Research Article

Study of the Physicochemical Behaviour of Zinc in some Soils North of Dhi Qar Governorate/ Southern Iraq

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A laboratory experiment was conducted on eight soil samples collected from areas north of Dhi Qar province with chemical and physical properties for the purpose of studying the mechanism of zinc adsorption in these soils. Zinc ions were added at levels (0, 5, 10, 15, 20 and 25) mg L^{-1} prepared from zinc sulphate $ZnSO_4$ in a volume of 25 ml containing 0.01 *M* $CaCl_2$ and 0.01 *M* NaCl at temperatures of 298 and 318 K. The concepts of equilibrium and thermal isotropy of the ion exchange equations (Langmuir equation, Freundlich equation and Temkin equation) were tested in their linear form for thermal isotropic equilibrium as well as the thermodynamic concepts which included (ΔG°), (ΔH°), (ΔS°) and (K_T°). The results of the study showed that the ion exchange equations were successful in describing the adsorption of zinc and took the sequence according to the value of the coefficient of determination (R^2) Langmuir equation > Freundlich equation > Temkin. The results of the study indicated that all values of ΔG° were negative and that the reaction of zinc in these soils was spontaneous in nature and the spontaneousness of the reaction increased with increasing temperature. The values of ΔH° were positive and the reaction was endothermic in nature. The positive value of entropy ΔS° indicates an increase in the randomness state and reflects the affinity of the surface to adsorption of zinc ions. The results also showed that the amount of adsorbed zinc increased under the conditions of 0.01 *M* $CaCl_2$ salt compared to 0.01 *M* NaCl Salt.

Received | March 03 2025; **Accepted** | July 02, 2025; **Published** | February 23, 2026
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Citation | Fakhir, S., R. Bedeeh A. Kazim, H. Chlaib, J. Ali and H.R. Zachi. 2026. Study of the physicochemical behaviour of zinc in some soils north of dhi qar Governorate/ Southern Iraq. *Pakistan Journal of Agricultural Research*, 39(1): 20-28.
DOI | https://dx.doi.org/10.17582/j.pjar/2026/39.1.20.28
Keywords | Zink adsorption, ΔG°, Randomness, Endothermic, Langmuir equation

Introduction

Soil pollution with heavy elements is one of the forms of environmental pollution resulting from natural and human activities such as the use of pesticides, chemical fertilizers, animal waste, factory waste and untreated sewage, which play a major role in environmental pollution due to the various pollutants they release such as heavy elements, including zinc (Al-Asadi *et al.*, 2011). In recent years, environmental specialists have been interested in studying heavy elements in terms of their presence and impact on human health, as heavy elements represent a serious environmental and health threat when they reach toxicity levels (Mansour, 2014; Liu, *et al.*, 2014). Soil physical and chemical properties such as soil pH, soil texture, organic matter and calcium carbonate affect the availability of heavy elements, as calcium carbonate is characterized by its high ability to adsorb and precipitate heavy elements, including zinc, thus reducing their availability for plants (Al-Mamooree, 2012: Alwan *et al*., 2025; Talib *et al*., 2025). Adsorption is one of the most important chemical processes that occur in the soil and affect the movement of nutrients and pollutants in the soil, as well as affect the electrostatic properties (Sparks, 2003). There are three types of adsorptions including including chemical, physical, and reciprocal adsorption. Physical adsorption is a non-specific adsorption that works due to weak attractive forces between molecules. Physical adsorption is completely reversible, while chemical adsorption results from the association of forces equal to those resulting from the formation of chemical compounds. The adsorption capacity is in the form of a single layer on the surface with a thickness of one molecule. These molecules are not free to move on the surface, chemical adsorption is rarely reversible (Chen *et al*., 2001). In order to know the soil's ability to adsorption, some adsorption equations were used: Langmuir equation, Freundlich equation, and Temkin equation

Thermodynamics is one of the important branches of chemistry, through which the possibility of a chemical reaction can be studied. By applying thermodynamic indicators (standard free energy of reaction (ΔG°), thermodynamic equilibrium constant (K_T°), reaction enthalpy (ΔH°), and reaction randomness (ΔS° Entropy), the final state of the element in the soil can be predicted through the initial state before equilibrium (Sposito, 1984). The values of ΔG° can be used to infer the spontaneity of the reaction in the soil, and through the values of ΔH°, it is possible to know whether the reaction is endothermic or exothermic. The values of ΔS° also indicate the extent of the randomness of the chemical reaction and its level of regularity (Al-Zubaidi, 2020). Due to the lack of available studies on the reactions of zinc in soil and the use of adsorption terms and thermodynamic indicators for the soils of northern Dhi Qar Governorate, this study came to know the effect of the properties of the studied soils on the adsorption of zinc and to reveal the nature of the reaction of zinc in the soil.

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Materials and Methods

Soil samples with different characteristics were collected from eight sites in Dhi Qar Governorate/ southern Iraq, from the surface soil layer (0-30 cm). The soil samples were air-dried, ground, and sieved, and some chemical and physical properties were determined Table 1 according to the measurement methods described in Page *et al*. (1982) and Black (1965).

To determine the ability of soil to adsorption of zinc (Zn), an adsorption experiment was carried out by taking 1 g of the study soil and placing it in a 50 ml plastic tube. A series of zinc concentrations (0, 5, 10, 15, 20 and 25) mg L^{-1} were added to each soil sample, prepared from zinc sulphate ($ZnSO_4$) in a volume of 25 ml, which contains 0.01 *M* $CaCl_2$ and 0.01 *M* NaCl. They were added to the tubes individually as electrolyte solutions. The tubes were closed and the solutions were shaken for half an hour, then left for 24 hours to reach a state of calm equilibrium at a temperature of 25 ± 1 °C and 45 ± 1 °C. The solutions were separated using a centrifuge at 3000 rpm^{-1} for 10 minutes, filtered, and the dissolved zinc concentration in the filtrate was determined using Atomic Absorption Spectrophotometer (AAS). The adsorbed amount of zinc was calculated using the following equation:

$$X = (C_o - C)V / W$$

Where:

Table 1: *Some primary characteristics of the study soils*

Soil No.	Location	EC1:1 dS.m^{-1}	pH 1:1	CEC Cmol Kg^{-1}	O.M gm Kg^{-1}	$CaCO_3$	Sand	Silt	Clay	Texture
1	Al-Shatra	5.40	7.20	23.30	9.77	540.00	253.00	355.00	392.00	CL
2	Al-Dawaea	7.30	7.25	24.04	19.25	550.00	250.00	393.00	357.00	CL
3	Al-Naser	6.01	7.13	25.98	21.80	650.00	191.00	330.00	479.00	C
4	Al-Alrifaee	9.30	7.21	20.45	19.89	400.00	379.00	358.00	263.00	L
5	Al-Alkalaa	11.80	7.80	23.18	8.57	490.0	379.00	321.00	300.00	CL
6	Akil	9.10	7.84	23.13	15.60	410.87	74.70	452.90	472.40	CL
7	Al-Alfajer	9.60	7.40	20.89	8.25	490.00	313.00	417.00	270.00	CL
8	Maysalon	13.87	8.23	7.34	6.93	323.15	898.10	39.30	62.60	SL

X = amount of adsorbed zinc ions (Zn mg.kg^{-1} soil),
C_o = initial zinc concentration (mg L^{-1}),
C = zinc concentration in the equilibrium solution (mg L^{-1}),
V = total volume of the extraction solution (ml),
W = weight of soil (g).

The results of the zinc adsorption reactions were tested using the Ionic exchange equation of Langmuir equation with a single surface, the Freundlich equation, and the Temkin equation in its linear form for isothermal equilibrium.

$$C/X = 1 / k_L b + C / b$$

$$qe = q_m \ln k_T + qm \ln C_e$$

$$\text{Log } X = \text{Log } K_f + 1/n \text{ Log } C$$

Where:
k_L,1/n is the binding energy coefficient (ml.µg^{-1})
b is the maximum adsorption limit (mg. kg^{-1})
k_t is the ability constant (ml.µg^{-1})
q_m is the adsorption capacity (mg. kg^{-1})
qe , x are the amount of ion adsorbed per unit surface area (mg .kg^{-1})
C , C_e is the ion concentration in the equilibrium solution (mg L^{-1})
To apply the thermodynamic concepts of adsorption, it is necessary to know the thermodynamic equilibrium constant (K), which is calculated as:
$K=X/C_e$

Where:
X is the amount of element adsorbed on the solid phase (mg. kg^{-1})
C_e is the concentration of the element in the equilibrium solution (mg.L^{-1})

By intersecting the values of X/C_e with X, K is calculated when X reaches zero. The change in standard free energy (ΔG°) is calculated from the equation:

$$\Delta G^\circ = - RT \ln K$$

where:
R is the universal gas constant (8.314 ×10^{-3} kj mol^{-1} K^{-1})
T is the absolute temperature (K).
The standard enthalpy change (ΔH°) was calculated from the integration of the Van't Hoff equation.

$$\ln K_2/K_1 = - \Delta H^\circ/R\,[1/T_2 - 1/T_1]$$

The change in randomness (entropy ΔS°) was calculated from the mathematical equation:

$$\Delta S^\circ = (\Delta H^\circ - \Delta G^\circ) / T$$

Results and Discussion

Sorption isotherm

To describe the behaviour of zinc in some soil samples studied in Dhi Qar Governorate/ southern Iraq, three equations were tested: the Langmuir equation, the Freundlich equation, and the Temkin equation to study the adsorption reactions. The values of the statistical coefficient of determination (R^2) were adopted as a criterion for comparison between the equations. Table 2 and Table 3 showed that all equations succeeded in describing zinc adsorption by the studied soil samples, and they obtained values of ($R^2 \geq 0.90$) for both salts $CaCl_2$ and NaCl, but these equations differed according to the studied soils in giving the best description of zinc adsorption, and this may be due to the multiplicity and difference of adsorption sites on soil surfaces. Tables 2 and Table 3 also showed the superiority of the Freundlich equation in the linear form in giving the highest value of the coefficient of determination $R^2 \geq 0.93$. The equations can be arranged according to their efficiency in describing zinc adsorption as follow: Langmuir equation > Temkin equation > Freundlich equation.

Also, Tables 2 and Table 3 showed the values of the constants of the Langmuir equation under the conditions of $CaCl_2$ salt, where the value of the constant (b), which represents the maximum adsorption capacity, ranged between (81.31 - 238.09) mg.kg^{-1}, the value of the binding coefficient K_L ranged between (0.05 - 0.44) L.mg^{-1}, the value of The maximum buffering capacity (MBC) ranged between (6.02 - 96.09) L.kg^{-1}, and the value of R^2 ranged between (0.981 - 0.997). Under the conditions of salt NaCl, the Langmuir equation constants (b, K_L) recorded the lowest value, as the constant (b) recorded a value ranged between (48.31 - 204.08) mg. kg^{-1} and the binding coefficient K_L ranged between (0.05 - 0.31) L.mg^{-1} and MBC values ranged between (4.15 - 36.71) L.kg^{-1} and the value of R^2 ranged between (0.933 - 0.996).

After applying Freundlich model for thermal desorption of zinc to the results of zinc adsorption in the study soil, it gave a description of the adsorption process, as the equation constants recorded values under the salt $CaCl_2$ conditions, where the value of K_f reached (8.05 - 76.93) mg.kg^{-1}, the value of n, which represents the value of the binding energy coefficient (1.42 - 2.66) L.mg^{-1}, and the value of R^2 was between (0.870 - 0.992). As for the equation constants under the salt NaCl conditions, the value of the K_f ranged between (6.18 - 37.49) mg.kg^{-1}, the value of n ranged between (1.46 - 4.15) L.mg^{-1}, and the value of R^2 ranged between (0.822 - 0.998).

The constants of the Temkin equation were also calculated under the conditions of $CaCl_2$ and NaCl salts, where the constant qm, which represents the maximum adsorption capacity, recorded values

Table 2: *Langmuir, Freundlich and Temkin ion exchange equation constants for zinc adsorption in the study soils using saline solution (0.01M $CaCl_2$)*

Soil No.	Location	Langmuir				Freundlich			Temkin		
		bmg kg^{-1}	K_LL mg^{-1}	MBC L Kg^{-1}	R^2	nL mg^{-1}	$K_f$mg kg^{-1}	R^2	qmmg kg^{-1}	K_tL mg^{-1}	R^2
1	Al-Shatra	217.39	0.44	96.09	0.991	2.66	76.93	0.870	22.89	4.45	0.989
2	Al-Dawaea	232.55	0.11	24.88	0.983	1.70	30.33	0.990	52.92	1.08	0.984
3	Al-Naser	238.09	0.26	62.86	0.995	2.23	62.10	0.981	55.61	6.55	0.987
4	Al-Alrifaee	136.98	0.05	6.99	0.997	1.42	8.81	0.992	27.79	3.97	0.997
5	Al-Alkalaa	175.44	0.23	40.88	0.989	2.18	42.52	0.939	42.78	3.82	0.966
6	Akil	142.85	0.16	22.71	0.981	2.06	27.89	0.969	34.40	1.73	0.967
7	Al-Alfajer	156.25	0.13	19.69	0.992	1.82	24.05	0.968	37.89	1.02	0.994
8	Maysalon	81.312	0.07	6.02	0.993	1.61	8.05	0.982	18.85	2.69	0.999

Table 3: *Langmuir, Freundlich and Temkin ion exchange equation constants for zinc adsorption in the study soils using saline solution (0.01M NaCl)*

Soil No.	Location	Langmuir				Freundlich			Temkin		
		bmg kg^{-1}	K_LLmg^{-1}	MBCLKg^{-1}	R^2	nL mg^{-1}	$K_f$mg kg^{-1}	R^2	qmmg kg^{-1}	K_tL mg^{-1}	R^2
1	Al-Shatra	117.65	0.31	36.71	0.994	2.74	37.49	0.914	26.29	11.09	0.942
2	Al-Dawaea	121.95	0.05	6.71	0.996	1.46	8.68	0.991	25.80	3.71	0.998
3	Al-Naser	204.08	0.12	23.88	0.983	1.78	29.43	0.986	47.63	1.03	0.982
4	Al-Alrifaee	67.56	0.26	17.30	0.946	2.40	18.13	0.797	16.75	3.93	0.803
5	Al-Alkalaa	106.38	0.14	14.47	0.953	2.28	21.59	0.982	23.94	1.78	0.945
6	Akil	103.09	0.14	14.02	0.948	1.20	10.03	0.998	47.69	5.86	0.965
7	Al-Alfajer	83.33	0.29	24.50	0.958	4.15	34.71	0.822	13.99	118.03	0.809
8	Maysalon	48.31	0.08	4.15	0.933	1.84	6.18	0.969	11.29	1.99	0.951

ranging from (18.85 - 55.61) mg.kg^{-1} to (11.29 - 47.69) mg.kg^{-1}, and the values of K_t ranged from (1.02 - 6.55) L.mg^{-1} to (1.03 - 118.03) L.mg^{-1}, while R^2 recorded values ranging from (0.966 - 0.997) to (0.803 - 0.998) for the $CaCl_2$ and NaCl salts, respectively.

The values of the adsorption equation constants for the study soils differed according to the properties of the studied soils Tabls 1 and the type of salt. The reason for this difference may be due to the variation in the clay content, organic matter, cation exchange capacity, calcium carbonate, soil reaction (pH), and ionic strength of the study soils, which play a role in determining the maximum adsorption limit and binding energy coefficient. Tables 2 and Table 3 show the adsorption constants of the three ion exchange equations, where the equation constants increased in soils with high content of clay particles, organic matter, calcium carbonate and high cation exchange capacity (CEC). These soils were characterized by low binding energy with high adsorption capacity. These results are consistent with what Reyhani *et al* (2010) reached regarding the existence of a significant correlation between clay content and CEC with the Langmuir equation constant (b) when they studied the adsorption of zinc in calcareous Iranian soils.

Al-Zubaidi (2020) also found a highly significant correlation between the values of the Langmuir and Freundlich equation constants with increasing soil clay content, organic matter and CEC under the conditions of $CaCl_2$ and NaCl salts when studying cadmium adsorption in calcareous soils, as the Freundlich equation constant (Kf), the Langmuir equation constant (b) and the Temkin equation constant (qm) which represent the maximum adsorption capacity of the soil give an idea about the movement or restriction of the element in the soil, as the high values of the constants indicate a decrease in the movement of the element and an increase in its retention by soil colloids, and the low values of the constants indicate that most of the zinc is present in a free and dissolved form in the soil solution and that the amount absorbed is low.

When comparing the amount of zinc adsorbed by the studied soil samples in the presence of $CaCl_2$ and NaCl salts, we find that the ionic exchange equation constants were higher in the case of $CaCl_2$ salt compared to NaCl salt. This is probably due to the association of calcium ions with carbonate and bicarbonate ions present in the equilibrium solution, forming calcium carbonate, which increases the adsorption of ions on their outer surfaces. Also, increasing the concentration of calcium ions in the soil solution under $CaCl_2$ salt conditions reduces the solubility of calcium carbonate due to the effect of the common ion on solubility (Mendham *et al*., 2000). The low ionic exchange equation constants in the case of NaCl salt may be attributed to the effect of sodium ions, which dissolve carbonate minerals and increase the release of zinc and other elements that were adsorbed on the exchange surfaces of the study soils. This is consistent with what Al-Shammari, 2019, found. Also, increasing the concentration of sodium ions in the soil solution increases the thickness of the electrical double layer compared to calcium ions (Sposito, 2008), which reduces the chance of zinc adsorption on the exchange surfaces of soil colloids.

The maximum buffering capacity (MBC) values were calculated from the Langmuir equation constants (b, k) and their values ranged for the study soils from (6.02 - 96.09) L.kg^{-1} to (4.15 - 36.71) L.kg^{-1} under the conditions of $CaCl_2$ and NaCl salts, respectively. It is noted from Tables 2 and Table 3 that the soils with a high clay particles content and a high cation exchange capacity (CEC) were superior in giving the highest MBC value, as Yassen and Fakher (2016) found a positive statistical relationship between the MBC values and the clay content and CEC in their study of copper adsorption in some calcareous soils in southern Iraq.

Al-Shammari (2019) also found a highly significant correlation between MBC values and soil properties of clay and CEC under $CaCl_2$ and NaCl salt conditions when studying cadmium adsorption in some calcareous soils from different areas of Iraq. The results of the study show that the highest MBC value for the study soils was under $CaCl_2$ salt conditions compared to NaCl salt. This is attributed to the superiority of the Langmuir equation constants (b, k) under $CaCl_2$ salt conditions compared to NaCl salt. In values MBC may be somewhat low for the study soils in the presence of salts. This indicates that the movement of zinc is restricted and not free, and that the dissolved amount of zinc in the soil solution is small and non-polluting to the environment in these soils.

Thermodynamic indicators of zinc adsorption

Researchers have tended to describe adsorption processes in soils using thermodynamic concepts, including (ΔG°, ΔH°, ΔS°, and K_t°), to predict the occurrence of reactions and understand the mechanism of element adsorption in soil. This approach is considered an accurate method for determining the interaction between the solid and liquid phases of soil (Zubieta *et al*., 2008).

Change in free energy (ΔG°)

The results of Tables 4 and Table 5 show the free energy values (ΔG°) for the thermodynamic equilibrium state of zinc. The values ranged between (-6.61 to -9.35) kJ.mol^{-1} for the study soils under $CaCl_2$ salt conditions and at a temperature of 298 K, and between (-8.44 to -10.46) kJ.mol^{-1} at a temperature of 318 K. The ΔG° values ranged between (-5.62 to -7.51) kJ. mol^{-1} for NaCl salt at a temperature of 298 K, and between (-7.02 to -8.84) kJ.mol^{-1} for the study soils under $CaCl_2$ salt conditions and at a temperature of 318 K. The study data Tables 4 and Table 5 indicated a high negative standard free energy in some of the study soils as a result of the high thermodynamic equilibrium constant (K_t°) , which depends on the amount of the element absorbed (see Figure 1, Figure 2, Figure 3 and Figure 4). These soils were distinguished by their ability to absorb as a result of the high CEC value and the increase in their content of clay particles and organic matter.

It is also noted that the standard free energy values of the study soils are higher under $CaCl_2$ salt conditions compared to NaCl salt for temperatures of 298 and 318 K, this may be attributed to the higher values of the thermodynamic equilibrium constant (K_t°) as a result of the increase in the adsorbed amount of zinc under $CaCl_2$ salt conditions compared to NaCl salt. This is consistent with what was found by Yassen and Fakher, 2016 and Al-Zubaidi, 2020) in their study of the adsorption of heavy elements in some Iraqi calcareous soils. The results of Tables 4 and Table 5 also show that all values of ΔG° were negative, which means that the zinc reaction in these soils is spontaneous in nature, i.e. it does not require energy from outside the system. There is also a decrease in the standard free energy values (increase in negativity) for zinc adsorption with increasing temperature,

Table 4: *Thermodynamic parameters for zinc adsorption in the study soils using 0.01M $CaCl_2$ solution*

Soil No.	Location	K_t°		ΔG°KJ mol^{-1}		ΔH°KJ mol^{-1}	ΔS°J mol^{-1}	
		298K	318K	298K	318K		298K	318K
1	Al-Shatra	27.60	43.04	- 8.23	- 9.95	18.51	89.73	89.49
2	Al-Dawaea	32.72	46.62	- 8.65	- 10.14	14.75	78.52	78.27
3	Al-Naser	43.41	52.63	- 9.35	- 10.46	8.02	58.29	58.11
4	Al-Alrifaee	16.92	28.34	- 7.01	- 8.84	21.50	95.67	95.41
5	Al-Alkalaa	26.05	37.06	- 8.08	- 9.53	14.69	76.41	76.16
6	Akil	22.33	33.45	- 7.70	- 9.28	16.84	82.35	82.14
7	Al-Alfajer	22.53	36.54	- 7.72	- 9.51	20.19	93.66	93.39
8	Maysalon	14.43	24.53	- 6.61	- 8.44	22.11	96.37	96.06

Table 5: *Thermodynamic parameters for zinc adsorption in the study soils using 0.01M NaCl solution*

Soil No.	Location	K_t°		ΔG°KJ mol^{-1}		ΔH°KJ mol^{-1}	ΔS°J mol^{-1}	
		298K	318K	298K	318K		298K	318K
1	Al-Shatra	20.69	28.35	- 7.51	-8.84	13.12	69.23	69.05
2	Al-Dawaea	19.15	22.67	- 7.33	-8.25	7.03	48.18	48.05
3	Al-Naser	19.53	25.05	-7.36	-8.52	10.37	59.49	59.40
4	Al-Alrifaee	9.71	19.81	5.64	-7.90	29.71	118.62	118.27
5	Al-Alkalaa	18.19	22.21	-7.19	-8.19	8.32	52.05	51.91
6	Akil	10.51	21.91	- 5.83	-8.16	30.61	122.28	121.91
7	Al-Alfajer	10.31	15.86	-5.78	-7.31	17.95	79.63	79.43
8	Maysalon	9.66	14.21	- 5.62	-7.02	16.08	72.81	72.64

i.e. there is an increase in the spontaneity of the reaction with increasing temperature. This confirms what was reached by (Al-Jumaily, 2015) in his study of thermodynamic indicators for zinc adsorption in some soils in northern Iraq and what was reached by Yousra *et al*., 2019 and Al-Zubaidi, 2020) in their study of cadmium adsorption in some calcareous soils of an increase in the spontaneity of the reaction with increasing temperature.

Change in enthalpy (ΔH°)

The results of the study in Tables 4 and Table 5 showed that the values of ΔH° were positive for all the studied soils, indicating that zinc adsorption on the adsorption surface is endothermic in nature. Its value for the studied soils ranged between (8.02 - 22.11) KJ.mol^{-1} under $CaCl_2$ salt conditions to (7.03 - 30.61) KJ.mol^{-1} under NaCl salt conditions. Helfferich (1962) mentioned that the enthalpy values ΔH° for heavy metals, which range in the adsorption process between (8.4 – 12.6) KJ.mol^{-1}, indicate that the nature of adsorption is ion exchange, since the ΔH° values for some of the study soils are higher than these ranges, this means that there may be other adsorption mechanisms such as precipitation or deposition in addition to ion exchange, these results confirm what Al-Jumaili (2015) reached in his study of zinc adsorption in some soils of northern Iraq, as well as what Al-Zubaidi (2020) found of an increase in enthalpy values ΔH° when studying cadmium adsorption in some calcareous soils of different areas of Iraq.

Change in entropy (ΔS°)

Tables 4 and Table 5 showed a positive value of entropy (ΔS°), which indicates an increase in the randomness of the interaction between the solid and liquid phases during the adsorption process. It also reflects the affinity of the surface for the adsorption of zinc ions. The high values of ΔS° indicate an increase in the randomness of the adsorption process of the element (Suman *et al*., 2023). The values of ΔS° ranged from (48.18 - 122.28) J.mol^{-1} to (48.05 - 121.91) J.mol^{-1} using NaCl salt at temperatures of 298 and 318 K, respectively. However, using $CaCl_2$ salt at the same temperatures, the values of ΔS° ranged from (58.29 - 96.37) J. mol^{-1} to (58.11- 96.06) J.mol^{-1} respectively. It is noted from the results of the study that the entropy value ΔS° decreases with increasing temperature. This may be attributed to the decrease in the randomness of the system and the transformation of zinc from the liquid phase to the solid phase of the soil by the adsorption process. The results of the current study are consistent with the results of many studies (Al-Zubaidi, 2020; Yassen and Fakher, 2016 and AL-jumaily, 2015).

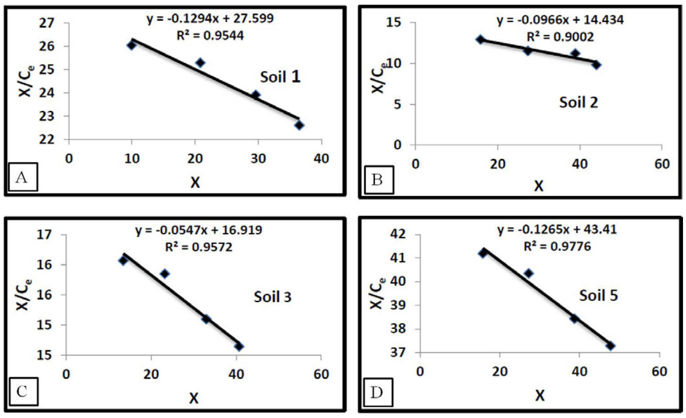

Figure 1: *Thermodynamic equilibrium constant* **(K_t°)** *for the studied soil samples in $CaCl_2$ saline solution at a temperature of 298K, A) Al-Shatra, B) Al-Dawaea, C) Al-Naser, and D) Al-Alkalaa soil samples.*

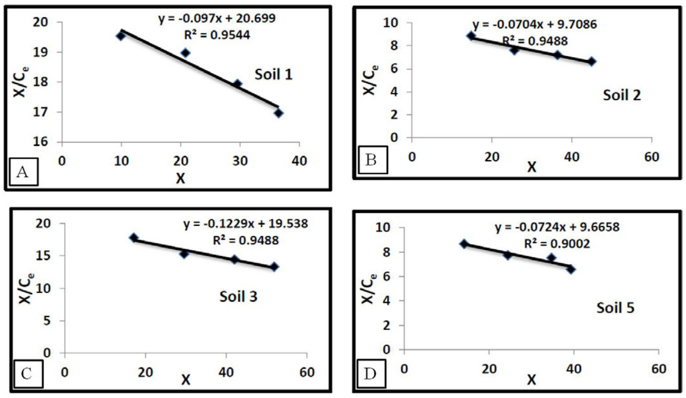

Figure 2: *Thermodynamic equilibrium constant* **(K_t°)** *for the studied soil samples in NaCl solution at a temperature of 298K, A) Al-Shatra, B) Al-Dawaea, C) Al-Naser, and D) Al-Alkalaa soil samples.*

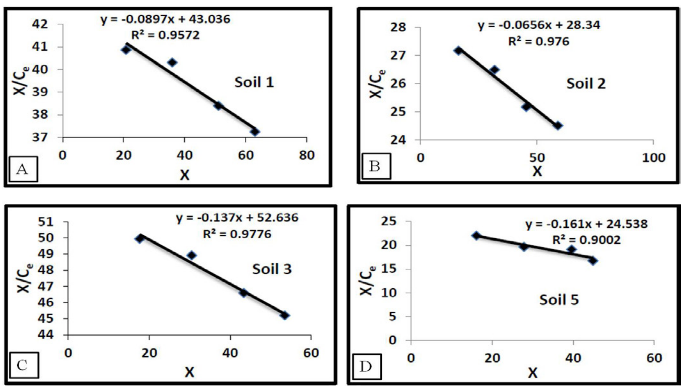

Figure 3: *Thermodynamic equilibrium constant* **(K_t°)** *for the studied soil samples in $CaCl_2$ saline solution at a temperature of 318K, A) Al-Shatra, B) Al-Dawaea, C) Al-Naser, and D) Al-Alkalaa soil samples.*

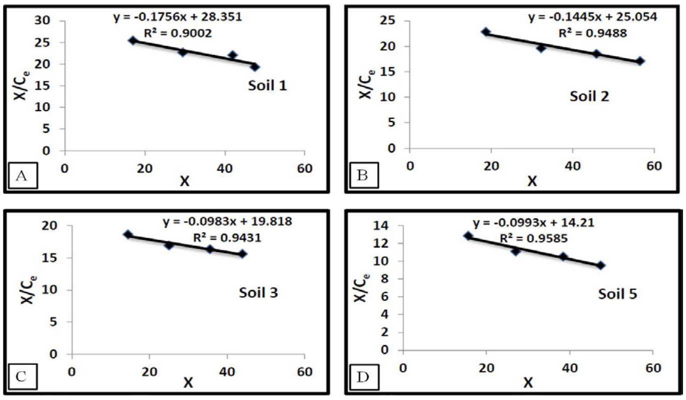

Figure 4: *Thermodynamic equilibrium constant* **(K_t°)** *for the studied soil samples in NaCl solution at a temperature of 318K, A) Al-Shatra, B) Al-Dawaea, C) Al-Naser, and D) Al-Alkalaa soil samples.*

Conclusions

The results of the study showed that the ion exchange equations (Langmuir, Freundlich, and Temkin) and the thermodynamic parameters (ΔG°, ΔH°, ΔS°, and K_t°) succeeded in providing a clear picture of the zinc adsorption process in the study soils. The amount of zinc adsorbed was greater in the presence of $CaCl_2$ than in the presence of NaCl. Increasing the temperature led to an increase in the amount of zinc adsorbed, zinc adsorption was endothermic and spontaneous. The spontaneity of the reaction increased with increasing temperature. The amount of dissolved zinc was small and non-polluting to the environment in these soils.

Acknowledgment

Authors would like to thank the soil sciences and water resources laboratory.

Novelty Statement

The researchers conducted this study due to its scientific and practical importance in the agricultural field in some of northern of Dhi Qar Governorate, specifically: The scarcity of available studies on zinc interactions in soil and the use of adsorption parameters and thermodynamic indicators for soils in northern Dhi Qar Governorate. Due to the existences of pollution problem in high percentage of soils, this study was conducted to determine the ability of the studied soils to adsorb zinc and mitigate the effects of heavy metal pollution, including zinc, resulting from farmers adding excessive amounts of chemical fertilizers, exceeding the recommended application rates.

Author's Contribution

Salwa Fakhir: Conceptualized the research idea and guided the overall study design, explained the results and discussion as well as interpret the results.
Riyadh Bedeeh: Conceptualized the research idea, guided the overall study design, explained the results and discussion, interpret the results as well as writing the draft of the manuscript.
Atarid Kazim: Did the field work containing soil samples' collection and laboratory work.
Hussein Chlaib: Did the field work containing soil samples' collection and laboratory work as well as writing the final version of the manuscript.
Jallal Ali: Supported the literature review and contextual framing.
Hakeem R. Zachi: Supported the literature review and contextual framing.
All authors contributed to refining the manuscript, approved the final version, and agreed to be accountable for the work's integrity.

Generative AI and AI-assisted technology statement:
The authors declare that no generative AI or AI-assisted technologies were used in the preparation, analysis, writing, or editing of this manuscript. All research design, data collection, analysis, and interpretation were conducted solely by the authors. Google translation was used partially to assist the translation.

Conflict of interest
The authors have declared no conflict of interest.

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