wastewater). The results showed that the use of different irrigation resources has increased the level of macro (sodium (Na), potassium (K), calcium (Ca), magnesium (Mg)), microelements (zinc (Zn), iron (Fe), manganese (Mn)), and heavy metals (copper (Cu), barium (Ba), lead (Pb) and cadmium (Cd)) in cucumber leaves and fruits. However, their levels were in the range that is safe for human health and the environment was as recommended by FAO maximum values of trace elements (Zn, 2.0; Fe 1.0; Mn, 0.2; Cu, 0.2; Pb, 5.0, and Cd, 0.01 mgL^{-1}). Based on observations, it was also revealed that among different irrigation resources, the use of dairy water in cucumber improved its agronomic attributes and maximum plant yield (1191.02 g), while the different irrigation resources showed a non-significant impact on fruit diameter. However, total soluble solid contents (TSS) were more significant in cucumber fruits treated with wastewater (2.26 °brix) followed by dairy water (2.06 °brix), while the least TSS contents (1.57 °brix) were observed in cucumber plants treated with tap water. The significance of non-conventional irrigation water use in agriculture, particularly greenhouse cucumber (*Cucumis sativus*) production, is discussed.

Keywords: climate change; environment; heavy metals; human health; resources; wastewater

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1. Introduction

Worldwide, climate change has an adverse impact on water quality, water availability, food security, and human health. Globally, about 40% of the earth's total area is comprised of arid, semiarid, and range lands [1] and nearly 50% of European countries are already facing water scarcity [2]. In previous decades, the amount of water required in agriculture has been tripled while the available freshwater resources are depleting, and the agriculture sector is experiencing water shortages. Under existing climatic conditions, almost half of the world population will be confronted with water scarcity by 2030 as the resources of freshwater are depleting day by day, and Middle East/Gulf countries will suffer severe water scarcity, with future conflicts over scarce water resources due to climatic and socioeconomic issues [3]. In the past few decades, drought and desertification cycles have affected particularly the semiarid zone. Therefore, under these circumstances, water is the most critical ingredient for a sustainable ecosystem and, even more importantly, for economic development. Irrigation-dependent agriculture comprises 20% of the worldwide cultivated land, accounts for approximately 40% of global food production, and agriculture is also responsible for 70% of global water usage [4]. Hydrological poverty is also being caused by population growth and poor management of water supplies as 70% of available freshwater is being consumed in agriculture. In arid and semiarid regions, water demand for domestic, industrial, and agricultural uses is steadily rising and it is estimated that more than 40% of the world's population could face water scarcity by 2050 [5].

Domestic water would be of high quality, but industrial and agricultural water should be of lower quality. A huge volume of fresh water is consumed in households and industries, out of which 50–80% is wasted in households. The re-evaluation or reuse of this wastewater is a viable, alternative, and sustainable approach to conserve freshwater [6]. Besides household wastewater, municipal, and livestock slurries may be used in agriculture as these are affordable and appealing resources of irrigation [7]. The use of wastewater in agriculture minimizes aquatic degradation by reducing sewage sludge.

Wastewater contains a high concentration of nutrients and it has a significant potential for application in agricultural irrigation as it provides soil organic carbon (SOC), nutrients (NPK), minerals, organic matter and inorganic micronutrients to crops [8]. The treating systems do not remove nitrogen and potassium from the wastewater and are harmful to aquatic life. However, they are important from an agronomic view as they improve soil fertility, crop yield, and minimize fertilizer use and input cost. The studies highlighted that the use of wastewater, particularly for crop irrigation, has enhanced crop production as it is enriched with nutrients [9,10], and the reuse of urban wastewater has fulfilled the phosphorus (P) and potassium (K) demands for maize crops in Saudi Arabia [11].

Like Saudi Arabia, Oman is an arid country with severe water problems, and the practice of wastewater irrigation may be an affordable and appealing resource of irrigation as this approach is continuously increasing throughout the world for water security [12,13]. The availability of different resources of wastewater has also emphasized the attention for farmers of crop selection and different resources of wastewater have increased the production of lettuce, spinach, onion, tomato, potato, carrot, cucumber, and other different vegetables [14–16]. The wastewater is enriched with macro and micronutrients required for plant growth and it may be a resource to enhance soil productivity and fertility level [17].

However, the improper use of wastewater may cause environmental issues and the application of wastewater may increase the uptake of heavy metals in vegetable crops [18]. The continuous use of wastewater may affect soil physical and chemical characteristics [19]. It has been argued that high electrical conductivity (EC) values in irrigation water, e.g., 2900, 3900, and 2400 S/cm, resulted in a 50% drop in production in onions, potatoes, and dry bean crops [20]. Similarly, it is reported that irrigation water with high biological oxygen demand (BOD) or chemical oxygen demand (COD) inhibits plant growth, while water carrying chlorine and fluorine can harm plant tissues severely [21]. However, the mung bean (*Vigna radiate*) growth and yield were found to be lower with raw sewage irrigation water compared to biologically treated wastewater irrigation water [11]. The investigations on the application of wastewater irrigation showed significantly enhanced trace metal concentrations (mg kg^{-1}) in cucumber crops, with Fe (393.2) > Pb (145.1) > Cu (92.3) > Cr (84.8) > Zn (46.6) > Ni (48.2) > Mn (46.6) > Cd (14.1) > Co (11.1) [22]. The use of wastewater in spinach, radish, cauliflower, and mustard may increase the uptake of heavy metals (Cd, Cr, Cu, Pb and Cd) [18]. However, the climatic conditions, rooting media and plant species selection may alter the adsorption rate of heavy metals, such as in spinach, there is a high accumulation of Pb and Ni during summer, while in winter the accumulation of Cd increases [23]. Moreover, the highest values of Hg and U were observed during the wet season as compared to the dry season [24]. Likewise, carrots favored the build-up of Zn and Cu while spinach and mint have shown the highest uptake of Mn and Fe [25]. Similarly, there were 20 times more concentrations of heavy metals observed in crops treated with sewage water as compared to European countries [26]. The studies have also shown the absence of health risk factors when contaminated heavy metal vegetables were consumed by humans [27,28]. However, it should be kept in mind that these trials were conducted for short period. It is also observed that wastewater irrigation has increased eggplant production and its nutritional status without contaminating it with heavy metals [29]. A similar finding has described that wastewater application in the arid regions increased the soil organic matter (SOM), electrical conductivity, nitrogen, and heavy metal concentrations in soil [30].

Despite having been studied, there is still a need to explore the impact of different wastewater irrigation resources on soil properties, vegetables, and fruit qualities, as the reuse of wastewater for irrigation will be greater in the future, especially in water deficit areas due to increased population and ever increasing demands for food and fresh water Therefore, non-conventional water resources such as wastewater should be tested for agriculture to supply food and careful management should be adopted to ensure long-term agricultural productivity. By considering all the above factors, an experiment was designed in Sultan Qaboos University, Oman, with the aim to re-utilize wastewater, greywater and dairy water in cucumber production and to investigate their environmental impact on growing media and plant nutrient uptake.

2. Materials and Methods

2.1. Experimental Conditions

The experiment was conducted in the greenhouse conditions located at the Agriculture Experiment Station facility, Sultan Qaboos University, Oman. Greenhouse cucumber "Beit Alpha" cultivar seeds were procured by Mr. Waleed Al-Busaidi (technician) Department of Plant Sciences, from the Island harvest trading LLC, Barka, Oman. In this experiment, the environmental conditions of the greenhouse, such as temperature (27/20 °C) and light (240 μmol), were maintained throughout. Greenhouse cucumber seeds were sown in nursery plug trays (50 holes) having compost as a growing substrate and were watered uniformly. After one month of sowing, uniform seedlings of 4 inches in length were transplanted in plastic pots of size $7 \times 10''$, each having an equal volume of compost. Pots were supplemented uniformly with Hoagland′s nutrient solution (H2395 Sigma-Aldrich, St. Louis, MO, USA) once a week. The experiment was laid out under a completely randomized design (CRD) and four treatments of varied water, with freshwater as control, treated wastewater, greywater, and dairy cleansing water, were applied uniformly with 500 mL concentration according to the crop requirement. There were three replicates used in the experiment and in each replication eight plants were used.

2.2. Water Analysis

Before irrigation, the water quality of all water resources of freshwater, treated wastewater, greywater and dairy water was analyzed to determine the concentrations of macronutrients (sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg), micronutrients (zinc (Zn), iron (Fe) and manganese (Mn), and heavy metals (copper (Cu), barium (Ba), chromium (Cr), lead (Pb) and cadmium (Cd) by using inductively coupled plasma atomic emission spectroscopy (ICP AES, Interpid Il XDL) [31].

2.3. Growing Substrate Analysis

The analysis of plant growing substrate (compost) was conducted before the experiment to analyze the nutrient status. Therefore, three samples of each replicate were collected randomly at 10 cm pot depth and were taken to the soil chemistry laboratory at the Department of Soil, Water and Agricultural Engineering, College of Agricultural and Marine Sciences, Sultan Qaboos University, Oman. The soil organic matter content, total N content, macroelements, microelements, and heavy metals were determined by ICP after nitric-perchloric acid (2:1) digestion.

2.4. Leaf and Fruit Analysis

After eight weeks of transplanting, six mature leaves from individual cucumber plants were collected and were immediately transported to the Department of Plant Sciences, College of Agriculture and Marine Science, Sultan Qaboos University, Oman, for laboratory analysis. Before analysis, samples were washed thoroughly with special detergent (Alconox 0.1%) and rinsed in tap water, after each sample was cleaned with a diluted solution of 0.005% HCL and was finally rinsed in distilled water. To dry out leaf samples were left on filter paper for 2 h and were oven-dried for 48 h at 65 °C. After that macro/microelements and heavy metals were determined by ICP [31].

2.5. Fruit Yield and Quality Analysis

The yield of each plant was taken at each picking and the total yield of the plant was calculated at final maturity and the unit was expressed in grams (g). For fruit quality analysis, fruit size was measured by using Vernier caliper (model CP33659-00, Company VWR, Radnor, PA, USA) and values were taken in millimeters (mm), while fruit total soluble solid content (TSS, °Brix) was determined by hand refractometer (model MASTER-53α, ATAGO, Bellevue, WA, USA). Macro/microelements and heavy metals were determined by ICP [31].

2.6. Statistical Analysis

The experiment was laid out under a completely randomized design (CRD) and eight plants were taken as per single replicate and a total of twenty-four plants were used in three replications. The data were statistically analyzed by using analysis of variance (ANOVA) and differences among treatments were compared at 5% level of probability by applying Tukey's HSD.

3. Results

3.1. Availability of Essential Elements and Heavy Metals in Irrigation Water Resources

The data regarding the assessment of water resources are shown in Table 1. The results revealed that the concentration of macro, micro and heavy metals was significantly different in diverse water resources. Among macro essential elements, the highest Na was observed in wastewater (5370 mg/L) followed by a dairy water resource (1.50 mg/g). The amount K was highest in dairy water (1430 mg/L) followed by wastewater (380 mg/L). Similarly, Ca (1960 mg/L) and Mg (940 mg/L) were observed at maximum in wastewater, while Mg was not observed in fresh water and grey water resources. Regarding micro essential elements, the highest amount of Zn (9.89 mg/L), Fe (17.63 mg/L) and Mn (0.81 mg/L) was observed in dairy water. Likewise, the number of heavy metals significantly varied with water resources. The maximum concentration of Cu (3.16 mg/L) was observed in greywater while its least amount (1.60 mg/L) was observed in freshwater. Similarly, the concentrations of Pb (4.25 mg/L), Cr (1.64 mg/L) and Cd (0.08 mg/L) were noted highest in greywater. Meanwhile Ba was found highest in wastewater (5 mg/L) at par with a freshwater source (4.62 mg/L) and its quantity was observed lowest (0.25 mg/L) in dairy water.

Table 1. Nutrients and heavy metal analysis of irrigation resources before application.

	Freshwater	Greywater	Dairy Water	Wastewater
Macroelements				
Na (mg/L)	320 ± 100 c	530 ± 90 c	1500 ± 80 b	5370 ± 90 a
K (mg/L)	190 ± 20 b	310 ± 90 b	1430 ± 80 a	380 ± 50 b
Ca (mg/L)	550 ± 100 b	100 ± 40 c	670 ± 90 b	1960 ± 80 a
Mg (mg/L)	0.00 ± 0.00 c	0.00 ± 0.00 c	590 ± 20 b	940 ± 20 a
Microelements				
Zn (mg/L)	6.40 ± 0.4 d	9.18 ± 0.9 b	9.89 ± 0.9 a	7.07 ± 0.2 c
Fe (mg/L)	2.95 ± 0.1 d	12.97 ± 0.2 b	17.63 ± 0.3 a	4.85 ± 0.1 c
Mn (mg/L)	0.20 ± 0.09 c	0.61 ± 0.10 ab	0.81 ± 0.08 a	0.40 ± 0.10 c
Heavy metals				
Cu (mg/L)	1.60 ± 0.18 c	3.16 ± 0.06 a	1.96 ± 0.01 b	1.85 ± 0.10 bc
Ba (mg/L)	4.62 ± 0.08 a	3.71 ± 0.20 b	3.76 ± 0.09 b	5.00 ± 0.20 a
Cr (mg/L)	0.40 ± 0.09 b	1.46 ± 0.10 a	1.33 ± 0.18 a	0.40 ± 0.04 b
Pb (mg/L)	0.70 ± 0.01 c	4.25 ± 0.10 a	0.25 ± 0.02 d	1.20 ± 0.20 b
Cd (mg/L)	0.05 ± 0.01 a	0.08 ± 0.01 a	0.05 ± 0.01 a	0.05 ± 0.02 a

Any two means in a column having similar letters indicate a non-significant relationship ($p \leq 0.05$).

3.2. Concentrations of Macro–Micro and Heavy Metal Elements Available in the Compost When Treated with Different Irrigation Water Resources

The nutrient analysis of compost after final crop harvesting is presented in Table 2. The results exhibited that among macro essential elements, the highest amount of Na (690 mg/L) was observed in compost treated with wastewater followed by the compost treated with dairy water (530 mg/L) and greywater (450 mg/L). Similarly, the highest contents of Ca (18,400 mg/L) were observed in compost treated with wastewater followed by dairy water (17,870 mg/L). While the highest amount of K was observed in compost treated with dairy water (800 mg/L) at par with wastewater (780 mg/L). Likewise, the concentration of all micro essential elements Zn (91.30 mg/L), Fe (862 mg/L), and Mn (52.57 mg/L) was found at maximum in dairy water while these micronutrients were observed in minimum quantity in compost treated with fresh water. Regarding heavy metals, the highest amount of Cu (172 mg/L), Cr (11.53 mg/L), Pb (12.22 mg/L) and Cd (1.82 mg/L) was noticed in compost treated with greywater. Meanwhile, the maximum amount of Ba (8.25 mg/L) was recorded in compost treated with fresh water at par with composts treated with wastewater (8.5 mg/L) and dairy water (8.11 mg/L), respectively.

Table 2. Nutrients and heavy metal contents of compost (growing medium) after irrigation applications.

	Freshwater	Greywater	Dairy Water	Wastewater
Macroelements				
Na (mg/L)	430 ± 40 b	450 ± 50 b	530 ± 110 b	690 ± 30 a
K (mg/L)	770 ± 20 a	780 ± 30 a	800 ± 50 a	780 ± 100 a
Ca (mg/L)	17,180 ± 170 c	17,070 ± 120 c	17,870 ± 100 b	18,400 ± 150 a
Mg (mg/L)	1390 ± 30 b	1370 ± 100 b	1640 ± 100 a	1710 ± 100 a
Microelements				
Zn (mg/L)	41.85 ± 5 d	62.00 ± 0.89 b	91.30 ± 20 a	51.55 ± 17 c
Fe (mg/L)	727.00 ± 100 b	746.67 ± 40 b	862.00 ± 30 a	728.67 ± 89 b
Mn (mg/L)	38.82 ± 0.05 d	41.96 ± 0.04 c	52.57 ± 0.03 a	42.65 ± 0.09 b
Heavy metals				
Cu (mg/L)	16.26 ± 0.45 d	172.0 ± 17 a	59.77 ± 0.12 b	20.77 ± 0.10 c
Ba (mg/L)	8.25 ± 0.10 a	7.71 ± 0.20 b	8.11 ± 0.11 a	8.15 ± 0.09 a
Cr (mg/L)	11.25 ± 0.22 a	11.53 ± 0.20 a	7.82 ± 0.3 b	3.63 ± 0.27 c
Pb (mg/L)	7.83 ± 0.13 b	12.22 ± 0.18 a	2.93 ± 0.03 d	7.46 ± 0.8 c
Cd (mg/L)	1.31 ± 0.10 b	1.82 ± 0.10 a	1.01 ± 0.09 c	0.73 ± 0.09 d

Any two means in a column having similar letters indicate a non-significant relationship ($p \leq 0.05$).

3.3. Accumulation of Essential Minerals and Heavy Metals in Plant Leaves

The application through different water resources has significantly affected the accumulation level of nutrients in plant leaf tissues as shown in Table 3. The results revealed that in macro elements, the highest concentration of Na (1940 mg/L) was observed in leaves that were supplied wastewater irrigation followed by dairy water irrigation application (1220 mg/L). The macronutrients, K (9470 mg/L) and Ca (45,080 mg/L) were found maximum in plant leaves that were treated with dairy water resources while the least quantity of these nutrients K (6730 mg/L) and Ca (42,830 mg/L) was observed in plants that were treated with a freshwater resource. For micronutrients, Zn (48.37 mg/L) was found highest in plant leaves that were treated with dairy water followed by grey water (44.58 mg/L) as the resource of irrigation, while the least amount of Zn (34.68 mg/L) was observed in plants treated with wastewater. Similarly, other micro essentials Fe (95 mg/L) and Mn (41 mg/L) were also found to be highest in plant leaves that were treated with dairy water. Regarding heavy metals, the concentrations of Cu (5.38 mg/L), Cr (5.24 mg/L) and Pb (4.34 mg/L) were noticed in leaves that were treated with greywater resources. Meanwhile, the concentrations of Cr (5.28 mg/L) and Pb (4.34 mg/L) were the least in plant leaves that were treated with dairy water. However, the concentration of Cd (0.46 mg/L) was found to be a minimum in plant leaves treated with fresh water.

Table 3. Distribution status of macroelements, microelements, and heavy metals in cucumber leaves irrigated with different irrigations resources.

	Freshwater	**Greywater**	**Dairy Water**	**Wastewater**
Macroelements				
Na (mg/L)	710 ± 20 c	690 ± 10 c	1220 ± 90 b	1940 ±80 a
K (mg/L)	6730 ± 160 c	7550 ± 190 b	9470 ± 120 a	6130 ± 90 d
Ca (mg/L)	42,830 ± 1000 c	44,830 ± 900 a	45,080 ± 800 a	44,120 ± 700 b
Mg (mg/L)	5460 ± 110 c	5430 ± 70 c	6580 ± 100 a	6030 ± 80 b
Microelements				
Zn (mg/L)	38.05 ± 0.10 c	44.58 ± 0.8 b	48.37 ± 0.9 a	34.68 ± 0.78 d
Fe (mg/L)	78.80 ± 1.78 b	50.56 ± 1.09 c	95.00 ± 3.00 a	76.18 ± 0.9 b
Mn (mg/L)	23.70 ± 1.80 b	31.10 ± 0.9 b	41.00 ± 0.10 a	31.16 ± 0.88 b
Heavy metals				
Cu (mg/L)	5.07 ± 0.08 b	5.38 ± 0.12 a	4.06 ± 0.08 d	4.63 ± 0.09 c
Ba (mg/L)	11.85 ± 1.79 a	7.40 ± 0.40 b	8.38 ± 0.08 b	6.72 ± 0.09 b
Cr (mg/L)	4.46 ± 0.04 b	5.28 ± 0.10 a	3.86 ± 0.12 c	4.28 ± 0.06 b
Pb (mg/L)	2.11 ± 0.09 c	4.34 ± 0.020 a	1.81 ± 0.09 c	3.13 ± 0.08 b
Cd (mg/L)	0.46 ± 0.04 c	0.78 ± 0.03 ab	0.73 ± 0.02 b	0.81 ± 0.01 a

Any two means in a column having similar letters indicate a non-significant relationship ($p \leq 0.05$).

3.4. Accumulation of Essential Minerals and Heavy Metals in Cucumber Fruit

The results regarding the minerals and heavy metals are shown in Table 4. The results indicated that the use of different irrigation resources has a significant effect on the accumulation of minerals and heavy metals in fruits. The highest amount of macro element accumulation was observed in the fruits that were irrigated with wastewater (Na (1360 mg/L) followed by the dairy water (790 mg/L). Regarding K, it was found highest (16,780 mg/L) in fruits treated with dairy water while the least amount of K (12,530 mg/L) was observed in fruits treated with wastewater. While the maximum amount of Ca (2420 mg/L) and Mg (1550 mg/L) was observed in dairy water, however, the minimum amount of Ca (1400 mg/L) and Mg (1090 mg/L) was detected in fruits irrigated with fresh water.

Table 4. Distribution status of macro, microelements, and heavy metals in cucumber fruit irrigated with different irrigation resources.

	Freshwater	Greywater	Dairy Water	Wastewater
Macroelements				
Na (mg/L)	620 ± 10 c	660 ± 20 bc	790 ± 40 b	1360 ± 80 a
K (mg/L)	14,330 ± 100 b	13,770 ± 160 c	16,780 ± 180 a	12,530 ± 190 d
Ca (mg/L)	1400 ± 90 c	1920 ± 30 b	2420 ± 17 a	1420 ± 50 c
Mg (mg/L)	1090 ± 40 c	1260 ± 10 bc	1550 ± 90 a	1370 ± 10 ab
Microelements				
Zn (mg/L)	24.11 ± 0.11 c	25.27 ± 0.07 b	28.13 ± 0.12 a	20.18 ± 0.05 d
Fe (mg/L)	33.88 ± 0.06 c	61.20 ± 3.58 b	67.96 ± 0.25 a	33.90 ± 0.11 c
Mn (mg/L)	10.35 ± 0.20 c	13.95 ± 0.27 b	15.68 ± 0.18 a	8.91 ± 0.04 d
Heavy metals				
Cu (mg/L)	5.31 ± 0.18 a	5.68 ± 0.16 a	4.67 ± 0.20 b	5.26 ± 0.08 a
Ba (mg/L)	2.25 ± 0.35 a	2.62 ± 0.51 a	0.71 ± 0.10 b	2.81 ± 0.09 a
Cr (mg/L)	3.00 ± 0.08 b	5.02 ± 0.02 a	2.73 ± 0.03 c	3.03 ± 0.03 b
Pb (mg/L)	0.86 ± 0.07 c	1.80 ± 0.27 a	1.15 ± 0.11 bc	1.50 ± 0.09 ab
Cd (mg/L)	0.13 ± 0.18 b	0.22 ± 0.02 a	0.15 ± 0.03 b	0.20 ± 0.02 a

Any two means in a column having similar letters indicate a non-significant relationship ($p \leq 0.05$).

For micronutrients, the highest amount of Zn (28.13 mg/L), Fe (67.96 mg/L) and Mn (15.68 mg/L) were found in fruits treated with dairy water while the least quantity Zn (20.18 mg/L), and Mn (8.91 mg/L) were found in fruits treated with wastewater, and the Fe (33.88 mg/L) minimum amount was observed in freshwater. In heavy metals, the highest amount of Cu (5.68 mg/L), Ba (2.62 mg/L), Cr (5.02 mg/L), Pb (1.80 mg/L) and Cd (0.22 mg/L) were observed in fruits treated with greywater.

3.5. Effect of Irrigation Water on Fruit Production and Quality

The results regarding fruit production and quality are shown in Figure 1. The results showed that the highest yield in cucumber (1191.02 g) was achieved through dairy water irrigation followed by wastewater (976.65 g) and freshwater irrigation (938.14 g), while the least amount of fruit yield (872.01 g) was obtained in plants irrigated with greywater as shown in Figure 1a. However, the different irrigations have shown a non-significant impact on cucumber fruit diameter as indicated in Figure 1b. With regard to the quality of the total soluble solids, maximum TSS (2.26 °brix) was observed in cucumber fruits that were irrigated with wastewater followed by the dairy water (2.06 °brix). However, the least amount of TSS (1.61 °brix) was observed in fruits that were irrigated with fresh water and grey water (1.57 °brix) as shown in Figure 1c.

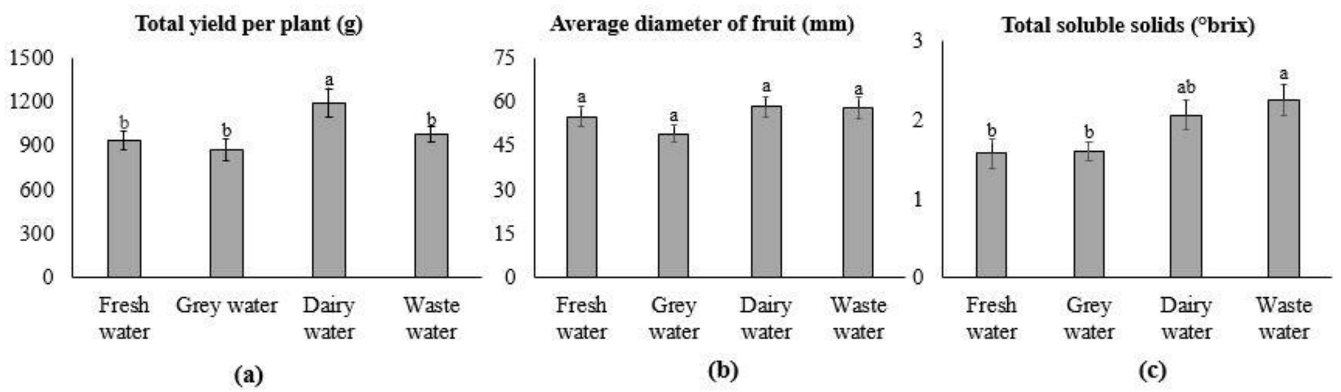

Figure 1. Effect of irrigation resources on (**a**) cucumber yield, (**b**) fruit diameter and (**c**) total soluble solids contents.

4. Discussion

Worldwide, the availability of fresh water is becoming a major concern, and the recycling of wastewater for crops irrigation has received a lot of interest. However, untreated or inadequately treated wastewater may harm soil, plants, and the environment, as well as cause serious risks to human health [32]. The presence of macro, micro, and heavy metals at high levels in wastewater disturbs plant physiological processes, metabolic processes and enzyme activities as the combination of different elements does not always increase growth and fruit yield [33,34]. However, the toxicity of these elements may affect plant yield, growth and may induce abnormal anatomical changes [35]. Furthermore, it is argued that heavy metals can accumulate in plants when municipal wastewater is used for irrigation, and an excessive amount can affect residents who consume crops and/or vegetables grown in these contaminated locations [36]. As a result, this could be the first food safety indicator.

In irrigation water, sodium (Na), magnesium (Mg) and calcium (Ca) are dominantly present and play an important role in plant growth and development. The wastewater carries significant amounts of nitrogen, phosphorus, potassium, calcium, magnesium, organic matter, and trace minerals, which are regarded as good sources of nutrients for plant growth and development [37]. After irrigation, some of the water is up taken and consumed by plants or evaporates directly from the soil. Among these salts, Ca and Mg often precipitate in carbonates while Na remains dominant in soil [38]. In our findings, a higher concentration of Na was observed in compost treated with wastewater. This higher accumulation in media may be due to wastewater as it already contains a higher amount of Na. However, the higher level of Na in soil may depress the plants' nutrient uptake and may increase the salts accumulation, particularly sodium chlorides (NaCl) that are most common in causing soil salinity. It has been reported that agriculture practices are increasingly pressurizing fertilizer demand; as a result, it is critical to find alternatives that maximize nutrient uptake by crop plants while minimizing the associated environmental impacts, and wastewater streams can be used as an alternate irrigation water supply [39]. The accumulation of Na generates osmotic potential and prevents water uptake, which creates similar conditions as drought [40]. Moreover, there may be accelerated drought and salinity due to an increase in low-quality water for irrigation, inadequate drainage and climate change [41]. Therefore, the increased level in Na may lead plants towards drought conditions and the application of wastewater to arid soils may enhance salinity and drought. The excess accumulation of other essential elements K, Ca, Cl and NO_3 in plant root zones may develop osmotic pressure in plant roots and imbalance cell ion homeostasis that leads towards photosynthesis inhibition, inactivates certain enzyme functions and damage to chloroplast and other organelles [42]. However, the presence of these elements up to optimal level promotes plant growth, development, photosynthesis and transpiration. Our results presented in Table 4 showed that the plant content of micronutrients and heavy metals surpassed (in most cases) the WHO permitted limits as shown in Table 5. However, Zn and Fe levels in cucumber fruit (Table 4) irrigated with freshwater and wastewater was lower compared to the threshold values.

Nevertheless, it was observed that heavy metals taken up by the vegetables produced under wastewater irrigation prefer to persist in the roots, a small percentage of the heavy metals translocated into the shoots, and an even less percentage reaches the fruit [47]. These elements also play a pivotal role in human health and their deficiency or toxicity may affect the metabolic functions occurring in the human body. Zinc is one of the essential elements required for the human body as it promotes cell growth, cell division, carbohydrates breakdown, wound healing, plays an important role in the defensive system and helps in developing immunity [48]. It is an omnipotent metal having amphoteric nature and its daily requirement is about 15–20 mg/day [49]. However, the high uptake of zinc may interfere with Cu uptake and may induce trauma due to zinc accumulation [50]. The researchers also reported that heavy metals in irrigation wastewater tend to collect in soils, where they may become bioavailable to crops and enhance bacterial populations linked with plant growth [51]. Besides, Iron (Fe) is a micronutrient that is vital for plant growth, it is a critical component in energy conversions required for syntheses and other cell life processes [52]. However, the Cu (5.26 mg/L) and Ca (1420 mg/L) were found in the highest concentrations in cucumber fruit from various irrigation resource water applications (Table 4), earlier studies indicate that minerals were extensively translocated from leaves to fruits in greenhouse tomato and cumbers [53]. It has also been reported that Cu plays an important role as a redox transition element in photosynthesis, respiration, and the metabolism of carbon and nitrogen, as well as protecting from oxidative stress [54].

Table 5. The World Health Organization (WHO), the United States Environmental Protection Agency (USEPA), Oman, the United Arab Emirates, Egypt, and Algerian Standards have established wastewater threshold levels for reuse applications [43–46].

Parameters	Units	WHO	US-EPA	Oman	UAE	Jordan	Egypt	Algeria
Na	mg/L	250		70	150	230		-
K	mg/L	100		-	12	-		-
Ca	mg/L	450		-	-	230		-
Mg	mg/L	80		30	0.4	100		-
Zn	mg/L	20	2	2	5	5	0.01	10
Fe	mg/L	50	5	1	0.2	5	0.5	-
Mn	mg/L	0.2	0.2	0.2	-	0.2	0.2	-
Cu	mg/L	0.2	0.2	0.2	1	0.2	0.01	0.5
Cr	mg/L	0.1	0.1	0.1	0.5	0.1	0.05	5
Pb	mg/L	5	5	0.1	0.1	5	0.01	10
Cd	mg/L	0.01	0.01	0.01	0.003	0.01	0.001	-

In our findings, the highest concentrations of K, Zn, Fe and Mn were observed in dairy water resources and the maximum yield was also obtained in cucumber in a similar resource of irrigation. However, heavy metals (Cr and Pb) were lower in all irrigation water types compared to the threshold values (Table 5). The highest yield may be due to the presence of K as it regulates plant stomata conductance and ensures optimal plant growth [55]. Further, it activates certain enzymes that trigger protein synthesis, sugar transport, and photosynthesis. Our finding has a resemblance with other researchers who stated that K is essential for cell growth and increases fruit yield and quality [56]. It has been also argued that K, on the other hand, is the most abundant cationic inorganic nutrient, with a large role in activating enzymatic reactions in plants and reducing heavy metal intake due to its availability as a nutrient in irrigation water and soil [57]. A similar finding was observed by [58] who stated that K is involved in stomatal opening, cell elongation and certain physiological processes that enhance plant yield. The studies have shown that Mn is an essential element; nevertheless, high quantities of Mn in the soil might smother plant growth. The current study found slightly elevated Mn levels in cucumber fruit, ranging from 8.91 mg/L to 15.68 mg/L, which could be hazardous to plants and soil media [52]. Likewise, Zn is an essential micronutrient that is required for plant growth and is involved in various enzymatic reactions as a catalyst, metabolism and energy transfer [59]. Therefore, it promoted plant yield attributes such as yield and fruit diameter in our study. Zn is equally essential for human health as it improves the immune system, prevents hair loss, muscle weakness, and memory loss. About 50% of the world population is suffering from Zn deficiency, and the ideal dose of 15 mg/day is required every day [60]. Likewise, according to FAO, 30% of world land is deficient in Zinc, therefore such cultivated areas are deficient in providing required range to the plants [61]. In our study, the range of Zn obtained in cucumber fruits treated with different irrigation resources was 20.18 to 28.13 mg/L, whereas in irrigation resources the level of Zn was less in fresh water, wastewater, greywater and followed by dairy water, respectively. Therefore, irrigation through these water resources may be used in some Zn deficient soils. It has been reported that Zn is a mineral that is required for plant nutrition, it serves structural and/or catalytic roles in a range of enzymes, including Cu–Zn superoxide dismutase, alcohol dehydrogenase, RNA polymerase, and DNA-binding proteins, and is important in carbohydrate metabolism [62]. However, it has also revealed that plants, on the other hand, are unlikely to absorb the excess Zn and Cu, which could be damaging to food consumers and hazardous to plants long before reaching a level that is toxic to humans [46].

In our study, the highest yield of cucumber was obtained in plants treated with dairy water. This might be due to the highest availability of essential macro and microelements in dairy water that promoted plant growth and fruit cell division and expansion. Our findings were in harmony with other researchers who reported that the application of wastewater boosted tomato yield compared to normal irrigation due to the presence of nutrients [63,64]. In our findings, TSS in cucumber fruits was within the range (1.57–2.26 °brix) that showed non-toxicity or non-accumulation of heavy metals. The highest TSS (2.26 °brix) was observed in fruits treated with wastewater while the least TSS (1.57 °brix) was observed in freshwater. The stress conditions and the abundance of elements might be a reason for the increase in soluble solids. Similar results were observed by other researchers who suggested that higher TSS concentrations provide a mechanism in plants to maintain osmotic pressure during stress conditions by metals [18,65]. However, high total soluble solids levels in fruits are also linked with consumer acceptance and are an important trait for crop harvest [66].

The reuse of wastewater in agriculture may be a greater source of saving freshwater consumption, as non-availability of fresh water and degraded water quality is a major issue for agriculture production [67]. Therefore, the reuse of wastewater in agriculture offers an ideal alternative source of irrigation to conserve precious freshwater resources particularly at a time of ever-changing climate scenarios [31]. Moreover, wastewater has been used as a source of fertilizer for different vegetable and fruit crops [68]. However, the use of wastewater requires consideration as it has an impact on soil physical, chemical, and microbial properties. Further, it has an influence on crop productivity and human health [69]. Therefore, precise monitoring and adequate strategies are required to minimize waste water risks for human and environment to ensure sustainable reuse practice [70].

5. Conclusions

The resources of freshwater are depleting rapidly due to climate change and urbanization. The utilization of wastewater is becoming popular in the agriculture sector, particularly in the arid and semiarid regions of the world because of the severe water scarcity. The irrigation of cucumber plants with different water resources, such as tap water, greywater, dairy water and wastewater enhanced the quantity of essential and non-essential elements. However, the level of these elements was within the range that was non-toxic to human consumption and the environment. Further, the use of dairy water revealed advantages in enhancing sustainable greenhouse cucumber production compared to other irrigation water resources. The application of alternate water resources offered marked opportunities for sustainable agriculture and conservation of ever-depleting precious water reserves.

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References

1. Becerra-Castro, C.; Lopes, A.; Vaz-Moreira, I.; Silva, M.E.F.; Manaia, C.M.; Nunes, O.C. Wastewater reuse in irrigation: A microbiological perspective on implications in soil fertility and human and environmental health. *Environ. Int.* **2015**, *75*, 117–135. [CrossRef]
2. Bixio, D.; Thoeye, C.; De Koning, J.; Joksimovic, D.; Savic, D.; Wintgens, T.; Melin, T. Wastewater reuse in Europe. *Desalination* **2006**, *187*, 89–101. [CrossRef]
3. UNDESA. International Decade for Action 'WATER FOR LIFE' 2005–2015. 2014. Available online: https://www.un.org/waterforlifedecade/ (accessed on 30 September 2021).
4. FAO. Growing More Food—Using less water. In Proceedings of the Fifth World Water Forum, Istanbul, Turkey, 16–22 March 2009. Available online: https://www.fao.org/land-water/news-archive/news-detail/en/c/267311/ (accessed on 30 September 2021).
5. Boretti, A.; Rosa, L. Reassessing the projections of the World Water Development Report. *NPJ Clean Water* **2019**, *2*, 1–6. [CrossRef]
6. Sato, T.; Qadir, M.; Yamamoto, S.; Endo, T.; Zahoor, A. Global, regional, and country level need for data on wastewater generation, treatment, and use. *Agric. Water Manag.* **2013**, *130*, 1–13. [CrossRef]
7. Sgroi, M.; Vagliasindi, F.G.; Roccaro, P. Feasibility, sustainability and circular economy concepts in water reuse. *Curr. Opin. Environ. Sci. Health* **2018**, *2*, 20–25. [CrossRef]
8. Alcalde-Sanz, L.; Gawlik, B. Minimum Quality Requirements for Water Reuse in Agricultural Irrigation and Aquifer Recharge. Towards a Legal Instrument on Water Reuse at EU Level. 2017. Available online: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC109291/jrc109291_online_08022018.pdf (accessed on 30 September 2021).
9. Maaß, O.; Grundmann, P. Governing Transactions and Interdependences between Linked Value Chains in a Circular Economy: The Case of Wastewater Reuse in Braunschweig (Germany). *Sustainability* **2018**, *10*, 1125. [CrossRef]
10. Hanjra, M.A.; Blackwell, J.; Carr, G.; Zhang, F.; Jackson, T.M. Wastewater irrigation and environmental health: Implications for water governance and public policy. *Int. J. Hyg. Environ. Health* **2012**, *215*, 255–269. [CrossRef] [PubMed]
11. Chojnacka, K.; Witek-Krowiak, A.; Moustakas, K.; Skrzypczak, D.; Mikula, K.; Loizidou, M. A transition from conventional irrigation to fertigation with reclaimed wastewater: Prospects and challenges. *Renew. Sustain. Energy Rev.* **2020**, *130*, 109959. [CrossRef]
12. Al-Rashed, M.F.; Sherif, M.M. Water Resources in the GCC Countries: An Overview. *Water Resour. Manag.* **2000**, *14*, 59–75. [CrossRef]
13. Mohammad, M.J.; Mazahreh, N. Changes in Soil Fertility Parameters in Response to Irrigation of Forage Crops with Secondary Treated Wastewater. *Commun. Soil Sci. Plant Anal.* **2003**, *34*, 1281–1294. [CrossRef]
14. Hussain, A.; Priyadarshi, M.; Dubey, S. Experimental study on accumulation of heavy metals in vegetables irrigated with treated wastewater. *Appl. Water Sci.* **2019**, *9*, 1–11. [CrossRef]
15. Woldetsadik, D.; Drechsel, P.; Keraita, B.; Itanna, F.; Erko, B.; Gebrekidan, H. Microbiological quality of lettuce (Lactuca sativa) irrigated with wastewater in Addis Ababa, Ethiopia and effect of green salads washing methods. *Int. J. Food Contam.* **2017**, *4*, 49. [CrossRef]
16. Lonigro, A.; Rubino, P.; Lacasella, V.; Montemurro, N. Faecal pollution on vegetables and soil drip irrigated with treated municipal wastewaters. *Agric. Water Manag.* **2016**, *174*, 66–73. [CrossRef]
17. Rusan, M.J.M.; Hinnawi, S.; Rousan, L. Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. *Desalination* **2007**, *215*, 143–152. [CrossRef]
18. Gupta, S.; Satpati, S.; Nayek, S.; Garai, D. Effect of wastewater irrigation on vegetables in relation to bioaccumulation of heavy metals and biochemical changes. *Environ. Monit. Assess.* **2010**, *165*, 169–177. [CrossRef] [PubMed]
19. Tabatabaei, S.-H.; Najafi, P.; Amini, H. Assessment of Change in Soil Water Content Properties Irrigated with Industrial Sugar Beet Wastewater. *Pak. J. Biol. Sci.* **2007**, *10*, 1649–1654. [CrossRef]
20. Ding, X.; Jiang, Y.; Zhao, H.; Guo, D.; He, L.; Liu, F.; Zhou, Q.; Nandwani, D.; Hui, D.; Yu, J. Electrical conductivity of nutrient solution influenced photosynthesis, quality, and antioxidant enzyme activity of pakchoi (Brassica campestris L. ssp. Chinensis) in a hydroponic system. *PLoS ONE* **2018**, *13*, e0202090. [CrossRef]
21. Chen, C.-Y.; Wang, S.-W.; Kim, H.; Pan, S.-Y.; Fan, C.; Lin, Y.J. Non-conventional water reuse in agriculture: A circular water economy. *Water Res.* **2021**, *199*, 117193. [CrossRef]
22. Shehata, H.S.; Galal, T.M. Trace metal concentration in planted cucumber (Cucumis sativus L.) from contaminated soils and its associated health risks. *J. Consum. Prot. Food Saf.* **2020**, *15*, 205–217. [CrossRef]
23. Sharma, R.K.; Agrawal, M.; Marshall, F. Heavy Metal Contamination in Vegetables Grown in Wastewater Irrigated Areas of Varanasi, India. *Bull. Environ. Contam. Toxicol.* **2006**, *77*, 312–318. [CrossRef] [PubMed]
24. Ricolfi, L.; Barbieri, M.; Muteto, P.V.; Nigro, A.; Sappa, G.; Vitale, S. Potential toxic elements in groundwater and their health risk assessment in drinking water of Limpopo National Park, Gaza Province, Southern Mozambique. *Environ. Geochem. Health* **2020**, *42*, 2733–2745. [CrossRef]

25. Arora, M.; Kiran, B.; Rani, S.; Rani, A.; Kaur, B.; Mittal, N. Heavy metal accumulation in vegetables irrigated with water from different sources. *Food Chem.* **2008**, *111*, 811–815. [CrossRef]
26. Muchuweti, M.; Birkett, J.; Chinyanga, E.; Zvauya, R.; Scrimshaw, M.; Lester, J. Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: Implications for human health. *Agric. Ecosyst. Environ.* **2006**, *112*, 41–48. [CrossRef]
27. Khan, S.; Cao, Q.; Zheng, Y.; Huang, Y.; Zhu, Y. Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environ. Pollut.* **2008**, *152*, 686–692. [CrossRef] [PubMed]
28. Avci, H. Trace metals in vegetables grown with municipal and industrial wastewaters. *Toxicol. Environ. Chem.* **2012**, *94*, 1125–1143. [CrossRef]
29. Al-Nakshabandi, G.; Saqqar, M.; Shatanawi, M.; Fayyad, M.; Al-Horani, H. Some environmental problems associated with the use of treated wastewater for irrigation in Jordan. *Agric. Water Manag.* **1997**, *34*, 81–94. [CrossRef]
30. Mojiri, A.; Aziz, H.A.; Aziz, S.Q.; Gholami, A.; Aboutorab, M. Impact of Urban Wastewater on Soil Properties and Lepidium sativum in an Arid Region. *Int. J. Sci. Res. Environ. Sci.* **2013**, *1*, 7–15. [CrossRef]
31. Pedrero, F.; Kalavrouziotis, I.; Alarcón, J.J.; Koukoulakis, P.; Asano, T. Use of treated municipal wastewater in irrigated agriculture—Review of some practices in Spain and Greece. *Agric. Water Manag.* **2010**, *97*, 1233–1241. [CrossRef]
32. Bañón, S.; Miralles, J.; Ochoa, J.; Franco, J.; Sánchez-Blanco, M. Effects of diluted and undiluted treated wastewater on the growth, physiological aspects and visual quality of potted lantana and polygala plants. *Sci. Hortic.* **2011**, *129*, 869–876. [CrossRef]
33. Rengel, Z.; Bose, J.; Chen, Q.; Tripathi, B.N. Magnesium alleviates plant toxicity of aluminium and heavy metals. *Crop. Pasture Sci.* **2015**, *66*, 1298–1307. [CrossRef]
34. Cole, J.C.; Smith, M.W.; Penn, C.J.; Cheary, B.S.; Conaghan, K.J. Nitrogen, phosphorus, calcium, and magnesium applied individually or as a slow release or controlled release fertilizer increase growth and yield and affect macronutrient and micronutrient concentration and content of field-grown tomato plants. *Sci. Hortic.* **2016**, *211*, 420–430. [CrossRef]
35. Hajihashemi, S.; Mbarki, S.; Skalicky, M.; Noedoost, F.; Raeisi, M.; Brestic, M. Effect of Wastewater Irrigation on Photosynthesis, Growth, and Anatomical Features of Two Wheat Cultivars (*Triticum aestivum* L.). *Water* **2020**, *12*, 607. [CrossRef]
36. Cao, C.; Zhang, Q.; Ma, Z.-B.; Wang, X.-M.; Chen, H.; Wang, J.-J. Fractionation and mobility risks of heavy metals and metalloids in wastewater-irrigated agricultural soils from greenhouses and fields in Gansu, China. *Geoderma* **2018**, *328*, 1–9. [CrossRef]
37. Taghipour, M.; Jalali, M. Impact of some industrial solid wastes on the growth and heavy metal uptake of cucumber (*Cucumis sativus* L.) under salinity stress. *Ecotoxicol. Environ. Saf.* **2019**, *182*, 109347. [CrossRef]
38. Taalab, A.S.; Ageeb, G.W.; Siam, H.S.; Mahmoud, S.A. Some Characteristics of Calcareous soils. A review. *Middle East J.* **2019**, *8*, 96–105.
39. Santos, F.M.; Pires, J.C. Nutrient recovery from wastewaters by microalgae and its potential application as bio-char. *Bioresour. Technol.* **2018**, *267*, 725–731. [CrossRef] [PubMed]
40. Jogawat, A. Osmolytes and their Role in Abiotic Stress Tolerance in Plants. *Molecular Plant Abiotic Stress* **2019**, 91–104. [CrossRef]
41. Machado, R.M.A.; Serralheiro, R.P. Soil salinity: Effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. *Horticulturae* **2017**, *3*, 30. [CrossRef]
42. Paranychianakis, N.; Chartzoulakis, K. Irrigation of Mediterranean crops with saline water: From physiology to management practices. *Agric. Ecosyst. Environ.* **2005**, *106*, 171–187. [CrossRef]
43. Cherfi, A.; Achour, M.; Cherfi, M.; Otmani, S.; Morsli, A. Health risk assessment of heavy metals through consumption of vegetables irrigated with reclaimed urban wastewater in Algeria. *Process. Saf. Environ. Prot.* **2015**, *98*, 245–252. [CrossRef]
44. Gabr, M. Wastewater Reuse Standards for Agriculture Irrigation in Egypt. 2019. Available online: https://www.researchgate.net/profile/Mohamed-Gabr-7/publication/333676905_WASTEWATER_REUSE_STANDARDS_FOR_AGRICULTURE_IRRIGATION_IN_EGYPT/links/5cfe991d4585157d15a1f2f3/WASTEWATER-REUSE-STANDARDS-FOR-AGRICULTURE-IRRIGATION-IN-EGYPT.pdf (accessed on 30 September 2021).
45. MEWR. Sultanate of Oman on the Conservation of the Environment and Prevention of Pollution. Regulations for Wastewater Re-Use and Discharge, Ministreial Decision 5/86 Dated 17th May, 1986. 1986; pp. 1–6. Available online: http://www.sustainableoman.com/wp-content/uploads/2016/05/MD-5-86.pdf (accessed on 30 September 2021).
46. Shakir, E.; Zahraw, Z.; Al-Obaidy, A.H.M. Environmental and health risks associated with reuse of wastewater for irrigation. *Egypt. J. Pet.* **2017**, *26*, 95–102. [CrossRef]
47. Emongor, V.; Ramolemana, G. Treated sewage effluent (water) potential to be used for horticultural production in Botswana. *Phys. Chem. Earth Parts A/B/C* **2004**, *29*, 1101–1108. [CrossRef]
48. Roohani, N.; Hurrell, R.; Kelishadi, R.; Schulin, R. Zinc and its importance for human health: An integrative review. *J. Res. Med Sci.* **2013**, *18*, 144–157.
49. Prashanth, L.; Kattapagari, K.K.; Chitturi, R.T.; Baddam, V.R.R.; Prasad, L.K. A review on role of essential trace elements in health and disease. *J. Dr. NTR Univ. Health Sci.* **2015**, *4*, 75–85. [CrossRef]
50. Plum, L.M.; Rink, L.; Haase, H. The Essential Toxin: Impact of Zinc on Human Health. *Int. J. Environ. Res. Public Health* **2010**, *7*, 1342–1365. [CrossRef]
51. Chaoua, S.; Boussaa, S.; El Gharmali, A.; Boumezzough, A. Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco. *J. Saudi Soc. Agric. Sci.* **2019**, *18*, 429–436. [CrossRef]
52. Hajar, E.W.I.; Bin Sulaiman, A.Z.; Sakinah, A.M. Assessment of Heavy Metals Tolerance in Leaves, Stems and Flowers of Stevia Rebaudiana Plant. *Procedia Environ. Sci.* **2014**, *20*, 386–393. [CrossRef]

53. Ekinci, M.; Esringu, A.; Dursun, A.; Yildirim, E.; Turan, M.; Karaman, M.R.; Arjumend, T. Growth, yield, and calcium and boron uptake of tomato (*Lycopersicon esculentum* L.) and cucumber (*Cucumis sativus* L.) asaffected by calcium and boron humate application in greenhouse conditions. *Turk. J. Agric. For.* **2015**, *39*, 613–632. [CrossRef]
54. Ramírez-Pérez, L.J.; Morales-Díaz, A.B.; De Alba-Romenus, K.; González-Morales, S.; Benavides-Mendoza, A.; Juárez-Maldonado, A. Determination of Micronutrient Accumulation in Greenhouse Cucumber Crop Using a Modeling Approach. *Agronomy* **2017**, *7*, 79. [CrossRef]
55. White, P.J.; Karley, A.J. Potassium. In *Cell Biology of Metals and Nutrients*; Springer: Berlin/Heidelberg, Germany, 2010; pp. 199–224. Available online: https://link.springer.com/book/10.1007/978-3-642-10613-2 (accessed on 30 September 2021).
56. Oosterhuis, D.M.; Loka, D.A.; Kawakami, E.M.; Pettigrew, W.T. The Physiology of Potassium in Crop Production. *Adv. Agron.* **2014**, *126*, 203–233. [CrossRef]
57. Farahat, E.; Linderholm, H.W. The effect of long-term wastewater irrigation on accumulation and transfer of heavy metals in Cupressus sempervirens leaves and adjacent soils. *Sci. Total. Environ.* **2015**, *512–513*, 1–7. [CrossRef]
58. Xu, X.; Du, X.; Wang, F.; Sha, J.; Chen, Q.; Tian, G.; Zhu, Z.; Ge, S.; Jiang, Y. Effects of Potassium Levels on Plant Growth, Accumulation and Distribution of Carbon, and Nitrate Metabolism in Apple Dwarf Rootstock Seedlings. *Front. Plant Sci.* **2020**, *11*, 904. [CrossRef] [PubMed]
59. ChitraMani, P.K. Evaluation of antimony induced biochemical shift in mustard. *Plant Arch.* **2020**, *20*, 3493–3498.
60. Hafeez, B.; Khanif, Y.; Saleem, M. Role of zinc in plant nutrition—A review. *J. Exp. Agric. Int.* **2013**, 374–391. [CrossRef]
61. Sillanpaa, M. *Micronutrient Assessment at the Country Level: An International Study*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 1990.
62. Lee, S.R. Critical Role of Zinc as Either an Antioxidant or a Prooxidant in Cellular Systems. *Oxidative Med. Cell. Longev.* **2018**, *2018*, 1–11. [CrossRef]
63. Khan, M.J.; Jan, M.T.; Farhatullah, N.; Khan, M.A.; Perveen, S.; Alam, S.; Jan, A. The effect of using waste water for tomato. *Pak. J. Bot.* **2011**, *43*, 1033–1044.
64. Jahan, K.; Khatun, R.; Islam, M. Effects of wastewater irrigation on soil physico-chemical properties, growth and yield of tomato. *Progress. Agric.* **2020**, *30*, 352–359. [CrossRef]
65. Verma, S.; Dubey, R.S. Effect of Cadmium on Soluble Sugars and Enzymes of their Metabolism in Rice. *Biol. Plant.* **2001**, *44*, 117–124. [CrossRef]
66. Petousi, I.; Daskalakis, G.; Fountoulakis, M.; Lydakis, D.; Fletcher, L.; Stentiford, E.; Manios, T. Effects of treated wastewater irrigation on the establishment of young grapevines. *Sci. Total. Environ.* **2019**, *658*, 485–492. [CrossRef]
67. Hoekstra, A.Y.; Mekonnen, M. Reply to Ridoutt and Huang: From water footprint assessment to policy. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, E1425. [CrossRef]
68. Cooper, P. Historical aspect of wastewater treatment. In *Decentralised Sanitation Reuse: Concepts, System and Implementation*; IWA Publishing: London, UK, 2001; pp. 11–38.
69. Ibekwe, A.M.; Gonzalez-Rubio, A.; Suarez, D.L. Impact of treated wastewater for irrigatioon soil microbial communities. *Sci. Total Environ.* **2018**, *622–623*, 1603–1610. [CrossRef] [PubMed]
70. Maaß, O.; Grundmann, P. Added-value from linking the value chains of wastewater treatment, crop production and bioenergy production: A case study on reusing wastewater and sludge in crop production in Braunschweig (Germany). *Resour. Conserv. Recycl.* **2016**, *107*, 195–211. [CrossRef]