EVALUATION OF POLLUTION OF DIYALA RIVER WATER QUALITY BY SOME HEAVY METALS (PB, CU, NI, CD) , BORON AND THEIR EFFECT ON POLLUTION OF AGRICULTURAL SOILS

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ABSTRACT

A study was conducted to evaluate the quality of Diyala River water with some heavy metals (Pb, Cu, Ni, Cd), Boron and their effect on pollution of agricultural soil surrounding river that is irrigated with river water. Nine areas located on river within Al-Jisr district of Al-Madain district, southeast of Baghdad Governorate / Iraq, were selected, namely Umm Al-Ubaid, Al-Uwaija, Al-Khafaji, Al-Kargouliya, Jurf Al-Naddaf, Al-Samadiyah, Abu Thila, Al-Arifiyah, Al-Tuwaitha, and northern shores of Salman Pak, for comparison purposes. Water samples were taken for three months during summer (June, July, and August) and three months during the winter (January, February, and March) of 2024, and average values for two seasons were taken. Soil samples were collected from agricultural soils adjacent to the river in above-mentioned areas at same time that water samples were taken. Results indicated a difference in chemical properties of studied water and soil during two seasons, as highest values for electrical conductivity, soil reaction, cataions and anaions dissolved, heavy metals ions and boron were in summer season compared to winter season in all sites, highest values were in Tuwaitha region. Water category was most dangerous in Al-Tuwaitha area C_3S_1 low-sodium high-salinity according to USDA system, while its classification was a severe problem and an increasing problem for two areas above, according to FAO system. Concentrations of Lead, Cadmium, Nickel and Copper exceeded permissible limits for irrigation water in both seasons for all sites except northern Salman Pak beaches (comparison). All agricultural soils are contaminated with Cadmium, not contaminated with Lead and Copper.

Keywords: Irrigation water; chemical pollutants; soil pollution, life below water

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تقييم تلوث نوعية مياه نهر ديالى ببعض العناصر الثقيلة (PB، CU ، NI ،CD) والبورون وتأثيرها في تلوث التربة الزراعية

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المستخلص

اجريت دراسة لتقييم نوعية مياه نهر ديالى ببعض العناصر الثقيلة (Pb ، Cu ، Ni، Cd) والبورون واثر ذلك في تلوث التربة الزراعية المحيطة بالنهر والتي تروى بمياه النهر.اختيرت تسعة مناطق تقع على النهر ضمن ناحية الجسر التابعة لقضاء المدائن جنوب شرق محافظه بغداد/ العراق وهي ام العبيد والعويجة والخفاجي والكرغولية و جرف النداف والصمدية وابو ثيله والعريفية والتويثة وشواطئ سلمان باك الشمالية لغرض المقارنة. اخذت عينات المياه لثلاث اشهر خلال فصل الصيف (حزيران وتموز واب) وثلاثة اشهر خلال فصل الشتاء (كانون الثاني وشباط واذار) لعام 2024 واخذ معدل القيم للفصلين. جمعت عينات التربة من الترب الزراعية المحاذية لمجرى النهر في المناطق المذكورة اعلاه وبنفس الوقت الذي تم اخذ عينات المياه فيه. اشارت النتائج الى اختلاف الصفات الكيميائية للمياه والترب المدروسة خلال الموسمين اذ كانت اعلى القيم لكل من الإيصالية الكهربائية وتفاعل التربة والايونات الذائبة الموجبة والسالبة وايونات العناصر الثقيلة والبورون في الموسم الصيفي مقارنة بالموسم الشتوي في جميع المواقع وقد كانت اعلى القيم في منطقه التويثة. اما صنف المياه فقد كان الاخطر في منطقه التويثة C_3S_1 قليل الصودية عالي الملوحة حسب النظام USDA في حين كان تصنيفه مشكلة حادة وزيادة المشكلة للمنطقتين اعلاه بالتعاقب حسب نظام FAO، وقد تجاوزت تراكيز كل من الرصاص والكاديميوم والنيكل والنحاس الحدود المسموح بها لمياه الري في كلا الموسمين ولجميع المواقع ماعدا شواطئ سلمان باك الشمالية (المقارنة). جميع الترب الزراعية ملوثة بالكاديميوم وغير ملوثة بعنصري الرصاص والنحاس.

الكلمات المفتاحية: مياه الري, الملوثات الكيميائية, تلوث التربة. الحياة في الماء

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INTRODUCTION

Water is the main factor in sustaining life on surface of globe. It is also one of most important resorses that must be provided and preserved. Verma *et. al*, (39) indicated that freshwater is most important water for various human activities, including drinking and irrigation, as well as other ecosystem processes. Need of societies increases as their progress increases and at same time water pollution increases. This leads to endangerment of ecosystems (19). Quality of water used in irrigation plays an important role in influencing properties of soil and thus affecting growth of productivity of crops in terms of quantity and quality. Importance of studying quality of irrigation water lies in fact that it contains different concentrations of dissolved salts, regardless of its sources and various pollutants that cause many problems for irrigated agriculture as a result of accumulation of salts and pollutants in soil that comes from irrigation water, so knowing quality of water and degree of its contamination with different pollutants is very important to indicate suitability of this water for irrigation , as it is likely to cause toxicity to plants and agricultural crops when irrigation, in addition to its harmful effect on physical and chemical properties of agricultural soil (16,21). Most complex environmental problems and most difficult to solve is problem of pollution of river water with heavy metals resulting from dumping waste and factory waste in water and the use of agricultural pesticides and chemical fertilizers (2, 36, 37). Al-Mashri *et al*, and Arji'ah (6,10) showed temporal and spatial changes in physical and chemical factors of river water in Iraq, including Euphrates River, based on total pollution index. Musa (26) showed that liquid and solid waste products discharged to surface water of various types (sewage, industrial waste and agricultural pollutants) are the main cause of water pollution. Wang *et al*, (40) explained waste water and industrial water lead to a significant increase in most of determinants of environmental danger, due to low level of water in all rivers in Iraqi cities, which leads to an increase in concentration of environmental determinants. Salman and Hussain (33) indicated that most of rivers and streams in Diyala Governorate suffer from high rates of environmental pollution due to several factors, most notably negligence of citizens and violations of many service departments that dispose of their waste directly into the rivers. Chyad *et al,*; Milad *et.al,*;Hameed and Naser (13,17, 25) indicated that the cause of pollution of water resources with heavy metals is due to growth of various industries and industries and resulting chemical residues, toxins and environmentally hazardous waste, as well as great expansion in use of agricultural pesticides, Al-Mayah and Rabee (5) said that most of Iraq's rivers, including Gharraf River, are currently suffering from water scarcity and pollution problems, as is case with rest of rivers in Iraq. Khuwaidam (22) was shown that increase in concentration of some heavy metals in waters of Diyala River may be attributed to dumping of sewage and household waste directly into river. Naser and Saleh (28) explain that irrigation with polluted water of Diyala River has led to deterioration of agricultural soils scattered around it, which are irrigated with river water. Heavy metals are one of most dangerous pollutants to environment, and their danger increases when they remain or undergo any chemical changes and lead to contamination of plants, vegetables and fruits eaten by humans, which negatively affects his health (35). Abbas *et al*, (1) explained that highest concentration of lead and cadmium is found in gills and muscles of fish living in water polluted with heavy metals and accumulates in metabolic organs, including liver and kidneys, of humans when they feed on them. Saleh (32) explained that Heavy metals such as Lead, Cadmium and Nickel are among most dangerous pollutants for soil and water, and most important sources of this pollution are factory waste and waste, cars exhaust, fuel combustion, thus productivity of agricultural crops decreases as a result of poor soil quality. Research aims to assess quality of Diyala River water, to indicate its suitability for irrigation purposes and its contamination with some heavy metals (Pb, Cu, Ni, Cd) and Boron and its effect on pollution of agricultural soils adjacent to river which irrigated with its water.

MATERIALS AND METHODS

Study was conducted in Al-Jisr sub-district, which is one of sub-districts of Mada'in district, located in southeast of Baghdad / Iraq at confluence of Diyala River with Tigris River, 30 km away, while district is 10 km away from district Within latitudes 33°-00' to 33°-28' and length 44°-21' to 44°-43', it is surrounded by Diyala Governorate from north and northeast, Rusafa District - Baghdad from northwest and Wasit Governorate from south and southeast. sub-district includes nine provinces, which are shown in Figure 1, all of which are located on Diyala River, and they are:- Umm Al-Ubaid, Al-Awija, Al-Khafaji (planted with grains and vegetables), Al-Kargo Leh, Jurf Al-Naddaf, Al-Samadiah, Abu Thaila, Al-Arifiah and Al-Tuwaitha. Province of northern beaches of Salman Pak, which is located on Tigris River after its confluence with Diyala River, was taken for purpose of comparison (planted with vegetables, palm orchards and citrus trees). Total area on both sides of bridge is 157,323 km^2. Water samples were taken for three months during summer, which is June, July and August for year 2023, and for three months during winter, which are January, February and March for year 2024, average values were taken for summer and winter. Water samples were placed in plastic bottles made of polyethylene with a capacity of one liter, after washing them with distilled water and contaminating them with river water several times. Then they were filled with river water and drops of toluen material were added to them to prevent bacterial growth and kept in refrigerator until conducting required chemical analyses. Soil samples were collected from agricultural soils adjacent to river in above-mentioned provinces, which are irrigated with river water, and for same periods of time referred to above when taking water samples. Chemical properties of water and soil were estimated according to methods given in APHA; Black *et.al,*; Richards (10,13 , 31). Concentration of heavy metals in soil and water was measured in an atomic absorption spectrophotometry (AAS) according to methods mentioned in (10), as heavy metals were extracted from the soil using chelating compound (ATPA) (Diethylene Triamine Penta acetic Acid) according to method of Norvall and Lindsay (29). Plant samples were digested with a mixture of nitric and pyrochloric concentrated acids in a ratio of 1:2 according to Jones (20). Concentration of Boron was estimated by colorimetric method using Carcumin dye. River water was classified according to the system of the American Salinity Laboratory (23, 30). Some mathematical relationships were used to determine the dangers of each of the Sodium-Magnesium and salinity inherent in river water as follows:

1-Soluobile Sodium Percentage (SPP):

$$\mathbf{SSP\ (\%)= (Na^{+})/(Ca^{+2} + Mg^{+2} + Na^{+} + K^{+}) \times 100}$$

If SSP value exceeds 60%, water is considered unfit for irrigation (23)

2- Sodium adsorption ratio (SAR):

$$\mathbf{SAR = (Na^{+})/(Ca^{+2} + Mg^{+2}/2)\ \wedge^{0.5}}$$

Since:

Na: sodium concentration (meq L^{-1})

Ca + Mg : the concentration of Calcium and Magnesium (meq L^{-1})

3-Danger of Magnesium : determined according to following equation :-

$$\mathbf{Mg\ (\%) = (Mg^{+2})/(Ca^{+2} + Mg^{+2})}$$

If percentage exceeds 50%, then this water causes plant damage (23)

Latent salinity:

4-Calculated from following equation :-

Latent salinity (meq L^{-1}) = Chloride ion concentration + 1/2 Sulfate ion concentration.

If value of 5-20 water is suitable for soils with good permeability, and from 3 - 15, then water is suitable for soils with medium permeability, and from 3 - 7, water is suitable for soils with low permeability (15).

5-Total amount of dissolved solids (TDS) (mg L^{-1}).

$$\mathbf{TDS\ (mgL^{-1}) = 640 \times EC\ (dS.m^{-1}).}$$

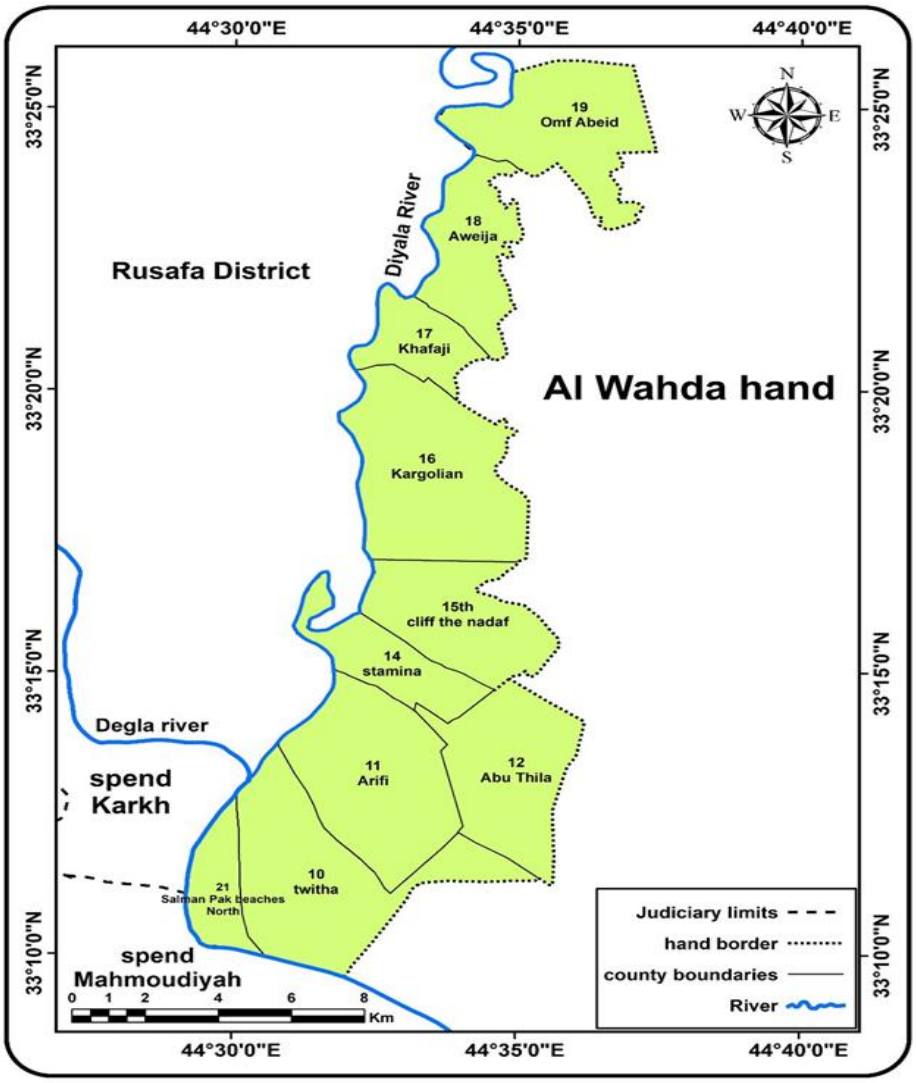

Figure 1. Map of study area (Scale: 1:10000000)

Source: Republic of Iraq,Ministry of water resources,Directorate of public survey.2020. Program outputs-Arc. Map 10.4.1

RESULTS AND DISCUSSION

Chemical properties of irrigation water

Results of Tables (1) and (2) indicate that there are differences in chemical properties of Diyala River water used in process of irrigating agricultural crops in different provinces for summer and winter , difference in electrical conductivity value is observed, it reached ahighest value in Al-Tuwaithah area 3.98 dS m^{-1}, while lowest values were in Umm Al-Obeid area, which amounted to 1.40 dS m^{-1}, which is higher than electrical conductivity value of comparison area (Salman Pak North beaches), which amounted to 1.12 dS m^{-1} for summer 2023. Thus, river water is of C4 class for regions Al-Khafaji, Al-Kargolia, Jurf Al-Naddaf, Al-Samdia, Al-Arifieh, Buthila and Al-Tuwaitha If they are 2.52, 2.88, 3.21, 3.69, 3.40, 3.80 and 3.98 dS m^{-1} respectively, they are prohibited, for agricultural use (4 , 11). It is noted that lower values of electrical conductivity of Diyala River water in studied areas for winter 2024 may be due to high temperatures in summer months, which leads to an increase in water evaporation and thus increases concentration of salts, so values rise compared to low temperature winter months, in addition to increase water dilution in winter due to rainfall, this is consistent with

Table 1. Average of some chemical characteristics of Diyala River water in summer 2023

Adjective	Unit	Northern beaches of Salman Pak	Al-Tuwaitha	Abu Thila	Al-Arifiah	Al-Samadiah	Jurf Al-Naddaf	Al-Kargoulia	Al-Khafaji	Al-Awija	Umm Al-Ubaid
EC	dSm^{-1}	1.12	3.98	3.80	3.40	3.69	3.21	2.88	2.52	2.10	1.40
pH	----	7.55	7.52	7.77	7.63	7.47	7.35	7.40	7.65	7.38	7.75
Ca		4.90	15.90	14.90	13.80	14.49	13.90	11.50	10.30	9.70	6.90
Mg		2.70	12.50	11.90	10.10	11.60	10.80	9.80	8.60	6.30	3.50
Na		2.80	9.60	9.00	8.90	8.60	7.00	6.30	5.40	4.70	2.50
K	$meql^{-1}$	0.18	1.90	1.60	1.20	1.38	1.25	1.14	1.01	0.89	0.52
Cl		8.20	38.83	31.50	25.81	28.17	24.90	21.56	19.21	16.82	10.50
HCO_3		1.20	2.90	2.80	2.70	2.30	2.10	1.80	1.70	1.50	1.30
CO_3		Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
SO_4		1.03	4.47	4.37	3.62	4.18	3.70	3.10	2.92	2.87	1.60
TDS	mgl^{-1}	716.80	1547.20	2432.00	2176.00	2361.10	2054.40	1843.20	1612.80	1344.00	896
NO_3	mgl^{-1}	0.82	2.51	2.31	2.08	1.87	1.56	1.33	1.18	0.98	0.60
Boron	mgl^{-1}	0.18	1.20	0.92	0.84	0.77	0.69	0.58	0.47	0.39	0.31
SSP	%	25.73	24.36	23.87	26.17	25.24	21.24	21.92	21.33	21.76	18.62
SAR		1.01	2.55	2.45	1.82	1.68	1.41	1.36	1.24	1.17	0.77
Mg Danger	%	35.52	44.01	44.40	42.25	44.46	43.72	46.00	45.50	39.37	33.65
Latent salinity	$meql^{-1}$	8.71	41.06	33.68	25.81	30.26	26.75	23.31	20.67	18.25	11.30
Water type USDA		C_2S_1	C_3S_1	C_3S_1	C_3S_1	C_3S_1	C_3S_1	C_3S_1	C_3S_1	C_2S_1	C_2S_1
Water type FAO		increase problem	severe problem	severe problem	severe problem	severe problem	severe problem	increase problem	increase problem	increase problem	increase problem

what was shown by Al-Mayah and Rabee; (5), who explained that temperatures are low in early morning, then rise in middle of day in summer and decrease in winter, thus, waters of Diyala River are classified in areas of Jurf Al-Naddaf, Samadiya, Al-Arifieh and Abu Theila it is prohibited to use for irrigation purposes, as electrical conductivity values are 2.40, 2.93, 3.11 and 3.32 dS m^{-1}, as it reached highest value At Al-Tuwaithah area 3.42 dS m^{-1} , lowest value in Umm al-Ubaid area is 1.10 dS m^{-1}, which is higher than that in northern Salman Pak beaches area, which was 1.03 dS m^{-1}, this may be due to dilution of concentrations of salts in waters of Diyala River at its confluence with Tigris River, which has a lower concentration of salts. pH values of water ranged between lowest value in Jurf Al-Naddaf area, which amounted to 7.35 and highest value in Abu Theila area, which amounted to 7.77, while in beaches area Salman Pak it was 7.55 for summer, all of which are considered neutral, and it rose slightly in winter, ranging from 7.37 at Al-Arifiah to 7.85 At Abu Thila area, while it was 7.60 at northern beaches of Salman Pak, all of them are neutral, slightly slanted to basal, and all are considered within permissible levels in systems for classifying water for agricultural purposes (31). Total dissolved solids, ranged from 886 mg L^{-1} in Umm Al-Ubaid area to 2547.2 mg L^{-1} at Al-Tuwaitha area, while it was 716.8 mg L^{-1} at northern beaches of Salman Pak for summer, and ranged between 704 mg L^{-1} at Umm Al-Obeid area reached 2188.8 mg L^{-1} in Al-Tuwaitha area, while it reached 659.2 mg L^{-1} at northern beaches of Salman Pak, values of winter have decreased compared to summer. It is noted that most of values are relatively high, natural sources of dissolved solids in water come from dredging of rainwater, torrents and human, agricultural and industrial waste, as water is a good solvent for salts (38). Concentrations of dissolved ions in river water changed between summer and winter. Concentrations of dissolved Calcium ranged from 6.9 meq L^{-1} in Umm Al-Ubaid area to 15.9 meq L^{-1} at Al-Tuwaitha area, while it was 4.9 meq L^{-1} in northern beaches of Salman Pak in summer and slightly decreased in winter as a result of dilution with rain water,

Table 2. Average of some chemical characteristics of Diyala River water in winter 2024

Adjective	Unit	Northern beaches of Salman Pak	Al-Tuwaitha	Abu Thila	Al-Arifiah	Al-Samadiah	Jurf Al-Naddaf	Al-Kargoulia	Al-Khafaji	Al-Awija	Umm Al-Ubaid
EC	dSm^{-1}	1.03	3.42	3.32	3.11	2.93	2.40	2.16	2.10	1.88	1.10
pH	----	7.60	7.52	7.85	7.37	7.47	7.40	7.45	7.63	7.52	7.48
Ca		4.00	14.70	14.50	12.40	12.20	8.80	8.70	8.90	8.20	4.80
Mg		2.50	10.20	10.00	8.80	9.80	8.90	5.80	7.30	5.40	2.80
Na		2.40	7.80	7.10	7.90	6.00	6.70	5.30	4.10	4.40	2.01
K	$meql^{-1}$	0.40	1.40	1.20	1.10	1.30	1.10	1.00	0.90	0.50	0.26
Cl		2.10	26.91	25.91	23.70	22.37	19.13	16.92	17.71	14.60	8.25
HCO_3		7.90	2.60	2.50	2.40	2.00	1.80	1.70	1.40	1.20	1.10
CO_3		Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
SO_4		1.00	3.50	3.36	3.12	3.91	2.50	2.22	2.31	2.10	1.32
TDS	mgl^{-1}	659.20	2188.80	2124.80	1990.40	1875.20	1536.00	1382.40	1344.00	1203.2	7.04
NO_3	mgl^{-1}	0.43	2.00	1.86	1.89	1.62	1.42	1.26	1.10	0.90	0.52
Boron	mgl^{-1}	0.11	0.78	0.63	0.55	0.50	0.46	0.42	0.34	0.27	0.20
SSP	%	25.80	22.87	22.27	26.15	20.47	26.27	25.24	19.34	23.78	20.78
SAR		0.94	2.21	2.02	1.71	1.28	1.59	1.38	1.02	1.19	0.73
Mg Danger	%	38.46	40.96	40.80	41.50	44.54	50.28	39.45	45.06	39.70	37.83
Latent salinity	$meql^{-1}$	2.30	28.66	27.59	25.26	24. 32	20.38	18.03	18.86	15.65	8.58
Water type USDA		C_2S_1	C_2S_1	C_3S_1	C_3S_1	C_3S_1	C_3S_1	C_2S_1	C_2S_1	C_2S_1	C_2S_1
Water type FAO		increase problem	severe problem	severe problem	severe problem	increase problem	increase problem	increase problem	increase problem	increase problem	increase problem

Lower temperatures and less evaporation, it ranged from 4.8 $meqL^{-1}$ at Umm al-Ubaid to 14.7 $meqL^{-1}$ at Tuwaitah Umm Al-Ubaid. Salman Pak North for the summer and decreased slightly in winter as a result of mitigation with rain water. The decrease in temperatures and decrease in evaporation ranged from 4.8 meq L^{-1} at Umm al-Ubaid to 14.7 meq L^{-1} at Tuwaitah, while it was 4.0 at northern beaches of Salman Pak. It is noted that all values exceed permissible limits for irrigation water according to standard set by Rhoades *et.al*, (31). Concentrations of dissolved Potassium were few, ranging between 0.52-1.50 meq L^{-1} in summer and from 0.26-1.4 meq L^{-1} in winter, this is consistent with findings of Al-Nour *et.al*, (7), who showed that Potassium concentrations in Diyala River water ranged between 1.6-12.6 mgL^{-1}. values of Sodium adsorption ratio (SAR) and e percentage of Sodium (SSP) were below critical limit of 60% (23), therefore, there is no danger from Sodium when irrigating with river water in summer and winter for all regions, as it is classified according to American salinity laboratory system of type S1 (30). Results of a water analysis for two seasons also indicate that there is no danger to this water due to its content of Magnesium ions in not exceeding 50% (23) for all regions, except for Jurf Al-Naddaf area in winter, which amounted to 50.28%, this area is dangerous if used for irrigation. Results of latent salinity of summer, it is clear that this water in all regions is not suitable for irrigation because it exceeds limits allowed by Don (14) except areas of Umm Al-Obeid and Al-Awija, where it reached in the first 11.30 $meqL^{-1}$, it is valid in soils with medium permeability, and in second it is 18.25 $meqL^{-1}$, and it is valid in soils with good permeability, while in winter, it was valid for irrigation in soils with medium permeability in Umm al-Ubaid region, where the value reached 8.58 $meql^{-1}$, while it was valid for irrigation in soils with good permeability in Uwaija region, which amounted to 15.65 $meqL^{-1}$, it is considered unfit for irrigation in

all other areas because it exceeds the permissible limits (14). Sulfate values ranged in summer between 1.60 - 4.47 $meqL^{-1}$ to 1.32 - 3.91 $meqL^{-1}$ in winter, so that all performances for both seasons are within permissible limits for irrigation water amount 4.5 mmol L^{-1}(11) , this is consistent with what was explained by Salwan *et.al*, (34), who showed that concentration of Sulfates in waters of Tigris River ranged between 65 - 314 mg L^{-1}. Chlorides concentrations exceeded permissible limits according to standard of Ayers and Westcot (11), which are 4 $meqL^{-1}$, it ranged between 10.5 - 30.50 $meqL^{-1}$ in summer to 8.25 - 23.70 $meqL^{-1}$ in winter, thus they are not allowed for irrigation purposes, as they cause major problems for soil and plants. Increase in Chloride concentrations in river water may be due to increase in release of water used in human activities for washing, cleaning and other sterilization materials, which contain a high content of Chloride, such as cleaning powders, into river, this is consistent with findings of Salwan *et.al*, (34), who showed an increase in Chloride concentration in Tigris River water as a result of dumping of human activities into river. Nitrate concentrations were low in both seasons and did not exceed permissible limits of Food and Agriculture Organization (15) of 50 mg L^{-1}. It is noticed from tables 1 and 2 that the order of dominance of cations as follows: Calcium > Magnesium > Sodium > Potassium in waters of Diyala River in summer and winter, while the order of anaions was Chloride > Sulfate > Bicarbonate > Nitrates in summer and winter. It was noted that there were clear differences in Boron concentration in river water for different locations and in two seasons, Its ranged between 0.31 at Umm Al-Ubaid to 12 mg L^{-1} in summer and slightly decreased in winter, ranged between 0.2 mg L^{-1} at Umm Al-Ubaid - 0.78 mg L^{-1} at Al-Tawatheh, while it was 0.18-0.11 mg L^{-1} at northern beaches of Salman Pak in two seasons, respectively. increase in Boron concentration at Al-Tuwaitha site may be due to discharge of heavy water from official heavy water treatment plant into river on both sides of river, which may contain high concentrations of Boron, resulting from adding different Boron fertilizers to soil, these results are consistent with Chyad *et al*, (13) who indicated, that the disposal of sewage water to river course leads to an increase in concentration of dissolved and suspended solids in water Increase in dissolved cations and anions concentrations negative and electrical conductivity in Al-Tuwaithah area is consistent with what was found by Hussein (19). When classification water according to American Salinity Laboratory system, water falls within category C_2S_1 of medium salinity with little Sodium at sites Umm Al-Ubaid, Al-Awija and northern beaches of Salman Pak, while all other sites fall within category C_3S_1, which means high salinity with low sodium, which leads to an increase in soil salinity when irrigated in summer, while water was in category C_3S_1 in Jurf Al-Naddaf, Al-Samdiyah, Al-Arifieh, and Abu Theila sites, while water classification according to Don (14), is second category, an increase in the problem in Umm Al-Ubaid, Al-Awija, Al-Khafaji, Al-Kargoli and northern beaches of Salman Pak, while all other sites fall within third row, a severe problem in summer ,but in winter, sites of Um Al-Obaid Al-Awija Al-Khafaji, Al-Kargouli, Jurf Al-Samadiah and north beaches of Salman, fall into second category, adding to problem, while all other sites fall into third row with severe problems.

Heavy metals concentration

Results of Tables (3 and 4) show that there are differences in concentrations of heavy metals ions dissolved in water in summer and winter. Lead values ranged from 5.06 mg L^{-1} at Umm Al-Ubaid to 9.86 mg L^{-1} at Al-Tawetah, which is very high compared to northern beaches of Salman Pak in summer. All values exceeded permissible limits according to World Health Organization (41), which amounted 0.5 mg L^{-1}, so that daytime water would be contaminated with Lead in all areas. In winter, all areas are contaminated with Lead, except Umm Al-Ubaid and Al-Awija, where concentrations reached 3.83 and 4.51 mg L^{-1}, respectively, according to classification of WHO (41), while all sites are contaminated with Lead according to Iraqi specifications, whose values ranged between 3.83 - 8.57 mg L^{-1}, these results are consistent with findings of (8), which showed that Lead concentrations in Tigris water were 0.36 mg L^{-1}. Decrease in

lead concentration in winter season is due to rise in water levels due to rain in rivers, which leads to an increase in dilution of heavy metals concentrations (8, 24). All sites contaminated with Cadmium because they exceeded permissible limits of WHO (40) of 0.01 mg L^{-1} and the Iraqi specifications of 0.1 mg L^{-1} and for the summer and winter season, as cadmium concentrations in the summer season ranged between 0.019-3.17 mg $L^{-1}$and between 0.04 - 1.7 mg L^{-1} in winter, this is consistent with what was indicated by Al-Anbary and Al- Mandalawi (3), who showed that Cadmium concentrations amounted to 0.021 mgL^{-1} in Tigris River water at borders of city of Baghdad

Table 3. Concentrations of some heavy metals in Diyala River water in summer 2023

Heavy metals	Unit	Northern beaches of Salman Pak	Al-Tuwaitha	Abu Thila	Al-Arifiah	Al-Samadiah	Jurf Al-Naddaf	Al-Kargouliya	Al-Khafaji	Al-Awija	Umm Al-Ubaid
Pb	mgl^{-1}	1.98	9.86	9.31	8.77	8.05	7.58	7.13	5.93	5.59	5.06
Cd		0.05	3.17	2.50	1.20	0.96	0.75	0.36	0.27	0.02	0.12
Ni		0.08	1.92	1.38	1.26	1.01	0.94	0.80	0.38	0.46	0.27
Cu		0.18	1.03	0.81	0.72	0.65	0.56	0.43	0.35	0.29	0.22

Table 4. Concentrations of some heavy metals in Diyala River water in winter 2024

Heavy metals	Unit	Northern beaches of Salman Pak	Al-Tuwaitha	Abu Thila	Al-Arifiah	Al-Samadiah	Jurf Al-Naddaf	Al-Kargouliya	Al-Khafaji	Al-Awija	Umm Al-Ubaid
Pb	mgl^{-1}	1.23	8.57	8.13	7.67	6.86	6.01	5.51	5.11	4.51	3.83
Cd		0.001	1.70	1.10	0.20	0.19	0.52	0.04	0.08	0.19	0.08
Ni		0.03	1.16	0.98	0.85	0.78	0.26	0.53	0.36	0.22	0.15
Cu		0.09	0.73	0.59	0.47	0.33	0.28	0.23	0.19	0.17	0.14

Nickel concentrations in summer ranged between 0.27-1.92 mg L^{-1} , thus all areas are considered contaminated with Nickel according to specifications of WHO (41) because they exceeded permissible limits of 0.2 mg L^{-1}, In winter concentrations ranged between 0.15-1.16 mg L^{-1} , Thus, all areas are contaminated with Nickel except Umm Al-Ubaid area, where concentration was 0.15 mg L^{-1} compared to Nickel concentrations in northern beaches of Salman Pak unpolluted, where the concentrations were 0.08 and 0.03 mg L^{-1} in summer and winter, respectively. All water and all regions are considered contaminated with Copper in two seasons because it exceeded permissible limits of (41) of 0.2, concentrations in summer ranged between 0.22 - 1.03 mg L^{-1} and 0.14 – 0.73 mg L^{-1} in winter it is high compared to copper concentrations in northern beaches of Salman Pak, which amounted to 0.18 and 0.09 mg L^{-1} in summer and winter respectively, these results are consistent with what was shown by Khuwaidam; Milad *et al,* (22, 25) who showed that an increase in concentrations of some heavy metals in Diyala River water can come from sewage disposal and household waste throwing directly into river. Hashim (18) indicated that waters of Diyala River have been greatly affected by the discharges of Rustumiyah stations into river, which negatively affects aquatic life on one hand and agricultural lands on both sides of river on other hand, as river water is used for irrigation.

Chemical characteristics of study soil

Results of Tables (5 and 6) show average of some physical and chemical properties of study soil adjacent to Diyala River, whose plants are irrigated with river water It is noted that electrical conductivity values of soil were high and ranged between 2.36-4.90 dSm^{-1} compared to northern beaches of Salman Pak which amounted to 1.92 dSm^{-1} in summer, this is consistent with high electrical conductivity value of Diyala River water in study area compared by comparison (Table 1), values decreased relatively in winter, as it ranged between 2.0 - 4.21 dSm^{-1} in study soil, while it reached 1.60 dSm^{-1} in soil of northern beaches of Salman Pak, this decrease may be due to decrease in amount of evaporation from water due to low temperatures in winter and lack of rain as well, which reduce concentration of salts in river water (24). Soil reaction (pH) values of soil were neutral inclined to basic in summer and winter, it ranged between 7.46 -

7.70 and 7.47 - 7.79 for two seasons, respectively. Irrigation water led to changes in concentration of dissolved ions in studied soil, this is consistent with what Al-Hadidi (4) indicated, which showed an increase in concentration of dissolved ions in soil as a result of irrigation with saline water, Calcium concentrations ranged between 10.6-19.7 meq L^{-1} compared with soil of northern Salman Pak beaches, which was 9.8 meq l^{-1} in summer and decreased in winter to 9.8-16.8 meqL^{-1} compared to control soil, which was 8.9 meq L^{-1} . Magnesium concentrations in summer ranged between 8.0-16.5 meq L^{-1}, compared to control soil, which was 6.8 meq L^{-1}, it decreased in winter season reached 6.5-14.5 meq L^{-1}, while in control soil was 4.3 meq L^{-1}. The same is true for Sodium and Potassium ions, they reached in summer 12.00 - 1.70 meq L^{-1} respectively, but in winter, highest values were 10.3 and 1.3 meq L^{-1}, respectively, in area of Tuwaitha, while it was 2.40 - 0.51 meq L^{-1} for comparison soil in winter, Na and K ions decreased to 2.2 and 0.40 meq L^{-1} for two ions, respectively.

Table 5. Average of some physical and chemical characteristics of study soil in summer 2023

Adjective	Unit	Northern beaches of Salman Pak	Al-Tuwaitha	Abu Thila	Al-Arifiah	Al-Samadiah	Jurf Al-Naddaf	Al-Kargouliya	Al-Khafaji	Al-Awija	Umm Al-Ubaid
EC	dSm^{-1}	1.92	4.90	4.72	4.62	4.11	4.05	3.76	3.11	2.75	2.36
pH	----	7.33	7.33	7.40	7.66	7.69	7.70	7.52	7.62	7.50	7.46
Ca	meq L^{-1}	9.80	19.70	18.30	18.32	16.00	15.30	14.00	12.10	11.90	10.6
Mg		6.80	16.50	16.30	15.60	14.00	13.70	12.60	11.10	9.80	8.00
Na		2.40	12.00	10.20	11.90	10.20	10.10	9.20	7.20	5.10	4.20
K		0.51	1.70	1.30	1.00	1.40	1.20	0.98	0.81	0.93	0.91
Cl		17.00	36.50	35.80	33.60	31.80	31.70	29.00	26.70	20.10	17.20
HCO_3		1.90	2.98	3.90	3.60	3.10	3.00	2.90	2.70	3.80	3.70
SO_4		1.30	9.00	8.80	8.90	1.10	6.10	5.10	3.80	3.60	2.80
Bulk density	$gm\ cm^{-3}$	1.64	1.66	1.62	1.56	1.49	1.63	1.59	1.60	1.60	1.34
Organic Matters	$g\ kg^{-1}$	0.85	0.80	0.60	0.46	0.60	0.59	0.73	0.80	0.75	0.90
Carbonate Minerals	$g\ kg^{-1}$	24.30	28.80	26.60	28.30	27.10	24.20	25.90	23.70	24.70	23.60
Boron	$mg\ kg^{-1}$	5.15	27.30	26.10	24.60	20.10	17.30	14.60	12.10	9.30	7.20
CEC	C.mole+ kg^{-1}	20.10	19.67	18.00	14.20	18.00	18.20	17.90	14.90	22.90	21.20
Sand	%	30.00	18.00	18.00	19.00	21.00	16.10	24.00	17.10	16.30	22.60
Silt		43.10	41.00	41.00	52.20	54.80	41.30	44.50	40.30	49.10	39.20
Clay		27.0	41.00	41.00	19.00	24.20	42.60	31.50	42.60	34.60	38.20
Texture		CL	SiC	SiC	SiCL	SiL	SiC	CL	SiC	SiCL	CL

Increasing of dissolved cations in soil was as follows: Calcium > Magnesium > Sodium > Potassium, this is consistent with dominance of these ions in the irrigation water (Table 1). For Anions, highest values of Chloride, Sulfate and Bicarbonate were reached in Al-Tuwaitha region, 36.50, 9.00 and 2.98 meq L^{-1} in succession in summer, and decreased in winter to 32.11, 7.3 and 2.90 meq L^{-1} for ions successively. Increase in dissolvedcatons and anions concentration in Al-Tuwaitha area may be attributed to increase in their concentrations in irrigation water due to what is thrown from river stream of sewage. loaded with dissolved materials and completely untreated salts from Al-Rustumiya heavy water station , this is consistent with Hashim (18) which showed that waters of Diyala River are greatly affected by discharges of Rustumiyah stations into river, which negatively affects aquatic life on one hand and agricultural lands on both sides of river on other hand, as river water is used for irrigation. Carbonate minerals quantity increased in summer compared to winter, its ranged between 23.6 - 28.8% in summer and decreased in winter to 21.5 - 28.1%, quantity increasing of quantity in summer may be attributed to increase in temperatures and evaporation of ground water that rises by capillary property to surface and is loaded with

Bicarbonate and Carbonate ions, which leads to an increase in its deposition in soil. Concentrations of Boron in soils differed between summer and winter, highest values were in summer, ranging between 7.2-27.3 mg kg^{-1}, compared to control soil, which amounted to 5.15 mg kg^{-1} and in winter ranged between 5.66 - 17.7 mg kg^{-1}, while in comparison soil was 3.77 mg kg^{-1}. All soils were contaminated with Boron in two seasons for exceeding permissible limits by WHO (41), which may be due to different releases of water and pollutants thrown into river.

Table 6. Average of some physical and chemical characteristics of study soil in winter 2024

Adjective	Unit	Northern beaches of Salman Pak	Al-Tuwaitha	Abu Thila	Al-Arifiah	Al-Samadiah	Jurf Al-Naddaf	Al-Kargouliya	Al-Khafaji	Al-Awija	Umm Al-Ubaid
EC	dSm^{-1}	1.60	4.21	3.73	4.03	3.77	3.46	3.10	2.70	2.25	2.00
pH	----	7.50	7.73	7.65	7.78	7.79	7.76	7.62	7.73	7.47	7.56
Ca		8.90	16.80	15.00	16.10	15.00	14.10	13.17	11.90	10.60	9.80
Mg		4.30	14.60	13.10	14.00	12.70	11.40	10.10	9.00	8.11	6.50
Na		2.20	10.30	8.10	10.00	9.10	8.31	7.20	6.00	3.10	2.80
K		0.40	1.30	1.00	0.80	1.00	1.90	0.81	0.60	0.73	0.50
Cl	$meql^{-1}$	14.30	32.11	29.00	29.80	25.50	27.90	26.10	22.50	17.30	16.10
HCO_3		0.67	2.90	1.80	2.80	2.60	2.80	2.30	2.00	3.00	1.90
SO_4		1.10	7.30	6.30	7.60	6.00	3.20	2.90	2.90	2.40	2.00
Bulk density	$gmcm^{-3}$	1.62	1.69	1.63	1.55	1.47	1.68	1.58	1.56	1.52	1.54
Organic Matters	%	0.92	0.87	0.62	0.49	0.66	0.62	0.68	0.87	0.82	1.01
Carbonate Minerals	gkg^{-1}	23.80	28.10	25.50	27.10	26.10	23.10	25.40	23.10	22.00	21.50
Boron	$mgkg^{-1}$	3.77	17.70	16.40	14.80	13.10	10.50	9.60	7.30	6.11	5.66
CEC	C.mole+ kg^{-1}	18.00	17.67	16.50	13.70	17.10	11.80	11.50	14.10	14.20	11.20
Sand		30.00	18.00	18.00	19.00	21.00	16.10	24.00	17.10	16.30	22.60
Silt	%	43.10	41.00	41.00	52.20	54.80	41.30	44.50	40.30	49.10	39.20
Clay		27.00	41.00	41.00	19.00	24.20	42.60	31.50	42.60	34.60	38.20
Texture		SiC	SiCL	SiL	SiC	CL	SiC	SiCL	CL		

Heavy metals in soil

Results of tables (7 and 8) show variation in concentrations of total heavy metals between study soil in summer and winter. Concentrations of Lead in summer ranged from 105.2 in Umm Al-Ubaid region to 225 mg kg^{-1} in Al-Tuwaitha compared to control soil, which amounted to 68.2 mg kg^{-1} In winter, it decreased slightly as a result of decrease in Lead concentrations in river water in winter (Table 2), it ranged from 62.2 in Umm Al-Ubaid area to 209.0 mg kg^{-1} in Al-Tuwaitha, which is high compared to control soil, which amounted to 51.0 mg kg^{-1}. All soils for both seasons are considered not contaminated with Lead, because they did not exceed permissible limits of WHO (42), which are from 50 to 300 mg kg^{-1}

Table 7. Average total concentrations of heavy metals (mg kg^{-1}) in study soils in summer 2023

Heavy metals	Unit	Northern beaches of Salman Pak	Al-Tuwaitha	Abu Thila	Al-Arifiah	Al-Samadiah	Jurf Al-Naddaf	Al-Kargouliya	Al-Khafaji	Al-Awija	Umm Al-Ubaid
Pb		68.2	225.0	223.0	218.0	196.0	169.0	142.0	121.0	112.1	105.2
Cd	$mgkg^{-1}$	2.1	30.6	29.0	25.3	21.0	18.8	12.5	9.04	6.59	5.52
Ni		58.6	145.0	139.0	136.0	122.0	116.0	103.1	91.2	83.1	78.7
Cu		9.0	55.0	52.3	46.8	40.2	33.7	24.6	17.2	14.2	11.3

Table 8. Average total concentrations of heavy metals in study soils in winter 2024

Heavy metals	Unit	Northern beaches of Salman Pak	Al-Tuwaitha	Abu Thila	Al-Arifiah	Al-Samadiah	Jurf Al-Naddaf	Al-Kargouliya	Al-Khafaji	Al-Awija	Umm Al-Ubaid
Pb	mgkg^{-1}	51.00	209.00	200.00	189.00	169.00	138.00	116.00	98.60	75.20	62.20
Cd		1.80	19.30	10.30	3.70	15.20	10.10	7.71	4.21	3.90	3.54
Ni		30.20	115.00	109.20	95.70	90.10	88.10	72.10	67.80	54.30	41.60
Cu		4.63	50.10	47.60	40.10	35.00	28.10	19.10	12.70	9.33	6.63

Cadmium concentrations ranged from 5.52 in Umm al-Ubaid to 3.06 mg kg^{-1} in Tuwaitha in summer, which is high compared to control soil, which amounted to 2.10 mg kg^{-1}, concentrations decreased relatively in winter, ranging from 3.54 in Umm al-Ubaid to 1.93 mg kg^{-1} in Tuwaitha, compared with control soil, which was 1.8 mg kg^{-1}. All soils are contaminated with Cadmium because they exceed permissible limits in WHO (42), which are 1-3 mg kg^{-1}. Nickel concentrations ranged from 78.7 in Umm al-Ubaid to 145.0 mg kg^{-1} in al-Tuwaitha, which is relatively high compared to control soil, which reached 58.6 in summer, while concentrations decreased slightly in winter ranged from 41.6 in Umm al-Ubaid to 115.0 mg kg^{-1} in Tuwaitha compared to control soil, which amounted to 30.2 mg kg^{-1} all areas are contaminated with Nickel in summer,according to WHO(42) of 30-75 mg kg^{-1},while areas of Jurf Al-Naddaf, Samadiya, Al-Arifiya, Abu Thaila and Al-Tuwaitha are considered to be contaminated with Nickel only in winter, as they exceed internationally permissible limits,these results are consistent with Naik (27), which showed that most important sources of soil pollution with heavy metals are industrial sources and various activities of man. These results are consistent with what Hashim (18) showed, who explained that waters of Diyala River were greatly affected by discharges of Rustumiyah stations into river, which negatively affects aquatic life on one hand and agricultural lands on both sides of river on other hand, as river water is used for irrigation. Copper concentrations in summer ranged between 11.3 in Umm al-Ubaid to 55.0 mg kg^{-1} in al-Tuwaitha, which is relatively high compared to control soil, which amounted to 9.01 mg kg^{-1}, while concentrations slightly decreased in winter to range between 6.63 mg kg^{-1} in Umm al-Obeid to 50.1 mg kg^{-1} in Tuwaitha, it is also high compared to control soil which was 4.63 mg kg^{-1}. When comparing these concentrations with permissible limits of WHO(42) of 50-140 mg kg^{-1}, all studied soils are not contaminated with Copper for both seasons.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DECLARATION OF FUND

The authors declare that they have not received a fund.

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