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USING TREATED WASTEWATER IN IRRIGATION AND ITS EFFECT ON SOME SOIL PROPERTIES AND THE GROWTH *MORINGA OLEIFERA* PLANT

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ABSTRACT

This study investigated the feasibility of using greywater from a school or treated wastewater from the Rustamiya wastewater treatment plant for irrigating *Moringa oleifera* plants and its effects on growth and some soil properties, including electrical conductivity, soil pH, and heavy metal content in the soil and plants. The experiment consisted of four treatments using a randomized complete block design (RCBD). The first treatment served as the control, irrigating the plants with river water; the second with greywater; the third with wastewater; and the fourth with a mixture of greywater and wastewater. The experiment lasted for 180 days. The results indicated statistically significant differences in the length and diameter of *Moringa oleifera* plants when using wastewater mixed with greywater compared to the other irrigation treatments. Statistically significant differences were observed in the electrical conductivity of soil paste derived from soils irrigated with a mixture of wastewater and greywater. The findings indicated an elevation in the height and diameter of Moringa seedlings, alongside a rise in heavy metal concentrations in both the soil and the plants, subsequent to watering with wastewater or the incorporation of greywater. Nevertheless, the majority of micronutrients and minerals stayed below permissible thresholds and did not surpass dangerous levels for the soil and vegetation.

INTRODUCTION

The majority of industrialized nations and a small number of Arab countries have agreed to use only potable water for human consumption. This includes reusing treated greywater for irrigation, as well as water from other sources such as car washing and toilets, which does not necessarily require high-quality water (Sherif et al., 2023). Domestic wastewater comprises two components. The first type, referred to as black water, originates from sewage and has a high concentration of organic matter, numerous biological contaminants, and additional nutrients such as nitrogen and phosphorus. Section two comprises greywater, which acquires a grey hue upon standing; this water is utilized for bathing, cleaning, and analogous functions (Pandey *et al.,* 2020). About 60-75% of all household wastewater is greywater, making it a significant and intriguing resource for many uses beyond providing potable water to people and protecting the environment (Mohan *et al.,* 2024). There are temporal and activity-dependent variations in the quality of the community's greywater (Pratama *et al.,* 2020). In addition to hair, fat, and other chemical components, greywater contains soaps, shampoos, shaving cream, and laundry detergents (Sangarpal, 2022). When left untreated, the high oxygen consumption and high percentage of suspended particles in household wash water pose a threat (Mohan *et al.,* 2024). Phosphate, nitrogen, chlorine, salt, magnesium, calcium, and other organic substances are among the many nutrients found in greywater (Ahmad *et al.*, 2022). While certain nutrients in greywater, such phosphate and nitrogen, promote plant growth, elevated levels of other minerals, such as sodium and boron, can adversely affect plants (Maimon *et al.*, 2023).

Wastewater is defined as "water that has been used for something else, or a community or a business produces that and contains dissolved or suspended materials," with a concentration of 99.9 percent water and 0.1 percent suspended particles (Desta and Bote, 2021). A large body of research indicates that wastewater's chemical and biological composition determines whether or not it is suitable for use as an irrigation fluid, and that this water may include dangerous chemicals, bacteria, and viruses that offer direct or indirect threats to the environment (Pandey *et al.,* 2020; Nishiyama *et al*., 2021). The produced salts in wastewater, originating from a drinking water source of generally high quality, are usually not present in such levels to render them unsuitable for agricultural use.

The UN Food and Agriculture Organization (FAO) formulated salinity recommendations for water to assist farmers. Nonetheless, certain countries have employed irrigation water with dissolved salt concentrations over 2000 mg L-1(Radhi *et al.,* 2025). To mitigate the adverse effects of salts on plant growth, effective management solutions, such as the amalgamation of wastewater with greywater, have been employed. Numerous studies indicate that wastewater exerts significant detrimental effects on rivers and soils, while it has minimal impact on the total ecosystem. The Moringa oleifera plant is substantial, has rapid growth, and is resilient to drought conditions (Mashamaite et al., 2024). Optimal growth conditions encompass elevated temperatures surpassing 48 °C, salt tolerance, and habitats in tropical, subtropical, and semi-arid desert regions. (Salsi *et al.,* 2025; Khoza *et al.,* 2025 and Abdelwanis *et al.,* 2024).

Many people believe that planting it in poor soil can help alleviate drought, as it doesn't require rich soil or fresh water, and its roots absorb nitrogen from the air. Instead, you can use treated wastewater for irrigation (Salite and Poskitt, 2019). Prior studies indicate that treated wastewater can be employed for irrigation throughout multiple seasons (Abbood et al., 2013), and numerous schools have recycled greywater treated with rice husks for this application (Pandey et al., 2020; Abbas and Alwan, 2024). This study evaluated the possibility of two unusual water sources for irrigation without inflicting economic or environmental damage: greywater discharged from several schools in Baghdad and wastewater from the Rustamiya plant. It subsequently assessed the impact of each source on the growth of forest trees and the characteristics of different soil conditions.

MATERIALS AND METHODS

The field part of the experiment was conducted at the facilities of the College of Agricultural Engineering Sciences, University of Baghdad, in the Al-Jadriya area, while the laboratory part was carried out at the Environment and Water Management Laboratories of the Ministry of Science and Technology. The treatments were performed on three-month-old *Moringa oleifera* seedlings of the same height, grown in 12-kilogram plastic containers filled with clay soil (Table 1). The measurements for the physical and chemical properties listed in Table 1 were carried out as described in conductivity (Alzoubi *et al.*, 2013).

Table (1). Some physical and chemical properties of the soil in the study.

Total Nitrogen (mg L^{-1})	Organic matter **(%)**	Lime	pH	EC (dS m^{-1})
0.053	10.6	271	7.48	3.17
Soil particle analysis (g kg^{-1})			Texture	
sand	silt	Clay	clay loam	
325	340	335		

The experiment was structured as a straightforward investigation utilizing a fully randomized block design including four sectors. The irrigation factor comprised four treatments, including a comparative treatment utilizing river water, denoted as (C). The second treatment involved irrigation using wastewater from the Rustamiyah wastewater treatment facility, located south of Baghdad, denoted as (W). The third treatment was irrigation with greywater (Al-Jayyousi, 2003), sourced from a secondary school in Baghdad, denoted as (G). The fourth irrigation water treatment involved the amalgamation of wastewater and greywater in equal proportions, denoted as (WG). The irrigation process continued for six months, and the gravimetric method was used to determine the amount of water to be added when irrigating the seedlings after losing half of the added amount of water. Water samples (river water, wastewater, greywater, and evenly mixed water, including wastewater + greywater) were passed through a membrane filter with a pore diameter of 0.45 µm, which ensured the passage of dissolved elements and main elements, and chemical heavy metals present in the different water samples. Quantitative analysis was performed according to what was stated in (Clesceri, 1998; Alzoubi *et al.*, 2013; APHA, 2017; Oteng-Peprah *et al.*, 2018; and Soromotin *et al.,* 2022), and the analysis was recorded in Tables 2-5. Additionally, different water samples were collected for chemical analysis, in order to analyse the pH and electrical conductivity (Alzoubi *et al.*, 2013). The concentrations and critical maximum permissible limits for each element in irrigation water and wastewater used for irrigation are established in Tables 3-5, according to the following sources. (Ayers and Westcot, 1994; Hashem and Qi, 2021, and Uslu *et al.,* 2025).

Measurements of heavy metals in leaves and soil samples were carried out according to the method of (Alzoubi *et al.*, 2013), where the concentrations of heavy metals (Pb, Cd, Cu, Zn, Mn and Fe) were estimated. The solutions of the digested leaf samples were measured using an Atomic Absorption Spectrophotometer and the concentrations of heavy metals were extracted in the unit (mg L^{-1}). The toxicity limits for heavy metals in plants were identified and recorded in Table 6, as stated in (Wijewardena and Gunaratne, 2004; Mark *et al.*, 2005; Chauhan *et al.*, 2008; CAC:

The Joint FAO/WHO, 2014; Farid *et al.*, 2015; and Guangjie *et* al., 2024). Maximum permissible levels of heavy metals in soils as stated in (CAC: The Joint FAO/WHO, 2014 and Chyad *et al.*, 2022).

The plant growth indicators, which include the diameter and length of the Moringa seedling stem, were measured after six months of treatment. Additionally, soil samples were collected for chemical analysis, in order to analyse the pH and electrical conductivity (Alzoubi *et al.*, 2013)

RESULTS AND DISCUSSION

The results of comparing the three water samples are shown in Table 2, a clear difference in their chemical properties. Wastewater recorded the highest levels of salinity and total dissolved solids (EC = 2.16 $dS \cdot m^{-1}$, TDS = 1392 $mg \cdot L^{-1}$), reflecting its high pollutant load compared to greywater and river water, which showed remarkably similar and lower values for these indicators. Regarding pH, all samples fell within the slightly alkaline range, from 7.34 for wastewater (closest to neutral) to 7.69 for river water (most alkaline). This suggests that greywater represents a promising and less polluted option compared to conventional wastewater due to its similarity to natural water (river water).

Table (2). Some chemical properties of irrigation water treatment.

Chemical properties	Wastewater	Greywater	River water
Electrical Conductivity (EC) ($dS\ m^{-1}$)	2.16	0.87	0.80
Acidic (pH)	7.34	7.51	7.69
TDS ($mg\ L^{-1}$)	1392	547	522

The analysis of dissolved elements showed in table 3 that wastewater had higher concentrations of all measured ions compared to the other samples. Sodium exceeded the critical limit (69 $mg \cdot L^{-1}$) in both wastewater (285 $mg \cdot L^{-1}$) and greywater (112 $mg \cdot L^{-1}$), indicating a risk of soil salinization with uncontrolled irrigation. In contrast, greywater showed superior quality, closely resembling river water in calcium, magnesium, and sulfate levels, while chloride and nitrate levels remained within safe limits for all samples.

Table (3). Content of chemical dissolved elements in irrigation water treatment.

Dissolved element ($mg\ L^{-1}$)									
irrigation water treatment	Ca	Mg	Na	K	SO_4	Cl	HCO_3	PO_4	NO_3
Wastewater	248	112	285	9.5	246	278	110	0.46	9.5
Greywater	87	47	112	3.0	89	115	37	0.45	1.2
River water	51	40	60	1.5	87	106	60	0	1.7
Critical maximum	N. T.	N. T.	69	N. T.	N. T.	355	518	N. T.	133

N.T.: Nontoxic.

Analysis of macronutrients (N, P, K) presented in Table 4, revealed a significantly richer nutrient content in both wastewater and greywater compared to the river water, which was scarce in these elements. Nitrogen (N) concentrations exceeded the critical maximum (30 $mg \cdot L^{-1}$) in wastewater, reaching 79 $mg \cdot L^{-1}$, and in greywater, they reached 39 mg·L⁻¹. This could potentially lead to excessive vegetative growth or nitrate leaching. Furthermore, greywater and wastewater showed remarkably similar levels of phosphorus and potassium (P = 3.00, K = 8.70 mg·L⁻¹), with these elements remaining within non-toxic (N.T.) ranges. The study suggests that both sources represent valuable fertilizer reserves (Almashhadani and Al-Hadethi, 2025).

Table (4). Content of chemical main elements of irrigation water treatment.

Main elements (mg L^{-1})			
irrigation water treatment	N	P	K
Wastewater	79	3.70	11.00
Greywater	39	3.00	8.70
River water	0	0.27	0.45
Critical maximum	30	N. T.	N. T.

N.T.: Nontoxic.

Analysis of heavy metals showed in Table 5, revealed varying levels of toxicity across water sources. Wastewater and greywater exceeded the maximum critical limits for manganese (Mn), iron (Fe), lead (Pb), and cadmium (Cd). Wastewater showed significantly higher levels of contamination, particularly for iron (5.433 mg·L^{-1}), cadmium (0.214 mg L^{-1}), and manganese (4.324 mg·L^{-1}). These sharp increases are attributed to industrial and domestic waste, including detergents. River water, however, remained within safe limits, except for a slight cadmium contamination level of 0.016 mg·L^{-1}.

Table (5). Content of chemical heavy metals in irrigation water treatment.

Heavy metals (mg L^{-1})						
irrigation water treatment	Zn	Mn	Fe	Pb	Cd	Cu
Wastewater	1.326	4.324	5.433	0.105	0.214	1.265
Greywater	0.446	0.381	0.521	0.076	0.085	0.069
River water	0.050	0.002	0.043	0.010	0.016	0.048
Critical maximum	2.000	0.100	0.300	0.010	0.003	2.000

Table 6 illustrates the substantial impact of the research treatments on Moringa plant growth metrics (seedling diameter and height) and heavy metal concentration in comparison to the control treatment utilizing river water irrigation. The simultaneous application of equal amounts of greywater and wastewater yielded the most substantial seedling diameter, measuring 60.91 mm, greatly surpassing all other treatments, including the river water control. Regarding seedling height, the wastewater treatment achieved the highest and most significant result at 1.66 m, followed by the combined treatment of irrigating with equal volumes of greywater and wastewater, resulting in a seedling height of 1.45 m. Both treatments significantly outperformed the river water and greywater treatments. The significant improvement in vegetative indicators (diameter and length) observed when applying the combined treatment of irrigating with equal volumes of greywater and wastewater, or the treatment of irrigating with wastewater, can be attributed to the positive role these treatments play in enhancing the availability and uptake of essential micronutrients such as iron, manganese, and zinc. These treatments recorded the highest plant accumulations of these elements (Table 6). These elements are cofactors for respiration enzymes, photosynthesis, and chlorophyll synthesis, which positively impacted photosynthetic efficiency and increased cell division and elongation in Moringa seedlings. These results are consistent with previous research indicating that wastewater with high concentrations of nutrients (potassium, phosphorus, and nitrogen), as well as other elements (as confirmed in Tables 3-5), can improve plant growth when used as an irrigation source (Pescod and Arar, 2013 and Paśmionka *et al.*, 2021).

Regarding the concentration of heavy elements in Moringa leaves, it was observed that the two treatments irrigated with wastewater and irrigated with equal amounts of greywater and wastewater led to a significant increase in the accumulation of lead, cadmium, zinc, manganese and iron compared to the control treatment irrigated with river water, while no statistically significant differences appeared between the treatments in the concentration of copper. Although these elements reached high concentrations in plant tissues compared to plants irrigated with river water, only lead and cadmium exceeded the established phytotoxicity limits, as shown in Table 6 for each element.

Table (6). Influence of treatments on plant growth indicators and the content of heavy metals in the Moringa plant.

Treatment	Diameter seedling (mm)	Length seedling (m)	Heavy metals (mg L^{-1})					
			Pb	Cd	Cu	Zn	Mn	Fe
C	51.00	1.02	0.56	1.081	4.2	16	42	54
G	49.46	0.98	0.61	1.085	3.8	19	39	60
W	51.10	1.66	1.87	1.196	3.6	39	62	88
G + W	60.91	1.45	1.86	1.187	3.5	32	54	80
LSD 0.05	9.03	0.35	1.16	0.096	1.00	12.0	12.0	16.1
Toxicity limits			0.20	0.40	10-20	500	300-500	15

C: Comparative treatment and irrigated with river water.
G: Treatment of greywater.
W: Treatment of wastewater.
G + W: Treatment of greywater mixed with wastewater.

Notwithstanding the elevated contents of lead and cadmium, the Moringa trees demonstrated a tolerance to these levels. The amounts of iron, copper, manganese, and zinc observed in all treatments were significantly below the phytotoxicity thresholds. Despite elevated levels of cadmium and lead, no indications of toxicity were observed. This signifies that the elevated concentrations of these elements in Moringa leaves, due to various treatments, stayed within a safe and nutritious range for the plant, without reaching levels that would limit growth or induce cytotoxicity. This elucidates the significant enhancement in the morphological traits of the seedlings. This permits the utilization of wastewater, either in its untreated form or diluted with an equal volume of greywater. (AL-Hamza, 2017 and Mangale *et al.*, 2012). To preserve human health and prevent harmful effects of these elements on crops, particularly lead and cadmium, which is extremely toxic to plants and animals when exceeded acceptable levels, we must exercise caution when utilizing wastewater for the irrigation of other crops that are eaten raw. Studies have shown that both are true (Pinto and Maheshwari, 2010).

The results, presented in Table 7, the irrigation treatment with wastewater recorded the highest soil salinity value of 5.49 $dS \cdot m^{-1}$, followed by the irrigation treatment with greywater and then irrigation with river water, while the mixture between wastewater and greywater equally achieved the lowest salinity value of 2.89 $dS \cdot m^{-1}$, which is a clear significant decrease compared to the rest of the treatments. However, the treatments did not appear to have a significant effect on the pH values, as they all fell in the light alkaline range and did not exceed the permissible limits. It is noted that mixing wastewater with greywater led to a positive synergistic effect that reduced the total degree of salinity compared to the separate use of each. This indicates the occurrence of precipitation or ion exchange reactions that led to a reduction in free dissolved ions responsible for electrical conductivity, which is an excellent indicator for improving the quality of the laboratory medium or treated soil. It is also noted that the concentration of lead and cadmium increased in the soil irrigated by treating the mixture between greywater and wastewater, reaching 6.19 and 5.88 $mg \cdot L^{-1}$, respectively. Although all values for lead remained safe and below the permissible limit, the concentration of cadmium exceeded the maximum permissible limit in practice, which poses a direct danger to soil pollution. The concentrations of copper and zinc also increased, reaching their peak in the treatment of the mixture between greywater and wastewater, reaching 13.99 and 22.79 $mg \cdot L^{-1}$, respectively, and these values remained within completely safe and internationally permissible limits. While the two irrigation treatments using wastewater alone or mixing it with greywater recorded slightly exceeding the maximum permissible limit, as the values reached 26.31 and 27.86 $mg \cdot L^{-1}$, respectively. The iron concentration in the irrigation treatment with a mixture of wastewater and greywater jumped to 53.7 $mg \cdot L^{-1}$, which is a huge significant increase compared to the irrigation treatment with river water, which recorded 18.10 $mg \cdot L^{-1}$, but it is still below the maximum permissible limit.

Table (4). Influence of treatments on some soil properties and its content of heavy metals.

Treatment	EC ($dS\ m^{-1}$)	Acidic (pH)	Heavy metals ($mg\ L^{-1}$)					
			Pb	Cd	Cu	Zn	Mn	Fe
C	3.70	7.49	1.25	0.131	4.00	9.26	12.18	18.10
G	3.86	7.52	1.31	1.260	3.35	10.11	13.25	17.23
W	5.49	7.56	3.16	2.160	5.85	18.42	26.31	33.12
G + W	2.89	7.53	6.19	5.880	13.99	22.79	27.86	53.7
LSD 0.05	1.23	0.09	2.89	1.061	1.71	3.81	7.96	8.77
Maximum permissible levels			0.20	0.40	10-20	500	300-500	15

C: Comparative treatment and irrigated with river water.
G: Treatment of greywater
W: Treatment of wastewater
G + W: Treatment of greywater mixed with wastewater.

The most prominent and dangerous phenomenon in these data is the large accumulation of cadmium in the soil when irrigated with wastewater, whether alone or mixed with greywater. Cadmium exceeding the permissible barrier (5.88 versus

3.00) mg·L^{-1} is most likely due to the wastewater containing high percentages of this element (Table 5), and when mixed with greywater, it led to an increased release of cadmium. Since cadmium is a highly toxic and highly mobile element, this percentage makes irrigation treatment with a mixture of wastewater and greywater unsafe for agricultural use related to human or animal feeding without prior treatment. As for the steady increase in the concentrations of iron, copper and zinc in irrigation treatment with wastewater mixed with greywater, it reflects the ability of this mixture to provide microelements that may be beneficial for plant growth, and the fact that it did not exceed the maximum limits, which means that the risk of its direct toxicity is currently low, but its continued application may lead to its accumulation in the long term, especially manganese. (Saleem and Bachmann, 2019; Kurniawan *et al.*, 2020).

CONCLUSIONS

Developing fast-growing, evergreen perennial forest species with both environmental and aesthetic benefits using treated or untreated greywater is a pressing national need, given the current water scarcity and fragile climate in the country and region. The *Moringa oleifera* tree is a fast-growing species suitable for cultivation in arid and semi-arid regions, and its successful cultivation using greywater represents an important first step. This highlights the significance of experimenting with greywater cultivation as a component of food and medical security, within the framework of environmental education and the sustainability of educational institutions. Calcareous soils possess a robust regulatory system that limits the amount of nutrients plants can absorb from greywater or greywater-sewage mixtures (Marzougui *et al.*, 2021; Florides *et al.*, 2024); thus, green spaces can be maintained without compromising plant health. To irrigate *Moringa oleifera* plants and dispose of polluted water in an environmentally friendly and economical way, the study recommends the possibility of using greywater or water mixed in equal proportions with sewage water as primary unconventional sources and as optimal options for irrigating Moringa trees.

CONFLICT OF INTEREST

There are no conflicts to declare.

استخدام مياه الصرف الصحي المعالجة في الري وتأثيرها في بعض خصائص التربة ونمو نبات المورينجا *Moringa oleifera*

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الخلاصة

تناولت هذه الدراسة إمكانية استخدام المياه الرمادية الخاصة بإحدى المدارس او مياه الصرف الصحي المعالجة من محطة الرستمية لري نباتات المورينجا أوليفيرا وتأثيراتها على النمو وبعض خصائص مركبات التربة، بما في ذلك التوصيل الكهربائي، ودرجة الحموضة التربة، ومحتوى المعادن الثقيلة في التربة والنباتات. تألفت التجربة من أربع معاملات باستخدام تصميم القطاعات الكاملة العشوائية (RCBD) وأربع قطاعات. كانت

المعاملة الأولى بمثابة معاملة المقارنة وهي ري النباتات بمياه النهر، والثانية ري النباتات بالمياه الرمادية، والثالثة ري النباتات بمياه الصرف الصحي، والرابعة ري النباتات بمزيج من المياه الرمادية ومياه الصرف الصحي. استمرت التجربة لمدة 180 يومًا. أشارت النتائج إلى وجود فروق ذات دلالة إحصائية في طول وقطر نمو نبات المورينجا أوليفيرا عند استخدام مياه الصرف الصحي والمخلوطة بالمياه الرمادية مقارنة بمعاملات الري الاخرى. كانت هناك فروق ذات دلالة إحصائية في قيمة التوصيل الكهربائي لعجينة التربة المستخرجة الترب المروية بمياه الصرف الصحي والمخلوطة بالمياه الرمادية. كما أظهرت النتائج أيضًا زيادة ارتفاع وقطر شتلات المورينجا فضلاً عن زيادة تركيز العناصر الثقيلة سواء في التربة أو النبات بمعاملة الري بمياه الصرف الصحي او معاملة الخلط مع المياه الرمادية. مع ذلك، ظلت اغلب العناصر الغذائية الدقيقة والمعادن ضمن الحدود المسموح بها، ولم تتجاوز الحدود السامة للتربة والنبات.

الكلمات المفتاحية: الخواص الكيميائية، المياه الرمادية، المعادن الثقيلة العناصر الرئيسية، العناصر الدقيقة.

REFERENCES

Ahmad, A., Chowdhary P., Khan N., Chaurasia D., Varjani S., Pandey A. and Chaturvedi P. (2022). Effect of sewage sludge biochar on the soil nutrient, microbial abundance, and plant biomass: A sustainable approach towards mitigation of solid waste. *Chemosphere*, *287*, 132112. https://doi.org/10.1016/j.chemosphere.2021.132112

Abbood, D. W., Mustafa A. S. and Ali S. A. K. (2013). Social Investigation of Greywater Reuse in Baghdad. *Civil and Environmental Research*, 3(12): 132-145. https://www.iiste.org/Journals/index.php/CER/article/view/8649

Abbas, H. H. and Alwan S. W. (2024). Evaluation of Water Quality and Sustainability of Treated Wastewater for Irrigation and the Municipal Uses in Karbala Province. *Kufa Journal for Agricultural Sciences*, 16(2): 1-17. https://doi.org/10.36077/kjas/2024/v16i2.11405

Abdelwanis, F. M., Abdelaty H. S. and Saleh S. A. (2024). Exploring the multifaceted uses of *Moringa oleifera*: nutritional, industrial and agricultural innovations in Egypt. *Discov. Food* 4(146). https://doi.org/10.1007/s44187-024-00221-5

Al-Jayyousi, O. R. (2003). Greywater reuse: towards sustainable water management. *Desalination*, 156(1-3): 181-192. https://doi.org/10.1016/S0011-9164(03)00340-0

AL-Hamza, J. S. (2017). The Use of Rice Husk for Greywater Treatment in Irrigation and for Improving the properties of leaching saline soil. *Al-Qadisiyah J. of Agric. Sci.*,7(2): 184-191. https://doi.org/10.33794/qjas.2017.162627

Almashhadani, B. M. and Al-Hadethi M. E. (2025). Effect of Irrigation Intervals and Poultry Manure in Growth of Olive Transplants (*Olea europaea* L.). *IOP Conference Series: Earth and Environmental Science,* 1487(1): 012033). https://doi.org/10.1088/1755-1315/1487/1/012033

Alzoubi, M. M., AlHossny A. M. and Drgham H. (2013). *Analysis methods for soil, plant, water and fertilizers*. General Commission for Scientific Agricultural Research (GCSAR), Ministry of Agriculture and Agrarian Reform.

APHA (2017). Standard Methods for the Examination of Water and Wastewater (23rd ed.). Washington DC: American Public Health Association. http://www.standardmethods.org/

Ayers, R. S. and Westcot D. W. (1994). Water Quality for Agriculture. FAO Irrigation and Drainage Paper No. 29, Rome, https://www.fao.org/4/t0234e/T0234E00.htm#TOC

CAC, (Codex Alimentarius Commission). (2014). General Standard for Contaminants and Toxins in Food and Feed (CODEX STAN 193–1995). The Joint FAO/WHO Food Standards Programme, 2014. https://doi.org/10.13140/RG.2.1.4910.2560

Chauhan, S. S., Thakur R. and Sharma G. D. (2008). Nickel: its availability and reactions in soil. *J. of Industrial Pollution Control*, 24(1):1-8. https:/www.icontrolpollution.com/nickel-its-availability.pdf

Chyad, A. A., Saee, A. M. and Alhendi A. S. (2022). Determination of Heavy Metals in Irrigation Water, Soil, Paddy, and Produced Rice of Some Paddy Fields of Iraq. *Iraqi Journal of Science*, 63(11): 4637-4649. https://doi.org/10.24996/ijs.2022.63.11.2

Clesceri, L. S. (1998). Standard methods for examination of water and wastewater. *American public health association*, *9*. https://cir.nii.ac.jp/crid/1571980074898839552

Desta, W. M. and Bote M. E. (2021). Wastewater treatment using a natural coagulant (*Moringa oleifera* seeds): optimization through response surface methodology. *Heliyon*, 7(11). https://doi.org/10.1016/j.heliyon.2021.e08451

Farid, G., Sarwar N., Ahmad A., Ghafoor, A. and Rehman M. (2015). Heavy Metals (Cd, Ni and Pb) Contamination of Soils, Plants and Waters in Madina Town of Faisalabad

Metropolitan and Preparation of Gis Based Maps. Advances in Crop Science and Technology. https://doi.org/10.4172/2329-8863.1000199

Florides, F., Giannakoudi M., Ioannou G., Lazaridou D., Lamprinidou E., Loukoutos N., ... and Katsoyiannis I. A. (2024). Water reuse: A comprehensive review. *Environments*, 11(4): 81. https://doi.org/10.3390/environments11040081

Guangjie, L., Jinlin W., Herbert J. K., Baohai L. and Weiming S. (2024). Physiological and molecular mechanisms of plant-root responses to iron toxicity. *Journal of Plant Physiology*, 297: 154257. https://doi.org/10.1016/j.jplph.2024.154257

Hashem, M.S. and Qi X.-B. (2021). Treated Wastewater Irrigation—A Review. *Water*, 13, 1527. https://doi.org/10.3390/w13111527

Khoza, T., Masenya A., Khanyile N. and Thosago S. (2025). Alleviating plant density and salinity stress in *Moringa oleifera* using *Arbuscular Mycorrhizal* fungi: A Review. *Journal of Fungi*, 11(4), 328. https://doi.org/10.3390/jof11040328

Kurniawan, S. B., Abdullah S. R. S., Imron M. F., Said N. S. M., Ismail N. I., Hasan H. A., ... and Purwanti I. F. (2020). Challenges and opportunities of bio coagulant/ bio flocculant application for drinking water and wastewater treatment and its potential for sludge recovery. *International journal of environmental research and public health*, 17(24): 9312. https://doi.org/10.3390/ijerph17249312

Maimon, A., Gilboa A. and Amit G. (2023). Greywater irrigation and soil quality: An assessment framework adjustment and application. *Soil & Environmental Health*, 1(3):1-10. https://doi.org/10.1016/j.seh.2023.100034

Mangale, S. M., Chonde S. G., Jadhav A. S. and Raut P. D. (2012). Study of *Moringa oleifera* (drumstick) seed as natural absorbent and antimicrobial agent for river water treatment. *J Nat Prod Plant Resour*, 2(1): 89-100. https:/scispace.com/study-of-moringa-oleifera.pdf

Mark, W. P., Alejandro V. and Edward F. R. (2005). Manganese toxicity thresholds for restoration grass species. *Environmental Pollution*, 135(2): 313-322. https://doi.org/10.1016/j.envpol.2004.08.006

Marzougui, N., Guasmi F., Dhouioui S., Bouhlel M., Hachicha M., Berndtsson R. and Sleimi, N. (2021). Efficiency of different *Moringa oleifera* (Lam.) varieties as natural coagulants for urban wastewater treatment. *Sustainability*, 13(23): 13500. https://doi.org/10.3390/su132313500

Mashamaite, C. V., Mukondeleli N. R. and Alen M. (2024). *Moringa oleifera* Lam.: A versatile climate-smart plant for nutritional security and therapeutic usage in semi-arid regions, *Journal of Agriculture and Food Research*, 16. https://doi.org/10.1016/j.jafr.2024.101217

Mohan, S., Manthapuri V. and Chitthaluri S. (2024). Assessing factors influencing greywater characteristics around the world: a qualitative and quantitative approach with a short-review on greywater treatment technologies. *Discov Water* 4 (37). https://doi.org/10.1007/s43832-024-00094-w

Nishiyama, M., Praise S., Tsurumaki K., Baba H., Kanamori H. and Watanabe T. (2021). Prevalence of antibiotic-resistant bacteria ESKAPE among healthy people estimated by monitoring of municipal wastewater. *Antibiotics*, 10(495): 1-9. https://doi.org/10.3390/antibiotics10050495

Oteng-Peprah, M., Acheampong M. A. and DeVries N. K. (2018). Greywater characteristics, treatment systems, reuse strategies and user perception—a review. *Water, Air, & Soil Pollution*, 229(8): 255. https://doi.org/10.1007/s11270-018-3909-8

Pandey, P., Khan F., Mishra R. and Singh S. K. (2020). Elucidation of the potential of *Moringa oleifera* leaves extract as a novel alternate to the chemical coagulant in water treatment process. *Water Environment Research*, *92*(7): 1051-1056. https://doi.org/10.1002/wer.1300

Paśmionka, I. B., Bulski K., Herbut P., Boligłowa E., Vieira F. M. C., Bonassa G., ... and Bortoli M. (2021). Evaluation of the effectiveness of the activated sludge process in the elimination both ATB-resistant and ATB-susceptible *E. coli* strains. *Energies*, 14(18): 5868. https://doi.org/10.3390/en14185868

Pescod, M. B. and Arar A. (Eds.). (2013). *Treatment and Use of Sewage Effluent for Irrigation: Proceedings of the FAO Regional Seminar on the Treatment and Use of Sewage Effluent for Irrigation Held in Nicosia, Cyprus, 7–9 October, 1985*. Elsevier. https:/rexresearch1.com/TreatmentUseSewageEffluent.pdf

Pinto, U. and Maheshwari B. L. (2010). Reuse of greywater for irrigation around homes in Australia: understanding community views, issues and practices. *Urban Water Journal*, 7(2): 141-153. https://doi.org/10.1080/15730620903447639

Pratama, M. A., Immanuel Y. D., Marthanty D. R. (2020). A multivariate and spatiotemporal analysis of water quality in code river, Indonesia, The Scientific World Journal, 8897029: 1-11. https://doi.org/10.1155/2020/8897029

Radhi, N. A. Dawood E. S. and Abdul-Sahib T. A. (2025). Groundwater quality analyses for irrigation purposes in Salah AlDin, Iraq: A Review. *Al-Esraa University College Journal for Engineering Sciences,* 7(11):94–106. https://doi.org/10.70080/2790-7732.1062

Saleem, M. and Bachmann R. T. (2019). A contemporary review on plant-based coagulants for applications in water treatment. *Journal of Industrial and Engineering Chemistry*, 72: 281-297. https://doi.org/10.1016/j.jiec.2018.12.029

Salite, D. and Poskitt S. (2019). Managing the impacts of drought: The role of cultural beliefs in small-scale farmers' responses to drought in Gaza Province, southern Mozambique. *International Journal of Disaster Risk Reduction*, 41: 101298. https://doi.org/10.1016/j.ijdrr.2019.101298

Salsi, G., Greco C., Laudicina V. A., Lucia C., Muscarella S. M., Greco G., Orlando S., Fascella G. and Mammano M. M. (2025). Preliminary results of *Moringa oleifera* Lam. grown in a semi-arid Mediterranean environment in a climate change scenario. Front. Sustain. Food Syst. 9:1576147. https://doi.org/10.3389/fsufs.2025.1576147

Sangarpal, S. (2022). Design optimization for greywater treatment. *International Journal for Research in Applied Science & Engineering Technology*, X(10): 1319-1337. https://doi.org/10.22214/ijraset.2022.47177

Sherif, M., Liaqat M. U., Baig F. and Al-Rashed M. (2023). Water resources availability, sustainability and challenges in the GCC countries: An overview. *Heliyon*, *9*(10): 1-22. https://doi.org/10.1016/j.heliyon.2023.e20543

Soromotin, A., Moskovchenko D., Khoroshavin V., Prikhodko N., Puzanov A., Kirillov V., Koveshnikov M., Krylova E., Krasnenko A. and Pechkin A. (2022). Major, Trace and Rare Earth Element Distribution in Water, Suspended Particulate Matter and Stream Sediments of the Ob River Mouth. *Water*, 14, 2442. https://doi.org/10.3390/w14152442

Uslu, O.S., Gedik O., Kaya A.R., Erol A., Babur E., Khan H., Seleiman M.F. and Wasonga, D.O. (2025). Effects of Different Irrigation Water Sources Contaminated with Heavy Metals on Seed Germination and Seedling Growth of Different Field Crops. *Water*, 17, 892. https://doi.org/10.3390/w17060892

Wijewardena, J.D.H. and Gunaratne, S.P. (2004). Heavy metal contents in commonly used animal manure. *Annals of the Sri Lanka Department of Agriculture*. 6:245 - 253. https://dl-doa.nsf.gov.lk/doa/api/core/bitstreams/8b8db7ad-8b2d-4bb2-b863-05e9b20d6b88/content