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Comprehensive Assessment of Soil Chemical Properties for Land Reclamation Purposes in the Toshka Area, EGYPT

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Abstract: Among soil parameters, Soil Chemical Properties (SCPs) are a crucial factor for the evaluation of chemical and fertility indices, proper decision-making regarding land reclamation, and land cultivation. In this work, 32 samples were collected from the surface (0–30 cm) and subsurface (30–60 cm) layers from 16 selected positions using GIS in the Toshka area (23°30′ and 23°60′ N latitude and 31°32′ and 31°36′ E longitude), Aswan, Egypt. Our results revealed that the soil reaction ranged from slightly (7.25) to moderately alkaline (8.19) and was characterized as a moderately saline and calcareous soil; however, the minimum ECe and $CaCO_3$ values exceeded 4.30 $dS{\cdot}m^{-1}$ and 12.80%, respectively. Furthermore, there was a significant decrease in the soil organic matter (not exceeding 0.11%) and available nutrient contents. The cation exchange capacity was moderate. The correlation coefficient between the studied SCPs fluctuated between positive and negative. In brief, the area can be reclaimed through a proper reclaiming plan and the selection of the most suitable crops to treat the undesirable characteristics.

Keywords: soil chemical parameters; spatial nutrients distribution; land reclamation and cultivation; chemical and fertility indexes

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1. Introduction

Globally, it is expected that the world's population will nearly double from 2020 to 2050 [1]. Furthermore, more than one billion people currently suffer from hunger, and about 33 countries in the developing world have extremely alarming hunger levels [2]. Egypt is a developing country that suffers from food insecurity resulting from extreme population growth [3] alongside limited agricultural land. Generally, economic development is significantly dependent on the agricultural sector, which represents 40% of the Egyptian workforce in Egypt. According to Sultana et al. [4], the agricultural sector is the third largest after tourism and cash remittance from Egyptian workers abroad. The best way to address these difficulties is to reclaim land and modify its undesirable properties to improve productivity [5]. Recently, the political leadership has launched agricultural investment projects in order to achieve agricultural sustainable development goals, especially in the border desert Governorates—such as Toshka, the East Oweinat, and 375,00 million-hectare projects for land reclamation—in order to overcome the gap between production and consumption and reduce importation volume, especially of strategic crops [6–8].

Generally speaking, the total area of Egypt is approximately 1,000,000 km^2. The cultivated area does not exceed about 4%, and is confined to the Nile valley and its delta. Accordingly, 96% is desert, comprising the Western and Eastern deserts. The total area of the Western desert of Egypt covers about 680,650 km^2, equivalent to two thirds of the land area of Egypt, and is untapped agriculturally. This area is inhabited; however, about 95% of Egyptian people live on the banks of the River Nile and its delta, with a population density of 1500 persons·km^2, whereas the Western Desert has a population density of 5 persons·km^2.

The River Nile is the second longest river in the world and is the main water source in Egypt. Our investigation was implemented in one of the most important agricultural investment attractions, the Toshka project, which is located in the southeastern part of the Western desert. It belongs to the Aswan Governorate and is situated about 250 km south of Aswan city. This area lies between latitude 22°30′ and 23°30′ N and longitude 30°30′ and 32°00′ E, and consists of many interconnected depressions covering about 540,000 acres. It falls into an extremely arid belt, with long hot summers and short warm winters, as well as markedly low precipitation. This project is aimed at maximizing the return of available resources and increasing agricultural exports, thereby helping to reduce the trade balance deficit and providing job opportunities for many young people. El-Sheikh Zayed canal is considered the main irrigation source in this area. This canal branches from the River Nile into four sub-branches, carrying Nile water for reclamation purposes [9]. Based on the aforementioned, the need to reclaim these lands and make them cultivable has become urgent in order to address the huge shortage in agricultural production resulting from the extreme increase in population growth, and to achieve self-sufficiency in strategic crops, especially after the Russian–Ukraine crisis.

The accurate determination of the spatial distribution of soil chemical characteristics, including soil fertility, is important for making proper reclamation plans [10], and is defined as the process of returning disturbed land to stability. The success of reclamation depends upon the evaluation of soil chemical and physical properties, as well as the development of favorable conditions, determining future crop patterns, and evaluating their productivity capabilities [11–14]. Due to soil productivity directly depending on soil fertility, most studies on soil productivity can be categorized into two main areas: (i) evaluation of soil productivity, and (ii) studying the influential factors in productivity. Soil fertility is a common term in agricultural sustainable development and can be defined as the ability of the soil to supply plants with the nutrients required in accurate quantities and correct proportions [15]. Salem et al. [16] and NajafiGhiri et al. [17] reported that climatic conditions, as natural factors including temperature, solar radiation, precipitation, evaporation, and wind speed, play an influential role in assessing the soil fertility and, thus, its impact on productivity. Accordingly, soil fertility can be defined according to the type of land use, with [17] determining it on the basis of soil chemical properties such as soil reaction (soil pH), Soil Organic Matter (SOM) content, and available nutrients. Pieri et al. [18] defined it as the quality and capacity of the land, including the soil, climate, topography, and biological characteristics, for production and environment management purposes, while [19] suggested that Soil Quality (SQ) is an account of the ability of the land to provide ecosystem and social services through its ability to perform its function under changing conditions. Williams et al. [20] defined it as soil's living ecosystems' ability to support plants, animals, and human activities, including agriculture. Therefore, the simplest definition of SQ is an assessment of the capabilities of soil performance. According to [21–23], there are several methods to assess SQ, including indicators of a physical, chemical, or biological nature. In general, Carter [24] indicated that there is no consensus on the definition of soil fertility.

Although there is a scarcity of available studies regarding new soil assessment in Egypt, the general trend is one of lands ranging from neutral to extremely alkaline, with a noticeable decrease in their SOM content and available nutrient content, while a wide variation has been observed in the Electrical Conductivity (ECe) and $CaCO_3$ values obtained depending on the nature of the parent materials and the predominant climatic conditions [9,25–28].

Therefore, this investigation aimed to determine the soil chemical properties at two depths (0–30 and 30–60 cm), representing the surface and subsurface layers, in order to evaluate the SQ as a first step towards implementing reclaiming strategies on a proper scientific basis, and thus, selecting the most suitable crops for cultivation in the study area to achieve self-sufficiency and place Egypt among the ranks of the agriculturally advanced countries.

2. Materials and Methods

2.1. Description of the Study Area and Climatic Conditions

This investigation was carried out in one of the most promising areas for agricultural investment in Egypt, the Toshka area. Geographically, the Toshka area is located between latitude 22°30′ and 23°30′ N and longitude 30°30′ and 32°00′ E, with a total area of 540,000 acres in the southern part of the Western Desert, belonging to the Aswan Governorate. It consists of many of interconnected depressions. The Sheikh Zayed Canal is the main source of irrigation water from the River Nile. It has four sub-branches carrying Nile water to irrigate different parts. The studied area lies between latitudes 23°20′00″ and 23°60′00″ N and longitude 31°32′00″ and 31°36′00″, as shown in Figure 1. The climatic data, as averages from the last 30 years (1992–2021), are presented in Table 1.

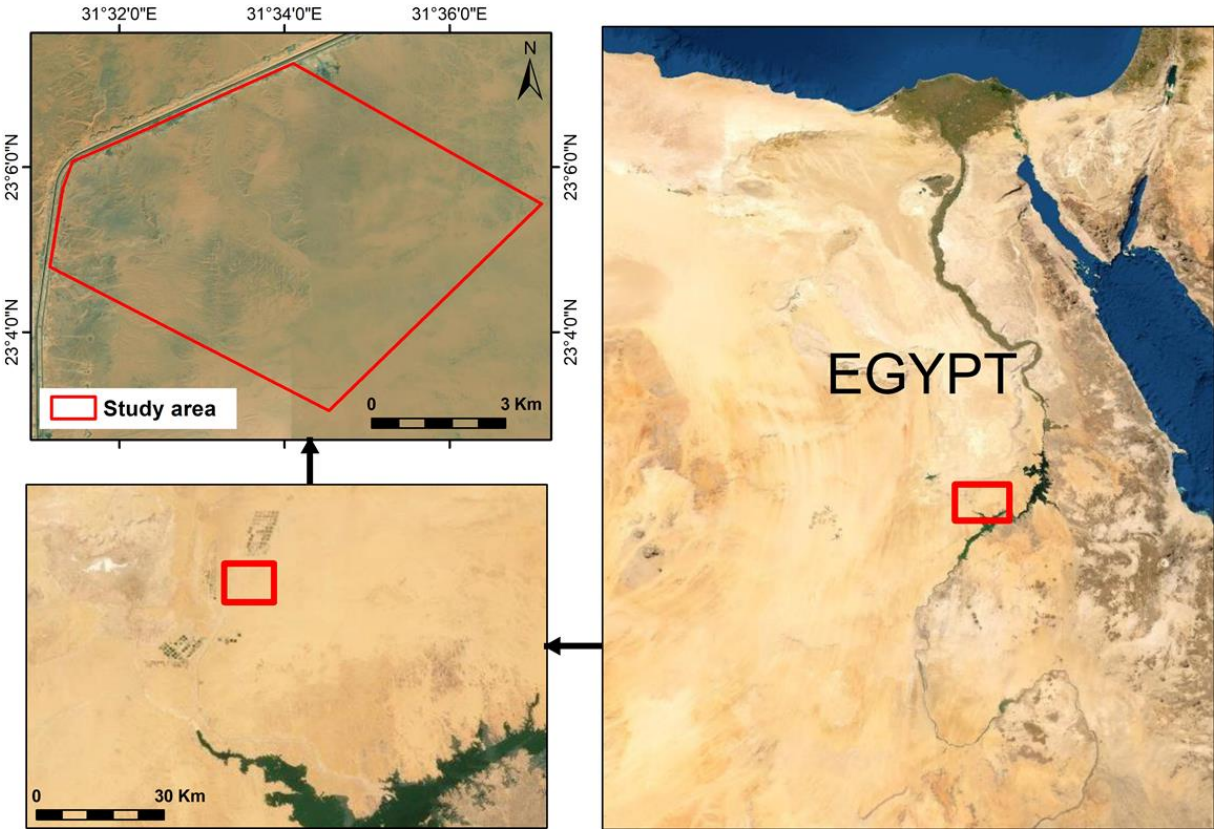

Figure 1. Map location of the studied area.

2.2. Soil Sample Collection and Preparation

Thirty-two soil samples were collected from sixteen positions. Soil samples were taken in February 2020 from two consequential depths, surface and subsurface (0–30 and 30–60 cm, respectively), as assigned by the Geographic Information System (GPS). GIS devices have proven successful in assessing and mapping soil fertility. Soil fertility maps can promote development with more precise and important data required for creating supplemental administration programs. The GPS was adjusted to acquire UTM coordinates of the soil samples. The collection of samples depended on the distance between positions and morphological characteristics of the soil in order to represent all soil variations. The obtained data included topographic maps that were digitized using the ArcGIS 10.8.2 software to produce the base map of the GIS soil map. The coordinates, sample numbers, and symbols are presented in Table 2.

Table 1. Climatic data of Toshka area, Aswan district, Egypt; average of last 30 years (1991–2021).

Month	Average Temperature			Average Humidity	Average Wind Speed	Average Precipitation
	Max.	Min.	Mean			
January	27.88	3.30	13.67	42.33	2.94	0.00
February	31.80	4.11	15.98	32.98	3.07	0.01
March	37.54	7.67	20.59	24.03	3.25	0.00
April	42.37	11.57	26.05	17.74	3.38	0.00
May	44.96	16.99	30.53	16.49	3.59	0.00
June	45.27	21.24	32.77	16.74	3.90	0.00
July	44.37	23.00	33.65	18.15	3.58	0.00
August	44.56	23.66	33.84	19.59	3.72	0.00
September	42.95	20.31	31.09	22.81	4.11	0.00
October	40.33	15.16	26.74	28.28	3.85	0.00
November	33.73	9.23	20.03	38.06	3.24	0.00
December	28.34	4.80	14.93	45.05	3.04	0.00
Average	46.24	2.72	25.03	26.84	3.47	0.00

Source: https://www.power.larnc.php, accessed on 22 August 2022.

Table 2. The position, coordinates, depth, number, and symbols of samples in study area.

Position	Coordinates		Depth (cm)			
			0–30		30–60	
	Latitude N	Longitude E	Sample No.	Symbol	Sample No.	Symbol
1	23, 016366	31, 562427	1	AA_1	17	aa_1
2	23, 106825	31, 579489	2	AA_2	18	aa_2
3	23, 098874	31, 597729	3	AA_3	19	aa_3
4	23, 095585	31, 603224	4	AA_4	20	aa_4
5	23, 107061	31, 545507	5	BB_1	21	bb_1
6	23, 098458	31, 564112	6	BB_2	22	bb_2
7	23, 090853	31, 582186	7	BB_3	23	bb_3
8	23, 084447	31, 600490	8	BB_4	24	bb_4
9	23, 099278	31, 529625	9	CC_1	25	cc_1
10	23, 090910	31, 545520	10	CC_2	26	cc_2
11	23, 084391	31, 565033	11	CC_3	27	cc_3
12	23, 077438	31, 581355	12	CC_4	28	cc_4
13	23, 081814	31, 530447	13	DD_1	29	dd_1
14	23, 075473	31, 549800	14	DD_2	30	dd_2
15	23, 068928	31, 564684	15	DD_3	31	dd_3
16	23, 059622	31, 578320	16	DD_4	32	dd_4

2.3. Soil Chemical Properties Determination

The soil samples were transported for soil, water, and plant analysis to the Faculty of Agriculture and Natural Resources, Aswan University. The collected samples were air-dried and crushed to pass through a 2 mm sieve. The particle size distribution was determined using the hydrometer method, in accordance with the methods of Bouyoucos [29]. The soil pH and ECe were directly measured in saturated soil paste and its extract using a pH meter (Jenway, UK), as described in [30], and an EC-meter (LF-191 Conduktometer, Germany), as according to Page et al. [31]. Total carbonates were determined as $CaCO_3$ using Collin's calcimeter [32].

Furthermore, the SOM content was determined with the wet digestion method as according to Walkey and Sommers [33] and as described by [34]. With 1 N NH_4AC at pH = 7.0 (W/V), the soluble cations, i.e., Na^+, K^+, Ca^{++}, and Mg^{++}, were extracted, kept overnight, filtrated using Whatman filter paper, kept overnight again, and filtrated with Whatman filter paper NO. 42 before the final volume was set to 100 mL with distilled water. Both Na^+ and K^+ were measured using flame photometry [35]. Ca^{++} and Mg^{++} were determined with the titration method using EDTA [35]. The soluble anions, i.e., HCO_3^-,

CO_3^{--} and Cl^-, were determined with the titration method according to [30], while sulfate (SO_4^{--}) was calculated by subtracting the total soluble cations from the total soluble anions. The CEC, i.e., Cation Exchange Capacity, was extracted using 1 M NH_4AC at pH = 7.0 and measured after leaching the NH_4AC from extracted soil samples with 10% Sodium Chloride (NaCl) solution. The Na^+ replaced the NH_4^+ ions and the amount of NH_4^+ was determined in the percolate by the micro-Kjeldahl method [36].

With regards to the determination of available macronutrients, i.e., nitrogen, these were determined by the modified micro-Kjeldahl procedure, as per [37], while phosphorus was extracted and determined by the method described by [35] and potassium was extracted using neutral normal ammonium acetate 1 N (NH_4OAC) at pH 7.0 and determined by flame photometer (Jenway model PFP-7), as described in [35]. The available micronutrients, i.e., iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu), were extracted with 0.005 M diethylenetriamine penta-acetic acid (DPTA) at pH = 7.3 (Lindsay and Norvell, 1978) [38]. DTPA-extractable Fe, Mn, Zn, and Cu were determined by inductively coupled plasma optical emission spectrometry (ICP-EOS, PerkinElmer OPTIMA 2001 DV, Norwalk, CT, USA), as described in [39].

3. Results

3.1. Particle Size Distribution and Soil Texture

The results, as seen in in Table 3, indicated that several categories were found in the surface and subsurface (0–30 and 30–60 cm, respectively) layers of the study location, according to the relative distributions of sand, silt, and clay as represented on a soil-texture triangle.

The data showed that the sand distribution ranged from 45.20 to 73.80 and 42.60 to 71.20%, with averages of 61.25 and 59.01%; the silt distribution ranged from 17.34 to 28.40 and 6.80 to 29.50%, with averages of 22.97 and 23.76%; and the clay distribution ranged from 8.50 to 26.40 and 7.90 to 27.90%, with averages of 15.78 and 17.23% in the surface and subsurface samples, respectively. Accordingly, the soil texture was predominantly sandy loam in about two thirds of the area (68.75 and 62.50%) in both layers. Samples 7, 10, and 15 (about 18.75%) in the surface layer, and samples 23, 26, 30, and 31 (about 25.00%) in the subsurface layer, were classified as sandy clay loam. The loamy texture (about 12.50%) was only present in the surface layer in samples 3 and 11, whereas the clay loam texture (18.75%) was only present in the subsurface layer in samples 17, 19, and 27.

Table 3. Spatial distribution of particle size distribution and assigned soil texture in surface and subsurface (0–30 and 30–60) layers in Toshka area, Aswan, Egypt.

Depth (cm)	Sample No	Symbol	Particle Size Distribution			Texture
			Sand	Silt	Clay	
			(%)			
0–30	1	AA_1	53.6	27.1	19.3	Sandy loam
	2	AA_2	70.4	20.3	9.3	Sandy loam
	3	AA_3	45.2	28.4	26.4	Loam
	4	AA_4	70.8	19.3	9.9	Sandy loam
	5	BB_1	72.5	18.6	8.9	Sandy loam
	6	BB_2	61.9	23.5	14.6	Sandy loam
	7	BB_3	47.5	27.2	25.3	Sandy clay loam
	8	BB_4	73.8	17.6	8.6	Sandy loam
	9	CC_1	72.5	19.0	8.5	Sandy loam
	10	CC_2	51.1	25.3	23.6	Sandy clay loam
	11	CC_3	45.7	28.2	26.1	Loam
	12	CC_4	70.1	20.3	9.6	Sandy loam

Table 3. *Cont.*

Depth (cm)	Sample No	Symbol	Particle Size Distribution			Texture
			Sand	Silt	Clay	
			(%)			
	13	DD_1	62.1	24.2	13.7	Sandy loam
	14	DD_2	59.5	24.1	16.4	Sandy loam
	15	DD_3	49.6	27.0	23.4	Sandy clay loam
	16	DD_4	73.3	17.4	8.9	Sandy loam
30–60	17	aa_1	43.1	29.4	27.5	Clay loam
	18	aa_2	69.8	19.1	11.2	Sandy loam
	19	aa_3	42.6	29.5	27.9	Clay loam
	20	aa_4	68.0	21.7	10.3	Sandy loam
	21	bb_1	70.1	20.4	9.5	Sandy loam
	22	bb_2	59.5	24.0	16.5	Sandy loam
	23	bb_3	48.9	26.5	24.6	Sandy clay loam
	24	bb_4	71.2	19.5	9.3	Sandy loam
	25	cc_1	73.7	18.4	7.9	Sandy loam
	26	cc_2	48.1	27.0	24.9	Sandy clay loam
	27	cc_3	43.3	29.5	27.2	Clay loam
	28	cc_4	69.9	20.8	9.3	Sandy loam
	29	dd_1	64.3	23.5	13.2	Sandy loam
	30	dd_2	51.5	26.1	22.4	Sandy clay loam
	31	dd_3	49.4	26.5	24.1	Sandy clay loam
	32	dd_4	70.8	19.3	9.9	Sandy loam

3.2. Soil Chemical Properties

3.2.1. Soil pH, $CaCO_3$ Content, Soil Organic Matter, and Cation Exchange Capacity

The spatial distributions of soil pH, $CaCO_3$, and SOM content, with ECe as an indicator for salinity and CEC at the surface and subsurface layers, are presented in Table 4.

The results showed that the maximum soil pH values (7.96 vs. 8.19) were detected in sample 1 (AA_1) at the surface layer and sample 22 (cc_3) at the subsurface layer.

The minimum soil pH values (7.76 vs. 7.25) were obtained in sample 16 (DD_4) at the surface layer and in sample 23 (bb_3) at the subsurface layer. The pH values indicated that about 87.50 and 12.50% of the measured samples fell into natural and mildly alkaline, respectively, while about 6.25, 62.50, and 31.25% were categorized as natural, mildly alkaline, and moderately alkaline in the subsurface layer, respectively. The SOM values did not exceed 0.19% in both surface and subsurface layers. These obtained values serve as clear evidence of the poverty in the study area in terms of SOM contents.

As shown in Table 4 and Figures 2 and 3, all the studied samples had $CaCO_3$ and ECe values of more than 11.00% and 4.00 $dS.m^{-1}$. The $CaCO_3$ content varied from 12.30 to 18.60 and 11.30 to 16.80%, with averages of 14.29 and 14.29% at both depths. These values for the overall studied samples were characterized as moderately calcareous. The ECe values had a wide variation between 5.00–10.70 and 4.30–12.50 $dS.m^{-1}$, with averages of 7.98 and 8.58 $dS.m^{-1}$, respectively, in both layers. Accordingly, the studied soil was classified as 43.75% ranging from 4.0 to 8.0 $dS.m^{-1}$ (moderately saline) and 56.25% ranging from 8.0 to 16.0 $dS.m^{-1}$ (highly saline) in both layers.

With regards to CEC, the results depicted in Table 4 showed that the samples overall had a moderate capacity (ranging from 12.00 to 25.00 $Cmol_c \cdot kg^{-1}$). However, 17.80 and 18.60 $Cmol_c \cdot kg^{-1}$ were the superior values and were detected in samples 9 and 11 in both depths, respectively. The minimum values (12.80 and 12.20 $Cmol_c \cdot kg^{-1}$) were observed in samples 9 and 18 in the surface and subsurface layers, respectively.

Table 4. Spatial distribution of soil chemical properties in surface and subsurface (0–30 and 30–60) layers in Toshka area, Aswan, Egypt.

Depth (cm)	Sample No.	Symbol	Soil pH	$CaCO_3$ (%)	SOM (%)	ECe ($dS \cdot m^{-1}$)	CEC ($Cmol_c \cdot kg^{-1}$)
0–30	1	AA_1	7.96	15.80	0.19	6.50	16.30
	2	AA_2	7.85	12.60	0.15	5.00	14.00
	3	AA_3	7.91	13.40	0.16	8.10	16.50
	4	AA_4	7.77	15.30	0.14	6.00	13.00
	5	BB_1	7.85	17.20	0.11	10.70	14.60
	6	BB_2	7.77	18.60	0.11	8.10	15.70
	7	BB_3	7.81	13.20	0.13	8.20	17.00
	8	BB_4	7.79	17.30	0.14	12.60	13.00
	9	CC_1	7.87	15.10	0.12	9.50	12.80
	10	CC_2	7.86	13.80	0.13	5.80	15.30
	11	CC_3	7.83	12.60	0.12	8.40	17.80
	12	CC_4	7.85	12.50	0.13	7.50	14.00
	13	DD_1	7.82	13.30	0.12	5.60	15.30
	14	DD_2	7.85	13.30	0.15	9.20	15.30
	15	DD_3	7.80	12.40	0.15	7.90	16.50
	16	DD_4	7.76	12.30	0.12	8.60	13.60
30–60	17	aa_1	7.87	13.80	0.13	5.40	16.50
	18	aa_2	7.81	14.80	0.11	4.30	12.90
	19	aa_3	7.97	16.50	0.19	12.50	17.00
	20	aa_4	7.86	14.80	0.12	8.20	14.20
	21	bb_1	7.81	15.10	0.13	6.60	13.30
	22	bb_2	7.99	15.80	0.17	9.40	16.40
	23	bb_3	7.25	16.80	0.16	12.60	18.60
	24	bb_4	7.81	15.20	0.12	10.30	12.60
	25	cc_1	7.83	14.20	0.11	7.60	12.20
	26	cc_2	7.91	16.20	0.15	10.20	15.60
	27	cc_3	8.19	13.50	0.15	10.30	18.60
	28	cc_4	7.81	11.80	0.11	7.60	13.80
	29	dd_1	7.87	14.50	0.13	9.10	14.40
	30	dd_2	8.10	12.60	0.12	8.30	14.60
	31	dd_3	7.85	11.30	0.12	7.20	18.00
	32	dd_4	7.82	11.70	0.13	7.80	12.60

Soil pH = soil reaction, $CaCO_3$ = calcium carbonate content, SOM = soil organic matter, ECe = electrical conductivity, and CEC = cation exchange capacity.

3.2.2. Soil Fertility Status

The results pertaining to the evaluation of fertility status in the studied location are given in Table 5 and Figures 4–6. Generally, the results were clear evidence of a lack of available nutrients. Values of 33.30, 12.90, and 380.70 $mg \cdot kg^{-1}$ at the surface layer and 35.30, 13.00, and 349.40 $mg \cdot kg^{-1}$ at the subsurface layer were recorded as the highest values obtained, with averages of 23.63, 8.25, and 249.73 $mg \cdot kg^{-1}$ for AvN, AvP, and AvK, respectively. In contrast, values of 14.50, 5.70, and 216.80 $mg \cdot kg^{-1}$ at the depth of 0–30 cm and 16.50, 6.50, and 211.30 $mg \cdot kg^{-1}$ at the depth of 30–60 cm were recorded as the lowest values, with averages of 25.53, 9.22, and 275.69 $mg \cdot kg^{-1}$ for the abovementioned nutrients, respectively.

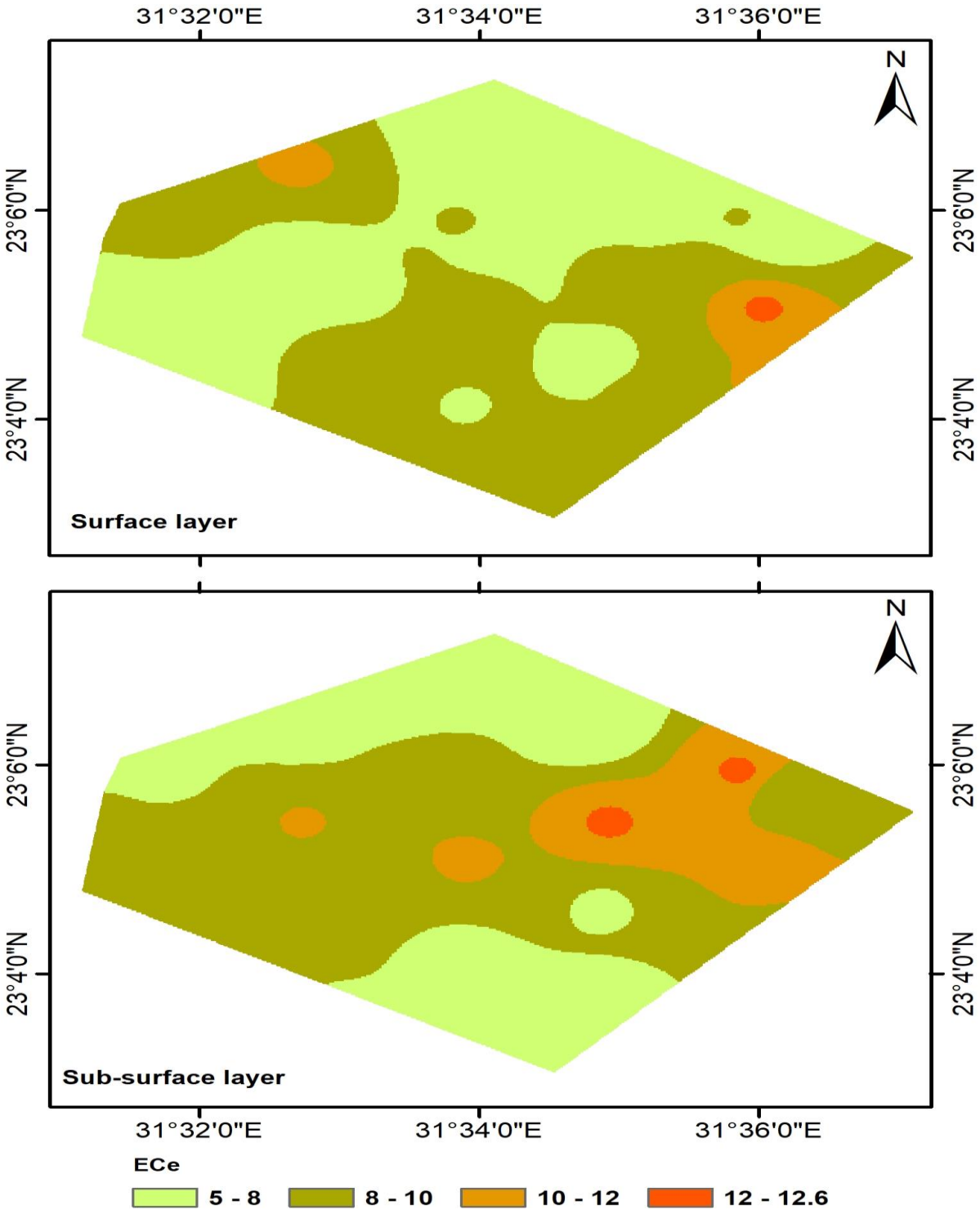

Figure 2. Spatial distribution of ECe values at the surface and subsurface layers (0–30 and 30–60 cm) of the studied area.

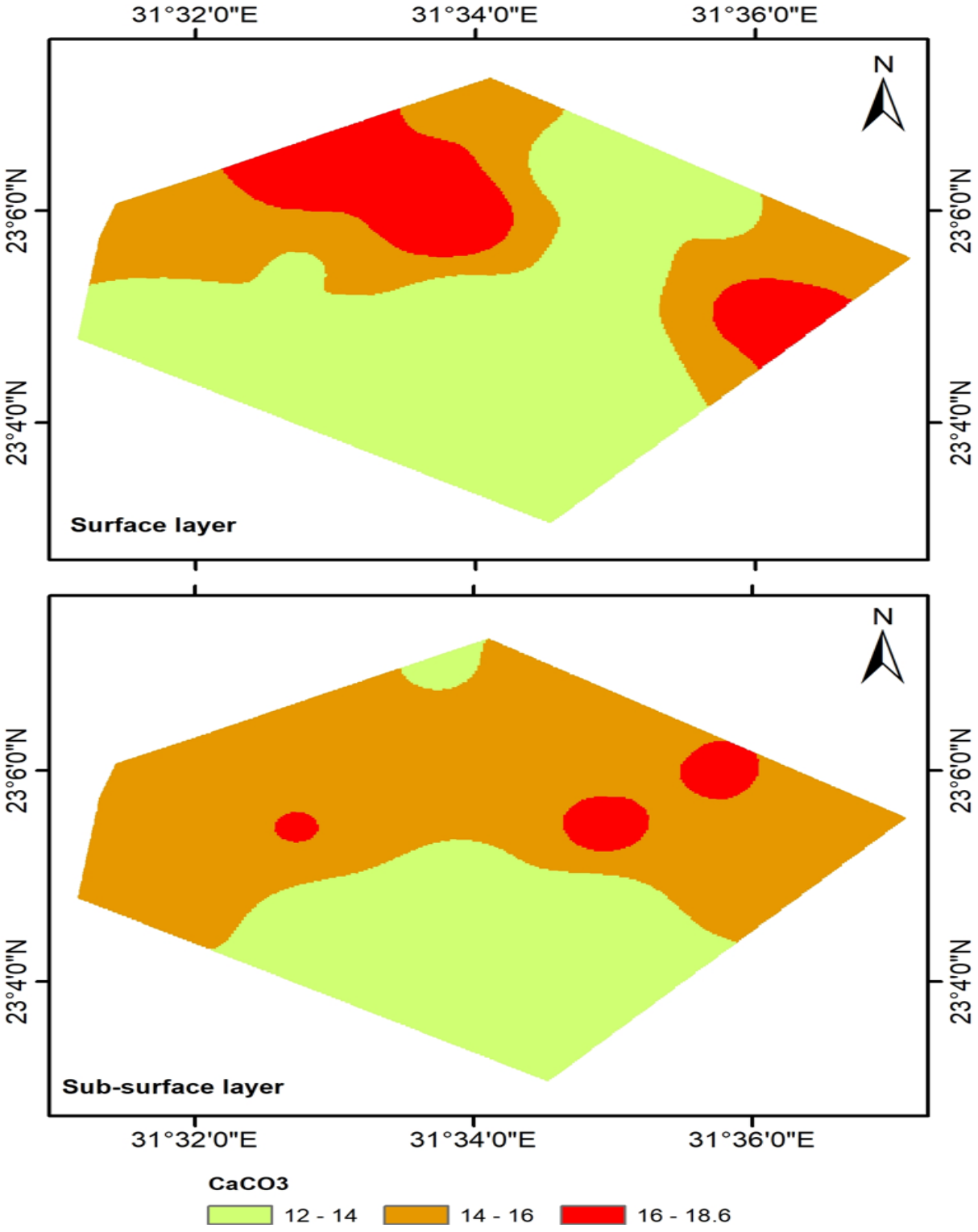

Figure 3. Spatial distribution of $CaCO_3$ content in the surface and subsurface layers (0–30 and 30–60 cm) of the studied area.

Table 5. Spatial distribution of some available macro- and micronutrient contents for surface (0–30) and subsurface layer (30–60) in Toshka area, Aswan, Egypt.

Depth (cm)	Sample No.	Symbol	Macronutrients			Micronutrients			
			AvN	AvP	AvK	AvFe	AvMn	AvZn	AvCu
			($mg \cdot kg^{-1}$)						
0–30	1	AA_1	23.6	12.8	380.7	3.9	1.8	1.1	0.4
	2	AA_2	21.4	9.4	223.2	2.9	1.5	0.9	0.3
	3	AA_3	29.6	12.9	227.8	3.6	1.6	0.9	0.2
	4	AA_4	18.7	11.6	244.7	2.2	1.8	0.7	0.5
	5	BB_1	19.3	6.8	206.7	2.7	1.4	0.6	1.4
	6	BB_2	31.4	7.6	264.2	3.2	1.4	1.1	1.4
	7	BB_3	14.8	6.3	239.8	3.6	1.5	1.3	1.5
	8	BB_4	19.5	7.5	236.5	3.8	1.8	0.9	1.8
	9	CC_1	14.5	5.3	246.2	3.4	1.6	0.9	0.4
	10	CC_2	21.6	6.2	274.5	3.5	1.3	1.2	0.3
	11	CC_3	21.8	5.7	239.6	3.6	1.5	0.7	0.2
	12	CC_4	31.3	7.2	216.8	3.6	1.7	1.3	0.2
	13	DD_1	21.1	5.9	271.1	3.2	1.3	1.1	0.4
	14	DD_2	27.9	11.2	266.2	3.2	1.5	1.1	0.4
	15	DD_3	28.3	8.0	236.5	3.6	1.5	1.1	0.2
	16	DD_4	33.3	7.6	221.2	3.4	1.8	1.3	0.3
30–60	17	aa_1	17.2	7.3	336.8	3.1	1.4	1.0	0.3
	18	aa_2	20.6	8.6	310.7	3.1	1.7	0.8	0.2
	19	aa_3	31.5	13.0	211.3	3.8	1.5	1.0	0.5
	20	aa_4	28.8	12.5	206.5	3.1	1.3	0.8	0.4
	21	bb_1	22.1	6.5	219.4	3.8	1.6	0.8	1.6
	22	bb_2	28.3	11.5	315.9	3.5	1.5	1.2	1.5
	23	bb_3	35.3	11.4	309.1	4.2	1.7	1.1	1.7
	24	bb_4	16.5	8.6	259.4	3.5	1.6	0.8	1.6
	25	cc_1	17.4	6.8	255.3	3.7	1.6	1.1	0.4
	26	cc_2	28.2	10.6	377.8	4.1	1.5	1.1	0.5
	27	cc_3	30.2	9.5	331.2	3.9	1.8	0.9	0.5
	28	cc_4	18.7	6.3	224.5	3.2	1.8	1.1	0.2
	29	dd_1	30.2	11.8	349.4	4.3	1.4	1.3	0.5
	30	dd_2	26.3	8.2	255.9	3.0	1.4	1.0	0.3
	31	dd_3	27.5	7.6	227.2	3.4	1.6	0.9	0.4
	32	dd_4	29.6	7.3	220.7	3.2	1.7	1.1	0.2

AvN, AvP, AvK, AvFe, AvMn, AvZn, and AvCu indicate available nitrogen, phosphorus, potassium, iron, manganese, zinc, and copper contents, respectively.

The results listed in Table 5 showed that the minimum and maximum values of AvFe and AvZn extracted by DTPA ranged from 2.20 to 3.90, 3.00 to 4.30, 0.60 to 1.30, and 0.80 to 1.30 $mg \cdot kg^{-1}$ at the surface and subsurface layers, respectively. Likewise, both AvMn and AvCu contents extracted by DTPA gave the same range, from 1.30 to 1.80 for AvMn and 0.20 to 0.50 $mg \cdot kg^{-1}$ for AvCu at the depths of 0–30 and 30–60 cm, respectively. Accordingly, mean values of 3.34 and 3.56 for AvFe, 1.56 and 1.57 for AvMn, 1.01 and 1.00 for AvZn, and 0.31 and 0.38 $mg \cdot kg^{-1}$ for AvCu were obtained at the respective depths. We observed that the overall sample values of the abovementioned micronutrients were in deficiency ranges. However, their contents in desert soils mainly depend on the rock derived from the parent materials and the prevailing weathering processes in the region.

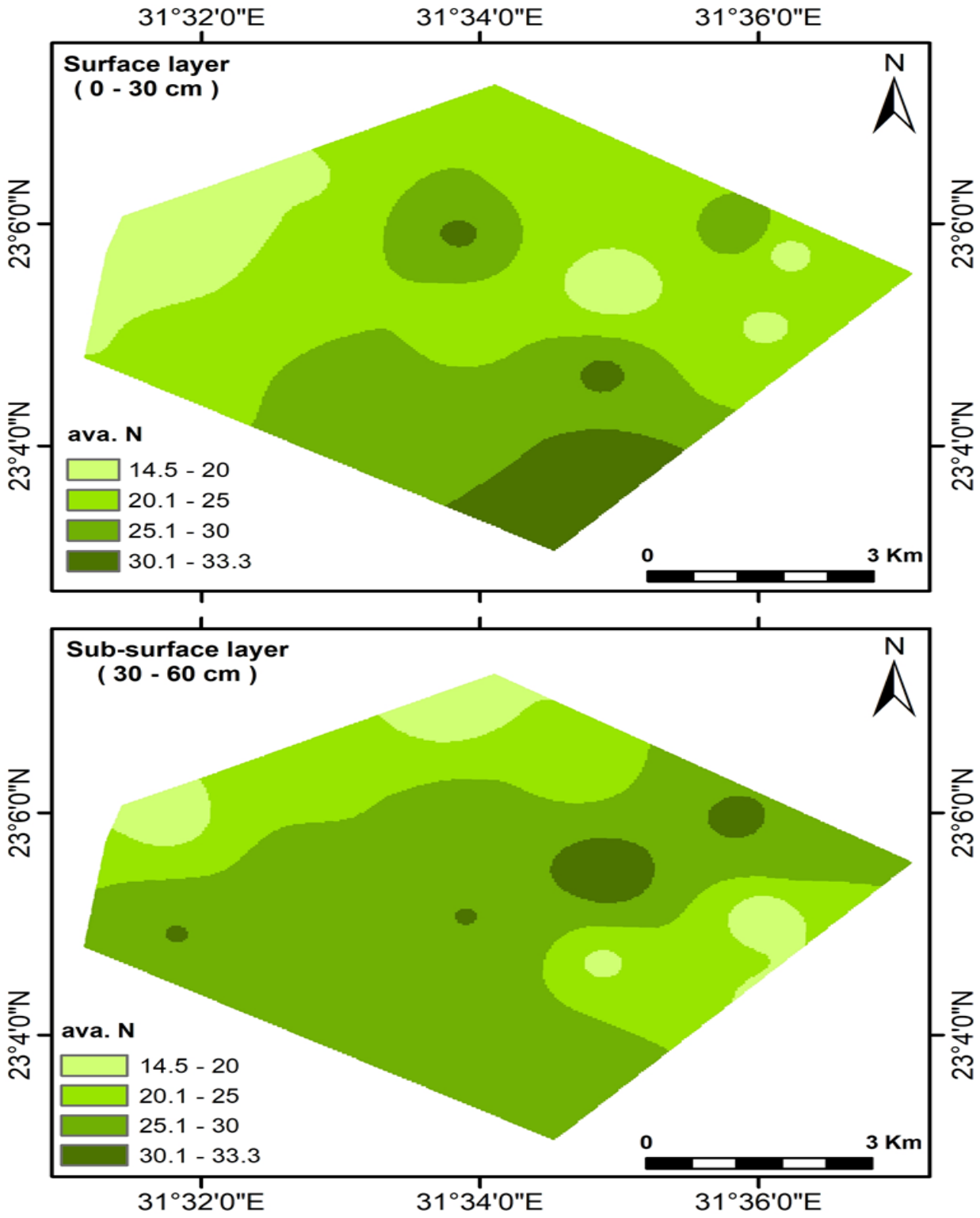

Figure 4. Spatial distribution of available nitrogen (AvN, mg·kg^{-1}) content in the surface and subsurface layers (0–30 and 30–60 cm) of the studied area.

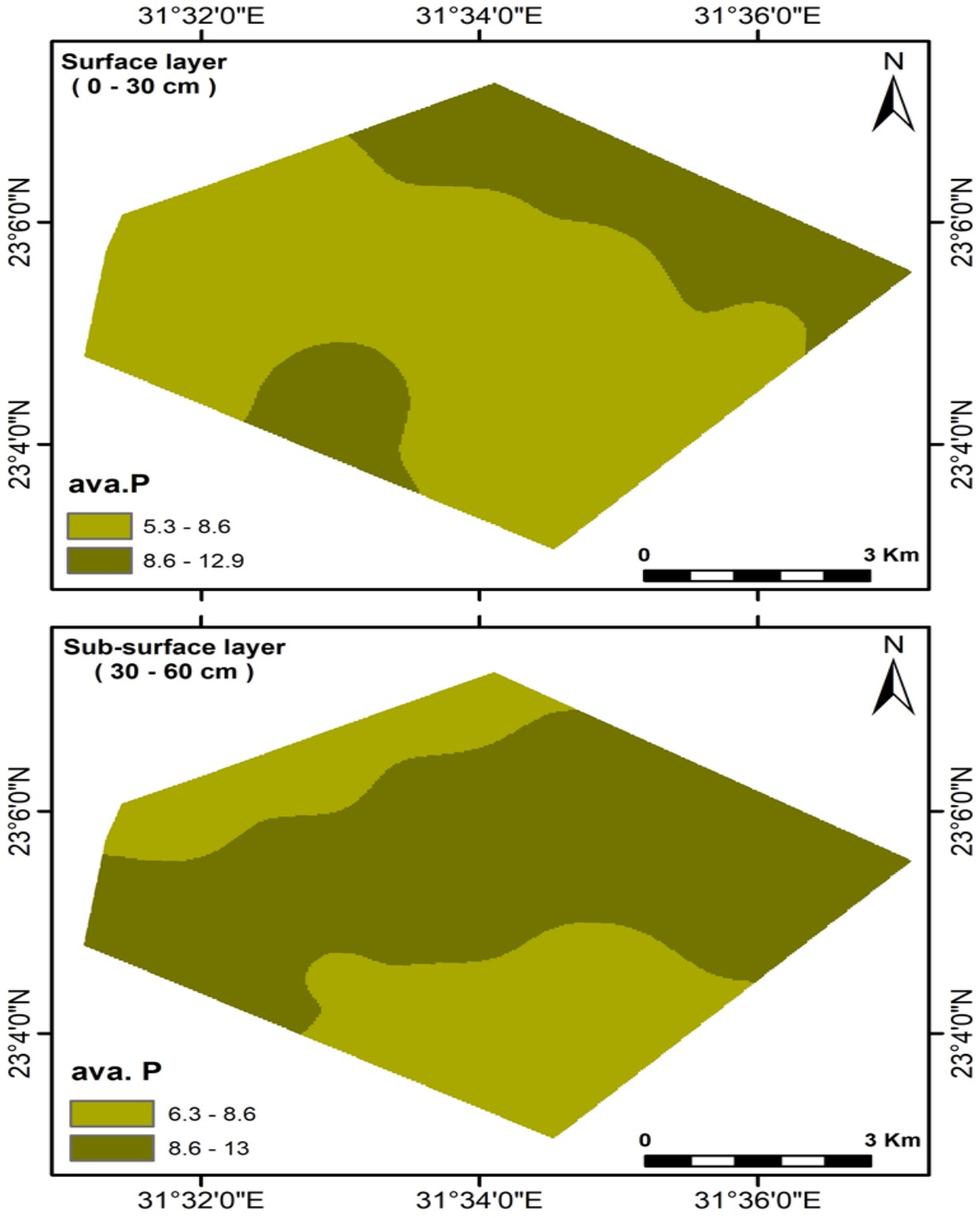

Figure 5. Spatial distribution of available phosphorus (AvP, mg·kg^{-1}) content in the surface and subsurface layers (0–30 and 30–60 cm) of the studied area.

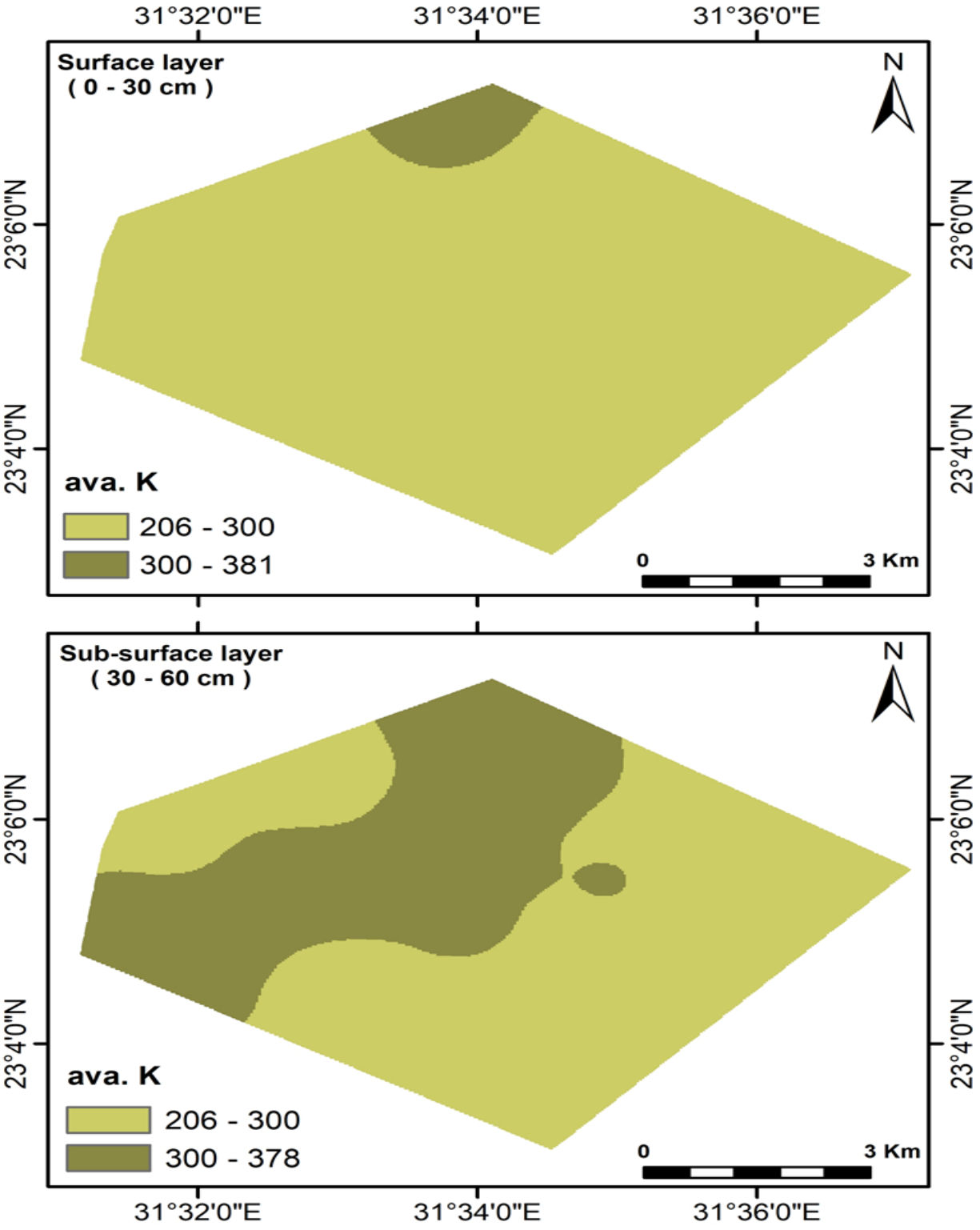

Figure 6. Spatial distribution of available potassium (AvK, mg·kg^{-1}) content in the surface and subsurface layers (0–30 and 30–60 cm) of the studied area.

3.2.3. Correlation Coefficient between Soil Texture and Soil Chemical Properties

Data presented in Table 6 show the correlation between the soil chemical properties studied and the particle size distribution in the surface (0–30 cm) and subsurface (30–60 cm) layers. The particle size has a profound effect on SOM. Sand content correlated negatively (r = −0.328 and −0.618 *) with SOM. On the other hand, silt content correlated positively (r = 0.381 and 0.629 **), as did clay (r = 0.292 and 0.608 *), with SOM in both the surface and subsurface layers. Meanwhile, the results revealed that SOM had a positive correlation (r = 0.102 and 0.645 **) with AvN, (r = 0.803 ** and 0.647 **) AvP, (r = 0.303 and 0.501 *) AvFe, and AvCu (r = 0.195 and 0.693 **) in both layers (0–30 and 30–60 cm).

A highly negative correlation (r = −0.922 ** and −0.886 **) of CEC was observed with sand content, while a strong positive correlation (r = 0.932 ** and 0.886 **) was found for silt and clay (r = 0.898 ** and 0.879 **) content in both the surface and subsurface layers.

Dissimilar data were obtained for the CEC and $CaCO_3$ content (r = −0.978 ** and 0.180) and SOM (r = −0.248 and 0.645 **) at the two depths (0–30 and 30–60 cm). CEC showed a positive correlation (r = 0.142 and 0.608 *) with AvN in both layers. The effect of ECe was found to be more correlated with $CaCO_3$ content, with correlation values of r = 0.102 and 0.508 * in the surface and subsurface layers, respectively. Moreover, positive correlation was found with SOM (r = 0.730 **) and CEC (r = 0.475) in the subsurface layers, while the effect was inverse between ECe and SOM (r = −0.248) and with CEC (r = −0.181) in the surface layer.

With regards to the correlation relationships for available nutrients, our results indicated that AvN had a positive correlation with AvP (r = 0.304 and 0.697 **), AvFe (r = 0.201 and 0.461), and AvZn (r = 0.419 and 0.312) in the surface and subsurface layers, respectively. Moreover, there was correlation with AvCu (r = 0.630 **) in the subsurface layer only. Similar data were observed between AvCu with some available nutrients; however, AvCu was correlated positively (r = 0.241 and 0.737 **) with AvP and (r = 0.456 and 0.413) AvK.

Meanwhile, AvCu had a strong significant positive correlation (r = 0.742 **) with AvFe in the subsurface layer, as well as a positive correlation (r = 0.364) with AvZn in the subsurface layer and (r = 0.309) AvMn in the surface layer. In general, the influence of pH was found to be negatively correlated with sand content (r = −0.338 and −0.179), with $CaCO_3$ content (r = 0.063 and 0.297), and with ECe (r = −0.173 and −0.141) in both sample layers, as well as with CEC (r = −0.018) in the subsurface layer. In contrast, soil pH values showed a positive correlation with SOM (r = 0.612 * and 0.028) in both layers and with CEC (r = 0.271) in the surface layer.

3.2.4. Stepwise Multi-Regression Analysis between Soluble Ions and ECe

The results for Total Soluble Cations (TSC) or Total Soluble Anions (TSA) are shown in Table 7, and indicate that they are closely related to the ECe values obtained in Table 3. Our results indicated that the highest values of soluble sodium (Na^+) ranged from 31.7 to 89.5 meq·L^{-1} in surface samples AA_4 and BB_4 and from 26.2 to 84.8 meq·L^{-1} in subsurface samples aa_2 and aa_3. The maximum values (27.4 and 28.3 meq·L^{-1}, respectively) of soluble calcium (Ca^{2+}) were detected in samples DD_4 and cc_3. Likewise, the highest values of soluble magnesium (Mg^{2+}) were recorded (14.5 vs. 15.4 meq·L^{-1}, respectively) in samples DD_2 and cc_3.

Table 6. A matrix of linear correlation coefficients and their significance levels between soil texture and soil chemical properties in Toshka area, Egypt.

Parameter	Sand	Silt	Clay	pH	ECe	$CaCO_3$	SOM	CEC	AvN	AvP	AvK	AvFe	AvMn	AvZn	AvCu
(0–30 cm)															
1	1.00	−0.978 **	−0.993 **	−0.338	0.251	0.326	−0.328	−0.922 **	−0.068	−0.145	−0.314	−0.463	0.349	−0.167	0.365
2		1.00	0.947 **	0.405	−0.328	−0.301	0.381	0.932 **	0.091	0.196	0.413	0.445	−0.369	0.174	−0.311
3			1.00	0.294	−0.302	−0.333	0.292	0.898 **	0.054	0.113	0.253	0.465	−0.331	0.160	−0.388
4				1.00	−0.173	−0.063	0.612 *	0.271	−0.098	0.395	0.516 *	0.358	−0.003	−0.062	−0.103
5					1.00	0.102	−0.248	−0.181	−0.067	−0.211	−0.319	0.239	0.237	−0.233	−0.111
6						1.00	−0.148	−0.978 **	−0.197	0.039	0.223	−0.184	0.051	−0.366	0.302
7							1.00	−0.248	0.102	0.803 **	0.580 *	0.303	0.426	0.084	0.195
8								1.00	0.142	0.055	0.279	0.416	−0.419	0.123	−0.487
9									1.00	0.304	−0.051	0.201	0.126	0.419	−0.394
10										1.00	0.371	−0.122	0.450	−0112	0.241
11											1.00	0.319	−0.093	0.216	0.456
12												1.00	0.125	0.505 *	−0.299
13													1.00	−0.004	0.309
14														1.00	−0.039
15															1.00
(30–60 cm)															
1	1.00	−0.990 **	−0.997 **	−0.179	−0.407	−0.156	−0.618 *	−0.886 **	−0.461	−0.347	−0.377	−0.236	0.147	−0.100	−0.542 *
2		1.00	0.978 **	0.229	0.418	0.151	0.629 **	0.886 **	0.459	0.376	0.351	0.233	−0.192	0.108	0.563 *
3			1.00	0.152	0.399	0.157	0.608 *	0.879 **	0.458	0.329	0.388	0.237	−0.123	0.095	0.528 *
4				1.00	−0.141	−0.297	0.028	−0.018	−0.106	−0.028	0.033	0.254	−0.216	−0.090	0.042
5					1.00	0.508 *	0.730 **	0.475	0.623 **	0.652 **	0.084	0.629 **	0.020	0.294	0.703 **
6						1.00	0.603 *	0.180	0.239	0.660 **	0.350	0.551 *	−0.242	0.030	0.560 *
7							1.00	0.645 **	0.647 **	0.673 **	0.211	0.501 *	−0.073	0.295	0.693 **

Table 6. *Cont.*

Parameter	Sand	Silt	Clay	pH	ECe	$CaCO_3$	SOM	CEC	AvN	AvP	AvK	AvFe	AvMn	AvZn	AvCu
								(0–30 cm)							
8								1.00	0.608 *	0.432	0.325	0.352	0.011	0.110	0.664 **
9									1.00	0.697 **	0.109	0.461	−0.082	0.312	0.630 **
10										1.00	0.244	0.426	−0.437	0.214	0.737 **
11											1.00	0.446	−0.062	0.394	0.413
12												1.00	0.103	0.403	0.742 **
13													1.00	−0.086	−0.274
14														1.00	0.364
15															1.00

* = $p \leq 0.05$, ** = $p \leq 0.01$ and ns-non significant.

Table 7. Spatial distribution of soluble ions for surface (0–30) and subsurface layers (30–60) in Toshka area, Aswan, Egypt.

Depth (cm)	Sample No.	Symbol	Cations				Anions				TSC/TSA
			K^+	Na^+	Ca^{++}	Mg^{++}	CO_3^{--}	HCO_3^-	$SO4^{--}$	Cl^-	
			mmol L^{-1}								
0–30	1	AA_1	0.40	42.80	15.20	7.60	0.00	1.00	7.40	57.60	66.00
	2	AA_2	0.20	32.00	12.00	5.80	0.00	0.80	6.10	43.10	50.00
	3	AA_3	0.30	54.50	17.30	10.30	0.00	0.80	6.10	75.50	82.40
	4	AA_4	0.30	31.70	15.50	12.50	0.00	1.00	5.70	53.30	60.00
	5	BB_1	0.40	65.70	25.30	15.60	0.00	0.90	8.50	97.60	107.00
	6	BB_2	0.20	55.10	16.40	9.30	0.00	0.70	7.30	73.00	81.00
	7	BB_3	0.30	54.20	17.30	10.20	0.00	0.80	6.00	75.20	82.00
	8	BB_4	0.40	89.50	22.60	14.40	0.00	1.30	9.80	115.80	126.90
	9	CC_1	0.30	66.10	18.60	10.00	0.00	1.30	9.50	84.20	95.00
	10	CC_2	0.20	38.30	12.40	7.10	0.00	0.60	5.20	52.20	58.00
	11	CC_3	0.30	53.00	24.20	11.50	0.00	0.90	7.00	81.10	89.00
	12	CC_4	0.20	46.90	18.60	9.30	0.00	1.10	7.40	66.50	75.00
	13	DD_1	0.20	38.20	12.20	7.10	0.00	0.60	5.00	52.10	57.70
	14	DD_2	0.30	57.30	27.40	14.50	0.00	1.20	8.10	90.20	99.50
	15	DD_3	0.20	49.50	18.10	9.50	0.00	1.10	7.30	68.90	77.30
	16	DD_4	0.30	52.50	22.10	11.20	0.00	1.00	7.90	77.20	86.10
30–60	17	aa_1	0.30	34.10	13.20	6.40	0.00	1.00	6.40	46.60	54.00
	18	aa_2	0.30	26.20	10.30	6.20	0.00	0.60	5.50	36.90	43.00
	19	aa_3	0.30	84.80	25.80	14.10	0.00	1.40	10.10	113.50	125.00
	20	aa_4	0.40	50.10	20.20	11.10	0.00	1.30	7.20	73.30	81.80
	21	bb_1	0.20	46.40	11.80	7.60	0.00	0.80	6.80	58.40	66.00
	22	bb_2	0.30	61.10	21.20	11.40	0.00	1.00	8.20	84.80	94.00
	23	bb_3	0.40	87.20	23.10	14.30	0.00	1.10	8.30	115.60	125.00
	24	bb_4	0.30	71.10	20.40	11.20	0.00	1.00	9.40	92.60	103.00
	25	cc_1	0.30	52.00	15.30	8.40	0.00	0.90	6.40	68.70	76.00
	26	cc_2	0.40	67.20	23.10	11.30	0.00	0.90	9.00	92.10	102.00
	27	cc_3	0.40	58.90	28.30	15.40	0.00	1.30	8.30	93.40	103.00
	28	cc_4	0.30	44.10	20.20	11.40	0.00	1.00	7.20	67.80	76.00
	29	dd_1	0.40	51.80	25.10	13.80	0.00	1.50	7.30	82.30	91.10
	30	dd_2	0.40	52.10	23.80	11.20	0.00	0.90	6.90	79.70	87.50
	31	dd_3	0.30	44.60	20.10	10.60	0.00	1.00	7.10	67.50	75.60
	32	dd_4	0.30	49.10	18.50	9.20	0.00	0.90	6.30	69.90	77.10

TSC = Total Soluble Cations and TSA = Total Soluble Anions.

The values of soluble potassium (K^+) ranged from 0.2 to 0.4 meq·L^{-1} in the surface and subsurface samples, with the highest values detected in surface samples AA_1, BB_1, and BB_4 and subsurface samples aa_4, bb_3, cc_2, cc_3, dd_1, and dd_2. On the other hand, the lowest values (0.2 meq·L^{-1}) were obtained in surface samples AA_2, BB_2, CC_2, CC_4, DD_1, and DD_3 and subsurface sample bb_1.

The values of soluble bicarbonate (HCO_3^-) ranged from 0.60 meq·L^{-1} in surface sample DD_1 to 1.30 meq·L^{-1} in surface sample BB_4, and from 0.60 meq·L^{-1} in subsurface sample aa_2 to 1.50 meq·L^{-1} in subsurface sample dd_1. The values of soluble chlorine (Cl^-) ranged from 43.10 to 115.90 meq·L^{-1} in surface samples AA_2 and BB_4 and from 36.90 to 115.60 meq·L^{-1} in subsurface samples aa_2 and bb_3, respectively. The highest and lowest values of soluble sulfate (SO_4^{2-}) in the soil were 5.70 and 9.80 meq·L^{-1} in surface samples AA_4 and BB_4, and 5.50 and 10.10 meq·L^{-1} in subsurface samples aa_2 and aa_3, respectively.

As an average across the studied Total Soluble Cations (TSC), which was calculated as total cations ($Na^+ + K^+ + Ca^{++} + Mg^{++}$), or as TSA, which was calculated as total anions

(CO_3^{--} + HCO_3^- + SO_4^{--} + Cl^-), and ECe values in Tables 3 and 7, the direct influence of ECe on TSC or TSA (dependent variable) is presented in Table 8.

Table 8. Proportional contribution in predicting electrical conductivity (ECe) using stepwise multiple linear regression in Toshka area, Aswan, Egypt (n = 16 in each layer).

Depth (cm)	r	R^2	Adjusted R^2	SEE	Significance	Fitted Equation
0–30	0.994	0.988	0.987	0.223	***	ECe = 0.141+0.097 TSC or TSA
30–60	0.998	0.996	0.996	0.148	***	ECe = −0.120+0.101 TSC or TSA

*** indicates differences at $p \leq 0.001$. (r) = correlation coefficient, (R^2) = coefficient of determination, and (SEE) = standard error of the estimates.

The results obtained from the stepwise regression analysis explored in Table 8 indicate the relationship between ECe values and TSC or TSA in both the surface and subsurface layers. The adjusted R^2 values were 0.987 and 0.996 (r = 0.994 and 0.998) for both depths, respectively. The fitted equation showed that variations in ECe values were related to variation in TSC (total K^+, Na^+, Ca^{++}, and Mg^{++}) or TSA (CO_3^{--}, HCO_3^-, $SO_4^{—}$, and Cl^-) in the soil textures obtained.

4. Discussion

Soil, as a vital resource, plays a significant role in the achievement of agricultural sustainable development objectives [40], and serves as the natural medium for plant growth [41]. It is the main reserve of water and plant nutrients. Therefore, it is necessary to study and evaluate the chemical, fertility, and physical properties of soil in order to implement reclamation strategies and modify undesirable characteristics on an accurate scientific basis to maximize productivity. Generally, the term "soil reclamation" can be defined as the process of reclaiming the soil's quality, including fertility and moisture, to make it fit for intensive use again. The first step of land reclamation begins with a comprehensive assessment of soil chemical properties, and this was the main objective of our study. Our results in Table 3 indicated that the changes in texture had not occurred over a short period of time, and instead were an inherent soil physical property related to the nature of the parent material [42,43]. Recently, Opeyemi et al. [44] revealed that the sandy nature of the study area is probably due to the underlying rocks from which the soil is formed. Additionally, Lema et al. [45] highlighted the effect of washing away of fine particles such as silt and clay as a result of erosion via wind. These results confirmed the findings of [46], who reported the spatial distribution of soil texture was probably due to variation in the parent material, topography, and weathering and translocation of clay. Soil texture is an important physical property of soil due to its effect on water holding capacity, soil structure, and nutrient availability [47]. Previously, Fisher and Binkley [48] indicated that the surface area of the particle size is the main factor in soil texture. Furthermore, soil texture affects air movement, horizontal and vertical movement of water in the soil, and the SOM content [49].

Soil pH values indicated that the studied area ranged from natural (7.25) to extremely alkaline (8.19). This may be attributed to the nature of the parent material and the domination of basic cations such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) accompanied by low precipitation [27]. Our findings were consistent with those of [50], who reported that the soil pH in upper Egypt ranged from 7.73 to 9.45, which is not conducive to nutrient availability as the optimum range for plant nutrition is from 6.5 to 7.5 [51]. The mean $CaCO_3$ value was the same (14.29%) in both the surface and subsurface layers. This value revealed that the soil was moderately calcareous. Similarly, these results could be explained due to the prevalent climatic conditions of the study location, related to which are a decrease in evaporation and depth percolation rates, as well as soil texture [52]. According to [53], about 37.5% (between 4.0–8.0 $dS.m^{-1}$) and 62.5% (between 8.0–16.0 $dS.m^{-1}$) of soil samples were moderately or highly saline. The results related to ECe values were closely related to

the results of the soluble cation and anion analysis. However, the high Ca^{++}, Mg^{++}, and Na^{+} concentrations in the soil solution could be associated with the high ECe values.

The results in Table 3 correspond to the low SOM content, the values of which did not exceed 0.11%, with an average of 0.14 and 0.13% in both layers, respectively. The notable decline indicated probable erosion of topsoil [54–56], or were a result of the coarse soil texture [27,57], as shown in Table 3, with SOM being attracted to fine soil particles. Similar results were reported by [53] in their study of the Dakhla Oasis, Egypt, where they found low SOM values ranging from 0.05% to 1.14%. These results were also similar to those found by [58]. Further explanation by [59] reported that the low SOM content may additionally be due to the slow rate of decomposition, as well as the impact of high temperature and relative humidity [60] and erosion, which increase the oxidation rate of SOM [61]. Data listed in Table 3 shows that overall soil samples had CEC values of more than 12.0 $Cmol_c \cdot kg^{-1}$, with averages of 15.04 and 15.05 $Cmol_c \cdot kg^{-1}$ at 0–30 and 30–60 cm, respectively, which indicates that the studied soil had a moderate to good capacity to adsorb soil nutrients against leaching losses, according to [62]. Another explanation was suggested by [63–65], who indicated that these values may have been related to the reduced SOM content.

The results of our investigation seen in Table 4 show noticeable decreases in AvN, which may be explained by the lower SOM content—the main source of AvN in soil [66]—and the higher mineralization rate [56]. The variation in AvP might be related to the $CaCO_3$ content of the soil, as well as differences in the soil properties and agronomic practices. These results closely align with those of [67]. The poor cation exchange capacity and higher hydraulic conductivity presented in Tables 4 and 8 could explain the low AvK [56,68]. The decreased values of the elements Fe, Mn, Zn, and Cu could be due to a low variability in geochemical characterization of the soil [69]. According to [70], 4.50 $mg \cdot kg^{-1}$ is the critical limit of AvFe. The AvFe values (2.20–4.30 $mg \cdot kg^{-1}$) indicated that all samples contained a low amount of AvFe. Additionally, the studies of [38] suggest that the critical level of AvMn is 3.00 $mg \cdot kg^{-1}$; thus, the values of all samples (1.30–1.80 $mg \cdot kg^{-1}$) represent a low amount of AvMn. With regards to AvZn, 0.50–1.00 $mg \cdot kg^{-1}$ is a critical limit for normal growth [70]. The AvZn values (0.70–1.30 $mg \cdot kg^{-1}$) indicate that the thirteen samples contained a low amount of AvZn. Sakal et al. [71] found that the critical limit of AvCu is 0.66 $mg \cdot kg^{-1}$, according to which the AvCu (0.20–1.80 $mg \cdot kg^{-1}$) of the twenty four samples indicates a low amount of AvCu.

Based on the aforementioned findings, the studied area can be reclaimed by developing a proper reclamation plan, including adjustment of soil pH to between 6.5 and 7.5 to improve soil nutrient absorption efficiency and implementation of a fertilization program that includes the application of acid fertilizers and organic manures at a rate of 950 $kg \cdot ha^{-1}$ [72] to reduce soil pH, increase the content of OM, and enhance the microbial activity. In addition to its positive influences on nutrient uptake [73] in Jerusalem artichoke plants, applying a soil conditioner such as humic and fulvic acid will enhance soil properties [74]. Reducing the ECe values through determination of leaching requirements (not calculated in this research) and the use of plowing under the soil layers in order to break up the impermeable layers resulting from $CaCO_3$ accumulation will make the medium more suitable for diffusion of roots. Furthermore, the selection of salt-tolerant (barley, triticale, sugar beet, rye, and cotton) and moderately salt-tolerant (oats, safflower, sorghum, and wheat) crops could be beneficial, as shown in Table 6.

5. Conclusions

This work was implemented at limited scale, in a total area of about 9500 acres between 23°20′ and 23°60′ N and 31°32′ and 31°36′ E in the Toshka region, which is considered one of the most promising agricultural investment areas in Egypt and is situated between 22°30′ to 23°30′ N and 30°30′ to 32°00′ E, belonging to the Aswan Governorate, Egypt. The main objective of this research was to aid in achieving self-sufficiency through increasing the agricultural area, as this is one of the goals of sustainable agricultural development.

For this purpose, 32 soil samples were collected from 16 selected positions to evaluate the soil chemical properties as a base for land reclamation and cropping. Our results indicated that the studied area has undesirable characteristics, such as a relatively high soil pH, low SOM, and limited available nutrients. Furthermore, wide variation in the ECe and $CaCO_3$% values was found. The studied area was characterized as a moderately saline and calcareous soil. The correlation was not stable within the studied soil properties; the results oscillated between negative and positive values. Generally, it could be concluded that this soil is reclaimable via implementing proper reclamation strategies, including salt leaching and selection of salt-tolerant and moderately salt-tolerant crops, along with the application of acid-based fertilizers and organic manures.

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