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Enhancement of heavy metal removal from salinity-polluted soil using an aerobic digestion food waste

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ABSTRACT

Agricultural sectors in Basra City experienced pollution and salinity when the Tigris and Euphrates rivers did not release enough water; therefore, the low quality of irrigation water, saline and contaminated soils increasingly attract researchers to further investigate this field in Iraq. Subsequently, the purpose of this project was to improve soil salinity and heavy metal removal using sustainable food waste. Anaerobic digestion food waste (ADFW) was treated to produce an acid stage and then added to salinity-polluted soil that was taken from the agricultural area of Basra city at depths of 5 and 20 cm in varying percentages (1%, 2%, and 4%). Fenugreek plants were planted in eighteen containers. Weka 3.8 model was built and evaluated to predict shoot length of plant at different adding percentage of ADFW. The outcomes of the FT-IR spectroscopy, sequential extraction and kinetic test were demonstrated that ADFW had a high affinity for Cd, Zn, Ni, and Pb. Sodium adsorption ratio, electrical conductivity, and exchangeable sodium percentage results, on the other hand, indicated that soil at a depth of 20 cm and remediation with 2% and 4% of ADFW fell within the salinity-sodic range. The result from Weka model predict that adding 7% of ADFW can reduce SAR and increase the shoot length of a plant. When compared to other pots, these results can enhance the growth and length of young branch of Fenugreek plant.

Keywords: Anaerobic digestion food waste, heavy metals, remediation, saline soil, Weka model

INTRODUCTION

Heavy metals (HMs) naturally occur in soils as a result of weathering and oxidising of the underlying parental rock. However, due to the use of unclean water with pollutants such as phenols (Al-Jwaid, 2018) or heavy metals (Orosun *et al.*, 2023) for irrigation, soil can become polluted with various toxins via sorption and/or precipitation processes. The main source of water in Basra city is the Shatt Al-Arab River, which is approximately 192 kilometres long. This river provides water for household use, irrigation, manufacturing, and transport. In 2017, this river suffered from increasing contamination, especially with heavy metals, as a result of water scarcity at the entry point and the presence of waste from industries, home sewage, and agricultural operations (Hamdan *et al.,* 2018).

Although the presence of high concentrations of HMs poses a considerable hazard to soil and ecosystem functioning, practical and dependable ways to rehabilitation of polluted regions are currently lacking. Identifying appropriate adjustments is particularly difficult due to the diverse speciation, mobility, and bioavailability of HMs.

Over the last few decades, there has been a lot of focus on remediation solutions of water via its treatment (Al-Jwaid *et al.*, 2018, Berillo *et al.*, 2021) or soil that has significant levels of contaminations. Nevertheless, heavy metals are primarily found in soil solutions as free or complexes of cations over a wide range of pH (between 4 and 8). Various methods were utilized for instance: physical/chemical processes, bioremediation methods, and thermal treatments as the potential treatment options (Camargo *et al.*, 2016).

Consequently, HM mobility can be impacted and the biological as well as physical characteristics of degraded polluted soils can be restored by adding sorbents containing organic matter, such as composts (Zhou and Haynes, 2010, Pennanen *et al.*, 2020). Composting could be a more sustainable and alternative method of reducing metalloid mobility and enhancing the physical, chemical, and biological characteristics of the soil (Manzano *et al.,* 2016). Anaerobic digestion of food solid waste (ADFSW) is a process where microorganisms break down organic materials into methane, carbon dioxide, inorganic nutrients, and compost in an oxygen-depleted atmosphere with hydrogen gas present. The negatively charged functional groups of ADFSW may have a role in HM binding (Wang and Mulligan, 2009).

Manzano et al., 2016 used Fe-WTR with municipal solid waste compost to amended soils polluted with heavy metals through sequential extraction procedures and leaching experiments. There results showed that the amendments considered were influenced to different extent by mobility of heavy metals and this depended on soil and amendment characteristics, as well as the type and amount of contamination. However, they did not study the effect of amendment on salt on soil.

Therefore, this study was aimed to prepare compost by shortening the acid-forming stage (ADFW) in order to prevent the synthesis of methane and create volatile fatty acids. Then, the influence of this material on the removal of salt and metal ions from salinity-polluted soil was evaluated. Moreover, the effect of this compost on the plant growth was evaluated.

MATERIALS AND METHODS

Description of sampling area

Samples of soil were collected from Abu al-khasib sector of Basra city's agricultural county. Three sites were randomly selected for the collection of surface soil (designated as S1 at a depth of 5 cm and S2 at a depth of 20 cm). All soil samples underwent a < 2 mm sieve. In 2017, the Shatt Al-Arab River's salinity-polluted water was used to irrigate this area. Consequently, most plants in this region died.

Preparation of anaerobic digestion food waste (ADFW)

Anaerobic digestion food waste was prepared in a glass basin with dimensions (80 cm, 140 cm) (ADFW). A layer of gravel (10 cm) was placed first as a drainage layer. Then, followed by a layer of food waste, after that covered with compacted clay soil. As shown in Figure 1, a basin was created with a slope of 1:1.5, and a valve was inserted into the bottom of the basin to drain waste leachate. Samples of ADFW were collected after 13 days, wrapped in aluminium foil and baked for two days at 60 °C. Finely ground ADFW were sieved to a mesh size of less than 2 mm.

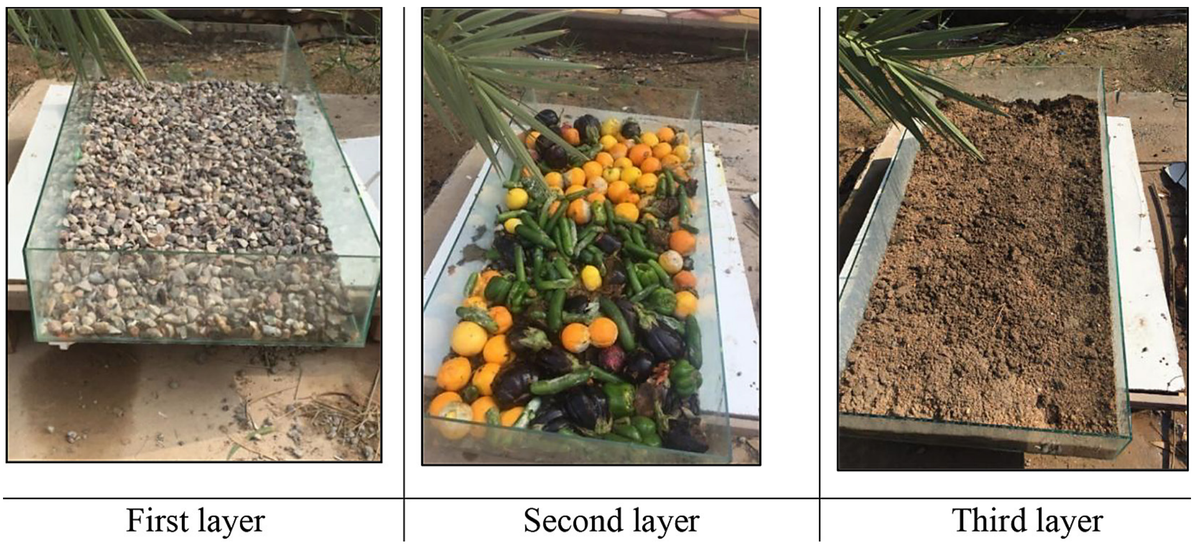

Figure 1. Stages of anaerobic digestion food waste preparation

Characterizations and analytical determinations of soil

Soil characterizations were conducted via comparative analysis strategy, on polluted soils with different degrees of improvement. Each microcosm held around 1 kg of soil at a depth of 10 cm, and it was individually mixed with the following amendments: 1, 2 and 4% (w/w) of ADFW. As indicated in Table 1, all treatments were administered in triplicate to microcosms, while two microcosms (polluted soil) remained untreated as controls.

After that, the treated mixed soils were moisture and water content was increased to 40% of their water retention capacity to avoid drainage of water with salts thought the pots. Then, samples were left for 120 days at 20 °C, mixed twice a week, and water content was kept between 40 and 50 percent using tap water. Following this period of contact, soil samples were air-dried and passed through a 2-mm mesh filter for analytical purposes.

The samples were analysed for pH and electrical conductivity (EC) using the BS ISO 10390:2005 methodology. The point of zero charge (PZC) was obtained using the solid addition technique as described by Mohan, S., and Gandhimathi, R., 2009.

The Ethylene Glycol Monoethyl Ether (EGME) method (Cerato, B., and Lutenegger, J., 2002) was used to quantify surface area. Total concentrations of Pb, Ni, Cd, and Zn in treated and untreated soils was measured using an inductively coupled plasma optical emission spectroscopy (ICP–OES) (Table 2), after using HNO_3 and HCl combination (1:3 v/v ratio) for digestion,.

Adsorption study – kinetic test

Batch experiments were utilised for investigation into the impact of equilibration time in order to analyse the kinetics of heavy metal adsorption by ADFW. For mixed solutions, the initial metal concentrations were determined to be 0.5 mg/L for Cd, 5 mg/L for Zn, 0.5 mg/L for Ni, and 5 mg/L for Pb. In the lab, the solutions for combined heavy metals were made with $PbCl_2$, $CdSO_4.83H_2O$, and $C_4H_6O_4Zn_2H_2O$ salts for Cd, Zn, Ni, and Pb, respectively. Using a rotational shaker, 100 ml of mixed heavy metal solutions was used to equilibrate 0.1, 0.5, 1, and 2 g of ADFW, which were then placed in 250 ml bottles and left for (5–180) minutes. At each set period of time, the mixture was taken out, filtered, and examined using Equation 1 for the elimination of each heavy metal.

$$Re = \frac{(Co-Ce)}{C0} \times 100\% \quad (1)$$

where: C_o and C_e (both in mg/L) are the initial and final heavy metals concentrations at equilibrium (*qe*), respectively at time (t = 0), *v* is the volume (L) of the solution and *m* (g) is the mass of ADFW used.

Sequential extraction of Cd, Zn, Ni and Pb sorbed by ADFW

The gradual extraction method of Castaldi *et al.,* (2015) was used to establish the bounding of heavy metals (Cd, Zn, Ni, and Pb) to the ADFW. In this experiment, ADFW samples, which were saturated with Cd, Zn, Ni, and Pb, were obtained from the last point of the kinetic isotherms.

FT-IR spectroscopy

The FT-IR spectra of the ADFW samples were obtained at room temperature by utilising a Shimadzu IR Affinity-1 spectrophotometer. These samples illustrate ADFW before and after doping with Cd, Zn, Ni, and Pb (relative to the

Table 1. Characterization of S1 and S2 soils, amended with ADFW. Mean ± SD

Parameter	S1+1%	S1+2%	S1+4%	S2+1%	S2+2%	S2+4%
pH	6.46±0.04	6.33±0.16	6±0.29	6.4±0.21	6.467±0.05	6.13±0.09
EC (ds/m)	5.93±0.48	5.84±0.51	5.82±0.47	3.31.6±0.14	3.13±0.90	2.68.6±0.30
TOC%	20.63±0.24	20.63±0.32	20.63±0.41	15.40±0.31	15.41±0.15	15.43±0.17
pHZ	7.2±0.49	6.4±0.51	5.67±0.73	6.32±0.62	5.52±0.54	5.17±0.44
SSA (m^2/g)	120.7±1.23	121.8±1.74	123.2±0.96	119.2±1.45	121.5±1.29	123.2±1.19
SAR (mmoles/l)$^{0.5}$	18.96±0.43	15.71±0.37	14.43±0.51	13.39±0.46	11.59±0.44	9.03±0.31
ECP%	21.07±0.33	17.97±0.42	16.68±0.51	15.60±0.47	13.67±0.31	10.76±0.16

Table 2. Characterizations of soils S1, S2 and ADFW. Mean ± SD

Parameter	S1	S2	ADFW
pH	6.6±0.001	6.6±0.16	4.231±0.17
EC (ds/m)	6110±298	3566.66±118	531±41
TOC%	20.638±0.45	15.395±0.24	98±1.45
pHZ	8.43±0.62	7.32±0.68	3.215±0.46
SSA (m2/g)	120±1.75	118.5±1.44	167.873±2.65
Cd (mg/kg)	0.213±0.03	0.1673±0.012	0.123±0.01
Zn (mg/kg)	32.453±1.34	23.321±0.83	5.23±0.12
Ni (mg/kg)	79.342±3.11	70.147±2.01	5.214±0.11
Pb (mg/kg)	16.789±2.43	9.432±1.62	2.4321v0.01
Mn (mg/kg)	290.635±4,12	261.345±3.35	91.12±2.21
Cl (mg/l)	1450.324±9.32	820.542±3.22	42.123±1.45
So4 (mg/l)	0.2891±0.1	0.0523±0.001	1.348±0.03
Mg (mg/l)	75.321±o.33	48.4521±1.28	10.214±1.72
Ca (mg/l)	100.23±3.251	61.342±2.33	20.212±1.43
Na (mg/l)	1125±9.22	502.43±5.78	9.132±2.11
K (mg/l)	58.341±2.11	28.321±1.32	40.231v0.75
SAR (mmoles/l)$^{0.5}$	20.588±0.73	11.590±0.64	-
ESP %	22.546±0.45	13.671±0.53	-

last point on the Kinetic isotherm). The FT-IR spectra occurred at 320 scans at 4 cm^{-1} resolution, covering the 4000–500 cm^{-1} range.

Software tool: Weka 3.8 model

The dataset was collected and prepared measurement of (soil depth, added elements, SAR and shoot length). All machine learning experiments were carried out using Weka 3.8, a popular open-source machine learning package. The models were built and evaluated using the Explorer interface. Particularly, the "Classify" tab was used for regression analysis. The M5P regression model was used to predict the shoot length (cm). M5P generates model trees by combining decision trees and linear regression models.

Salinity in soil

Salinity is one of the primary sources of soil deterioration and reduced agricultural output. The sodium adsorption ratio (SAR) in (mmoles/l) $^{0.5}$ is the ratio of sodium (Na^{+}) to calcium (Ca^{+2}) and magnesium (Mg^{+2}) in a water extract from saturated soil paste (meq/l). Soil exchangeable sodium percentage (ESP) and SAR are often employed to assess soil sodicity (Table 3).

RESULT AND DISCUSSION

Properties of amendments

ADFW was reduced at the end of the acid-forming step. This stage produces simple organic acids including acetic, propionic, and butyric acid, as well as ethanol, carbon dioxide, and hydrogen (Ljupka 2010). The pH is 4.2 and pHz is 3.2, confirming acidic formation; SSA was determined to be 167.873 m^2/g. The wide surface area of ADFW is a favourable property when utilised as absorbed. Furthermore, the study involved the kinetic adsorption of metal ions in order to determine the ideal contact time for the achieved adsorption. Recently, sequential extraction patterns have been increasingly popular in soil analysis because they make it possible to detect various metal ion fractions in the materials under examination and, consequently, evaluate the mobility and availability of metal ions for plants (as discussion below).

Adsorption kinetics of metal ions

Removal of metal ions was quantified as a function of identification time to determine the ideal contact time for adsorbing these ions on ADFW. Figure 2 illustrates the percentages of metal removal (%) as a function of ADFW

Table 3. Equations used to calculate SAR and ECP (Gazia et al., 2008, Richards, 1954)

Equation	Range
$SAR = \frac{Na^{+}}{\sqrt{\frac{Mg^{+2} + Ca^{+2}}{2}}}$	• Saline: the soil with EC ≥ 4 dS/m and ESP<15 or SAR < 13. • Saline-sodic: the soil with EC ≥ 4 dS/m and ESP ≥15 or SAR > 13. • Sodic: the soil with EC ≤ 4 dS/m and ESP ≥15 or SAR > 13.
$ESP = \frac{100(-0.0126 + 0.01475\,SAR)}{1 + (-0.0126 + 0.01475\,SAR)} \times 100$	

loading for various metal ions. The figure makes it clear that the response rates rise sharply when the dosage of ADFW is increased up to 10 g/L, after which they essentially remain constant. These results might be an indication of an enough subsurface area being available for adsorption, which would rise as the dosage of ADFW increased. The adsorption of metal ions was then saturated on the adsorbent sites at a dosage of I0 g/L.

All metal ions exhibited aggressive adsorption during the first few minutes (10 min), indicating a quick initial sorption at which point 76%, 55%, 63%, and 52% of Pb, Ni, Zn, and Cd respectively, were eliminated. This outcome might be the result of the strong cationic exchange capacity brought about by the low pHz (3.2) and high SSA (167.873 m^2/g) of ADFW, as seen in (Table 2) (Della *et al.,* 2013). Afterwards, there was a slower rate of sorption, and for all metal ions, the minimum contact time required for equilibrium was set at 120 minutes. At this point, the clearance rates for Pb, Ni, Zn, and Cd were 90%,66%,90%, and 68%, respectively.

Sequential extraction of metal ions sorbed by ADFW

The sequential extraction methods (Basta and Gradwohl, 2000) were applied for the ADFW samples containing Pb, Ni, Zn, and Cd as well as amendment soil in order to evaluate the influence of amendments on the mobility and bioavailability of metal ions. By using a progressive extraction process, the metal fraction that was adsorbed, exchangeable, and water soluble was identified. This process makes it possible to determine which metals are available to microbes and plants. Zn>Ni>Cd>Pb (20.1%, 15.2%, 15.1%,

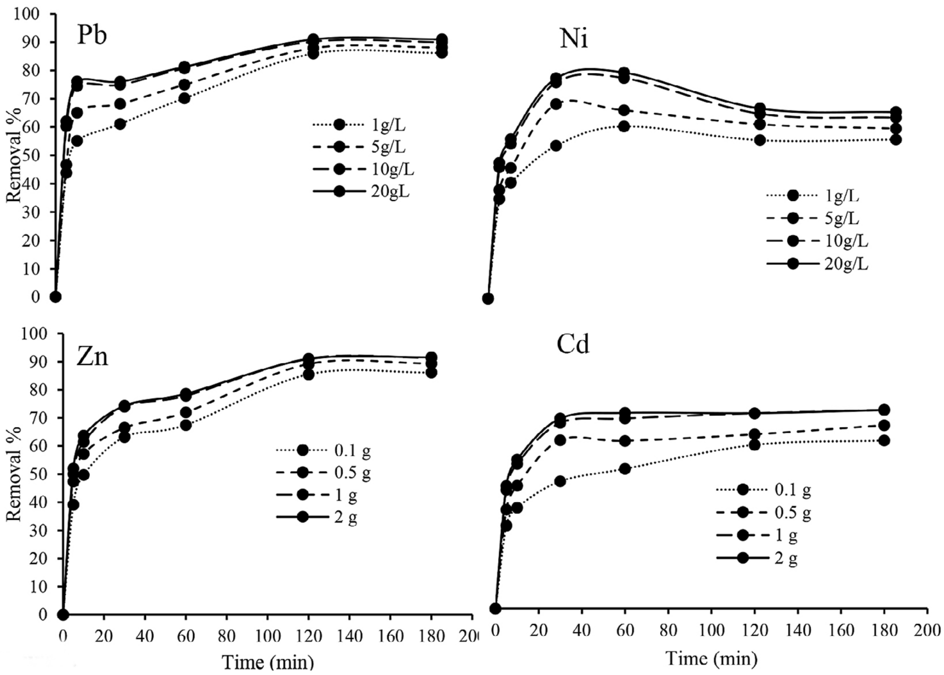

Figure 2. Percentages of metal removal by different concentrations of ADFW

and 13.8%, respectively) was the percentage of metal fractions extracted by water; these fractions are efficiently leachable and accessible for plants and microbes (Figure 3).

The water-soluble fractions may have formed as soluble complexes between dissolved organic matter and metal ions, as suggested by several of authors (Bradl 2004). The metal fractions that were extracted with Ca $(NO_3)_2$ and were relatively labile and potentially bio-available exchangeable ranged from 7.4% for Zn to 22.4% for Cd. The pattern for Zn appears to be controlled by the propensity of metal ions to form inner sphere complexes with organic matter in ADFW (Garau 2014), while the flow pattern of other metal ions appeared to be partially influenced by the charge density of the divalent metal cations.

The amounts of non-bioavailable or easily leachable metal ions that were removed using EDTA were greater for Pb (39%), Cd (20.6%), Ni (12.5%), and Zn (6.2%). The nature of the metal adsorption of surface functional groups and whether the metal binding is bidentate or monodentate could have an impact on these outcomes. Furthermore, the electrical characteristics of the interface have an impact on the adsorption mechanism (Bradl 2004). The high metal ion retention capacity of ADFW (Zn 66.3%>Ni 62.1%>Cd 41.9%>Pb 35%) may be due to various interactions between the inorganic and organic components of ADFW. The complication reactions that take place within the macro and/or micropores and on the exterior surfaces of organic acid may be the mechanism by which the metal ions remain attached.

FTIR spectroscopy

FTIR spectroscopy was used to analyse untreated ADFW and ADFW that had been contaminated with metal ions in order to determine the impact of both the organic acid and inorganic components of the ADFW performed in the sorption process of the metal ions (Figure 4).

The FTIR spectra of ADFW (Figure 4) revealed a broad band with a high range in the 590–3350 cm^{-1} region. This could be the result of the final scraps of food waste digestion, which are a combination of organic and inorganic compounds derived from the heterogeneity of ADFW. This broad band represented the overlap of the following bands, as inferred from the FTIR spectra of ADFW that were polluted and those were not polluted with metal ions: a band range of 500–800 cm^{-1} that was attributed to alcohols that are produced when fruit sugars break down into carbon dioxide and alcohol (Lambert *et al.,* 1987). On the basis of the acetic acid produced by ADFW, the shifting and overlapping in the broadband at 1432, 1678, 1739, and 2939 cm^{-1} were inferred (Liao *et al.,* 2001). The presence of propionic acid in ADFW is indicated by overlapping in a band at approximately 2500 and 3300 cm^{-1} (Ibrahim *et al.,* 2005).The butyric acid linked to the ADFW is identified by the shifting and overlapping in the broadband between 900 and 1700 cm^{-1} (Pretorius, 2024). The FTIR finding validates the synthesis of organic acids in ADFW, and the deformation in contaminated ADFW shows the strong attraction for metal ions of these acids.

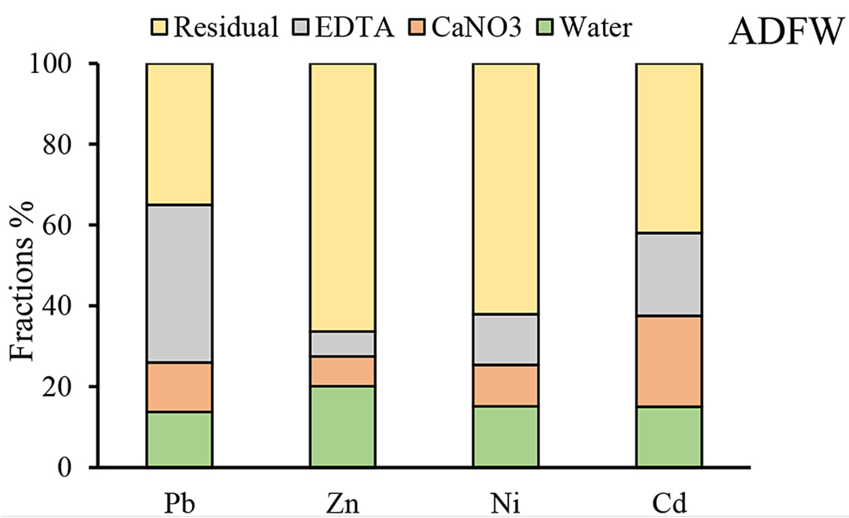

Figure 3. Percentage distribution of heavy metals between various fractions determined by the sequence extraction test

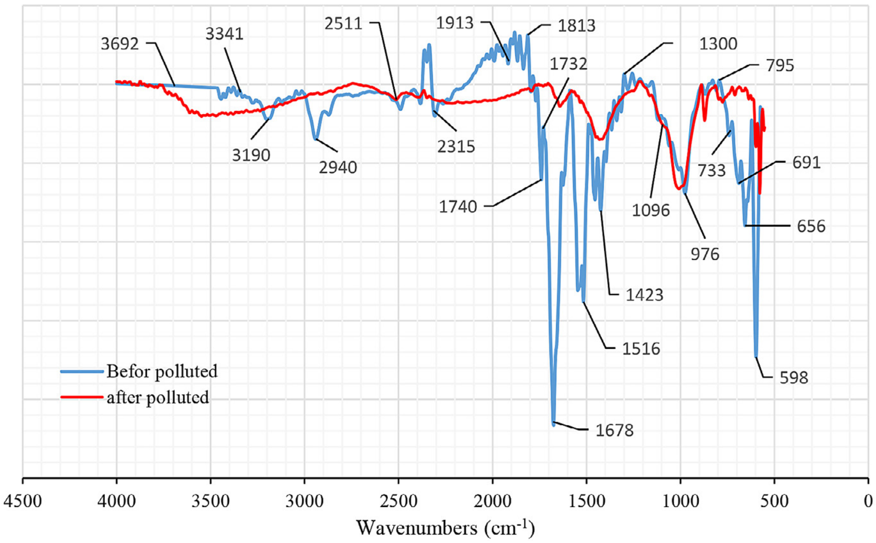

Figure 4. FTIR spectra of ADFW polluted with metal ions and not polluted with metal ions

Effect of amendments on soil properties

The physicochemical properties of the soil samples varied as soon as ADFW was added to the S1 and S2. A modest drop in treated soils was seen for both pH values and pHz; this could be attributed to the formation of volatile fatty acids during the shorter ADFW process. Conversely, the EC cation in both treated soils has significantly decreased. The high salinity of the irrigated water may have contributed to the highest EC in these samples. In all of the treated samples, there has been a rise in both the specific surface area and the percentage of total organic carbon. According to Emmanuel Arthur's research, there is a favourable association between SSA and TOC, with the TOC in ADFW being approximately 98%.

Salinity in soil and Fenugreek growth

Soil can become saline, as soon as salts build up in the soil structure, which inhibits plant growth. The structure of soil is harmed by too much sodium. Both the exchangeable sodium level and the sodium absorption ratio in soil can be used to assess the sodium risk. The level of sodium danger in soil seems to be connected to the soil ESP. The problems in the soil become difficult when the SAR increases above 6. These issues include the soil becoming more alkaline and saline as a result of sodium replacing calcium and magnesium, which causes a decrease in permeability and an increase in hardness. While many crop and pasture plants might experience a decrease in growth and production, certain plant species are more tolerant to salts than others.

SAR, ESP, and EC for S1 in this investigation were 20.5 (mmoles/l)$^{0.5}$, 22.5%, and 6.1 ds/m, respectively, while for S2, they were 11 (mmoles/l)$^{0.5}$, 13.6%, and 3.1 ds/m (Table 2). As shown in Table 1, the greatest values for SAR, ESP, and EC in amendment soils were observed in S2+4% (10.03 (mmoles/l)$^{0.5}$, 11.92%, and 2.68 ds/m, respectively. The plant used in this study, Fenugreek, is thought to be most sensitive to salinity when it is in its vegetative growth stage. Additionally, this plant can thrive in environments that are mildly to moderately salinize. The result from control pots showed there is no growth of Fenugreek.

In Figure 5 illustrates that the Fenugreek plant flourished more in S2 than in S1 that had been amended with 1% ADFW. This may be due to soil being classified as sodic (where the concentration of sodium ions is high relative to other cations) when the SAR of the soil is greater than 13 (mmoles/l) $^{0.5}$ or the ESP is greater than 15 (Shahid, 2012).

The development of Fenugreek growth was assessed by measuring the length of its shoots after a period of two months. On average, Fenugreek shoot lengths were 28 cm>25 cm>15 cm>11 cm>8 cm for S2+4%>S2+2%>S2+1%>S1+4%>S1+2%. Fenugreek grew best in S2 modified with 4% ADFW. However, salinity can not only impact Fenugreek development growth, metal ions existent in soil may also have an impact. Certain heavy metals, like Zn and Ni, are necessary for plant growth. Pb and Cd, conversely, have no positive

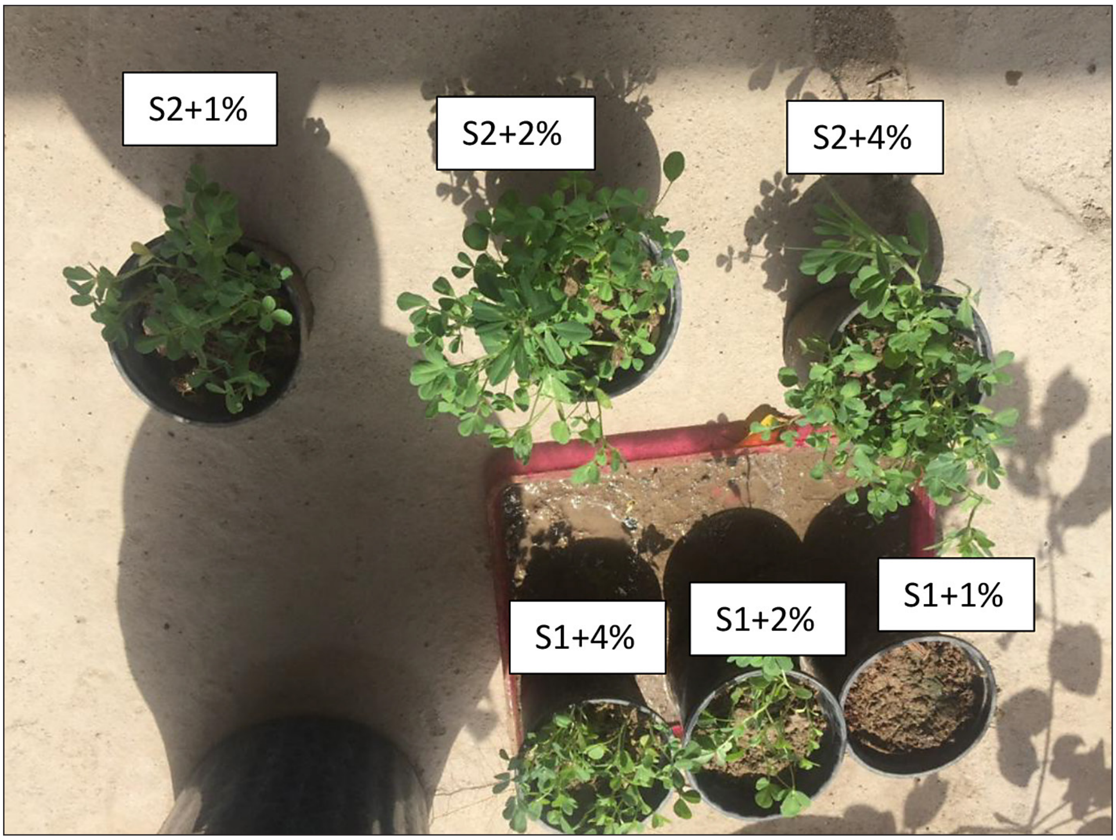

Figure 5. Fenugreek growth in S1 and S2 soils, amended with ADFW

effects on the growth of plants. Nevertheless, an excessive absorption causes harmful consequences for the plant. On land, plants typically take up Pb and Cd from the soil and store the majority of these metals in their roots (Asati, *et al.,* 2016, Alya, *et al.,* 2022). Meanwhile, other researchers highlighted that Pb has a negative impact on plants' photosynthetic activities. Additionally, excessive lead and copper inhibit seed germination, and cadmium damages photosynthetic systems I and II (Asati *et al.,* 2016, FAIZY *et al.,*2022). Despite being a necessary nutrient for plants, little Ni is needed for normal plant growth (Asati, *et al.,* 2016). According to a study by (FAIZY *et al.,*2022), the Fenugreek plant content increases when there is nickel (50 mg/kg) in the soil.

As a nutrient for plants, zinc has an impact on a number of their metabolic functions (Asati *et al.,* 2016). Nonetheless, the increased Na content can negatively impact the zinc content of the soil. Zn availability decreased but Na uptake increased as a result of the elevated ESP (Jakhar *et al.,* 2013). Fenugreek shoot length may increase in salt-sodic soil containing 10–20 mg/kg of zinc (Jakhar *et al.,* 2013).

The necessary range of metals in plants, as reported by Asati *et al.* in 2019, is Pb 1–13, Cd 0.1–2.4, Ni 1, and Zn 8–100 mg/Kg dry weight on plants. All other metal ions in this study, as indicated in Table 4, are within the range of significant metals for plants, with the exception of Ni.

Weka 3.8 model results

The Weka model was used to predict the shoot length of a Fenugreek plant (cm) and SAR at different ADFW added percentage. The dataset was directly divided into training and testing sections. The model was trained on a predefined training set of measured SAR and shoot length (cm). Predictions were made using a given test set that comprised the same attributes but had the actual target values hidden. It is noted from Figure 6 that shoot length increased sharply and it was more pronounced in 7% of ADFW added in both S1 and S2 reaching 22 cm and 40 cm in S1 and S2 respectively. After this point, the shoot length increases slightly, reaching 20 cm and 45 cm in S1 and S2 respectively. Meanwhile, SAR in both S1 and S2 was linearly decrease reaching zero and 3 $(mmoles/l)^{0.5}$ at 10% in S1and S2, respectively.

Table 4. Metals ions that accumulate in a Fenugreek plant

Metals ions mg/kg	S1+1%	S1+2%	S1+4%	S2+1%	S2+2%	S2+4%
Pb	9.321	5.356	2.123	3.435	1.784	1.213
Cd	0.214	0.198	0.153	0.175	0.1.384	0.0934
Ni	22.475	18.432	12.549	12.432	9.324	6.352
Zn	15.312	11.876	8.534	7.321	4.543	2.542

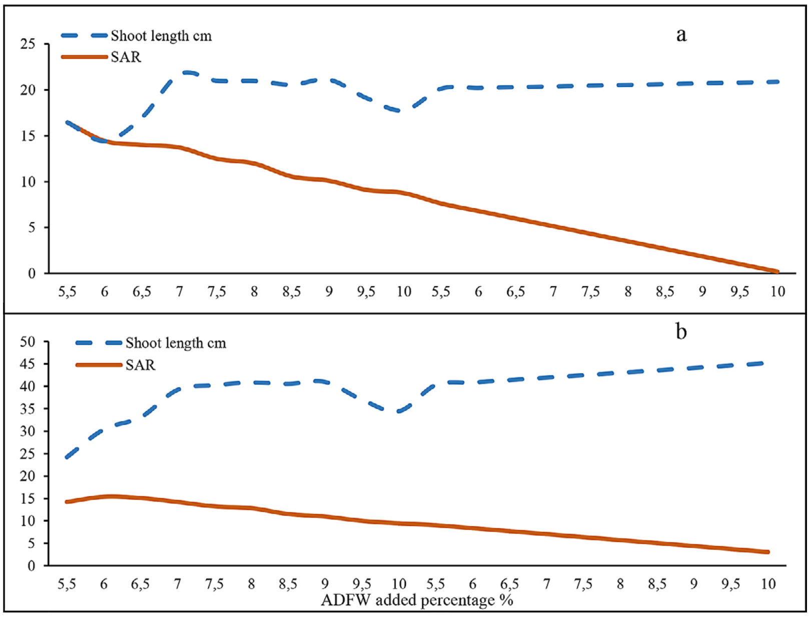

Figure 6. The relationship between ADFW added percentage and SAR and shoot length, a) at S1 b) at S2

CONCLUSIONS

In last decades, salinity and pollutants have spread in the agricultural lands in Basra city, so the aim of this study was using ADFW as sustainable remediate material. Overall, the results showed that this material was high affinity towards Cd, Zn, Ni and Pb. The results from sequential extraction and FT-IR spectroscopy showed that ADFW have high capacity of retain the metal ions. Fenugreek, which is considered moderately sensitive to salinity, cannot growth in high salinity soil (at depth 5 cm) when EC > 6 ds/m. Moreover, salinity can be evaluated by both the exchangeable sodium level and the sodium absorption ratio in soil. After soil remediation with ADFW at 2% and 4%, fenugreek grow with average shoot high 9 cm and 11 cm respectively. The best growth of this plant was at soil at depth 20 cm with EC 2.68 ds/m, ESP 10.76% and SAR 9.03 (mmoles/l $)^{0.5}$ when was ADFW used at 4%. The average shoot high was 28 cm. The result from Weka model predict that adding 7% of ADFW can enhance soil properties and shoot length of a plant.

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