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Utilisation of Four Natural Absorbents in Removing Heavy Metals from Sewage Water and Reducing their Accumulation in Maize Leaves

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The general water quality has a direct influence on the ability to sustain life on the Earth. The aim of this study was to evaluate the efficiency of different natural adsorbents, namely phosphate rock, clay mineral (bentonite), peat moss, and soil in wastewater treatment. The laboratory experiment included columns experiment conducted as two factorial experiments. The first factor was water quality, which involved six types of water: river, untreated sewage water, sewage water treated with phosphate rock, sewage water treated with bentonite, sewage water treated with peat moss, and sewage water treated with soil. The second factor included two types of soil (two different soil textures), the first was clay loamy soil and the second was loamy soil. The treatments were randomly distributed following a randomized complete block design with three replications. The field study was represented by a pots experiment that included two types of soil textures, namely clay loamy and loamy soil. Heavy metals such as zinc, manganese, and iron were analysed in the water output from the columns to be used in the cultivation experiment as irrigation water. Overall the treatment combinations and the obtained results showed a significant reduction in the considered heavy metals. In this context, phosphate rock led to a decrease in zinc, manganese, and iron to 60.33, 54.00 and 55.30 mg/kg compared to untreated water which gave 63.33, 62.23 and 78.8 mg/kg. From an economic perspective, phosphate rock, was the most significant among the adsorbents under study, due to its availability and sustainability.

Key words: wastewater treatments, phosphate rock, bentonite, heavy metals

Rapid continuous population growth along with rapid economic development, climate change, and considerable water consumption are key factors in the decline of water resources. In this context, water consumption is expected to rise at a faster rate than the human population growth globally (Islam & Karim 2019). In developed and developing countries the agriculture sector plays a crucial role in poverty reduction, raising incomes and improving food security. Accordingly, to meet plant water requirements and avoid water stress, which adversely affects plant physiological and morphological processes, leading to a decline in crop yields and lower crop production, the agricultural sector needs to sustain water supply (Sadras *et al.* 2016) agronomic, economic, breeding and modelling perspectives. Our primary focus is wheat; we consider forage crops, sorghum and legumes where relevant aspects of water-nitrogen interactions have been advanced. From a physiological perspective, we ask: How

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does nitrogen deficit influence the water economy of the crop? How does water deficit influence the nitrogen economy of the crop? How do combined water and nitrogen deficit affect crop growth and yield? We emphasise synergies, and the nitrogen-driven trade-off between the efficiency in the use of water and nitrogen. The concept of nitrogen-water co-limitation is discussed briefly. From agronomic and economic perspectives, the need to match supply of nitrogen and water is recognised, but this remains a challenge in dryland systems with uncertain rainfall. Under-fertilisation commonly causes gaps between actual and water-limited potential yield. We discuss risk aversion and the role of seasonal rainfall forecasts to manage risk. From a breeding perspective, we ask how selection for yield has changed crop traits relating to water and nitrogen. Changes in nitrogen traits are more common and profound than changes in water-related traits. Comparison of shifts in the wheat phenotype in Australia, UK, Argentina and Italy suggests that improving yield per unit nitrogen uptake is straightforward; it requires selection for yield and allowing grain protein concentration to drift unchecked. A more interesting proposition is to increase nitrogen uptake to match yield gains and conserve protein in grain. Increased stomatal conductance is a conspicuous response to selection for yield which partially conflicts with the perception that reduced conductance at high vapour pressure deficit is required to increase water-use efficiency; but high stomatal conductance at high vapour pressure deficit may be adaptive for thermal stress. From a modelling perspective, water and nitrogen are linked in multiple ways. In crops where water limits growth, reduced biomass reduces nitrogen demand. Reciprocally, nitrogen limitation during crop expansion reduces leaf area index and increases the soil evaporation:transpiration ratio. Water-nitrogen interactions are also captured in the water-driven uptake of nitrogen by mass flow and diffusion and in the water-driven processes of nitrogen in soil e.g., mineralisation. Currently, reusing wastewater is an efficient technique as an alternative to ensure a sustainable and reliable supply of irrigation water. Worldwide, only around 20% of produced wastewater is reused (Jones *et al.* 2021), while the remaining is discharged into the environment. Globally, Freshwater shortage for agricultural purposes has led to increased exploitation of treated wastewater (TWW), establishing it as a crucial and reliable water supply of irrigation water. However, many studies reveal that long-term uses and not good management of treated wastewater may adversely affect soil functioning and plant productivity. Moreover, poses a threat to human life (Yalin *et al.* 2023) establishing it as a significant and reliable source of irrigation water. However, years of research indicate that if not managed adequately, TWW may deleteriously affect soil functioning and plant productivity, and pose a hazard to human and environmental health. This review leverages the experience of researchers, stakeholders, and policymakers from Israel, the United-States, and Europe to present a holistic, multidisciplinary perspective on maximizing the benefits from municipal TWW use for irrigation. We specifically draw on the extensive knowledge gained in Israel, a world leader in agricultural TWW implementation. The first two sections of the work set the foundation for understanding current challenges involved with the use of TWW, detailing known and emerging agronomic and environmental issues (such as salinity and phytotoxicity. Recently, adsorption gained high attention with nanomaterials developing. The selection of adsorbent materials is based on factors such as high efficiency, simplicity of use, cost-effectiveness, and eco-friendliness (Murtazaouglu *et al.* 2023). Lately, there has been increasing interest in investment in natural minerals such as phosphate rock, clay minerals and peat moss as modified materials to enhance adsorption (Zhao *et al.* 2021). In this regard, phosphate rock was widely used to manage water heavy metal pollution (Zhang *et al.* 2022). Even though several studies have already been conducted to adopt alternatives and potentially cost-effective sorbent materials to remove the heavy metals from polluted water, more attention has recently transformed to clay minerals owing to their significant individual metal-binding capacities, accessibility, eco-friendliness and low cost (Babel & Kurniawan 2003). Due to its abundance, bentonite is extensively utilised for removing toxic metal ions from aqueous solutions (adsorption processes). Bentonite is a versatile clay material well-suited for composite formation in many applications such as water treatment, improved binding and mechanical strength and thermal stability and resistance (Kotal & Bhowmick 2015). Peat moss has a high capacity to combine with cations for surface processes of chelation, adsorption, and ion exchange, due to its high content of complex organic matter, including lignin, cellulose, and humic substances at various stages of decomposition (Champagne *et al.* 2008). The work aimed to assess the ability of rock phosphate, clay mineral (bentonite), peat moss, and soil to remove zinc, manganese, and iron from wastewater and the concentrations of these heavy metals in two different soil textures and corn leaves.

MATERIALS AND METHODS

The study was conducted at Anbar University, Centre of Desert Studies, during the spring season of 2023. The cultivation study was conducted in two types of soil (different textures), namely clay loam and loam soil. Both soils were collected from ploughed layers (0−30 cm) of agricultural fields in the College of Agriculture, University of Baghdad. The soils under study were previously exploited for the cultivation of various crops and classified within the great soil groups (Typic Torrifluvent) according to the modern American classification (Soil Survey Staff, 2014). Table 4 shows some of the chemical and physical properties of the cultivated soil (pots experiment) before planting. The study involved two parts, columns laboratory experiment and pots experiment, the laboratory experiment was conducted to determine the phosphate rock, bentonite, peat moss, and soil efficiency in treating sewage water. The pots experiment was conducted to evaluate the effect of treated sewage water on zinc, manganese and iron concentrations in maize leaves. The columns laboratory experiment was performed as two factorial experiments. The first factor was water quality, which involved six types of water, namely water river (Wr), untreated sewage water (UW), sewage water treated with phosphate rock (WR), sewage water treated with bentonite (WB), sewage water treated with peat moss (WO), and sewage water treated with soil (WS). The second factor included two types of soil (two different soil textures), the first was clay loamy soil (S1) and the second was loamy soil (S2). The treatments were randomly distributed according to a randomised complete block design (RCBD) with three replications. While pots experiment was conducted in perforated bottom plastic pots with a capacity of 14 kg (30 cm high, 30 cm in diameter at the top, and 26 cm at the bottom). The pots were filled with 12 kg of soil for each. Two different soil textures were used, loam clay and loam soil. In each pot, ten seeds of *Zea mays* were planted in mid-March 2017. After 7 days of germination, the plants were thinned out to 3 seedlings per pot. Immediately, after germination, the pots were watered with 6 types of water according to treatments distribution. The fertilisation was according to the recommendation mentioned by Ali (2007). Four adsorbent materials were used in this study, namely phosphate rock, bentonite mineral, peat moss (as a source of organic material), and soil. The four adsorbent materials were used due to their availability in Iraq to propose cost-effective techniques for wastewater treatment. Some specifications of considered adsorbent materials are listed in Table 1 and 2.

Raw sewage water

Untreated sewage water was brought from the collection centre in Ramadi, affiliated with the Ra-

Table 1

Some specifications of phosphate rock and bentonite

Parameter	Phosphate rock	Bentonite	Unit
pH	13.00	7.10	
Electrical conductivity (EC)	9.24	12.40	[dS/m]
Ca^{2+}	2,089.00	5,745.00	[mg/kg]
Mg^{2+}	1,420.00	3,132.00	[mg/kg]
Na^{+}	2,125.00	6,527.00	[mg/kg]
K^{+}	215.00	510.00	[mg/kg]
SO_4^{-2}	2,545.00	6,506.00	[mg/kg]
Cl^{-1}	2,493.00	7,180.00	[mg/kg]
HCO_3	680.00	NT	[mg/kg]
Total phosphorus	10.22	NT	[%]
PO_4	NT	2,235.00	[mg/kg]
NO_3	NT	2.90	[mg/kg]

NT: is not measured

T a b l e 2

Some specifications of peat moss and soil

Parameter	Peat moss	Soil	Unit
pH	7.50	7.64	[dS/m]
Electrical conductivity (EC)	0.614	3.12	[mg/kg]
Ca^{+2}	425.00	9.57	[mg/kg]
Mg^{+2}	255.00	5.41	[mg/kg]
Na^{+1}	384.00	7.65	[mg/kg]
K^{+1}	86.00	0.48	[mg/kg]
SO_4^{-2}	480.00	10.75	[mg/kg]
Cl^{-1}	467.00	16.34	[mg/kg]
HCO_3	205.00	4.70	[mg/kg]
Nitrogen	2.15	53.00	[mg/kg]
Phosphorus	0.46	15.00	[mg/kg]
Potassium	0.91	176.00	[mg/kg]
Calcium	0.35	NT	[%]
Magnesium	0.12	NT	[%]
Iron	0.075	NT	[%]
Manganese	0.035	NT	[%]
Zinc	0.013	NT	[%]
Organic matter	NT	12.30	[g/kg]
Gypsum	NT	1.72	[g/kg]

NT: is not measured

T a b l e 3

Some chemical characteristics of used raw sewage water

Parameter	Wastewater	River water	Unit
pH	7.13	7.81	–
Electrical conductivity (EC)	1.43	0.725	[dS/m]
Total potassium	32.00	Not measured	[mg/kg]
Total phosphorus	19.00	–	[mg/kg]
Total nitrogen	76.00	–	[mg/kg]
NO_3	–	2.10	[mg/kg]
$N-NO_3$	22.00	–	[mg/kg]
$N-NH_4$	25.00	–	[mg/kg]
Dissolved Ions			
Ca^{+2}	4.20	75.64	[mg/kg]
Mg^{+2}	3.62	39.00	[mg/kg]
Na^{+1}	7.17	81.33	[mg/kg]
K^{+1}	0.28	3.81	[mg/kg]
SO_4^{-2}	1.16	78.02	[mg/kg]
Cl^{-1}	4.85	69.20	[mg/kg]
HCO_3	2.14	46.31	[mg/kg]
Heavy metals			
Cd^{+2}	0.95	–	[mg/kg]
Pb^{+2}	1.61	–	[mg/kg]
Cu^{+2}	1.99	–	[mg/kg]
Zn^{+2}	7.00	–	[mg/kg]
Mn^{+2}	6.51	–	[mg/kg]
Fe^{+2}	10.70	–	[mg/kg]

madi District Sewage Directorate. During the storage, chloroform was added to the raw sewage water to inhibit the activity of microbial to conduct chemical and physical analyses, according to (Rice *et al.* 2012).

Heavy metals preparation and treatment process

The study used three heavy metals, namely zinc, iron, and manganese. They were prepared at a concentration of 5,000 mg/kg from their salts. Where 8.15 g, 6.71 g, and 19.63 g from each salt of zinc, manganese, and iron were dissolved in 1 liter of distilled water, individually for each element. Four high-density Polyethylene Pipes were prepared, 80 cm long and 10 cm in diameter. The pipes were designed to be opened from the upper part and closed at the bottom. To control the process of opening and closing the Pipe, it was provided with a tap. A 5 cm layer of clean sand was placed at the bottom of the pipes. The sand layer was covered with a filter paper that acts as a filter. The materials used in the treatment process were applied to a 40 cm depth of pipes. The raw sewage water was passed through the top of the filtration column. The extract was collected after the sewage had remained in the column for two hours. The extract was stored in polyethylene containers to be used for irrigation purposes. The Plants in the pots experiment. To determine the heavy metals in the extract, a sample of the extract was taken at each collection interval (2 hours), preserved in polyethylene containers, and transferred to the laboratory.

Chemical measurements

Soil salinity electrical conductivity (EC) and soil reaction (pH) were measured using EC and pH-meter respectively according to the method given in (Richards 1954). Phosphorus was determined according to the colourimetric method using the ascorbic acid method using a spectrophotometer according to the Olsen method (Olsen *et al.* 1982). Nitrate was determined using a Micro Kjeldahl device according to the method described in (Black 1965). The cations (Ca and Mg^{+2}) were estimated using the atomic absorption according to (Page 1982). Potassium and sodium ions in the samples were measured using a Flame Photometer according to (Page 1982). Sulfate ions were determined using the turbidity method using a Philips spectrophotometer (Pu 8670) as described in (Rice *et al.* 2012). Chloride ions were determined by titration with silver nitrate and using the potassium chromate index as described in (Rice *et al.* 2012). Bicarbonate was estimated by titration with sulfuric acid (0.01) according to Jackson (1967). The micronutrients and heavy metals, (Fe, Mn, Pb, Zn, Cu, and Cd) were determined using an atomic absorption device after extracting them from the soil with DTPA according to (Lindsay & Norvell 1978). The concentration of copper, lead and cadmium was measured using an atomic absorption device. Organic carbon in the soil was estimated using the Walkly-Black method according to (Black 1965). Gypsum was determined by the acetone precipitation method according to the method given in (Page 1982). The hydrometer method was used to determine the Soil texture according to (Gee & Bauder 1986). The Gen Stat software was used to analyse the obtained results where the averages were compared using the least significant difference test *LSD* at the probability level of 0.05 (Genst 1997).

RESULTS AND DISCUSSION

Zinc content in soil and plant leaves

In general, a significant difference was observed in overall study treatments Figure 1. However, zinc content in the clay loam soil was higher compared to loam soil over all treatments under study. In this context, zinc content in clay loam soil irrigated with a water river was 58.33 mg/kg compared to 39.33 mg/kg in loam soil. The reason can be attributed to the high clay content in clay loam soil compared to loam soil. Table 4 utilising untreated sewage water led to a significant increase in soil zinc content in both considered soils. Where zinc content was 63.33 and 41.33 mg/kg in clay loam and loam soil respectively. The high zinc content, before treatment, showed the vital role of soil texture in chelating heavy metals from aqueous solutions (irrigation water). Regarding the treatment process, the statistical analysis of the obtained results showed a significant

T a b l e 4

Some physical-chemical properties of the considered soils before planting

Parameter	S1	S2	Unit
pH	7.39	7.51	
Electrical conductivity (EC)	3.12	2.15	[dS/m]
Lime	269.00	210	[g/kg]
Organic matter	10.70	9.00	[g/kg]
Cation exchange capacity (CEC)	28.50	21.3	$cmol^{(+)}$/kg
Content of available nutrients soil			
Potassium	145.00	95.20	[mg/kg]
Phosphorus	12.60	7.20	[mg/kg]
Nitrogen	52.50	36.00	[mg/kg]
Dissolved ions			
Calcium	9.12	8.80	[mmol/L]
Magnesium	7.10	5.66	[mmol/L]
Sodium	16.90	9.34	[mmol/L]
Sulfate	3.69	2.49	[mmol/L]
Chlorine	11.40	6.19	[mmol/L]
Bicarbonate	3.03	2.31	[mmol/L]
Soil moisture-holding capacity			
0bar	47.60	39.20	[%]
0.33 bar	24.30	18.00	[%]
15 bar	14.70	11.40	[%]
Soil particles			
Sand	300	450	[g/kg]
Silt	330	350	[g/kg]
Clay	370	200	[g/kg]
Texture	Clay loam	Loam	[g/kg]

S1 − clay loamy soil; S2 − loamy soil.

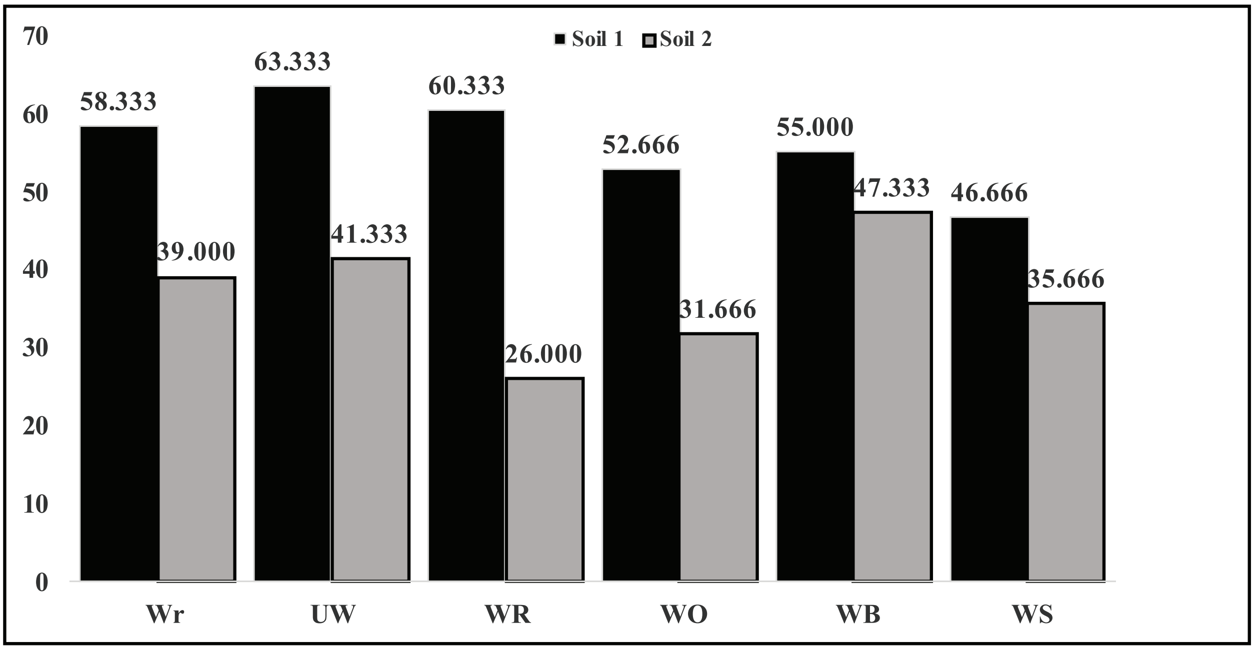

Figure 1. Zinc leaves content: S1 − clay loam soil; S2 − loam soil, the results in the figure represent the average of three replications. Wr − water river; UW − untreated sewage water; WR − sewage water treated with phosphate rock; WB − sewage water treated with bentonite; WO − sewage water treated with peat moss; WS − sewage water treated with soil.

superiority of water treated with soil (WS) in clay loam soil. In this sense, the lowest zinc leaves content was observed under the effect of this treatment reached 46.66 mg/kg. While in the loam soil, the lowest zinc leaves content was observed under the effect of water treated with phosphate rock (WR) reached 26.00 mg/kg. The superiority of water treated with soil (WS) treatment in clay loam soil might be attributed to the combined effect of two soil textures (treatment soil and cultivation soil) in chelating some zinc ions on their particles (clay particles) and preventing it to absorbed by the plant (Wirosoedarmo *et al.* 2018). The superiority of water treated with phosphate rock (WR) can be assigned to the high pH of phosphate rock as mentioned in the specifications of phosphate rock Table 1. This finding agrees with (Chen *et al.* 2023). However, the increasing zinc content in the leaves in clay loam soil (WR) is probably due to the adsorption completion between clay particles and phosphate rock. In the water treated with bentonite and water treated with organic matter, the role of clay particles (clay loam soil) appears in chelating zinc ions, consequently releasing them to be absorbed by the plant. The results in loam soil support these findings, where water treated with bentonite treatment superior to water treated with organic matter which gave 47.33 and 31.66 mg/kg respectively.

Regarding soil zinc content, the results listed in Table 5 show a reduction in zinc content compared to its content in plant leaves. The reduction can be attributed to the fact that Iraqi soils are deficient in micronutrients such as Fe, Zn and Mn. Therefore, in this case, the plant deals with treated irrigation water as a reservoir of micro-elements to support plants with essential micro-nutrients (Mandal *et al.* 2023).

T a b l e 5

Zinc soil content after cultivation [mg/kg]

Water type	Soil	
	Clay loam (S1)	Loam (S2)
River water	4.366	3.800
Untreated water	4.900	4.200
Water treated with phosphate rock	3.833	2.833
Water treated with organic matter	3.866	3.400
Water treated with bentonite	4.600	4.133
Water treated with soil	3.566	3.600
LSD (α = 0.05)	S = 0.3208	W = 0.4813

Manganese content in soil and plant leaves

Micronutrients, such as manganese (Mn) are essential for plant growth. Manganese element plays a vital role in a range of physiological and biochemical processes which are required for plant development. Nevertheless, the overabundance of manganese is toxic and inhibits crop production. Therefore, removing heavy metals from sewage water is crucial to mitigate their adverse effects on human health. In this direction, Figure 2 showed that the water Manganese decreased from 62.23 in the untreated water (sewage water) to 54.00 mg/kg in the water treated with phosphate rock in clay loam soil.

Under the same treatment (water treated with phosphate rock) in loam soil the water manganese content decreased to 47.00 mg/kg compared to untreated water which gave 52.00 mg/kg. In comparison between the results, the findings show that the leaves manganese content was higher in clay loam soil. Probably due to its clay content led to hold manganese ions more compared to loam soil. Consequently, absorbed by the plant after cultivation. Additionally, the high pH of phosphate rock (Table 1) led to remove the manganese ions from sewage water. On the other hand, the obtained results show that the removal efficiency of peat moss (Water treated with organic matter) and bentonite (Water treated with bentonite) are very close for both considered soils Figure 2 (Viraraghavan & De Maria Alfaro 1998). Regarding treating water with soil (Water treated with soil), the results did not differ in comparison with peat moss and bentonite. Regarding the soil manganese content, the findings show that the manganese content in the soil was lower compared to leaves manganese content. Likely because manganese is considered an essential nutrient and is therefore absorbed by the plant. Overall treatments under study, soil manganese content after cultivation was higher compared to zinc soil content. Generally, the reason can be attributed to the fact that if soil pH value exceeds 6, manganese starts to be relatively insoluble. Consequently, precipitated in the soil (Chiswell & Huang 2006). Based on the study treatment, in both soils, the water was treated with phosphate rock and organic matter. In the phosphate rock treatment, the clay loam soil manganese content was high reached 7.966 mg/kg followed by 7.80 mg/kg resulted from water treated with organic matter due to its high pH which led to precipitate the manganese in the soil by converting it to MnO_2. In the same soil, also the soil manganese content was high compared to other treatments reached 7.80 mg/kg, where organic matter led to precipitate manganese due to organic presence that converted it to man-

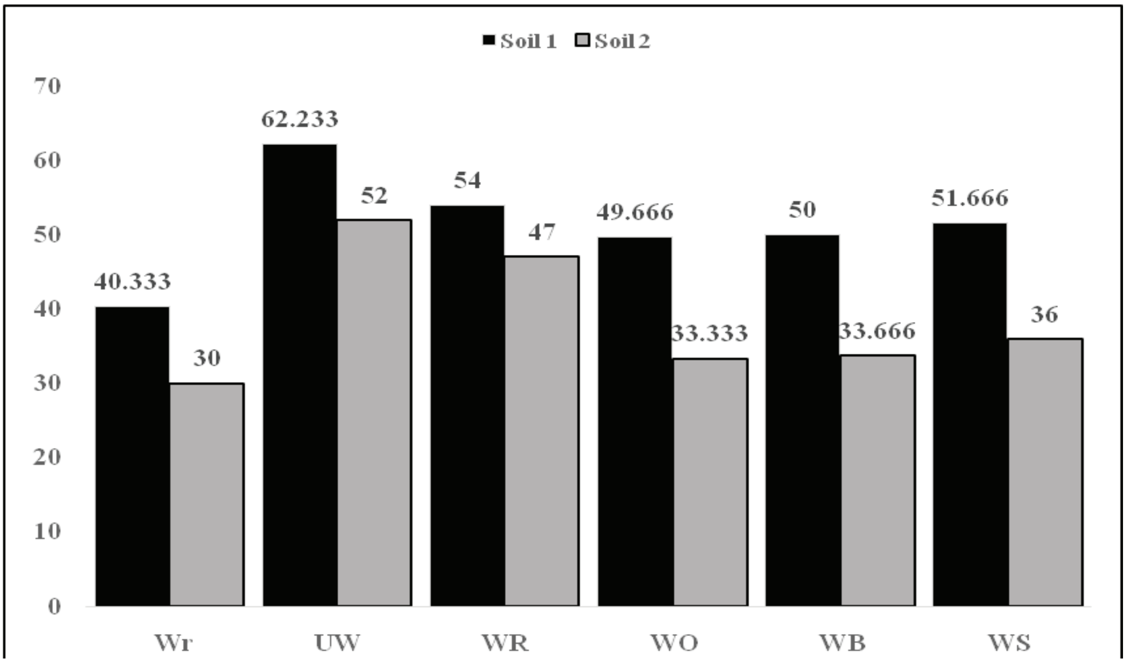

Figure 2. Manganese leaves content: S1 − clay loam soil; S2 − loam soil, the results in the figure represent the average of three replications. WR − sewage water treated with phosphate rock; WB − sewage water treated with bentonite; WO − sewage water treated with peat moss; WS − sewage water treated with soil.

ganese dioxide (MnO_2) (Chiswell & Huang 2006). The same trend was observed in loam soil for both water (treated with phosphate rock and water treated with organic matter) up to 6.60 and 6.89 mg/kg respectively.

Iron content in soil and plant leaves

Figure 3 shows the effect of the varying techniques for iron removal from sewage water. Initially, in both soils, the concentration of iron was high (untreated sewage water). Under the effect of phosphate rock (WR), a significant reduction in iron concentration was observed compared to untreated water which reduced from 78.80 and 75.60 to 55.20 and 52.20 mg/kg for clay loam and loam soil respectively. The reduction in iron concertation can be attributed to the precipitation role of phosphate rock, the mechanism involves the reaction between dissolved iron irons and phosphate ions producing an insoluble iron phosphate compound. Accordingly, these compounds have been released from water by sedimentation. Because of its high specific surface area and its content of organic compounds with functional groups, such as humic and fulvic acids, Peat moss led to a significant reduction in iron ions concentration in sewage water consequently in plant leaves. Where iron ions decreased to 49.20 and 45.20 mg/kg in clay loam and loam soil respectively. This reduction can be attributed to the fact that peat moss functional groups have a high affinity for binding metal ions, such as iron (Kasiuliene 2019). On the contrary, a reduction in bentonite efficiency was observed in removing iron from sewage water compared to phosphate rock and peat moss treatments. But in general, it also led to a decrease in iron concertation in sewage water where it gave 57.60 and 54.20 mg/kg for clay loam and loam soil respectively. The relative decrease in iron adsorption in bentonite treatment is the insufficient number of active sites on bentonite to adsorb more

T a b l e 6

Soil manganese content after cultivation [mg/kg]

Water type	Soil	
	Clay loam (S1)	Loam (S2)
River water	6.500	6.333
Untreated water	8.866	7.100
Water treated with phosphate rock	7.966	6.600
Water treated with organic matter	7.800	6.899
Water treated with bentonite	5.700	5.533
Water treated with soil	6.266	6.766
LSD (α = 0.05)	S = 0.142	W = 0.246

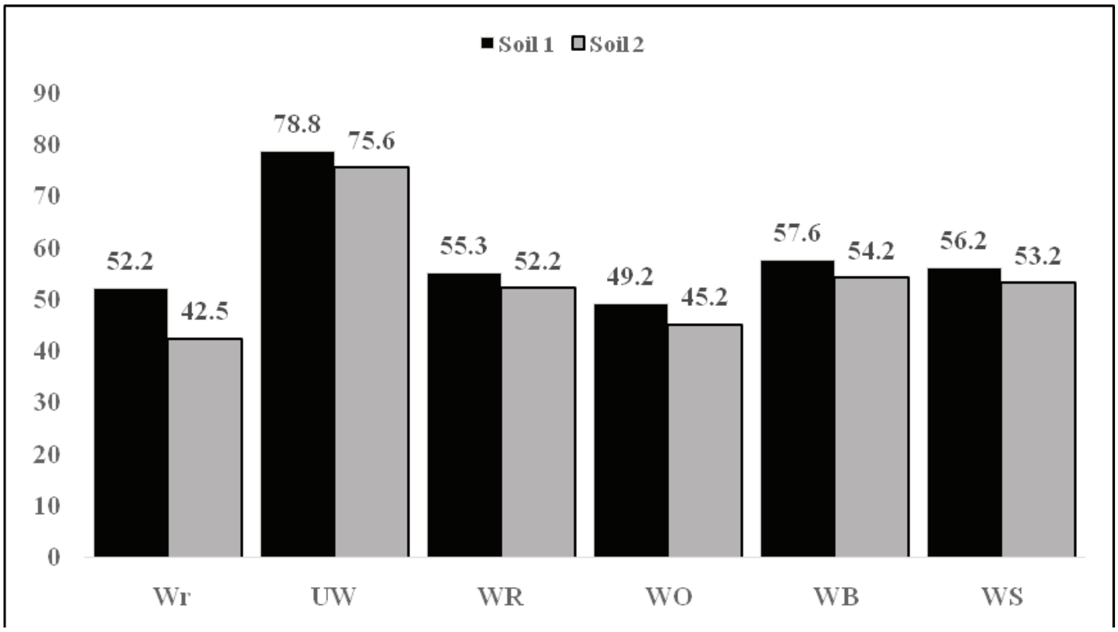

Figure 3. Iron leaves content: S1 − clay loam soil, S2 − loam soil, the results in the figure represent the average of three replications. Wr − water river; UW − untreated sewage water; WR − sewage water treated with phosphate rock; WB − sewage water treated with bentonite; WO − sewage water treated with peat moss and WS is the sewage water treated with soil.

metal ions in the solution. Therefore, the percentage removal was influenced by the initial concentration of metal ions (Kasiuliene 2019). The same trend was observed in soil treatment, where the iron concentration was 56.20 and 53.20 mg/kg for clay loam and loam soil respectively.

Generally, soil iron content after cultivation did not significantly differ from manganese soil content. The results study listed in Table 7 showed that the ion exchange efficiency of iron decreased at higher pH (< 4) because of the formation of iron hydroxide (Victor-Ortega *et al.* 2016). As shown in Table 8 pH for both soils is < 7. Therefore, under these conditions, iron ions might form various oxides such as hematite (Fe_2O_3), magnetite (Fe_3O_4) and limonite ($FeO(OH){\cdot}H_2O$). Consequently, the iron soil content increased.

CONCLUSIONS

In this study, natural, abundant, and low-cost adsorbent resources have been used. The adsorbent in this study included phosphate rock, peat moss, bentonite, and soil. The study findings showed superiority in phosphate rock treatment followed by bentonite treatment to mitigate the effect of zinc concentration in sewage water. While in manganese and iron, the adsorbents exhibit a relatively equal efficiency. From an economic point of view, all used absorbents are low cost-effective, and available. However, phosphate rock as a by-product is considered an efficient absorbent due to its availability sustainable source. Additionally, the adoption of phosphate rock in sewage water treatment could mitigate the polluting effect of phosphate rock as a by-product. Consequently, achieves the sustainability goal in addition to providing a sustainable source of water for agricultural purposes. Good management and planning, to treat the sewage water can be a safe and effective alternative method to reduce using freshwater and shift towards exploiting treated irrigation water to encourage sustainable agriculture.

T a b l e 7

Soil iron content after cultivation [mg/kg]

Water type	Soil	
	Clay loam (S1)	Loam (S2)
River water	8.049	7.280
Untreated water	11.580	9.840
Water treated with phosphate rock	9.620	7.216
Water treated with organic matter	8.766	6.883
Water treated with bentonite	9.120	8.636
Water treated with soil	8.150	7.383
LSD (α = 0.05)	S = 0.366	W = 0.635

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