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Contribution to the study of ammonium leaching and its influencing factors in the soils of Al-Sin Lake Catchment, Banias, Syria

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ABSTRACT

In this study, the sites of Beit Aana, Al-Qutailbiya, Quorfase and Al-Waha Spring were characterized by high levels of leaching whereas the highest concentrations of ammonium leaching were measured in December 2019 and March 2020, ranging between 5.74 and 5.81 mg/L. However, the lowest concentration (0.97 mg/L) was recorded in February 2020 in the sites of Bestwair, Beit Al-Alouni, Geiboul and Al-Rahbeyia with lower levels of leaching. The highest concentrations of ammonium leaching were obtained during November 2019 and April 2020, ranging between 3.51 and 4.31 mg/L whilst the lowest concentration of ammonium (0.59 mg/L) was determined in January 2020. It was found that the levels of ammonium leaching decreased with depth. The statistical study showed a correlation between ammonium leaching and the following variables: organic matter (OM), the saturated hydraulic conductivity (SHC) and pH. Regression equations representing ammonium leaching in soil horizons and their role were also obtained.

Key words: ammonium leaching, hydraulic conductivity, organic matter, pH

INTRODUCTION

Ammonia (NH_3) emissions to the atmosphere increasingly contribute to the occurrence of acid rain (ApSimon *et al.* 1987). They represent an indirect source of greenhouse gas emissions. Ammonium intrusion into rivers and lakes can also cause eutrophication, which, in turn, leads to excessive growth of aquatic weeds and algae, with adverse effects on the environment (Cameron *et al.* 2013). Several studies confirmed that the use of nitrogenous (ammonia-based) fertilizers for irrigated crops growth and production is the widest cause of groundwater pollution with ammonium ion although ammonium ion is poorly mobile in soils compared to the nitrate ion (Xiong *et al.* 2010; Khan *et al.* 2018; Lwimbo *et al.* 2019; Singh & Craswel 2021). However, the sandy soil with low content of clay and organic matter (OM) can easily move down the soil section and, in turn, into the groundwater (Lord & Mitchell 2007; Zarabi & Jalali 2012; Rusydi *et al.* 2021).

There have been numerous studies to determine the factors that affect the leaching and transfer of the ammonium ion into the soil, and they have been divided into several factors, the most important of which are:

1. The effect of added agricultural fertilizers, and the intensity of agricultural activities, which increase the ammonium ion leaching in the soil (Teutscherova *et al.* 2018).
2. The effect of municipal, agricultural and industrial waste on the accumulation of OM and ammonium ion in the soil and its leaching to the subsurface horizons (Dong *et al.* 2022).
3. The effect of geographical and climatic conditions, the nature of the soil, its content of clay minerals and pH, on the transport and washout of ammonium (Jabloun *et al.* 2015; Dong *et al.* 2022).

Many researchers have studied the sources of ammonium ion in the environment, the problems resulting from the excessive use of fertilizers and the factors affecting this transition (Radersma & Smit 2011; Cameron *et al.* 2013; Van Grinsven *et al.* 2015; Chen *et al.* 2021; Dong *et al.* 2022). A completed study showed that the ammonium ions after entering the interlayers of clay minerals decreased nitrification, and thus were protected from leaching to the subsurface horizons as a kind of buffer for the ammonium ion in the soil (Radersma & Smit 2011).

A study carried out by Cameron *et al.* (2013) showed that proper management of ammonium ion levels in the soil using best management practices and newly developed technologies could increase the sustainability of natural resources and reduced their impact on the environment (Cameron *et al.* 2013).

A study conducted by Van Grinsven *et al.* (2015) showed that the increased use of ammonium-based nitrogen fertilizers contributed to reducing nitrogen losses, which decreased as a result of the increase in the concentrations of ammonium ions liberated in the soil, and the fixation of the ammonium ion in the soil on clay minerals or adsorption on organic soil components (Van Grinsven *et al.* 2015). Another study showed that the increased levels of leaching fertilization, significant accumulation of OM and soil content of clay minerals and pH led to the accumulation of high concentrations of ammonium ion and thus increased the risk of leaching into subsurface horizons and ultimately into water sources (Chen *et al.* 2021). A two-year tracking investigation conducted on a semi-tropical red soil using field lysimeters carried out in China to evaluate the effect of fertilization, climatic data and soil type on ammonium ion leaching and total nitrogen accumulation in the soil concluded that if the levels of fertilization were applied in those areas (200 kg N·ha/yr) ammonium ion accumulation and leaching would be continuous, and decreased with depth. It was recorded that at a depth of 20 and 100 cm the levels of fertilization decreased to 91.5 and 57.9 kg N·ha/yr, respectively. This could pose a potential threat to groundwater quality or the safety of drinking water. In order to reduce ammonium ion leaching, effective management practices should be carried out, and the role of vegetation cover and water drainage system should be evaluated (Dong *et al.* 2022).

This study may contribute to the environmental assessment resulting from fertilization and human activities and clarify the role of soil properties and climatic factors and their impact on ammonium leaching within the soil horizons. The study aimed to estimate the loss of ammonium ion washing for different soils in terms of physical structure, OM and clay content using statistical methods (correlation and regression) in evaluating ammonium leaching processes.

METHODS AND MATERIALS

First: characteristics of the study area

Location and general features

The study area is located within the following coordinates: Longitude: (35°54′57.40″ and 36°14′59.41″), Latitude: (35°13′55.54″ and 35°22′49.50″) and forms part of the central region of the coastal mountains. The study area can be divided into two regions: The first region: shallow hills consisting of relatively inclined slopes composed of marl and limestone marl rocks ranging in height between 250 and 700 m and interrupted by transverse valleys in addition to the main streams sloping from the top of the chain, while the second one consists of the coastal plain and semi-flat terraces, slightly inclined to the west as well as the floodplains of the valleys, and the watercourses that are partially intersected by small canyons.

Climate

The average monthly maximum temperatures in the region were recorded around July and August 2020, while the minimum ones were observed in January 2021. However, the temperature changes played an important role in determining the moisture diffusion between the atmosphere and the soil as well as in the activity of physical weathering processes and the degradation or accumulation of the OM. Figure 1 shows the monthly averages of temperature changes in some monitoring stations adjacent to the studied area during 2019 and 2020 (General Directorate of Meteorology 2020).

Rainfall

The region is characterized by abundant rainfall. It was distributed in winter from November to April at varying rates, most of which fell between December and February, and the rest was during October, November, March and April. The average annual rainfall ranged between 600 and 1,099 mm. In contrast, rainfall rarely occurred during summer months. Figure 2 shows the monthly and annual rainfall in the study area during five years from 2016 to 2020 (General Directorate of Meteorology 2020).

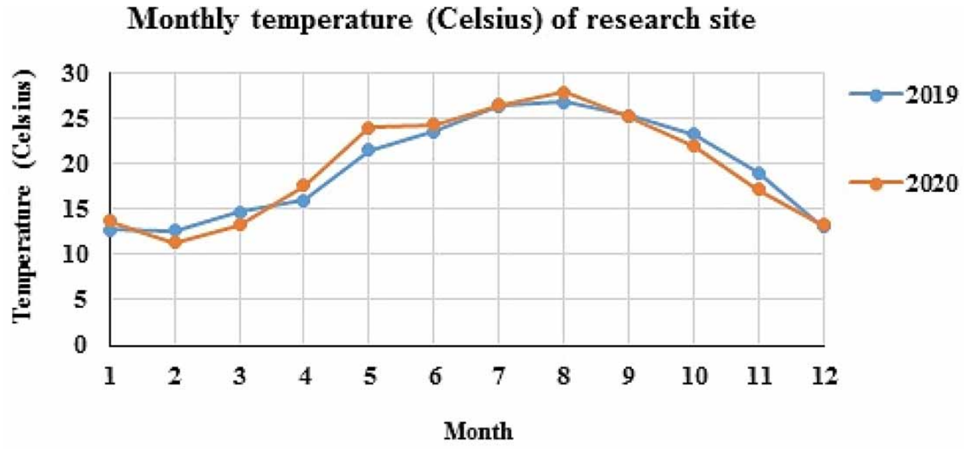

Figure 1 | Monthly averages of temperatures in the study area for 2019 and 2020.

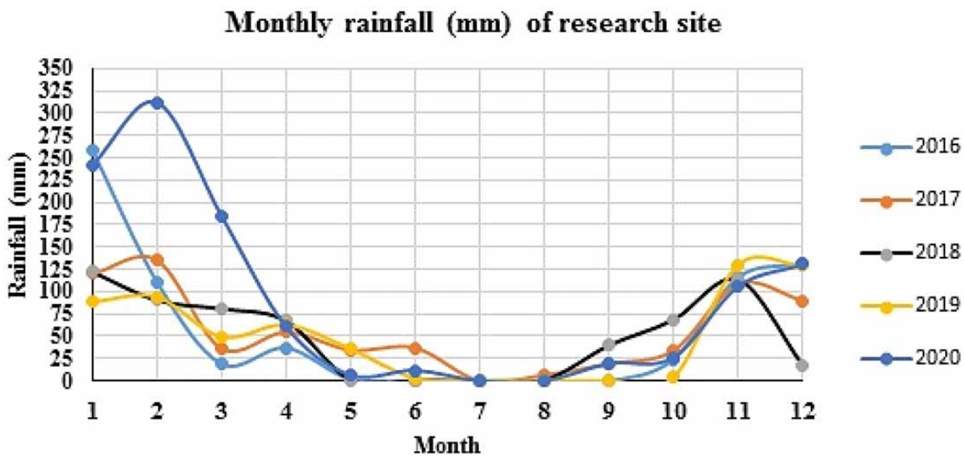

Figure 2 | Monthly and annual averages of rainfall in the study area between 2016 and 2020.

Lysimeters installation

To assess the processes of ammonium ion accumulation and leaching within the soil sections, field experiments were conducted by installing lysimeters in eight locations and in three horizons distributed over the entire study area. These were as follows: Beit Aana (1), Bestwair (2), Beit Al-Alouni (3), Geiboul (4), Quorfase (5), Al-Qutailbiya (6), Al-Rahbeyia (7) and Al-Waha Spring (8). These sites represented different soils in terms of physical and chemical properties, human and agricultural activities, in addition to being on the main carrier of the Sin River and its tributaries, as shown in Figure 3.

Second: experiments and measurements

All experiments and measurements were carried out in the laboratories of the Higher Institute of Environmental Research at Tishreen University, and the Agricultural Scientific Research Center in Al-Hennady in Lattakia.

Soil

A set of physical and chemical analyses were carried out and summarized as follows:

The physical analyses.

1. Mechanical analysis of soil by the hydrometer method (Gupta 2007).
2. Determination of saturated water conductivity of soil in the laboratory as well as by applying Darcy's law (Carter & Gregorich 2008).

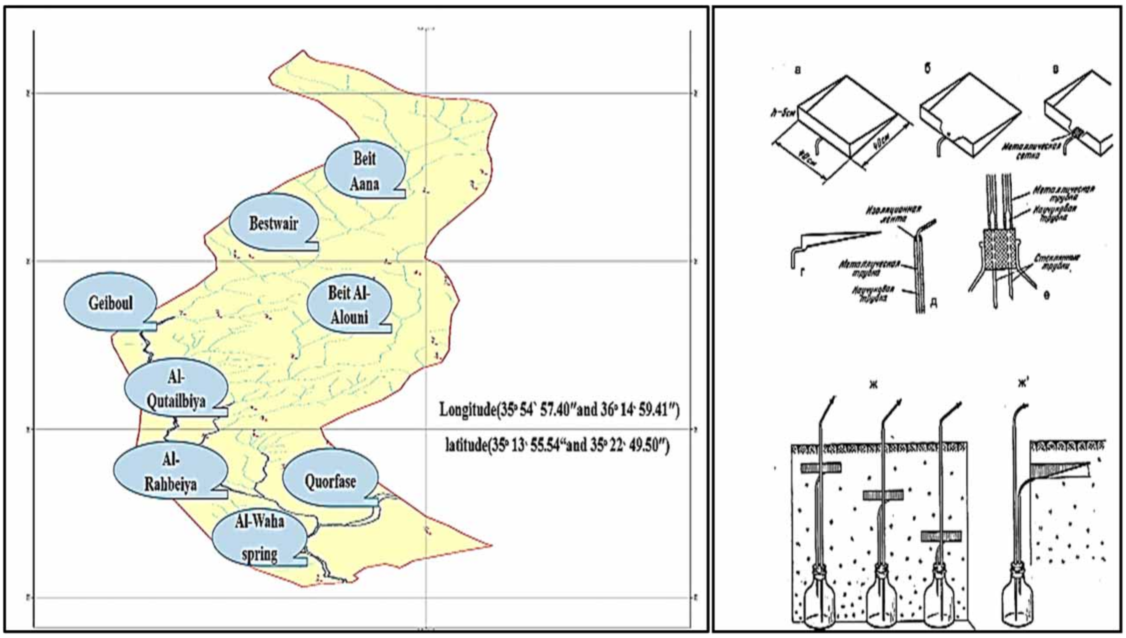

Figure 3 | The locations of the installed lysimeters in the study area.

The chemical analyses.

1. Determining the pH value (pH) in a ratio 1:2.5 soil/water using a field pH device; Metrohm 744 pH Meter (Marx *et al.* 1999).
2. Determining the electrical conductivity (EC) using an EC meter in an aqueous soil extract 1:5 soil/water (Jones 2001).
3. Determination of calcium carbonate in soil using volume titration of 1 N hydrochloric acid solution (Jackson 2005).
4. Determination of calcium and magnesium concentrations (Bashour & Sayegh 2007).
5. Determining the amount of OM by oxidation of organic carbon with potassium dichromate solution in an acidic medium, then titration of excess dichromate by ferric sulfate (Moore's salt) in the presence of ferroin indicator (Nelson & Sommers 1983).
6. Determination of total nitrogen content in the soil using the Kjeldahl method by digesting soil samples in strong sulfuric acid (Bremner 1960).

Water

The soil infiltration solutions were collected using a set of lysimeters placed in the horizons of the soil at the sampling sites and the following analyses were performed:

1. Determination of the EC of the water samples using an electrical conductivity meter (APHA 1998).
2. Measuring the pH value using a field pH device (Metrohm 744 pH Meter), where this process took place on site immediately after obtaining the water samples (Mhlla 2011).
3. Determination of ammonium ion concentration in the lysimeter solution using a spectrophotometer at a wavelength of 420 nm (Bolleter *et al.* 1961).

RESULTS AND DISCUSSION

Study of the ammonium ion leaching according to the soil horizons of the studied sites

The following findings were resulted in based on the physical and chemical properties of the soil samples obtained from the horizons of the studied sites:

The first horizon was characterized by having moderate acidity, slightly inclined to alkalinity and a high content of calcium carbonate and OM. The soils of the first horizon were characterized by a high percentage of clay, then loamy soils and with a lesser percentage of loamy soils. The saturated water hydraulic conductivity ranged between 0.85 and 1.88 cm/min. Table 1 shows the results of the analysis of the physical and chemical properties of soil of the first horizon for the studied sites.

Table 1 | Results of the analysis of the physical and chemical properties of the first soils horizon depth 0–30 cm

Studied sites	pH	EC (ds/m)	OM (%)	$CaCO_3$ (%)	N (total) (%)	Ca (mg/kg)	Sand (%)	Silt (%)	Clay (%)	SHC (cm/min)	N (leaching) average (mg/L)
Beit Aana	7.24	0.78	2.60	30	0.18	2,700	27	30	43	1.30	28.626
Bestwair	7.71	0.35	3.48	47	0.18	2,200	22	31	47	1.09	26.544
Beit Al-Alouni	7.28	0.34	4.66	29	0.48	7,020	9	19	72	0.85	21.276
Geiboul	7.81	0.34	3.47	52	0.47	1,840	25	36	39	1.10	22.084
Quorfase	7.04	0.85	1.89	28	0.32	6,100	14	22	64	1.88	41.129
Al-Qutailbiya	7.26	0.45	1.99	43	0.64	3,210	36	20	44	1.79	31.833
Rahbeyia	7.68	0.26	4.22	61	0.48	5,730	7	39	54	0.87	26.750
Al-Waha Spring	7.21	0.17	2.89	33	0.51	1,560	19	58	23	1.12	30.423

Figure 4 shows the change in ammonium ion concentrations on the first horizon in relation to the date of sample collection.

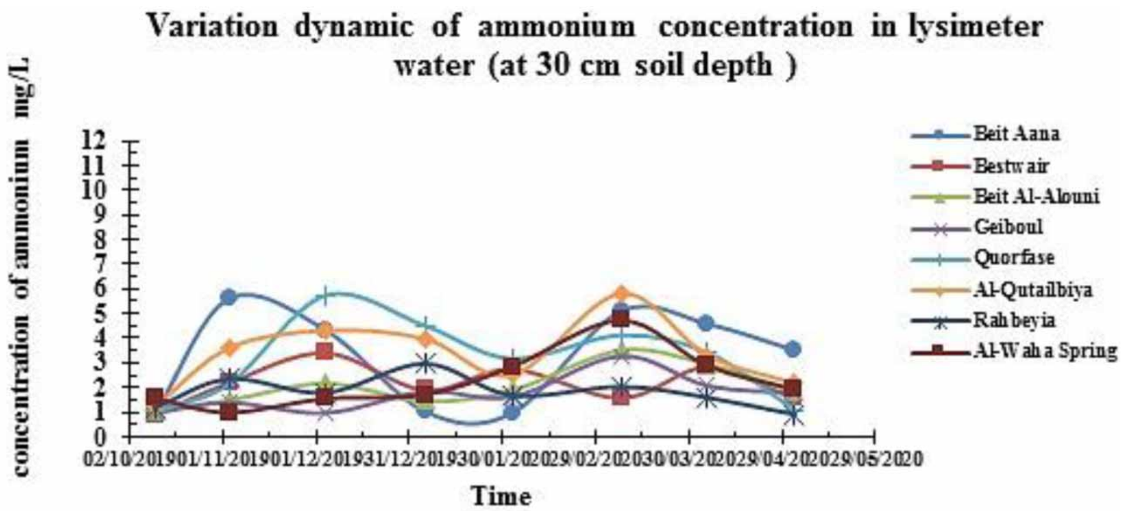

Figure 4 | The graphic representation of the change in ammonium ion concentrations on the first horizon in terms of the date of sample collection.

It can be found from Figure 4 that the leached ammonium ion concentrations in the lysimetric water in the first horizon during the study period, which continued over the entire rainy season for the studied areas, were characterized by high ammonium leaching concentrations in two periods. The first one is high during November and December, when the levels of concentrations in it ranged between 0.97 and 5.74 mg/L, as a result of the effect of two synergistic factors: the first one was due to the accumulation of ammonium ion in the soil as a result of mineralization of OM during the summer period and weak rainfall and the release of ammonium in the soil as a result of autumn fertilization. The second period was March after the spring mineral and organic fertilization at the beginning of February. The level of concentrations ranged between 1.57 and 5.81 mg/L. This was largely due to the accumulation of ammonium ion in the soil as a result of mineralization of OM.

The second horizon was characterized as having moderate acidity compared to the first horizon, and a high content of calcium carbonate and OM. The content of physical clay was slightly lower compared to the first horizon, and its texture was clay with a high percentage, loamy clay. Also noticed is a decrease in the value of hydro-hydraulic conductivity compared to the first horizon, where its value ranged between 0.74 and 1.70 cm/min. Table 2 shows the analysis of the physical and chemical properties of the second horizon soils for the studied sites.

Table 2 | The analysis of the physical and chemical properties of the second soils horizon depth 0–60 cm

Studied sites	pH	EC (ds/m)	OM (%)	$CaCO_3$(%)	N (total) (%)	Ca (mg/kg)	Sand (%)	Silt (%)	Clay (%)	SHC (cm/min)	N (leaching) average (mg/L)
Beit Aana	7.11	0.71	2.38	28	0.14	3,900	16	20	64	1.10	33.8013
Bestwair	7.29	0.31	2.73	42	0.14	2,440	20	28	52	0.88	28.6388
Beit Al-Alouni	7.06	0.29	3.49	21	0.30	6,420	11	15	74	0.74	25.5025
Geiboul	7.48	0.27	2.86	43	0.14	1,820	27	36	37	0.92	24.6725
Quorfase	7.10	0.73	1.72	27	0.38	6,280	13	17	70	1.70	44.2025
Al-Qutailbiya	7.26	0.39	1.65	39	0.24	2,340	37	23	40	1.58	34.0313
Rahbeyia	7.64	0.27	3.67	60	0.30	2,410	19	39	42	0.76	29.5063
Al-Waha Spring	7.13	0.19	2.64	33	0.38	2,890	19	35	46	1.35	32.7825

Figure 5 shows the graphic representation of the change in ammonium ion concentrations on the second horizon in terms of the date of sample collection.

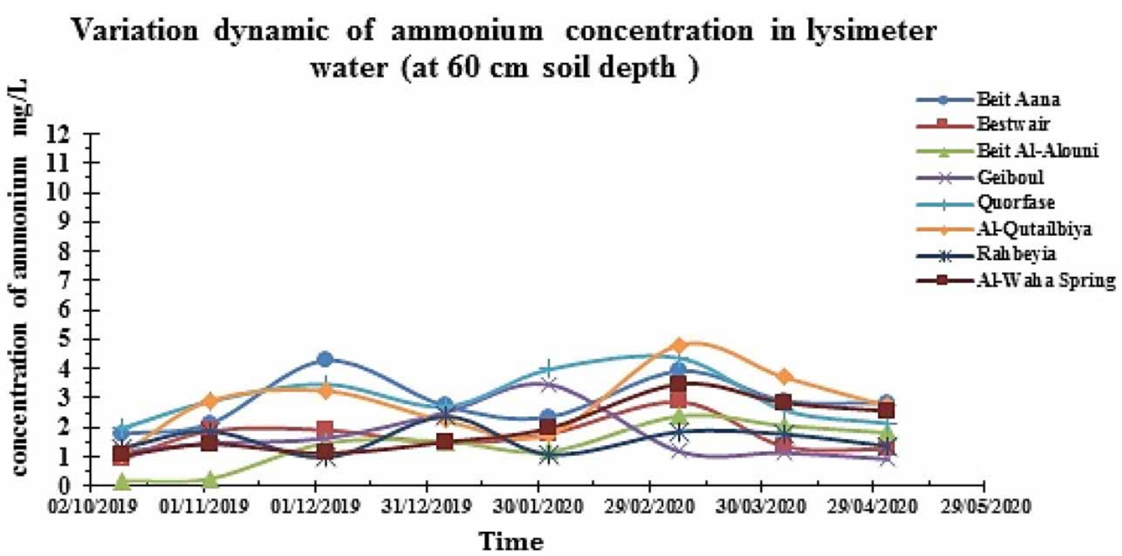

Figure 5 | The graphic representation of the change in ammonium ion concentrations on the second horizon in terms of the date of sample collection.

It can be noticed from Figure 5 that the concentrations of the washed ammonium ion in the lysimetric water from the second horizon during the study period, which lasted for a whole year for the studied areas, were lower than the first horizon due to the adsorption of part of the ammonium ion on the OM and clay minerals within the first horizon. The leached ammonium ion concentrations were high during two periods. The first one was during November and December, ranging between 0.26 and 4.28 mg/L. This was a result of the effect of two synergistic factors. The first factor was due to the accumulation of ammonium ion in the soil as a result of mineralization of

OM and weak rainfall during summer, and the release of the ammonium ion in the soil as a result of autumn fertilization. However, the second period was during March, after spring mineral and organic fertilization in the beginning of February, and the level of concentrations was within the range of 1.18–4.81 mg/L. These were due to two synergistic factors. The first one was a result of the increase in the concentration of the ammonium ion liberated from the first horizon in the soil, and the second one was the decrease in the volume of lysimetric water leaching through the soil section in the second horizon. These led to higher concentrations of the washed ammonium ion. The third horizon was distinguished by its alkaline nature compared to the first and second horizons. It had a high content of calcium carbonate and OM. The soil in the region had a high content of physical clay, compared to the first and second horizons. Its texture ranged between clay and lumpy clay. The saturated water hydraulic conductivity ranged between 0.54 and 1.21 cm/min. It was noted that the value of the saturated water hydraulic conductivity of the third horizon was lower than that of the first and second horizons. This could be attributed to the increased amount of physical clay in the third horizon. Table 3 shows the results of the analysis of the physical and chemical properties of the third horizon soils of the studied sites.

Table 3 | The analysis of the physical and chemical properties of the third soils horizon depth 0–90 cm

Studied sites	pH	EC (ds/m)	OM (%)	$CaCO_3$ (%)	N (total) (%)	Ca (mg/kg)	Sand (%)	Silt (%)	Clay (%)	SHC (cm/min)	N (leaching) average (mg/L)
Beit Aana	7.38	0.73	1.78	31	0.43	3,680	22	16	62	0.88	34.60
Bestwair	7.65	0.29	1.96	47	0.17	2,080	25	28	47	0.65	30.0825
Beit Al-Alouni	7.43	0.44	2.39	26	0.11	5,280	9	15	76	0.71	28.6313
Geiboul	7.72	0.31	2.16	51	0.09	1,820	16	47	37	0.84	29.3063
Quorfase	7.48	0.75	1.44	27	0.48	3,700	15	23	62	1.21	45.7263
Al-Qutailbiya	7.71	0.37	1.55	45	0.15	1,580	52	24	24	1.04	41.6075
Rahbeyia	7.96	0.20	3.17	69	0.32	2,215	12	41	47	0.54	30.6938
Al-Waha Spring	7.45	0.18	1.99	35	0.56	1,985	19	35	46	1.11	36.3075

Figure 6 shows the graphic representation of the change in ammonium ion concentrations on the third horizon in terms of the date of sample collection.

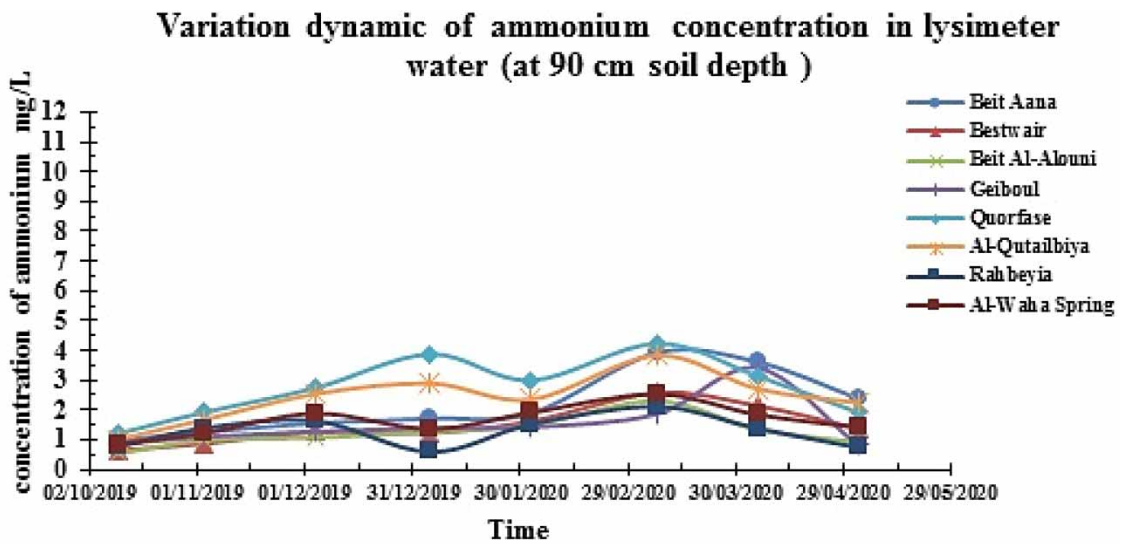

Figure 6 | The graphic representation of the change in ammonium ion concentrations on the third horizon in terms of the date of sample collection.

Noticed from Figure 6 is a decrease in the concentrations of the leached ammonium ion in the lysimetric water from the third horizon compared to the top horizons of the studied areas during one year of the study period. This can be likely attributed to the occurring adsorption of part of the ammonium ion on the OM and clay minerals within the first and second horizons. The concentrations of the leached ammonium ion were high in two periods. The first one was during November and December, ranging between 0.59 and 3.87 mg/L while the level of concentrations during the second period of March ranged between 1.86 and 4.23 mg/L. This may have been occurred as a result of the accumulation and transformation of the ammonium ion from the first and second horizons to the lysimetric water that was washed to the third part of the horizon.

Study of the ammonium ion leaching according to the study areas

The soils of the study areas can be divided according to the leached ammonium ion concentrations into two parts:

1. Soils with high levels of concentrations of leached ammonium ion were Beit Aana, Al-Qutailbiya, Quorfase and Al-Waha Spring. These areas were characterized by multiple human activities, whether agricultural, as a result of the diversity of crops, especially green houses, and livestock and cows breeding, in addition to the large number of tourist areas. This might have resulted in high concentrations of ammonium ion in the surrounding soils and waters. The highest values of the washed ammonium ion concentrations were recorded in November and March whereas the lowest was in February.
2. Soils with low concentrations of ammonium leaching were, in contrast, the sites of Bestwair, Beit Al-Alouni, Geiboul and Rahbeyia. The highest of which was recorded in November and March whereas the lowest was recorded in January.

Figure 7 shows the curves of the changes in the leached ammonium ion concentrations for the three horizons together in the soils of the studied areas.

Statistical study of the correlation and regression coefficients of the washout ammonium ion in relation to the soil horizon properties of the studied sites

Determining the main parameters of water pollution with ammonium ion is critical in order to determine reasonable agro-environmental indicators that support the design, enforcement and control of regulatory policies. Therefore, it was important to use statistical analysis data to determine the factors affecting the transport of ammonium ion within the soil horizons, and their eventual access to water sources (Schweigert *et al.* 2004). These factors were divided into three categories:

(1) Soil properties that affect the leaching of the ammonium ion within the soil sections, and its leaching to groundwater.
(2) Climatic factors such as precipitation and temperature.
(3) The predictive ability of ammonium ion leaching.

First horizon

Table 4 shows the values of the correlation coefficients of the parameters in the first horizon. It is noticed from the correlation matrix that the leached ammonium ion is associated with the variables OM, saturated hydraulic conductivity (SHC), pH and EC as follows: 0.760, 0.741, 0.851 and 0.846, respectively. When applying multiple regression according to Enter to find the equation that linked the variables, the following values were obtained as shown in Table 5.

This is expressed in the equation:

$$NH^{+}_{4\,(Leaching)} = 8.207 + 0.756(EC) + 0.172(SHC) - 0.281(OM) - 0.729(pH) \quad (1)$$

It is noted from Table 5 that the statistical significance values for each of the independent and constant variables are greater than the significance level (0.05), which indicates that the equation cannot be adopted to predict changes since the parameters are not significant, although the value of the correlation coefficient reached the value $R = 0.932$ and the coefficient of determination $R^2 = 86.9\%$. This can be attributed to the fact that the values of the correlation coefficient between the variables are large, which causes a problem in predicting

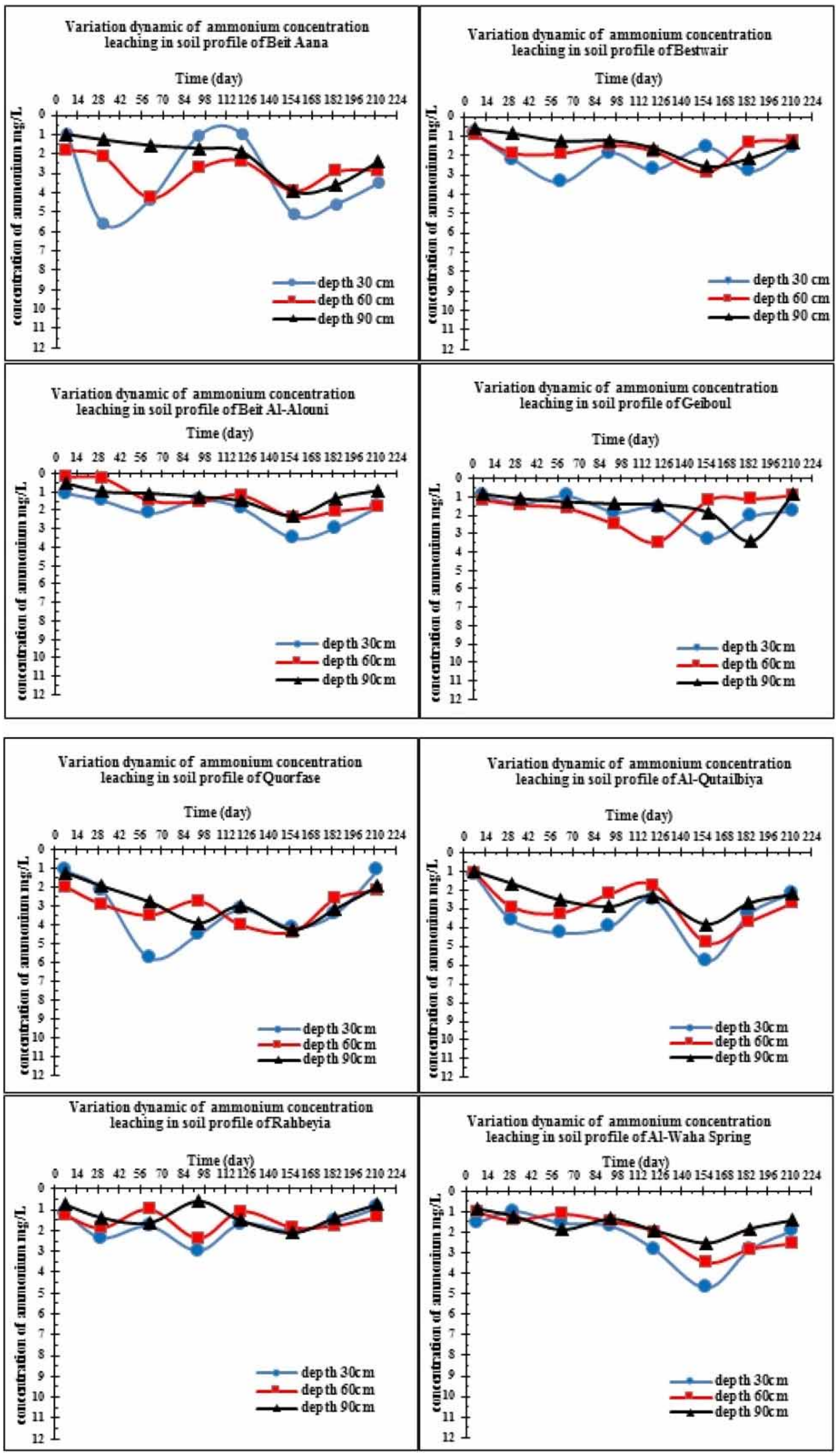

Figure 7 | The curves of the changes of the leached ammonium ion concentrations for the three horizons together in the soils of the studied areas.

the washout process. To solve the problem, the multiple regression test was used via a stepwise method. Therefore, the following values were tabulated as shown in Table 6.

It is expressed by the equation:

$$NH^{+}_{4\,(\mathrm{Leaching})} = 0.626 + 1.477(\mathrm{SHC}) \quad (2)$$

Table 4 | Parameter correlation matrix of the first horizon

Correlations

		NH_4^+ leaching	N–total	$CaCO_3$	EC	OM	pH	SHC	Clay	Silt	Sand	Ca
NH_4^+ leaching	Pearson correlation	1	−0.138	−0.556	0.760*	−0.846**	−0.741*	0.851**	0.015	−0.426	0.539	−0.004
	Sig. (two-tailed)		0.745	0.152	0.029	0.008	0.035	0.007	0.971	0.293	0.168	0.992
	N	8	8	8	8	8	8	8	8	8	8	8
EC	Pearson correlation	0.760*	−0.520	−0.520	1	−0.617	−0.533	0.682	0.350	−0.554	0.187	0.228
	Sig. (two-tailed)	0.029	0.187	0.186		0.103	0.174	0.062	0.396	0.154	0.657	0.587
	N	8	8	8	8	8	8	8	8	8	8	8
OM	Pearson correlation	−0.846**	0.069	0.362	−0.617	1	0.557	−0.931**	0.313	0.108	−0.633	0.317
	Sig. (two-tailed)	0.008	0.871	0.379	0.103		0.152	0.001	0.450	0.799	0.092	0.445
	N	8	8	8	8	8	8	8	8	8	8	8
pH	Pearson correlation	−0.741*	−0.043	0.862**	−0.533	0.557	1	−0.587	−0.160	0.215	−0.034	−0.301
	Sig. (two-tailed)	0.035	0.919	0.006	0.174	0.152		0.126	0.704	0.609	0.937	0.469
	N	8	8	8	8	8	8	8	8	8	8	8
SHC	Pearson correlation	0.851**	0.030	−0.360	0.682	−0.931**	−0.587	1	0.013	−0.404	0.514	−0.018
	Sig. (two-tailed)	0.007	0.944	0.382	0.062	0.001	0.126		0.975	0.321	0.192	0.966
	N	8	8	8	8	8	8	8	8	8	8	8

**Correlation is significant at the 0.01 level (two-tailed).

*Correlation is significant at the 0.05 level (two-tailed).

Table 5 | Multiple regression matrix of the first horizon

Coefficients						
		Unstandardized coefficients		Standardized coefficients		
Model		B	Std. Error	Beta	*t*	Sig.
1	(Constant)	8.207	5.422		1.514	0.227
	OM	−0.281	0.389	−0.413	−0.721	0.523
	SHC	0.172	1.079	0.099	0.160	0.883
	pH	−0.729	0.628	−0.307	−1.161	0.330
	EC	0.756	0.813	0.273	0.930	0.421

Table 6 | Stepwise regression analysis of the first horizon

Coefficients						
		Unstandardized coefficients		Standardized coefficients		
Model		B	Std. Error	Beta	*t*	Sig.
1	(Constant)	0.626	0.485		1.291	0.244
	SHC	1.477	0.373	0.851	3.964	0.007

It is noticed from the table of parameters that the statistical significance values of the independent variable (SHC) are less than the significance level (0.05), which indicates that the equation is well represented and can be adopted to predict changes in the ammonium leaching.

Second horizon

Table 7 shows the values of the correlation coefficients of the parameters in the second horizon.

According to the correlation matrix shown in Table 7, it is clear that ammonium leaching is associated with the independent variables: OM, SHC and EC where the statistical significance is less than 0.05. The correlation values were 0.821, 0.894 and 0.844, respectively.

When applying the multiple regression analysis in order to obtain the equation that links the variables, the values shown in Table 8 were obtained:

It is expressed by the multiple regression equation:

$$NH^{+}_{4\,(Leaching)} = 1.649 + 1.513(EC) + 0.571(SHC) - 0.291(OM) \tag{3}$$

It is noticed from the table of parameters that the values of statistical significance for each of the independent variables: OM and SHC are greater than the significance level (0.05), which indicates that the equation cannot be adopted to predict changes because the parameters are not significant, although the value of the correlation coefficient R reached 0.970 and the coefficient of determination $R^2 = 94.2\%$. This can be attributed to the fact that the values of the correlation coefficient between the variables are large, which causes a problem in predicting the washout process, to solve the problem a multiple regression test in a stepwise method was applied to obtain the values shown in Table 9.

It is noted from Table 9 that there are two corrected linear models:

The first one is expressed by the equation:

$$NH^{+}_{4\,(Leaching)} = 4.277 - 0.815(OM) \tag{4}$$

The value of the correlation coefficient was $R = 0.894$, and the coefficient of determination $R^2 = 76.5\%$.

Table 7 | Parameter correlation matrix of the second horizon

Correlations

		NH_4^+ leaching	N−total	$CaCO_3$	EC	OM	pH	SHC	Clay	Silt	Sand	Ca
NH_4^+ leaching	Pearson correlation	1	0.076	−0.333	0.821*	−0.894**	−0.419	0.844**	0.191	−0.458	0.180	0.191
	Sig. (two-tailed)		0.858	0.420	0.012	0.003	0.302	0.008	0.651	0.253	0.670	0.650
	N	8	8	8	8	8	8	8	8	8	8	8
EC	Pearson correlation	0.821*	−0.042	−0.435	1	−0.599	−0.435	0.494	0.570	−0.641	−0.273	0.497
	Sig. (two-tailed)	0.012	0.922	0.281		0.116	0.282	0.213	0.140	0.087	0.514	0.210
	N	8	8	8	8	8	8	8	8	8	8	8
OM	Pearson correlation	−0.894**	−0.033	0.343	−0.599	1	0.434	−0.915**	−0.037	0.407	−0.387	−0.067
	Sig. (two-tailed)	0.003	0.938	0.406	0.116		0.282	0.001	0.931	0.317	0.343	0.876
	N	8	8	8	8	8	8	8	8	8	8	8
SHC	Pearson correlation	0.844**	0.416	−0.320	0.494	−0.915**	−0.430	1	0.039	−0.308	0.275	0.168
	Sig. (two-tailed)	0.008	0.306	0.440	0.213	0.001	0.288		0.927	0.457	0.510	0.691
	N	8	8	8	8	8	8	8	8	8	8	8

**Correlation is significant at the 0.01 level (two-tailed).

*Correlation is significant at the 0.05 level (two-tailed).

Table 8 | The multiple regression matrix of the second horizon

Coefficients

Model		**Unstandardized coefficients**		**Standardized coefficients**		
		B	**Std. Error**	**Beta**	***t***	**Sig.**
1	(Constant)	1.649	1.442		1.143	0.317
	SHC	0.571	0.542	0.319	1.052	0.352
	OM	−0.291	0.300	−0.319	−0.968	0.388
	EC	1.513	0.490	0.472	3.091	0.037

Table 9 | Stepwise regression matrix of the second horizon

Coefficients

Model		**Unstandardized coefficients**		**Standardized coefficients**		
		B	**Std. Error**	**Beta**	***t***	**Sig.**
1	(Constant)	4.277	0.457		9.367	0.000
	OM	−0.815	0.167	−0.894	−4.874	0.003
2	(Constant)	3.069	0.512		5.990	0.002
	OM	−0.572	0.139	−0.627	−4.114	0.009
	EC	1.428	0.488	0.446	2.926	0.033

The second linear model is expressed by the equation:

$$NH_{4\ (Leaching)}^{+} = 3.069 + 1.428(pH) - 0.572(OM) \quad (5)$$

The value of the correlation coefficient R and the coefficient of determination R^2 were 0.962 and 92.6%, respectively. It is also noted from the table of parameters that the significance values of the variables and the constant were less than the significance level (0.05), which indicates that the two equations are a very well representative for the study of predicting the process of ammonium washout.

Third horizon

Table 10 shows the values of the correlation coefficients of the parameters in the third horizon. It is noticed from the correlation matrix that the variable is associated with the variables: OM, SHC and EC, with the following values: 0.709, 0.796 and −0.816, respectively.

When applying multiple regression analysis according to the Enter method for obtaining the equation that links the variables, the values shown in Table 11 were obtained as follows:

It is expressed by the equation:

$$NH_{4\ (Leaching)}^{+} = 0.966 + 0.993(EC) + 1.072(SHC) - 0.246(OM) \quad (6)$$

It is noted from the table of parameters (Table 11) that the values of the statistical significance (Sig.) for each of the independent and constant variables are greater than the significance level (0.05), which indicates that the equation cannot be adopted to predict changes since the parameters are not significant, although the value of the correlation coefficient reached the value $R = 0.907$ and the coefficient of determination $R^2 = 82.3\%$. This can be attributed to the fact that the values of the correlation coefficient between the variables are large, which causes a problem in predicting the leaching process. To solve the problem, we apply the multiple regression test by stepwise method to obtain the values shown in Table 12.

Table 10 | Parameter correlation matrix of the third horizon

Correlations

		NH_4^+ leaching	N^- total	$CaCO_3$	EC	OM	pH	SHC	Clay	Silt	Sand	Ca
NH_4^+ leaching	Pearson correlation	1	0.387	−0.432	0.709*	−0.816*	−0.319	0.796*	0.219	−0.504	0.180	0.274
	Sig. (two-tailed)		0.344	0.286	0.049	0.014	0.440	0.018	0.602	0.203	0.669	0.512
	N	8	8	8	8	8	8	8	8	8	8	8
EC	Pearson correlation	0.709*	0.258	−0.655	1	−0.574	−0.589	0.415	0.723*	−0.785*	−0.378	0.664
	Sig. (two-tailed)	0.049	0.537	0.078		0.137	0.125	0.307	0.042	0.021	0.356	0.072
	N	8	8	8	8	8	8	8	8	8	8	8
OM	Pearson correlation	−0.816*	−0.192	0.652	−0.574	1	0.584	−0.799*	−0.241	0.560	−0.204	−0.216
	Sig. (two-tailed)	0.014	0.649	0.080	0.137		0.128	0.017	0.565	0.149	0.627	0.607
	N	8	8	8	8	8	8	8	8	8	8	8
SHC	Pearson correlation	0.796*	0.518	−0.587	0.415	−0.799*	−0.513	1	0.126	−0.313	0.130	0.261
	Sig. (two-tailed)	0.018	0.188	0.126	0.307	0.017	0.194		0.767	0.451	0.758	0.533
	N	8	8	8	8	8	8	8	8	8	8	8

**Correlation is significant at the 0.01 level (two-tailed).

*Correlation is significant at the 0.05 level (two-tailed).

Table 11 | Multiple regression matrix of the third horizon

Coefficients

Model		Unstandardized coefficients B	Std. Error	Standardized coefficients Beta	*t*	Sig.
1	(Constant)	0.966	1.574		0.614	0.572
	SHC	1.072	0.846	0.445	1.267	0.274
	OM	−0.246	0.404	−0.237	−0.608	0.576
	Ec	0.993	0.661	0.388	10.503	0.207

Table 12 | Stepwise regression matrix of the third horizon

Coefficients

Model		Unstandardized coefficients B	Std. Error	Standardized coefficients Beta	*t*	Sig.
1	(Constant)	3.538	0.518		6.830	0.000
	OM	−0.844	0.245	−0.816	−3.452	0.014

It is expressed by the equation:

$$NH^{+}_{4\,(\text{Leaching})} = 3.538 - 0.844(\text{OM}) \tag{7}$$

It was noticed from the table of the parameters that the significant values of the independent variable (OM) were less than the significance level (0.05). This may indicate that the equation is very well represented and can be adopted to predict the potential changes in the ammonium ion leaching.

CONCLUSIONS

(1) When studying the ammonium ion leaching according to the soil horizons of the studied sites, the leaching levels were decreasing with depth, as the highest concentrations of the leached ammonium ion were in the first horizon, due to the positive charge of the ammonium ion and its adsorption on OM and clay minerals.
(2) When studying the ammonium ion leaching according to the studied area, it was found that the sites of Beit Anna, Qutaibiya, Qurafis and the Oasis Spring were characterized by their soil and horizons with high leaching levels. The highest concentration of ammonium ion leaching was obtained in two periods, the first in December and the second in March, The lowest concentration was recorded in February, while it was in the sites: Pastoer, Beit Al-Alouni, Jebol and Al-Rahbeya, which had lower levels of leaching compared to the previous sites, and the highest concentration of ammonium ion leaching was recorded in the first two periods in December and the second in March, and the lowest concentration was recorded in the month of January.
(3) The statistical study showed that the washed ammonium ion concentration is a statistically significant indicator of ammonium pollution, and the main factors for the increase in ammonium ion transfer within soil horizons are the OM and the saturated water hydraulic conductivity. Hydro-conductivity and pH, the predictive power can be improved if average rainfall is taken into account.
(4) The regression equations, which were devised in the study, can be used as a representative mathematical model of the ammonium ion leaching in the three horizons, and its role in evaluating the leaching of the ammonium ion in the soil horizons.

RECOMMENDATIONS

(1) Follow-up on conducting laboratory experiments to develop mathematical models, in order to identify agricultural environmental indicators that support the design of management and control policies.

(2) Studying the effect of climatic data separately on the ammonium ion leaching from soil to groundwater.
(3) Study of the different levels of fertilization and its effect, in relation to soil factors, on the process of transporting and washing away the ammonium ion and its accumulation in the soil and its transfer to groundwater and water bodies.
(4) Studying the effect of human activities, especially industrial and sewage water, on the ammonium ion leaching.
(5) Adding urea fertilizer to the soil, with higher frequency and smaller quantities.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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