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GIS-Based Assessment of Soil Chemical and Physical Properties as a Basis for Land Reclamation in Toshka Area, Aswan, EGYPT

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Abstract

The accurate assessment of soil properties is a crucial factor for composing and implementing reclamation plans. The main objective of this study was to evaluate soil chemical and physical properties and calculate the chemical and fertility index for assisting land reclamation in Toshka area. The Toshka area is located between latitudes 31˚32'N and 31˚36'N and longitudes 32˚40'E and 32˚60'E. GIS was used to select 16 sites. The results revealed the soil has undesirable characteristics. The soil pH ranged from slightly alkaline to moderately alkaline. Furthermore, it was characterized as saline (with a ECe of 4.65 - 11.45 dS·m^{-1}) and moderately calcareous soil (with $CaCO_3$ at 11.85% - 17.20%). The soil had a low soil organic matter content which did not exceed 0.18%. The soil was dominated by a sandy loam texture (62.50%) followed by a sandy clay loam texture (18.75%). The bulk density, total soil porosity and saturated hydraulic conductivity values varied with 1.38 - 1.55 Mg·cm^{-3}, 41.85% - 48.45% and 1.20 - 3.34 cm·h^{-1}, respectively. The chemical index ranged from low to moderate quality. The correlations between the parameters osculated between negative and positive. Therefore, the soil may be reclaimed if the soil properties are improved and crop selection is optimized for this soil.

Keywords

Land Reclamation, Soil Chemical and Physical Properties, Chemical Quality Index, Fertility Quality Index

1. Introduction

In the past 30 years, Egypt's population has increased from 20 to 90 million. It is expected that by 2050 the population will exceed 150 million. Nevertheless, there is a limited agricultural area in Egypt. The cultivated area does not exceed 4% of the total area, which is approximately 1,000,000 km^2. The cultivated area is confined to the Nile valley and its delta. Accordingly, 96% of Egypt's land is desert, represented by both the Western and Eastern Deserts. The Western Desert of Egypt covers an area of 680,650 km^2, equivalent to two-thirds of the land area of Egypt and remains agriculturally untapped even though soil reclamation and farming may be the best solution to achieve food security. However, the cultivated area is inhabited, approximately 95% of Egyptian people live on the banks of the River Nile and its delta, with a population density of 1500 persons·km^{-1}. Conversely, the Western Desert has a population density of 5 persons·km^{-1}. In addition, Egypt has abundant natural resources, including the River Nile, which is the second longest river in the world and the main water source in Egypt [1]. We urgently need to exploit these vast areas for reclamation and cultivation to decrease the widening gap between consumption and production to achieve food security and reduce the volume of imported food commodities.

The accurate measurement and evaluation of soil chemical and physical properties provide a scientific base for reclamation plans to determine the suitability of cultivating different crops and determine the productive capacity of the soil. Therefore, the political leaders of Egypt have launched agricultural investment projects for the reclamation including 1.5 million acres, Toshka and Sharq Elowainat projects to achieve self-sufficiency using strategic crops (such as grain crops, covering crops, and oil crops) in response to the Russian-Ukraine crisis. However, the reclamation of new soils is one of the most important challenges hindering the Egyptian government from the ultimate capability of overcoming the increasing annual food consumption [2]-[7]. Our research was conducted at a limited scale (of approximately 15,000 acres) in the Toshka area which is in the southern eastern region of the Western Desert. The area belongs to the Aswan Governorate in upper Egypt which encompasses approximately 540,000 acres. We measured and assessed soil chemical properties (SCP) including soil acidity (soil pH), electrical conductivity (as an indicator of salinity), calcium carbonate ($CaCO_3$), soil organic matter (SOM) and cation exchange capacity (CEC). We also determined the nutritional status through the availability of macronutrients (nitrogen, phosphorus and potassium) and micronutrients (iron, manganese, zinc and copper). In addition, we investigated the soil physical properties (SPP) including soil texture, soil bulk density (SBD), total soil porosity (TSP) and saturated hydraulic conductivity as indicators of permeability and water movement.

Available information remains very limited, despite recent pilot studies on the reclamation of new lands in Egypt. [1] provides recent research in the Toshka area, reporting the soil pH varied from 6.80 - 8.52, the SOM content was very low (0.03% - 0.94%) and the available iron (AFe) content did not exceeded 4.5 mg·kg^{-1} in approximately 80% of the soil samples. In a more comprehensive study in the El-Dakhla Oasis (upper Egypt) involving SCP and SPP, [8] indicated a relatively high alkalinity (7.56 - 8.83), with a $CaCO_3$ content varying from

2.85% - 26.82%, SOM content ranging from 0.07% - 1.53% and CEC ranging from 10.23 - 37.97. Very recently, [9] in the El-Qattara depression belongs to a new valley Governorate is located in the upper Egypt) found the concentration of available Fe, Mn, Zn and Cu were low and the chemical and physical properties osculated between positive and negative correlations.

Several studies [10]-[17] state Egyptian soils can be divided into two main categories: a) Deseret sand and calcareous soil with undesirable characteristics that negatively influence their available micronutrient content; b) transported alluvial soils characterized by their available micronutrient content.

The main objective of the present study was to evaluate soil physico-chemical properties in one of the most important new agricultural investment areas in Egypt (the Toshka area). We assess the chemical and fertility indexes for optimum land reclamation planning to use the results to select the most suitable crops in the future.

2. Materials and Methods

2.1. Study Location Description and Climatic Conditions

The Toshka area is considered one of the most important agricultural investment areas in Egypt. It belongs to the Aswan Governorate and is situated in the southern Eastern section of the Western Desert between the latitudes 23˚06'N and 23˚10'N and longitudes 30˚54'E and 30˚90'E with a total area of approximately 6000 km^2 (see Figure 1). The study location was between 23˚40'N and

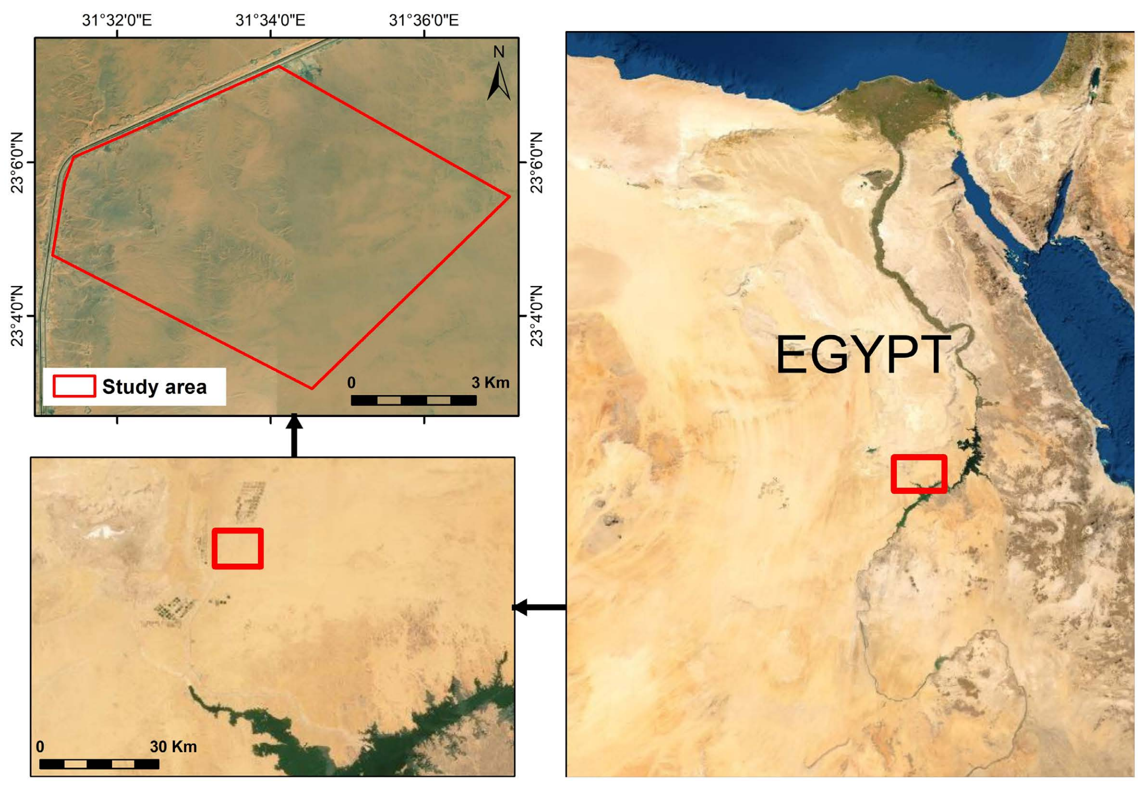


Figure 1. Show location map of the studied area.

32˚60'N and 31˚32'E and 31˚36'E. The climatic conditions from 1992-2022 are presented in Table 1.

2.2. Collection and Preparation of Soil Samples

We collected 32 samples from 16 locations with 2 sample depths (0 - 30 and 30 - 60 cm) which were selected by the geographic information system (GIS). The samples from both depths from each location were combined and transferred to the Laboratory of Soil, Water and Plant at the Faculty of Agriculture and Natural Resources, Aswan University. All 16 soil samples were crushed and air oven-dried at 30˚C for 72 h before being sieved (2 mm sieve) in preparation for the analysis. The coordinates and sample numbers are provided in Table 2.

2.3. Determination of Soil Chemical Properties

Soil pH was determined using the method of saturation soil paste and a pH meter (Jenway, UK) according to [18]. The ECe provided an indicator of soil salinity and was measured using the extracted saturated soil paste and an EC-meter (LF-191 Conduktometer, Germany) as described in [19]. The total calcium carbonate ($CaCO_3$) was determined using a Collin's calcimeter following [20]. The percentage of soil organic matter (SOM) was determined using the method of wet digestion following [21] as described by [22]. The soluble cations of potassium (K^+), sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) were extracted

Table 1. Climatic data of Toshka area (22˚30'N and 23˚30'N and 30˚30'E and 32˚00'E), 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://power.larc.nasa.gov/index.php.

Table 2. Show the positions coordinates and their number in the studied area (23˚40'N and 32˚60'N and 31˚32'E and 31˚36'E) in Toshka area, Aswan, Egypt.

Coordinates		position No.	Coordinates		position No.
N	E		N	E	
23.116366	31.562427	1	23.099278	31.529625	9
23.106825	31.579489	2	23.090910	31.545520	10
23.098874	31.597729	3	23.084391	31.565033	11
23.095585	31.603224	4	23.077438	31.581355	12
23.107061	31.545507	5	23.081815	31.530448	13
23.098458	31.564112	6	23.075473	31.549800	14
23.090853	31.582186	7	23.068928	31.564684	15
23.084447	31.600490	8	23.059622	31.578320	16

with 1 N NH_4AOC (at pH = 7) and filtrated (with whatman paper No. 42) until 100 ml was achieved as the final volume. Both Na^+ and K^+ ions were determined using flame photometry [23]. The Ca^{2+} and Mg^{2+} ions were determined using the titration method with EDTA [24]. Soluble anions (*i.e.*, carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and chlorine (Cl^-) were determined following the titration method described in [18]. Sulphate (SO_4^{2-}) was calculated by subtracting the total cations and anions. The cation exchange capacity (CEC) was extracted using 1 M NH_4AOC (at pH = 7.0) and measured following [24].

The available macronutrients (such as nitrogen (AN)) were determined by modifying the method of Micro Kjeldahl [25]. The available phosphorus was extracted and determined following Jackson, 1973. The available potassium (AK) was extracted using neutral normal ammonium acetate 1 N (NH_4OAC) (at pH = 7.0) and determined using a flame photometer (Jenway model PFP-7) as described in [24]. Following [26], the available micronutrients (*i.e.*, iron (AFe), manganese (AMn), zinc (AZn) and copper (ACu)) were extracted using 0.005 M diethelenetriamine penta-acetic acid (DPTA) (at pH = 7.3). The extractable Fe, Mn, Zn and Cu were determined by inductivity coupled plasma optical mission spectrometry (ICP-EOS, PerkinElmer OPTIMA 2001 DV, Norwalk, CT, USA), as described in [27].

2.4. Determination of Soil Physical Properties

The soil particle size distribution was measured using the hydrometer method [28]. Soil bulk density (SBD, $Mg \cdot cm^{-3}$) was measured using a core sampler following [29]. The soil particle density (SPD, $Mg \cdot cm^{-3}$) was calculated using the average of 2.65 [30] [31] [32] with the SBD and SPD values. The total soil porosity (TSP, %) was determined using the following equation:

$$TSP = (1 - SBD/SPD) \times 100 \quad [33].$$

The saturated hydraulic conductivity (K_{sat}, $cm \cdot h^{-1}$) was measured following

[34] using the equation:

$$K_{sat} = VL/At\Delta H$$

where V = infiltrated water volume, L = soil water length, A = flow section area, t = water collection time and ΔH = the change in water potential between its entry and exit point for understanding the level of soil resistance to penetration.

2.5. Assessment of Soil Quality and Nutrient Index

The chemical index (SQI) and fertility index were calculated according to [35] [36] with the chemical, fertility and physical indicates using these equations:

$$\text{CI} = \left(C_{\text{ECe}} \times C_{\text{pH}} \times C_{\text{CaCO}_3}\right)^{1/3}$$

where CI = chemical index; C_{ECe} = soil salinity; C_{pH} = soil pH and C_{CaCO_3} = content of calcium carbonate.

$$\text{FI} = \left(F_{\text{N}} \times F_{\text{P}} \times F_{\text{K}} \times F_{\text{Fe}} \times F_{\text{Mn}} \times F_{\text{Zn}} \times F_{\text{Cu}} \times F_{\text{SOM}}\right)^{1/3}$$

where FI = fertility index, F_{N}, F_{P}, F_{K}, F_{Fe}, F_{Mn}, F_{Zn}, F_{Cu} = available nitrogen, phosphorus, potassium, iron, manganese, zinc and copper, respectively; F_{SOM} = content of soil organic matter.

The soil nutrient index (SNI) was calculated following the equation developed by [37], which is: Nutrient index (NI) = $\left(N_L \times 1 + N_M \times 2 + N_H \times 3\right)/N_T$

Where N_L = number of samples in the low class of nutrient status; N_M = number of samples in the medium class of nutrient status; N_H = number of samples in the high class of nutrient status; N_T = total number of samples analysed in a given area.

2.6. Statistical Analysis

The inter-relationships between the data were statistically compared using Pearson correlation coefficient (r) with 1% and 5% identified as significant levels using Statistical Package for Social Science (IBM SPSS version 21 Wizard). Stepwise regression recognized the extent of the relationship between ECe and total soluble ions using the GENSTAT statistical package (version 9.2).

3. Results

3.1. Spatial Distribution of Soil Chemical Properties

To evaluate the potential reclamation and cultivation of soils, it is necessary to identify the relevant chemical and physiological properties of the soil in the Toshka area between the latitudes 31˚32'N and 31˚36'N and longitudes 32˚40'E and 32˚60'E.

Data presented (in **Table 3** and **Figure 2**) demonstrate the soil pH of the saturated soil paste ranged from slightly alkaline (7.53) to moderately alkaline (8.01) with an average of 7.85. The lowest and highest pH was 7 and 11, respectively. The electrical conductivity in the soil paste extraction (ECe, dS·m^{-1}) varied from 4.65 - 11.45 dS·m^{-1}, with an average of 8.28 dS·m^{-1}. The calcium

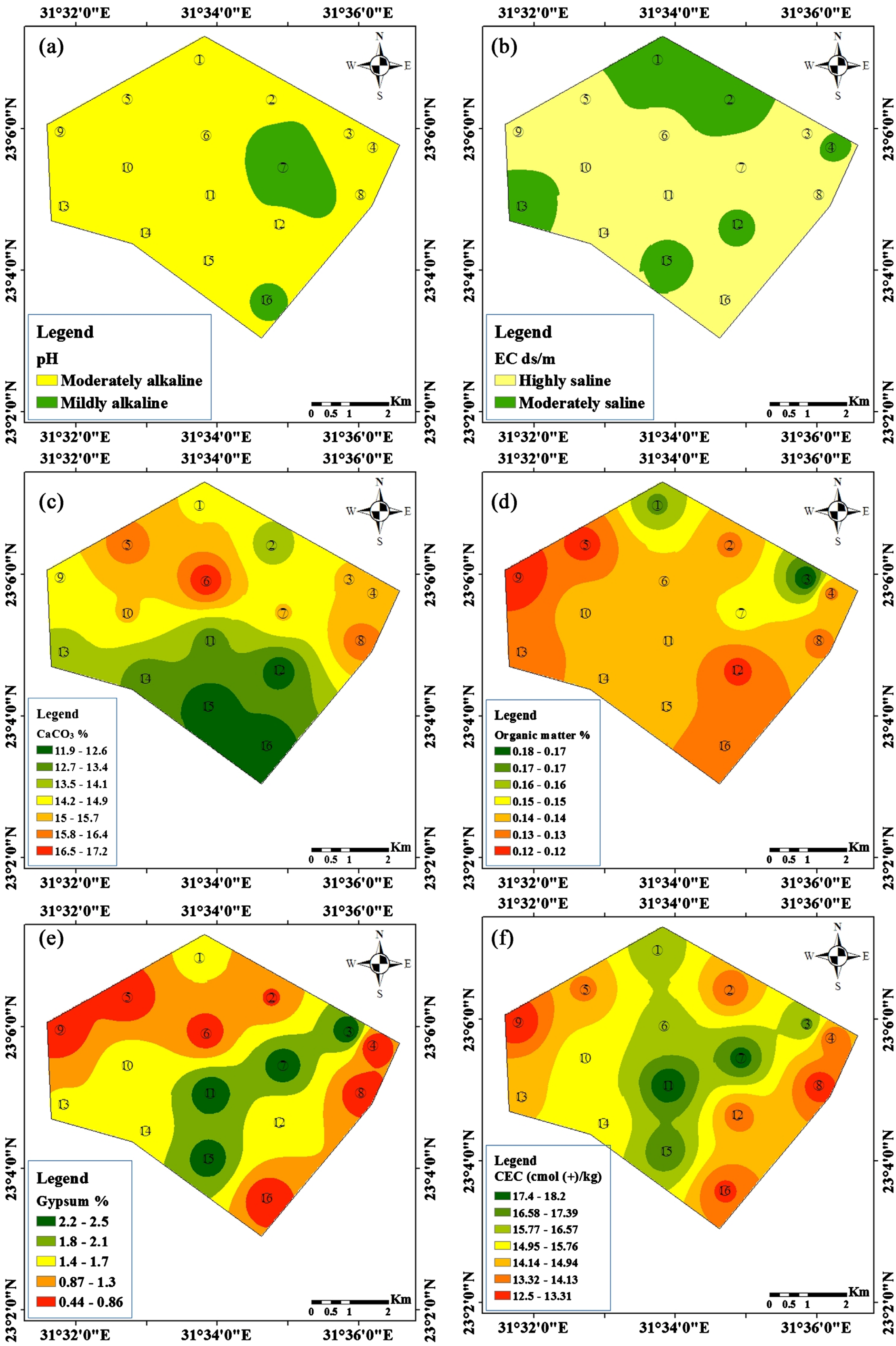


Figure 2. Show the spatial distribution of some soil chemical properties (Soil pH, ECe, $CaCO_3$, SOM, GC and CEC) in Toshka area (23˚40'N and 32˚60'N and 31˚32'E and 31˚36'E), Aswan, EGYPT.

Table 3. Spatial distribution of some soil chemical properties in (23˚40'N and 32˚60'N and 31˚32'E and 31˚36'E) in Toshka area, Aswan, Egypt.

Sample NO	N	E	Soil pH	ECe ($dS \cdot m^{-1}$)	$CaCO_3$ (%)	SOM (%)	GC (%)	CEC ($Cmol \cdot kg^{-1}$)
1	23.116366	31.562427	7.92	5.95	14.80	0.16	1.45	16.40
2	23.106825	31.579489	7.83	4.65	13.70	0.13	0.80	13.45
3	23.098874	31.597729	7.94	10.30	14.95	0.18	2.55	16.75
4	23.095585	31.603224	7.82	7.10	15.05	0.13	0.46	13.60
5	23.107061	31.545507	7.83	8.65	16.15	0.12	0.46	13.95
6	23.098458	31.564112	7.88	8.75	17.20	0.14	0.52	16.05
7	23.090853	31.582186	7.53	10.35	15.00	0.15	2.50	17.80
8	23.084447	31.600490	7.80	11.45	16.25	0.13	0.53	12.80
9	23.099278	31.529625	7.85	8.55	14.65	0.12	0.44	12.50
10	23.090910	31.545520	7.89	8.00	15.00	0.14	1.60	15.45
11	23.084391	31.565033	8.01	9.35	13.05	0.14	2.50	18.20
12	23.077438	31.581355	7.83	7.55	12.15	0.12	1.30	13.65
13	23.081815	31.530448	7.85	7.35	13.90	0.13	1.32	14.85
14	23.075473	31.549800	7.98	8.75	12.95	0.14	1.50	14.95
15	23.068928	31.564684	7.83	7.55	11.85	0.14	2.40	17.25
16	23.059622	31.578320	7.79	8.20	12.00	0.13	0.49	13.10

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

carbonate ($CaCO_3$, %) content varied from 11.85% - 17.20%, with an average of 14.29%. The ECe minimum was sample 2 and maximum was sample 8. The $CaCO_3$ was lowest in sample 6 and highest in sample 15. The results suggest the soil is characterized as saline and moderately calcareous, with ECe and $CaCO_3$ values higher than 4.0 $dS \cdot m^{-1}$ and 11.85%, respectively. Furthermore, the very low soil organic matter (SOM, %) content does not exceeded 0.18% (which was sample 3), while the lowest (0.12%) SOM detected in three different locations (samples 5, 9 and 12). There is clear evidence that the location has very poor SOM (**Table 3**). Conversely, the cation exchange capacity (CEC, Cmol (+) kg^{-1}) was classified as moderate [38], varying from 12.80 - 17.80 Cmol (+) kg^{-1} with an average of 15.05 Cmol (+) kg^{-1}. The gypsum content (GC, %) ranged from 0.44% - 2.50% with an average of 1.30%.

The total macronutrients including available nitrogen (AN), available phosphorus (AP) and available potassium (AK) are provided (in **Table 4** and **Figure 3**). The percentage of AN varied from 15.95% (in sample 9) to approximately 31.45% (in sample 16), with an average of 24.58%. The AP and AK ranged from 7.60% - 12.95% and 213.05% - 358.75%, with an average of 8.73% and 262.71%,

Table 4. Spatial distribution of some available nutrients in the studied area (23˚40'N and 32˚60'N and 31˚32'E and 31˚36'E) in Toshka area, Aswan, Egypt.

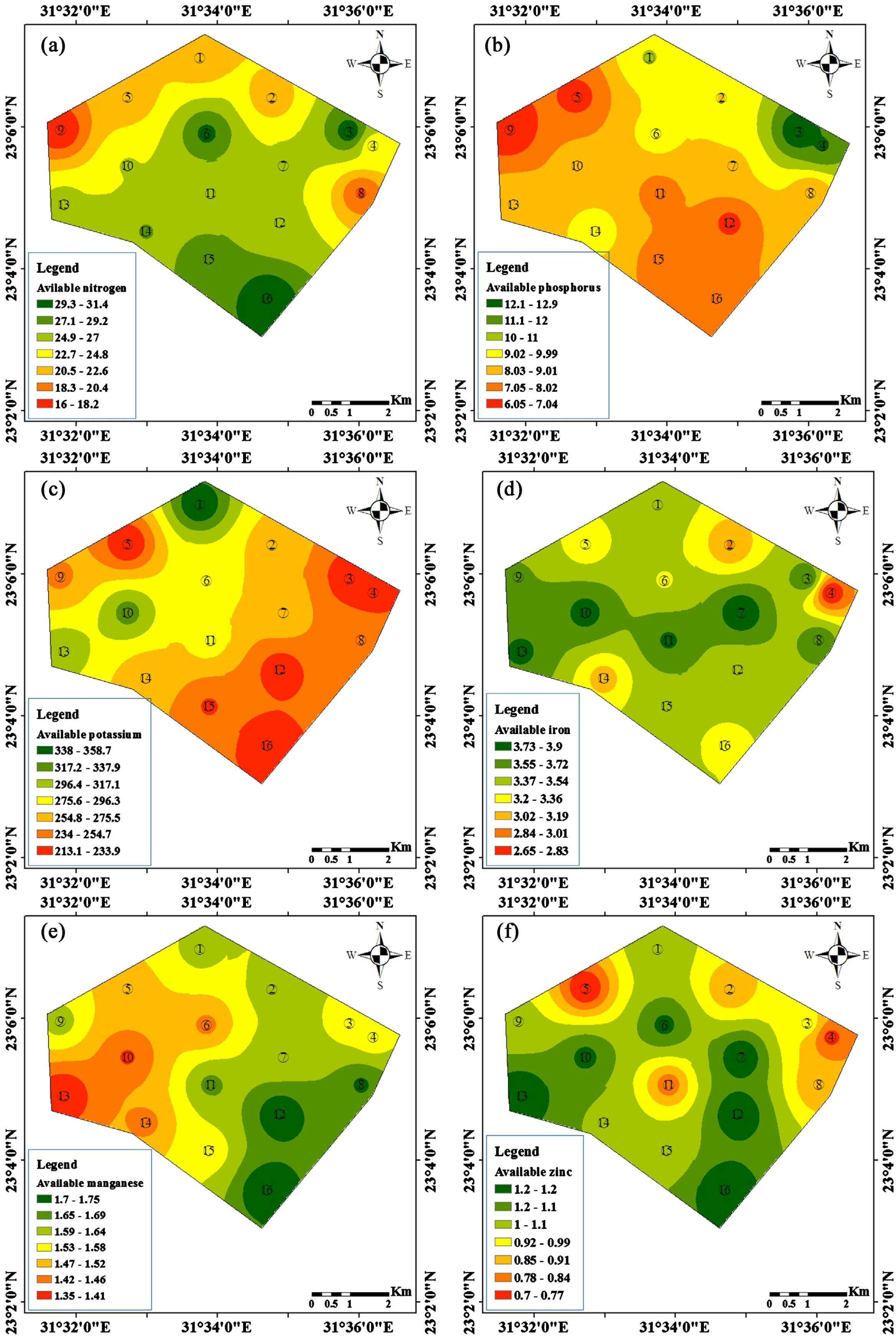
Sample NO	N	E	Available macronutrients			DTPA-Extractable micronutrients			
			*Av*N	*Av*P	*Av*K	*Av*Fe	*Av*Mn	*Av*Zn	*Av*Cu
			(mg·kg⁻¹)						
1	23.116366	31.562427	20.40	10.05	358.75	3.50	1.60	1.05	0.35
2	23.106825	31.579489	21.00	9.00	266.95	3.00	1.60	0.85	0.25
3	23.098874	31.597729	30.55	12.95	219.55	3.70	1.55	0.95	0.35
4	23.095585	31.603224	23.75	12.05	225.60	2.65	1.55	0.75	0.45
5	23.107061	31.545507	20.70	6.65	213.05	3.25	1.50	0.70	0.25
6	23.098458	31.564112	29.85	9.55	290.05	3.35	1.45	1.15	0.40
7	23.090853	31.582186	25.05	8.85	274.45	3.90	1.60	1.20	0.40
8	23.084447	31.600490	18.00	8.05	247.95	3.65	1.70	0.85	0.35
9	23.099278	31.529625	15.95	6.05	250.75	3.55	1.60	1.00	0.40
10	23.090910	31.545520	24.90	8.40	326.15	3.80	1.40	1.15	0.40
11	23.084391	31.565033	26.00	7.60	285.40	3.75	1.65	0.80	0.35
12	23.077438	31.581355	25.00	6.75	220.65	3.40	1.75	1.20	0.20
13	23.081815	31.530448	25.65	8.85	310.25	3.75	1.35	1.20	0.45
14	23.075473	31.549800	27.10	9.70	261.05	3.10	1.45	1.05	0.35
15	23.068928	31.5646843	27.90	7.80	231.85	3.50	1.55	1.00	0.30
16	23.059622	31.578320	31.45	7.45	220.95	3.30	1.75	1.20	0.25

*Av*N, *Av*P, *Av*K, *Av*Fe, *Av*Mn, *Av*Zn and *Av*Cu indicate available nitrogen, phosphorus, potassium, iron, manganese, zinc and copper, respectively.

respectively. The lowest percentages of available micronutrients were 2.65% (AFe), 1.40% (AMn), 0.70% (AZn) and 0.20% (ACu) which were detected in samples 4, 10, 5 and 12, respectively. Conversely, the maximum AFe (3.95%) and ACu (0.45%) were from samples 7 and 13, respectively. Similarly, the maximum AMn (1.75%) and AZn (1.22%) were in both samples 12 and 16. The overall available micronutrient averages were 3.45% (AFe), 1.75% (AMn), 1.01% (AZn) and 0.34% (ACu).

3.2. Spatial Distribution of Soil Physical Properties

The soils were dominated by sand > silt > clay (in Table 5 and Figure 4). Among the 16 samples, the minimum and maximum sand, silt and clay contents varied from 43.90% (sample 3) - 73.10% (sample 9). 18.05% - 28.95% detected in samples 8 and 3 and 8.20% - 27.15% detected in samples 9 and 3 with an average 60.26, 23.24 and 16.51%, respectively. Moreover, no gravel was detected in any sample. The soil categories were sandy loam at 62.50% (in soil samples 2, 4, 5, 6, 8, 9, 12, 13, 14 and 16) followed by sandy clay loam at 18.75% (in soil samples


31°32'0"E
31°34'0"E
31°36'0"E
23°6'0"N
23°4'0"N
23°2'0"N
(a)
Legend
Avilable nitrogen
29.3 - 31.4
27.1 - 29.2
24.9 - 27
22.7 - 24.8
20.5 - 22.6
18.3 - 20.4
16 - 18.2
(b)
Legend
Available phosphorus
12.1 - 12.9
11.1 - 12
10 - 11
9.02 - 9.99
8.03 - 9.01
7.05 - 8.02
6.05 - 7.04
(c)
Legend
Available potassium
338 - 358.7
317.2 - 337.9
296.4 - 317.1
275.6 - 296.3
254.8 - 275.5
234 - 254.7
213.1 - 233.9
(d)
Legend
Available iron
3.73 - 3.9
3.55 - 3.72
3.37 - 3.54
3.2 - 3.36
3.02 - 3.19
2.84 - 3.01
2.65 - 2.83
(e)
Legend
Available manganese
1.7 - 1.75
1.65 - 1.69
1.59 - 1.64
1.53 - 1.58
1.47 - 1.52
1.42 - 1.46
1.35 - 1.41
(f)
Legend
Available zinc
1.2 - 1.2
1.2 - 1.1
1 - 1.1
0.92 - 0.99
0.85 - 0.91
0.78 - 0.84
0.7 - 0.77
N
S
W
E
0 0.5 1 2 Km

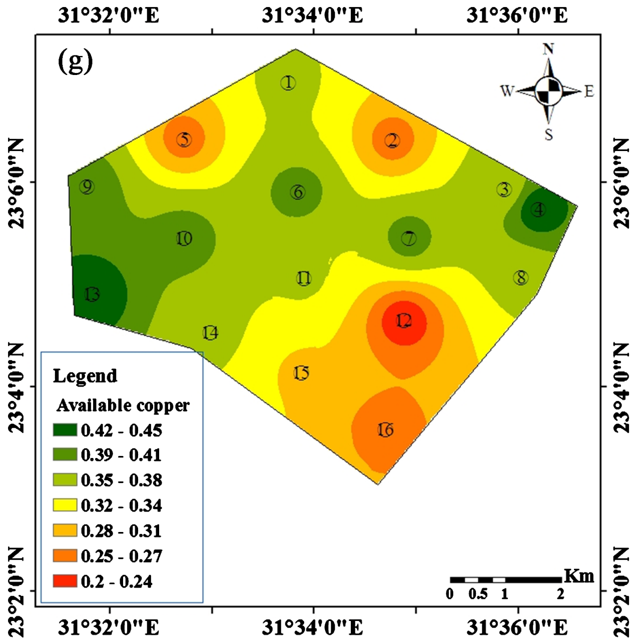


Figure 3. Show the spatial distribution of some available nutrients in Toshka area (23˚40'N and 32˚60'N and 31˚32'E and 31˚36'E), Aswan, EGYPT.

Table 5. Spatial distribution of particle size distribution and some soil physical properties in the studied area (23˚40'N and 32˚60'N and 31˚32'E and 31˚36'E) in Toshka area, Aswan, Egypt.

Sample No	N	E	Sand (%)	Silt (%)	Clay (%)	Textural Class	SBD ($Mg \cdot cm^{-3}$)	TSP (%)	K_{sat} ($cm \cdot h^{-1}$)
1	23.116366	31.562427	48.35	28.25	23.40	Loamy	1.47	42.05	2.15
2	23.106825	31.579489	70.10	19.65	10.25	Sandy loam	1.54	42.25	2.85
3	23.098874	31.597729	43.90	28.95	27.15	Clay loam	1.38	48.45	1.20
4	23.095585	31.603224	69.40	20.00	10.60	Sandy loam	1.51	43.55	3.05
5	23.107061	31.545507	71.30	19.50	9.20	Sandy loam	1.53	42.65	2.55
6	23.098458	31.564112	60.70	23.75	15.55	Sandy loam	1.46	45.25	1.80
7	23.090853	31.582186	48.20	26.85	24.95	Sand clay loam	1.50	46.00	1.75
8	23.084447	31.600490	73.00	18.05	8.95	Sandy loam	1.48	44.70	2.80
9	23.099278	31.529625	73.10	18.70	8.20	Sandy loam	1.52	43.00	2.55
10	23.090910	31.545520	49.60	26.15	24.25	Sandy clay loam	1.47	44.90	1.90
11	23.084391	31.565033	44.50	28.85	26.65	Loamy	1.45	45.60	2.05
12	23.077438	31.581355	71.50	19.05	9.45	Sandy loam	1.55	41.85	3.45
13	23.081815	31.530448	63.20	23.85	12.95	Sandy loam	1.46	44.80	1.70
14	23.0754731	31.549800	55.50	25.10	19.40	Sandy loam	1.45	45.60	2.05
15	23.068928	31.564684	49.50	26.75	23.75	Sandy clay loam	1.52	43.00	2.90
16	23.059622	31.578320	72.25	18.35	9.40	Sandy loam	1.55	41.85	3.45

SBD = soil bulk density, TSP = total soil porosity and K_{sat} = saturated hydraulic conductivity.

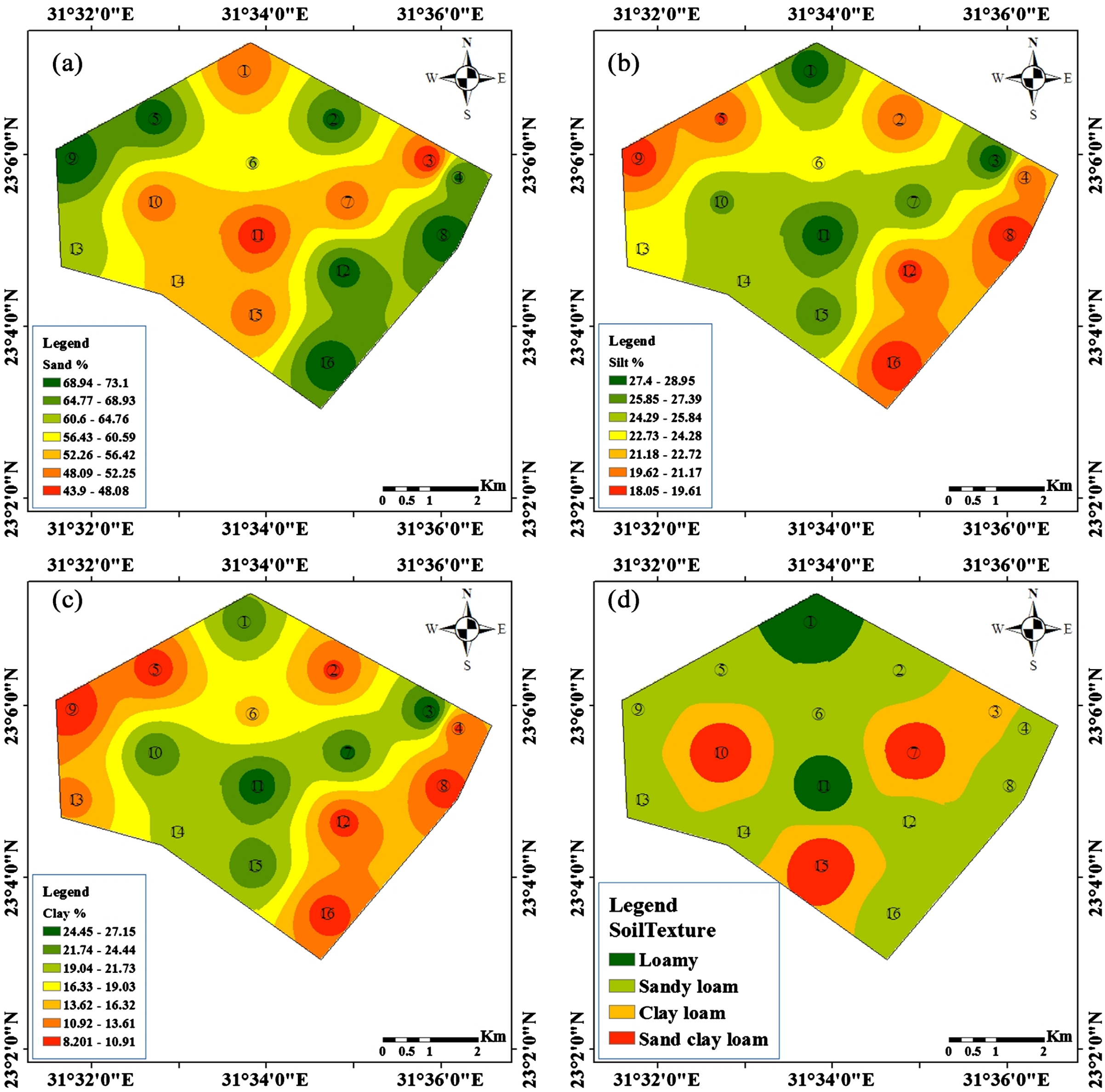


Figure 4. Show the spatial distribution of particles size distribution and soil textures in Toshka area (23˚40'N and 32˚60'N and 31˚32'E and 31˚36'E), Aswan, EGYPT.

7, 10 and 15) and loamy at 12.50% (in samples 1 and 11) of the 16 soil samples, only sample 3 was clay loam (in Table 5). As shown (in Table 5 and Figure 5), the soil bulk density (SBD, Mg·cm^{-3}) and saturated hydraulic conductivity (K_{sat}) ranged from 1.38 Mg·cm^{-3} and 1.2 cm·h^{-1} (in sample 3) to 1.55 Mg·cm^{-1} and 3.45 cm^{3}·h^{-1} (in samples 12 and 16), with an average of 1.49 Mg·cm^{-1} and 2.39 cm^{3}·h^{-1}, respectively. Contrarily, the lowest and highest total soil porosity (TSP, %) varied from 41.85% (in samples 12 and 16) to 48.45% (in sample 3) with an average of 44.09%.

3.3. Pearson's Correlation Coefficient Results

The linear correlation coefficients of the 12 chemical and physical parameters

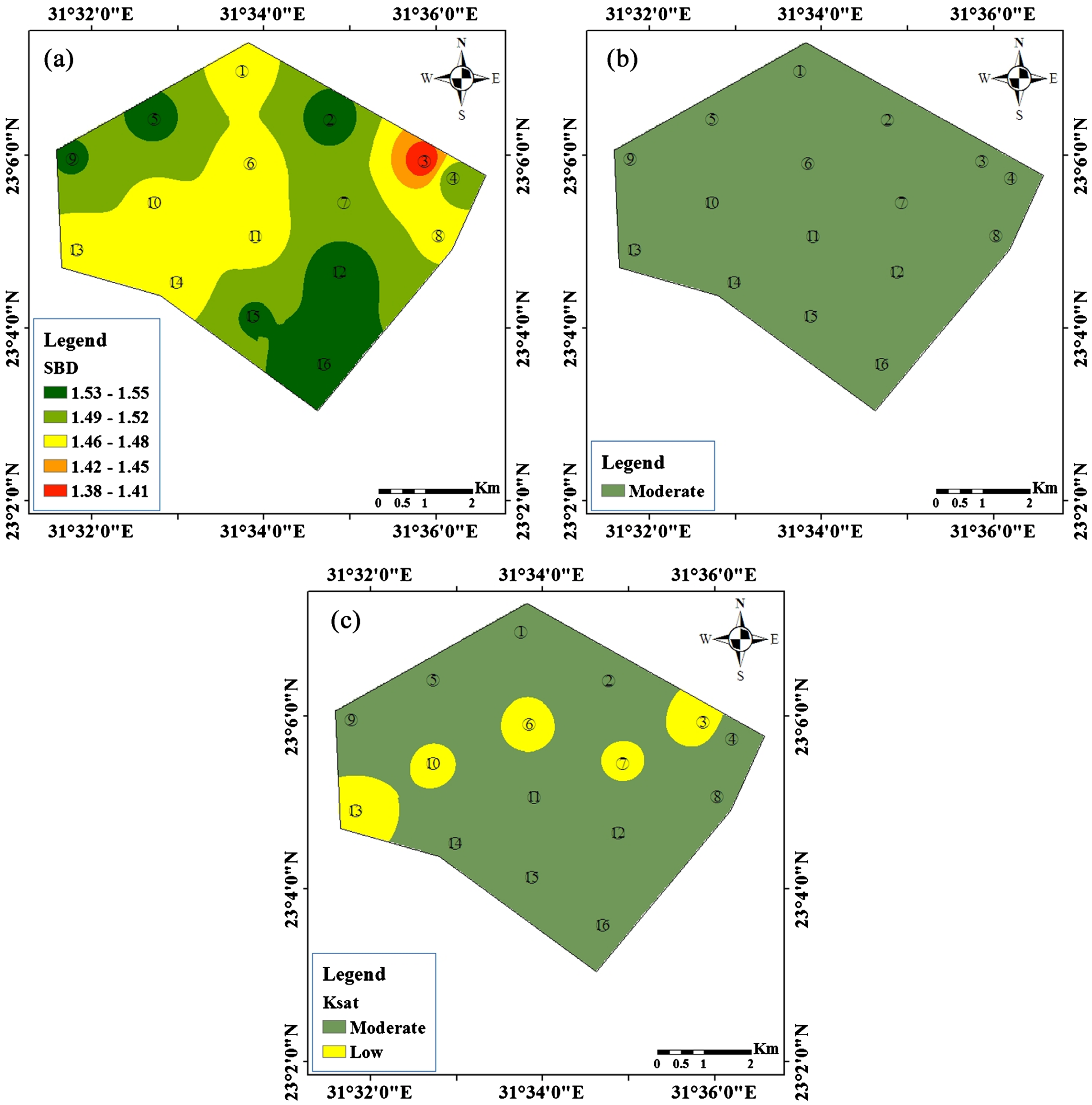


Figure 5. Show the spatial distribution of some physical properties in Toshka area (23˚40'N and 32˚60'N and 31˚32'E and 31˚36'E), Aswan, EGYPT.

(soil pH, ECe, $CaCO_3$, SOM, CEC, particle size distribution including sand, silt and clay, GC, SBD, TSP and K_{sat}) are provided (in Table 6). Highly significant ($p < 0.01$) positive correlations (r = 0.683**, 0.802**, 0.805**, 0.664** and 0.639**) were obtained between SOM with CEC and both silt and clay contents with GC and TSP, respectively. Highly significant negative correlations (r = −0.810**, −0.658** and −0.678**) occurred between sand content with SBD and K_{sat}. Highly significant positive correlations (r = 0.931**, 0.921** and 0.861**) were observed between CEC with silt and clay content, as well GC, respectively. Significant positive correlations existed between CEC and TSP ($P < 0.05$). Highly significant negative correlations (r = −0.931**, −0.535** and −0.622**) existed

Table 6. Paerson's correlation coefficient and their significance levels between some soil chemical and physical parameters in studied area (23˚40'N and 32˚60'N and 31˚32'E and 31˚36'E) in Toshka area, Aswan, EGYPT.

Parameter	Soil pH	ECe	$CaCO_3$	SOM	CEC	Sand	Silt	Clay	GC	SBD	TSP	K_{sat}
1	1.00	−0.126	−0.121	0.166	0.073	−0.223	0.274	0.192	0.048	−0.480	0.133	−0.193
2		1.00	0.324	0.211	0.187	−0.169	0.114	0.199	0.226	−0.417	0.649**	−0.329
3			1.00	0.127	−0.049	0.070	−0.049	−0.081	−0.340	0.320	0.323	−0.434
4				1.00	0.683**	−0.810**	0.802**	0.805**	0.664**	−0.658**	0.639**	−0.678**
5					1.00	−0.931**	0.931**	0.921**	0.861**	−0.535**	0.533*	−0.622**
6						1.00	−0.988**	−0.996**	−0.884**	0.672**	−0.600**	0.694**
7							1.00	0.971**	0.855**	−0.707**	0.592*	−0.738**
8								1.00	0.891**	−0.646**	0.598*	−0.662**
9									1.00	−0.491	0.547*	−0.510*
10										1.00	−0.865**	0.858**
11											1.00	−0.819**
12												1.00

between CEC with sand, SBD and K_{sat}, respectively. The particle size distribution had a profound influence on most of the physical properties (Table 6). However, the SBD was significantly positively correlated (r = 0.672**) with sand content and significantly negatively correlated (r = −0.707** and −0.649**) with silt and clay content, respectively. Furthermore, there was a highly significant negative correlation (r = −0.600** and −0.865**) between TSP with sand content and SBD, respectively. There was a significant positive correlation (r = 0.592*, 0.598* and 0.547*) between TSP with silt, clay and GC, respectively. The K_{sat} was highly significantly positively correlated (r = 0.694**) with sand content. The K_{sat} was significantly negatively correlated (r = −0.738**, −0.662**, −0.819** and −0.510*) with clay, silt, TSP and GC, respectively.

3.4. Assessment of Chemical Quality Index and Nutrient Index

Soil chemical and fertility assessments are important when implementing land reclamation. The chemical index (CI) and fertility index (FI) following [35] [36] uses the spatial distribution of the chemical properties and available nutrient contents (in Table 3 and Table 7). Approximately 43.75% of the soil samples were of moderate quality, with the CI ranging from 1.13 - 1.46 with approximately 56.25% of samples higher than 1.46, suggesting the soils are low quality. The fertility index (FI) revealed all soil samples conformed to the low quality classes as demonstrated (in Table 7).

4. Discussion

Soil is a dynamic system, consisting of three phases (solid, liquid and gaseous). Soil is the main environment for plant growth and productivity and its properties

Table 7. Classes and the corresponding weight assigned for the calculation of the chemical index and fertility index the studied area (23˚40' and 32˚60' N and 31˚32' and 31˚36') in Toshka area, Aswan, Egypt.

Sample NO.	N	E	CI	Class	FI	Class
1	23.116366	31.562427	1.43	S_2	1.51	S_3
2	23.106825	31.579489	1.43	S_2	1.58	S_3
3	23.098874	31.597729	1.50	S_3	1.58	S_3
4	23.095585	31.603224	1.43	S_2	1.58	S_3
5	23.107061	31.545507	1.50	S_3	1.67	S_3
6	23.098458	31.564112	1.50	S_3	1.51	S_3
7	23.090853	31.582186	1.50	S_3	1.51	S_3
8	23.084447	31.600490	1.50	S_3	1.67	S_3
9	23.099278	31.529625	1.50	S_3	1.70	S_3
10	23.090910	31.545520	1.43	S_2	1.51	S_3
11	23.084391	31.565033	1.61	S_3	1.67	S_3
12	23.077438	31.581355	1.43	S_2	1.60	S_3
13	23.081815	31.530448	1.43	S_2	1.51	S_3
14	23.075473	31.549800	1.50	S_3	1.51	S_3
15	23.068928	31.564684	1.43	S_2	1.60	S_3
16	23.059622	31.578320	1.50	S_3	1.60	S_3

Cl = Chemical index, FI = fertility index and S_2 (1.13 - 1.46) and S_3 (>1.46) indicate moderate and low quality, respectively.

are continuously changing [39]. Crop productivity mainly depends on soil quality (SQ) and is affected by soil chemical (SCP) and physical (SPP) properties. We assess both the SCP and SPP to evaluate SQ for potential land reclamation and cultivation. The soil pH ranged from slightly alkaline to moderately alkaline. This relative increase in soil pH was probably due to the sufficient content of $CaCO_3$ and the nature of the parent materials in the soil [40]. The results support the findings of [1] [9]. However, [8] Hamed and Khalafallh, 2017 suggested dominant base cations (such as Na^+, Ca^{++} and Mg^{++}) in the soil combine with low precipitation to cause a high soil pH. This pH range is not suitable for the uptake of most nutrients as the optimum range for plant absorption varies from 6.5 - 7.5 [41] (Kusumandari *et al.*, 2018). In general, the soil was saline calcareous, with mean values (8.28 $dS \cdot m^{-1}$ and 14.29%) exceeding 4.0 $dS \cdot m^{-1}$ and 11.0% for ECe and $CaCO_3$, respectively. The soil is categorized as moderately saline in approximately 37.50% of the sample sites. At this level, yields of several crops would be affected, but only to varying degrees although highly saline conditions (62.50%) are only suitable for salt tolerant crops. The results support the findings of [42]. The pronounced high levels of $CaCO_3$ could be attributed to the accumulation of Ca^{++} ions in high soil salinity. Conversely, the ECe positively correlated (r = 0.324) with $CaCO_3$. Furthermore, the nature of the parent material accompanied by the prevalent climatic conditions (such as high temperatures and low precipitation) affect evaporation rates [43]. All soil samples had very low SOM contents which did not exceed 0.18%, with an average SOM of 0.14%. This result was expected due to the high sand content, however most of the samples had a sandy loam texture [44] with eroded topsoil, which increases oxidation rates [45] [46] [47] [48]. The results may be explained by the correlation coefficient values, SOM was significantly negatively correlated (r = −0.810**) with sand content and significantly positively correlated (r = 0.802** and 0.805**) with silt and clay contents, respectively. Therefore, the low SOM was probably due to the slow rate of decomposition as a result of the high temperature and low relative humidity [49].

CEC is a good indicator of soil productivity and is a crucial indicator for recommending the levels of some elements in the soil (such as, phosphorus, calcium, and magnesium). Overall, the mean CEC of the samples was 15.05 $Cmol·kg^{-1}$. Therefore, the all studied samples were characterized with moderate CEC, ranging from 12.00 - 25.00 $Cmol·kg^{-1}$. The results are not constant with many previous studies [42] [50] reporting high CEC is strongly positively correlated with SOM content (r = 0.683**) in the soil owing to SOM being the main source of negative charges [51] [52]. In our investigation, the high CEC values may be attributed to the silt and clay content in combination with the relatively high soil pH [53] [54]. **Table 6** demonstrates the CEC was highly significantly positively correlated (r = 0.931** and 0.921**) with both silt and clay, respectively, and was strongly significantly negatively correlated (r = −0.931**) with sand content. The clay content is considered a source of nutrients as it attracts cations and provides additional exchange sites. Generally, the unexpected trend of high CEC in the soil requires further mineralogical research.

As mentioned in **Table 5**, the means of the available nitrogen (AvN) (24.58 $mg·kg^{-1}$) and available phosphorus (AvP) (8.73 $mg·kg^{-1}$) were relatively low according to [55]. The low levels are explained by the low SOM content [56] [57]. The mean available potassium (AvK) (262.71 $mg·kg^{-1}$) was relatively high. The relatively high AvK may be attributed to the silt and clay content adsorbing K ions in the particles (silt and clay). The particles were smaller than 0.2 mm (both silt and clay) and positively correlated (r = 0.428 and 0.388) with SOM content. All soil samples were deficient in the micronutrients of available iron (AvFe) and manganese (AvMn). However, the levels were also low for AvFe (at 4.50 $mg·kg^{-1}$) and AvMn (3.5 $mg·kg^{-1}$). In contrast, the available zinc (AvZn) was approximately 93.5% in all samples. The available copper (AvCu) averaged from 1.01 to 0.34 $mg·kg^{-1}$ with is medium levels. However, one sample (site 13) had an AvCu of 6.25%, which is within the high range. However, levels of 0.6 $mg·kg^{-1}$ for AvZn and 0.2 $mg·kg^{-1}$ for AvCu are the critical levels for these elements [37]. The low levels of both AvFe and AvMn are probably due to the low variability in geochemical characteristics [58].

The textural classes ranked in descending order were sandy loam (62.50%) > sandy clay loam (18.75%) > loamy (12.50%) > clay loam (6.25%). Although several previous studies have suggested soil texture is affected by several factors (such as agricultural practices including tillage and the addition of OM), texture is an inherent characteristic which is related to the prevalent parent material [59]. Therefore, altering soil texture remains very limited. [60] revealed a sandy texture was probably due to the underlying rocks which form the soil. [61] proposed fine particles (such as silt and clay) are the effects of washing in erosion by water and wind. Soil texture is an important soil physical property which effects water holding capacity, soil structure, and nutrient availability [62].

As presented in **Table 5**, the general SBD and TSP were moderate. While, the K_{sat} values ranged from 1.20 - 3.45 $cm^3 \cdot h^{-1}$. The averages were 1.49 $Mg \cdot cm^{-3}$ for SBD, 44.09% for TSP and 2.39 $cm^3 \cdot h^{-1}$ for K_{sat}. Our results are in accordance with previous findings [63] [64] [65]. However, the SBD was positively correlated (r = 0.672**) and TSP was negatively correlated (r = −0.600*) with coarse-textured soils and the high $CaCO_3$ content [66]. The SBD were significantly negatively correlated with silt (r = −0.707** and −0.646**) and significantly positively correlated with clay (r = 0.592* and 0.598*). The reverse relationship between SBD and TSP was previously suggested by [67] (see **Table 6**). [61] Lema *et al.* 2019 suggests high SBD can be attributed to a relatively low SOM content due to their reverse relationship. However, the correlation coefficient revealed the SOM content was significantly negatively correlated with SBD (r = −0.758**). These results support the findings of [68]. The low SBD was highly negatively correlated with high TSP (r = −0.865**). Soil texture is an important property for regulating water movement in the soil profile. The K_{sat} values indicated the soil has moderately rapid infiltration, based on the texture [69]. Therefore, the soil is suitable for irrigation with occasional runoff. The Pearson correlation coefficient revealed the K_{sat} was affected by many factors. The SOM, CEC, Silt and clay contents were significantly negatively correlated with K_{sat} (r = −0.678**, −0.622*, −0.738** and −0.662**, respectively). A highly significant positive correlation (r = 0.694**) existed between K_{sat} and sand content.

The chemical (CI) and fertility (FI) index assessments varied with the soil chemical and physical properties. The soil exhibited low values for both indexes with approximately 56.25% and 100% of the samples categorized as low quality for both CI and FI, respectively. These values are explained by the undesirable soil property results. In summary, this location is considered one of the most promising areas to contribute to solving food insecurity in Egypt which is a developing country suffering from increasing population growth. The soil could be improved by adjusting and modifying the undesirable properties by methods such as enhancing the texture by adding River Nile clay particles from the reserves behind the High Dam. This would contribute to modifying the soil nutrient content, increasing CEC and reducing salinity. Further research is required into calculating the leaching levels which has not previously been estimated. Additional soil improvement suggestions include selecting salt-tolerant crops and adding organic matter. Furthermore, optimum fertilization recommendations based on the chemical and fertility index values are required.

5. Conclusion

We evaluated the soil chemical and physical properties in an area located between 23˚40'N and 32˚60'N and 31˚32'E and 31˚36'E (about 6300 ha) in Toshka, in the South western section of the Eastern Desert which belongs to Aswan Governorate in upper Egypt. The findings suggest the soil ranges from slightly to moderately alkaline. The soil had a remarkably low SOM content which did not exceed 0.18%. The soil was characterized as saline and moderately calcareous, however the lowest values were 4.65 $dS \cdot m^{-1}$ (ECe) and 11.85% ($CaCO_3$), with an average of 8.28 $dS \cdot m^{-1}$ (ECe) and 14.29% ($CaCO_3$). The available nutrient contents varied greatly. Results of the correlation coefficients osculated widely. The chemical index ranged from moderate (43.75%) to low quality (56.25%), and all samples possessed low fertility.

Authors' Contributions

The Conception of the project, A.A.M.A; field works and sampling, M.M.A.A.; data curation, A.A.M.A. and M.M.A.A.; formal analysis A.A.M.A.; investigation, A.A.M.A.; methodology, A.A.M.A. and M.M.A.A.; resources, A.A.M.A. and M.M.A.A.; software, A.A.M.A. writing-original draft, A.A.M.A. and M.M.A.A. and writing-review and editing A.A.M.A.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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