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The Vital Roles of Parent Material in Driving Soil Substrates and Heavy Metals Availability in Arid Alkaline Regions: A Case Study from Egypt

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Abstract: Despite studies focusing on soil substrates (carbon and nitrogen) and heavy metal availability, the impact of diversified parent materials in arid alkaline regions has received little attention. To reveal the influence of parent material, we investigated four different parent materials: fluvio-marine, Nile alluvial, lacustrine, and aeolian deposits. We assessed the effect of soil parent materials through selected soil physical and chemical properties, such as clay content, bulk density, pH, and available phosphorus (AP). The Tukey HSD test (SPSS ver. 23) was used to assess the soils derived from these different sediments. Using the R "glmulti" package, we examined this effect in a model of mixed-effects meta-regression. The sum of Akaike weights for models that contained each element was used to estimate the importance of each factor. The average contents of soil organic carbon (SOC) and total N in alluvial deposits were greater ($p < 0.001$) than those of marine, aeolian, and lacustrine deposits. A multivariate analysis in arid regions revealed that parent material, soil pH, and the availability of P had the greatest effects on SOC concentration, whereas clay content, available P, soil pH, parent material, and bulk density had the greatest effects on soil total nitrogen. The average content of Fe in the aeolian deposits was greater ($p < 0.001$) than those of marine, alluvial, and lacustrine deposits, without any significant differences between the latter two deposits. We found that the highest average contents of zinc (Zn), manganese (Mn), and copper (Cu) were recorded in alluvial deposits, with significant differences between other deposits. Soil parent material was the major factor impacting soil iron (Fe) content, along with clay content and soil pH. However, soil bulk density was the most important factor controlling soil Zn and Mn contents, while SOC drove Cu content. This study will help in developing a more accurate model of the dynamics of soil substrates and availability of heavy metals by considering readily available variables, such as parent materials, soil pH, soil bulk density, and clay content.

Keywords: SOC stocks; soil substrate availability; soil heavy metals; soil forming factors; soil genesis; alkaline soils

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1. Introduction

Along with climate, biota, relief, and time, parent material is widely recognized as a significant soil-forming factor [1]. The variability of the mineralogical and physicochemical characteristics of soils reflects the parent material origin [2]. In agricultural, environmental, and geological investigations, parent material is used as a significant factor in soil classification and explaining soil units [3]. Under identical conditions of vegetation and topography, various parent materials impact the chemistry and morphology of soils, particularly in arid and semiarid areas [4]. Parent material is frequently associated with critical soil physical properties (clay mineralogy, soil texture, soil structure, soil thickness, erodibility, and shrinkage and swelling potential) and chemical properties (cation exchange capacity (CEC), nutrient status, heavy metals, sodicity, salinity, and acidity) [5]. With the notable exceptions of oxygen, carbon (C), nitrogen (N), and hydrogen, which are taken predominantly from the atmosphere and organic matter, the majority of nutrients required for plant growth are derived primarily from parent material [5]. Soil organic C (SOC) and total N, known as soil substrate, are vital soil components for agricultural production, soil fertility, and, consequently, its quality [6,7]. Parent material type plays a primary role in soil C and N mineralization [8]. Moreover, variations in parent materials affect soil attributes, such as texture, soil bulk density, pH, and calcium carbonate ($CaCO_3$) [9]. On a global scale, numerous studies have identified that variations in soil substrate content have been correlated with vegetation type and climate [10]. Soil total N and SOC storage increased as the revegetation chronosequence progressed [11,12]. Various parent materials and soil texture influence bacterial diversity and nutrients, particularly SOC [13]. Heavy metals, such as manganese (Mn), zinc (Zn), iron (Fe), and copper (Cu), are fundamental for crop production, yield quantity, and holding yield responses to frequent NPK fertilizer [14]. However, an increase of these elements in soil beyond the permissible limit can reduce crop yields and be poisonous [15]. Soil parent material controls the original supply of those heavy metals from the weathering process and affects the balance between heavy metal retention and loss [16]. Exudates and organic acids produced by plants and microorganisms improve minerals weathering, and, ultimately, heavy metal release [17]. Heavy metals may be adsorbed to SOM and clay or interact with organic substances, thereby decreasing their mobility and speciation in soils [17]. These processes are influenced by soil formation, which alters the environment at various depths as soil horizons develop [16]. However, the impact of parent material on the original soil heavy metals supply in arid alkaline regions remains largely unknown [17].

The studied regions are situated in Egypt and have an important role in population, environmental, and agricultural development. These regions include a variety of parent material types, regionally derived from either alluvial, aeolian, marine, or lacustrine deposits. Aeolian sandy soils are those that develop on sand-based parent material as a result of wind action. In such soils, a sandy layer of $\geq$1 m is common, consisting primarily of fine sand with approximately 80% of particles falling between 0.25 and 0.05 mm in size [18]. Whatever the climatic circumstances, the prevalence of quartz in the bedrock makes it exceedingly unlikely that the suite of clay minerals present in the soil is the result of weathering [19]. The parent material of $CaCO_3$-rich soil in the northwestern coastal region of Egypt is composed of a variety of rocks, e.g., limestone, sandstone, $CaCO_3$-rich shale, or marl, formed as a result of weathering, translocation, and deposition processes under the arid climatic conditions [20,21]. The following parameters were used to choose the marine soil profiles: $CaCO_3$, soil texture, electrical conductivity (EC), and hydrogen power; macronutrients such as nitrogen, phosphorus, potassium, and organic carbon; micronutrients such as manganese, zinc, iron, and copper; and other sodium and CEC [20]. High $CaCO_3$ content has an impact on soil pH, soil buffering capacity, CEC, base saturation, and nutrient availability, as well as the soil hydraulic conductivity and permeability [22]. Organic matter, clay content, soil texture, pH, Aluminum, Fe, and Calcium contents influenced P sorption [23]. Thus, poor P and K availability in plants results in issues that are more severe than their shortages. One of the key goals of plant nutrition is to increase the availability of these nutrients. The morphological features and particle size distribution show that the texture class is sandy loam and sand clay loam for the subsurface horizon [24]. Alluvial soils are among the most important and productive soil resources. The silt deposited by fluvial systems, such as streams and rivers, is alluvium, the parent material of alluvial soils [3]. Depending on the depositional environment and geologic materials source, alluvium can have a wide range of textures and compositions. Alluvium can be found in all temperate zones and sits beneath geomorphic surfaces with ages ranging from zero to millions of years; it is therefore widely diverse [3].

Lacustrine deposits are sedimentary rock formations that developed at the bottom of ancient lakes [25]. Such deposits frequently have silt that was transported into the basin by a river or stream and frequently contain beds that are extensively laminated with silt, clay, and even carbonates. In geologic time, lakes are momentary; once the water stops flowing into them, they dry out and produce a formation [26]. In terms of Egypt, lacustrine deposits cover considerable areas, particularly in the northern parts near the lakes and the Mediterranean coastal zone, which are characterized by moist conditions that prevail most of the year [26]. Most of the profiles here have medium texture; the enrichment of lime or gypsum occurs in some profiles, and the soil color is characterized by a 10YR hue with a value between 3 and 5 and a chroma of mostly 2 [26]. Bluish or brownish mottling occurs in most of the profiles. The wetness is mostly associated with a high salinity due to the high groundwater table [27]. Furthermore, the solum of these soils is mostly shallow (45–100 cm) [28]. To our knowledge, our study is one of the first to elucidate the impact of contrasting parent materials on soil substrates and heavy metal availability in arid alkaline regions. Our study's objectives were to: (1) elucidate the patterns and controlling factors of soil substrates (SOC and total N) and heavy metals (Fe, Zn, Mn, and Cu) availability in arid alkaline regions under contrasting parent materials, and (2) compare soil metrics and features in various parent materials. Our study hypothesized that parent material would be the most important factor affecting soil substrates and heavy metal availability in arid alkaline regions.

2. Materials and Methods

2.1. Site Specification

Eight soil profiles were selected from four soil catchments of different parent materials in Egypt. These regions are situated in eastern, western, southern, and middle Egypt: Profile 1 (P1)—elevation 31 m a.s.l., 30°48′56.008″ N and 29°23′38.764 E; Profile 2 (P2)—elevation 26 m, 30°53′5.766″ N and 29°43′2.444″ E; Profile 3 (P3)—6 m, 30°41′20.103″ N and 31°40′50.089″ E; Profile 4 (P4)—14 m, 30°23′24.156″ N and 31°10′1.891″ E; Profile 5 (P5)—13 m, 30°58′58.057″ N and 31°46′32.347″ E; Profile 6 (P6)—2 m, 30°53′5.766″ N and 31°49′57.703″ E; Profile 7 (P7)—224 m, 29°45′23.546″ N and 30°24′58.047″ E; Profile 8 (P8)—56 m, 30°14′2.767″ N and 30°14′7.755″ E (Figure 1).

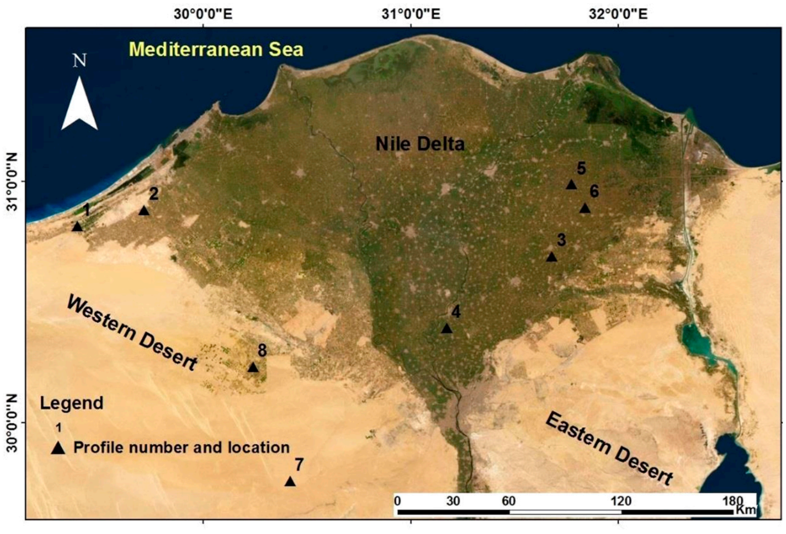

Figure 1. Location map of the soil profiles.

The soil survey was performed during the year 2021, and the pedons were dug according to soil morphological observations, to their depth, to the hard layer, or to the parent rock. The soil profile consists of a number of horizons, which were sampled in all 27 of the profiles. The representative soil samples were air-dried and sieved to 2 mm three times for chemical and physical analyses. According to the key of Soil Taxonomy [29], the field morphological description of these profiles and the main physical and chemical characteristics revealed that the soils were formed from fluvio-marine, Nile alluvial, lacustrine, and aeolian deposits. According to [30], the parent material of P1 and P2 was related to fluvio marine deposits, which consisted of sandy clay loam deposits and were produced by Pleistocene marine regressions. The parent material of P3 and P4 was related to alluvial deposits of silty clay sediments, while P5 and P6 were related to lacustrine deposits composed of clay sediments, and P7 and P8 were related to aeolian plains and inherited from shale, limestone, or sandstone as a parent material, which were composed of sandy sediments.

2.2. Soil Sampling and Laboratory Analysis

The international pipette method was used to perform the particle-size analysis [31]. The soil pH was determined by electrode immersion 1 h after stirring with a glass rod in a suspension of 1:2.5 soil:water. With intermittent agitation for one hour and centrifugation at 2000 rpm for 15 min, the EC of the soil was measured in a 1:1 soil-to-water ratio [32]. Soil CEC was estimated using the sodium acetate method [31]. The exchangeable sodium percentage (ESP, %) was computed as follows [33]:

$$ESP = (Na^{+}/CEC) \times 100, \tag{1}$$

where Na^{+}: measured exchangeable Na, cmol kg^{-1}; CEC: cation exchange capacity, cmol kg^{-1}.

The following equation was used to determine the amount of coarse fraction in the soil (particles larger than 2 mm) [34]:

$$\text{Gravel content (\%)} = (\text{coarse materials weight}/\text{coarse and fine materials weight}) \times 100, \tag{2}$$

The SOC concentration was determined using the SOC pool calculation (SOCP). By multiplying the SOM by a factor of 0.58, the content of SOM for each horizon was first converted to a SOC percentage [34]. The SOC% was multiplied by the soil depth, soil bulk density (Mg m^{-3}), and soil fraction (<2 mm in size) to determine the SOCP (kg C m^{-2}) for each soil horizon [34]:

$$SOCP = [L \times B.D \times SOC \times (1 - F/100)]/10, \tag{3}$$

where SOCP refers to the soil organic carbon pool for each soil horizon (kg m^{-2}), L is the thickness of soil horizon, SOC is the soil organic carbon content (wt%), F is equal to 10 mm for coarse soil fragment and 5 mm for fine soil fragment (wt%), and BD is the soil dry bulk density (Mg m^{-3}).

Available N was determined according to [35]. Available P was determined using the ascorbic acid method [35]. Ammonium acetate (1.0 N) was used to extract available potassium (K) at pH 7.0 and quantified by the flame photometer [35]. Total N in soil was digested by 10 mL H_2SO_4 + 5 mL $HClO_4$ and determined using the micro-Kjeldahl method [35]. Diethylene triamine penta-acetic acid (DTPA) was used to extract the available micronutrients from the soil samples (Zn, Fe, Cu, and Mn), which were then measured using an atomic absorption spectrometer [36].

2.3. Mineralogical Analysis

The original samples, which were derived from different deposits, were dried. Using bromoform, they were all set for mineral separation (Sp. Gr. 2.86 g cm^{-3}). Individual grains of heavy minerals were subjected to chemical analyses using a Phillips XL-30 environmental scanning electron microscope (ESEM), while semi-quantitative EDX was used for the mineralogical analysis of the mineral components [37].

2.4. Data Analyses

The comparisons between deposits were analyzed using the test of Tukey HSD (SPSS version 23). The "stats" package in R was used to analyze the correlation coefficients among the soil attributes. We used the variance inflation factor (VIF) to test the collinearities among factors and excluded factors with a VIF value greater than 10. We studied the soil parent materials' impact and the soil' physical (e.g., clay content and bulk density) and chemical (e.g., pH and available P) properties on the SOC, soil total N, and soil heavy metals (Fe, Zn, Mn, and Cu) content in a model of mixed-effects meta-regression using the "glmulti" package in R. The total of the Akaike weights for models that included a certain component was used to estimate the relevance of that factor, which can be viewed as the overall support for that factor across all models. The threshold was set at 0.8 to focus on the most crucial elements.

3. Results

3.1. Morphological Properties of Studied Soils

The surveyed soils were divided into four types: fluvio-marine, Nile alluvial, lacustrine, and aeolian deposits, based on soil classification, morphological description, and mineralogical, physical, and chemical properties. Diagnostic horizons descriptions and morphological aspects were identified using the criteria of [29] (Table 1). The soils of P1 and P2 were derived from marine deposits (limestone) with varying $CaCO_3$ levels, where the B_{ca} horizon developed as a result of $CaCO_3$ accumulation in the subsurface layer [38]. P3 and P4 were derived from the alluvium deposits, where the argillic B horizon developed. Salic and Natric B horizons developed in the soils of lacustrine deposits in profiles 5 and 6. Soils that originated from aeolian deposits (P7 and P8) were weakly developed and have no pedogenetic horizons. The solum thickness of the studied soil profiles varied from 60 cm in the soils originating from aeolian deposits to 2.0 m in alluvium soils. In dry conditions, the soil color ranged between very pale brown (10YR 7/3), dark grey (10YR 4/1), very dark greyish brown (10YR 5/2), and yellow (10YR 7/6) for marine, alluvium, lacustrine, and aolian deposits, respectively. Clay content was the highest in alluvium- and lacustrine-originated soils, while the sand content was the highest in marine- and aeolian-derived soils (Figure 2). The uppermost surface of the marine deposit's soils had a massive structure that was subangular and blocky downward. The structure was granular in the topsoil horizons of alluvial deposits, while it was subangular in the topsoil of lacustrine deposits and changed to massive profiles downward. The aeolian deposits were characterized by a weak structure along the profiles. In the coarse and fine textured horizons, respectively, the soil consistency ranged from non-sticky to moderately sticky and from non-plastic to moderately plastic (Table 1).

Table 1. Morphological description and mineralogy of the studied soil profiles.

Horizons	**Depth, Topography, Munsell soil color (dry, moist), Soil texture, Soil structure, Stickiness (wet), Plasticity (wet), Soil consistency (moist), Soil consistency (dry); Calcium Carbonate, Clay and Sand Mineralogy ***
	P1 (parent material: Fluvio-Marine); land cover (alfalfa plant)
A0	0–40 cm; flat; Dark grayish brown (10YR 4/1) dry; Dark gray (10YR 4/2) moist; SL; Ma; Sst; Spl; Lo; slightly hard dry; Moderately calcareous; quartz (+++), plagioclase (+), orthoclase (+).
B1	40–80 cm; Dark yellowish brown (10YR 3/6); Dark brown (10YR 3/2); SCL; Ma; Sst; Spl; Fi; slightly hard dry; Moderately calcareous; quartz (+++), plagioclase (+), orthoclase (+).
B2	80–120 cm; brown (10YR 5/3); Dark grayish brown (10YR 4/3); SCL; Sb; St; Pl; Vfi; hard dry; quartz (+++), plagioclase (+), orthoclase (+).
C	120–150; brown (10YR 5/3); Dark grayish brown (10YR 4/3); SCL; Sb; St; Pl; Vfi; very hard dry; quartz (+++), plagioclase (+), orthoclase (+).

Table 1. *Cont.*

Horizons	Depth, Topography, Munsell soil color (dry, moist), Soil texture, Soil structure, Stickiness (wet), Plasticity (wet), Soil consistency (moist), Soil consistency (dry); Calcium Carbonate, Clay and Sand Mineralogy *
	P2 (parent material: Fluvio-Marine); land cover (wheat)
At	0–30 cm; very pale brown (10YR 7/3) dry; yellowish brown (10YR 5/4) moist; L; Ma; Sst; Spl; Fi; slightly hard dry; extremely calcareous; quartz (+++), plagioclase (++), orthoclase (++).
B1	30–80 cm; light brown (7.5YR 6/4) dry; brown (10YR 5/6) moist; L; Sb; Vst; Vpl; Vfi; very hard dry; extremely calcareous; quartz (+++), plagioclase (++), orthoclase (++).
C	80–150 cm; Yellowish brown (10YR 5/6) dry; brownish yellow (10 YR 6/6) moist; L; Sb; Vst; Vpl; Vfi; extremely hard dry; extremely calcareous; quartz (+++), plagioclase (++), orthoclase (++).
	P3 (parent material: Nile alluvial deposit); land cover (alfalfa plant)
A0	0–60 cm; Almost flat; Gray (10YR 5/1) dry; dark gray (10 YR 4/2) moist; CL; Gr; Sst; Spl; Fi; slightly hard dry; Slightly calcareous; Montmorillonite (++++), kaolinite (++), mica (++), plagioclase (+), orthoclase (+), Microcline (+), quartz (+),
B1	60–100 cm; Dark gray (10YR 4/1); very dark gray (10 YR 3/1); CL; Sb; St; Pl; Fi; very hard dry; Montmorillonite (++++), quartz (++), kaolinite (+), plagioclase (+), orthoclase (+), Microcline (+).
B2	100–150 cm; Dark gray (10YR 4/1); very dark gray (10 YR 3/1); lC; Sb; St; Pl; Vfi; very hard dry; Montmorillonite (++++), quartz (++), plagioclase (+), Albite (+), orthoclase (+), Microcline (+).
C	150–200 cm; Dark gray (10 YR 4/1); very dark gray (10 YR 3/1); lC; Sb; Vst; Vpl; Vfi; extremely hard dry; Montmorillonite (++++), quartz (++), plagioclase (+), Albite (+), orthoclase (+), Microcline (+).
	P4 (parent material: Nile alluvial deposit); land cover (vegetables)
At	0–30 cm; Light gray (10YR 7/2) dry; Light brownish gray (10 YR 6/2) moist; SL; Gr; Sst; Spl; Lo; soft dry; Non calcareous; Montmorillonite (+++), quartz (+), kaolinite (+), plagioclase (+), orthoclase (+), Microcline (+).
B1	30–60 cm; SL; Sb; Sst; Spl; Fi; soft dry; Montmorillonite (++++), quartz (++), kaolinite (+), plagioclase (+), orthoclase (+), Microcline (+).
C	60–150 cm; SL; Sb; Sst; Spl; Fi; slightly hard dry; Montmorillonite (++++), quartz (++), kaolinite (+), plagioclase (+), orthoclase (+), Microcline (+).
	P5 (parent material: Lacustrine); land cover (alfalfa plant)
A1	0–20 cm; Almost flat; Grayish brown (10YR 5/2) dry; Dark gray (10 YR 4/1) moist; lC; Sb; St; Pl; Fi; hard dry; Moderately calcareous; Montmorillonite (++++), kaolinite (++), Vermiculite (+), illite (+), plagioclase (++), orthoclase (++), quartz (+).
A2	20–35 cm; grayish brown (10YR 5/2); Dark grayish brown (10 YR 4/2); lC; Sb;; Vst; Vpl; Vfi; very hard dry; Montmorillonite (++++), plagioclase (++), orthoclase (++), kaolinite (+), Muscovite (+), quartz (+).
BC	35–85 cm; Dark clay (10YR 4/1); Very dark gray (10 YR 3/1); lC; Co; Vst; Vpl; Efi; very hard dry; Montmorillonite (++++), plagioclase (++), orthoclase (++), kaolinite (+), quartz (+).
C	85–135 cm; Dark clay (10YR 4/1); Very dark gray (10 YR 3/1); lC; Co; Vst; Vpl; Efi; extremely hard dry; Montmorillonite (++++), plagioclase (++), orthoclase (++), kaolinite (+), quartz (+).
	P6 (parent material: Lacustrine); land cover (onion)
A1	0–10 cm; Almost flat; Grayish brown (10YR 5/2) dry; Dark gray (10 YR 4/1) moist; lC; Sb; St; Pl; Fi; slightly hard dry; Moderately calcareous; Montmorillonite (+++), kaolinite (+), Vermiculite (+), illite (+), plagioclase (+), orthoclase (+), quartz (+).
A2	10–35 cm; grayish brown (10YR 5/2); Dark grayish brown (10 YR 4/2); lC; Sb; Vst; Vpl; Vfi; hard dry; Montmorillonite (+++), plagioclase (+), orthoclase (+), kaolinite (+), Muscovite (+), quartz (+).
BC	35–90 cm; Dark clay (10YR 4/1); Very dark gray (10 YR 3/1); lC; Ma; Vst; Vpl; Efi; very hard dry; Montmorillonite (++), plagioclase (+), orthoclase (+), kaolinite (+), quartz (+).
C	85–135 cm; Dark clay (10YR 4/1); Very dark gray (10 YR 3/1); lC; Ma; Vst; Vpl; Efi; extremely hard dry; Montmorillonite (++), plagioclase (+), orthoclase (+), kaolinite (+), quartz (+).

Table 1. *Cont.*

Horizons	Depth, Topography, Munsell soil color (dry, moist), Soil texture, Soil structure, Stickiness (wet), Plasticity (wet), Soil consistency (moist), Soil consistency (dry); Calcium Carbonate, Clay and Sand Mineralogy *
	P7 (parent material: Aeolian); land cover (Non-cultivated)
A	0–30 cm; Almost flat; Yellow (10YR 7/6) dry; Brownish yellow (10 YR 6/6) moist; S; We; Nst; Npl; Lo; loose dry; calcareous; quartz, opaques as; magnetite, ilmenite, leucoxene, hematite and the second is the non-opaques include zircon, garnet, monazite, rutile, silica (yellow and red silica) and green silicates (pyroxene and amphibole groups, epidote and mica group) (++++).
C	30–50 cm; Rock.
CD	50–100 cm; Hard rock
	P8 (parent material: Aeolian); land cover (Non-cultivated)
A	0–30 cm; Almost flat; Pale brown (10YR 6/3) dry; Very pale brown (10YR 7/3) moist; S; We; Nst; Npl; Lo; soft dry; Calcareous; quartz, opaques as; magnetite, ilmenite, leucoxene, hematite and the second is the non-opaques include zircon, garnet, monazite, rutile, silica (yellow and red silica) and green silicates (pyroxene and amphibole groups, epidote and mica group) (++++).
CD	30–60 cm; Hard rock.

Notes: * **Soil texture** according to [29]: SL: sandy loam; SCL: sandy clay loam; L: loam; CL: clay loam; lC: light clay; S: Sandy. **Soil structure:** We = Weak; Sb = Sub angular blocky; Co = Columnar; Ma = Massive; Gr= Granular. **Stickiness (wet):** Vst = Very sticky; St = Sticky; Sst = Slightly sticky; Nst = non-sticky. **Plasticity (wet):** Vpl = Very plastic; Pl = Plastic; Spl = Slightly plastic; Npl = non-plastic. **Soil Consistency (moist):** Lo = loose; Fi = Firm; Vfi = very firm; Efi = Extremely firm. **Soil mineralogy**: + = few; ++ = common; +++ = many; ++++ = abundant.

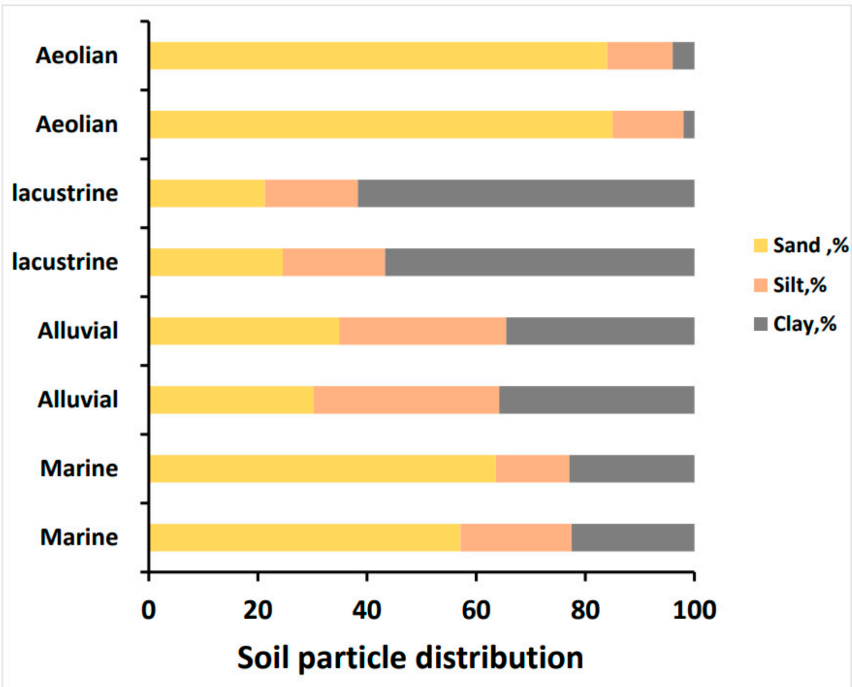

Figure 2. Soil texture of the studied sediments.

3.2. Soil Taxonomy of the Studied Pedons

According to [29], the soil classification was based on the presence or absence of diagnostic horizons, soil moisture, temperature regimes, morphological traits, and chemical and mineralogical composition. The soil temperature regime was hyperthermic, while the moisture regime was aridic. The studied soils were classified as aridisols, entisols, or vertisols based on soil taxonomy [29] (Table 2).

Table 2. Soil classification according to [29] of the studied soil profiles.

Profile	Order, Suborder, Great Group, Subgroup, Family
P1	Aridisols, Calcids, Petrocalcids, Typic Petrocalcids, Fine loamy, mixed, thermic
P2	Aridisols, Calcids, Petrocalcids, Natric Petrocalcids, Fine loamy, mixed, thermic
P3	Aridisols, Calcids, Haplocalcids, Typic Haplocalcid, mixed, thermic
P4	Aridisols, Calcids, Haplocalcids, Typic Haplocalcid, mixed, thermic
P5	Aridisols, Salids, Aquisalids, Typic Aquisalids
P6	Vertisols, Torrerts, Haplotorrerts, Sodic Haplotorrerts
P7	Entisols, Samments, Torripsamments, Lithic Torripsamments
P8	Entisols, Samments, Torripsamments, Lithic Torripsamments

3.3. Mineralogy of Sand and Clay Fractions

The sand and clay fractions are listed in Table 1. The sand fraction for all profiles showed that quartz predominated, with calcium-sodium feldspars (plagioclase) being the most common feldspar type. The aeolian and marine deposits had more quartz than the other types of deposits. Plagioclase, orthoclase, illite, kaolinite, quartz, and calcite formed the majority of the clay fraction in the marine deposits, with trace amounts of feldspar, dolomite, and iron oxides. On the other hand, alluvial deposits were formed of montmorillonite, kaolinite, mica, feldspars, and quartz. The lacustrine deposits were dominated by smectite, primarily in the form of montmorillonite, and kaolinite. The main constituents of the heavy fraction were opaque minerals, such as ilmenite, leucoxene, rutile, zircon, garnet, monazite, red silica, and green silicates (Table 3). Individual grains of heavy minerals were subjected to chemical studies utilizing a Phillips XL-30 Environmental Scanning Electron Microscope (ESEM) and semi-quantitative Energy Dispersive X-ray Analysis (EDX) to investigate the mineral composition (Figures 3 and 4).

Table 3. The content of total heavy minerals (g kg^{-1}) of the studied sediments.

Profile	Ilmenite	Leucoxene	Rutile	Zircon	Garnet	Monazite	Red Silica	Green Silicates
P1	3.222 ± 0.23	0.145 ± 0.03	0.250 ± 0.04	0.302 ± 0.06	0.155 ± 0.02	0.010 ± 0.00	0.616 ± 0.03	0.219 ± 0.04
P2	2.344 ± 0.31	0.205 ± 0.020	0.525 ± 0.07	0.306 ± 0.04	0.444 ± 0.02	0.030 ± 0.00	0.822 ± 0.06	0.323 ± 0.03
P3	0.064 ± 0.01	0.027 ± 0.00	0.017 ± 0.00	0.013 ± 0.00	0.027 ± 0.00	0.000 ± 0.00	0.245 ± 0.02	0.135 ± 0.01
P4	0.111 ± 0.00	0.062 ± 0.01	0.021 ± 0.00	0.003 ± 0.00	0.077 ± 0.01	0.011 ± 0.00	0.544 ± 0.06	0.212 ± 0.01
P5	0.053 ± 0.00	0.022 ± 0.00	0.011 ± 0.00	0.009 ± 0.00	0.025 ± 0.00	0.000 ± 0.00	0.237 ± 0.01	0.126 ± 0.02
P6	0.050 ± 0.00	0.024 ± 0.00	0.011 ± 0.00	0.009 ± 0.00	0.022 ± 0.00	0.000 ± 0.00	0.237 ± 0.01	0.124 ± 0.02
P7	3.930 ± 0.42	0.494 ± 0.05	0.740 ± 0.13	0.607 ± 0.04	0.543 ± 0.03	0.060 ± 0.01	0.943 ± 0.08	0.678 ± 0.05
P8	2.310 ± 0.22	0.159 ± 0.01	0.290 ± 0.06	0.212 ± 0.01	0.319 ± 0.04	0.000 ± 0.00	5.491 ± 0.35	0.794 ± 0.03

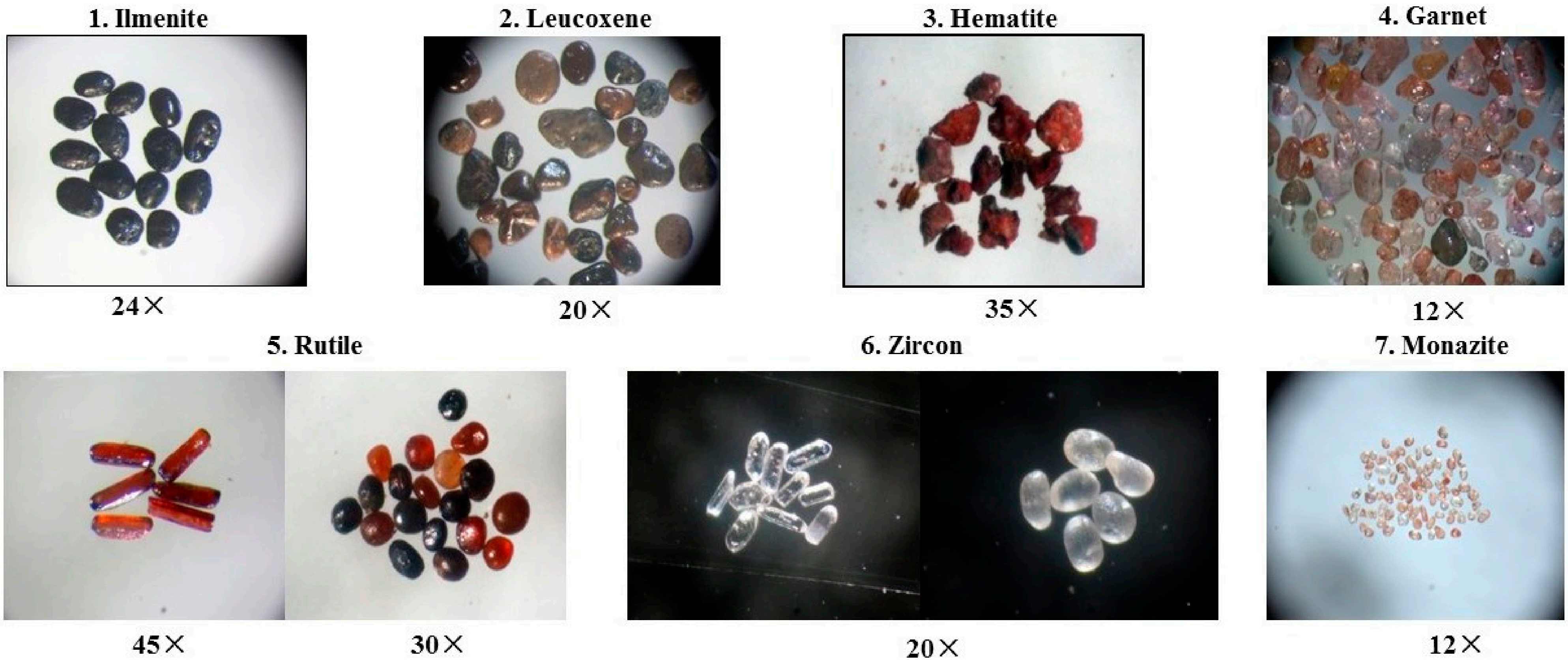

Figure 3. Photomicrograph showing the heavy minerals in the studied sediments.

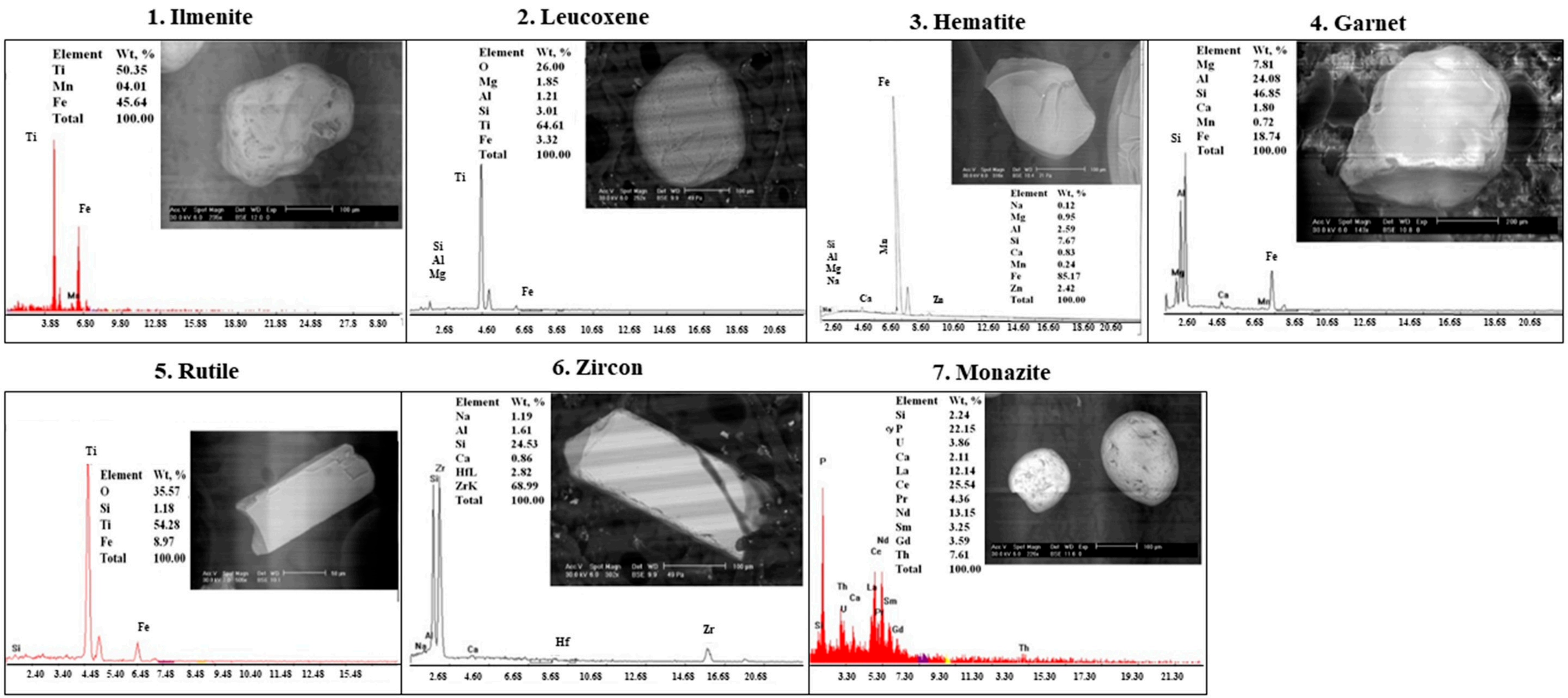

Figure 4. EDX and BSE of heavy minerals for the studied sediments.

3.4. Patterns and Controlling Factors of Soil Substrate Availability in Arid Regions

The soil physiochemical properties of the studied deposits are listed in Table 4. According to [36], the pH mean values in the studied soil profiles were from slightly to strongly alkaline. The soils ranged from being non-saline to very strongly saline, where lacustrine-originated soils had the greatest values. The studied soils ranged from being non-calcareous to extremely calcareous. The highest $CaCO_3$ levels were found in soils that were marine and aeolian in origin. Moreover, alluvial- and marine-derived soils had higher values of the CEC and available NPK content (g kg^{-1}) than the aeolian- and lacustrine-derived soils. Soil bulk density decreased in the alluvial- and lacustrine-derived soils and increased in the marine- and aeolian-derived soils. SOC and total N (mg kg^{-1}) also differed with deposits (Figure 5a), ranging from 0.74 to 5.50 and from 0.29 to 1.87, with an average of 2.90 $\pm$ 0.39 and 0.96 $\pm$ 0.12, respectively. The average contents of SOC and total N in the alluvial deposits were greater ($p < 0.001$) than those of the marine, aeolian, and lacustrine deposits.

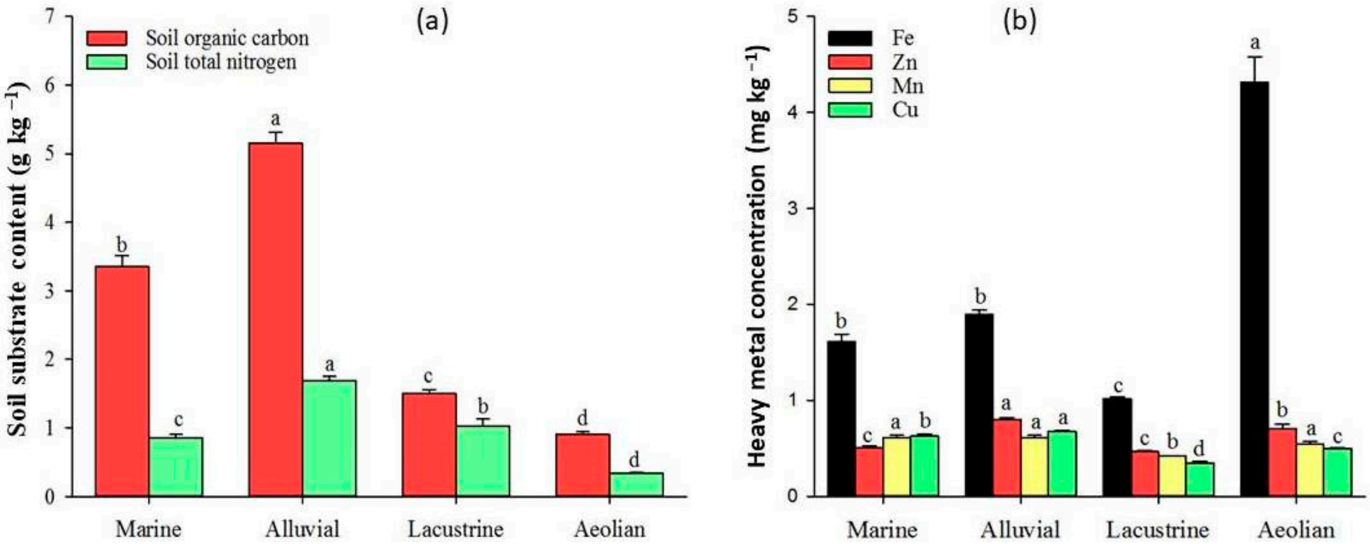

Figure 5. Effect of different parent material deposits (fluvio-marine, Nile alluvial, lacustrine, and aeolian) on (**a**) soil organic carbon (SOC) and soil total N content and (**b**) soil heavy metal (Fe, Zn, Mn, and Cu) content using variance analysis. Values are presented as means $\pm$ standard deviation (SD) using the number of the studied soil profiles ($n = 8$). For each attribute, bars with different superscript letters (a, b, c, and d) denote a significant difference between the effects of types of parent material at $p < 0.05$. The appearance of the same letter means that the difference was not significant.

The results of the multivariate analysis (Figure 6a) revealed that parent material, soil pH, and available P were the most important factors influencing SOC content in arid regions. Clay content, available P, soil pH, parent material, and bulk density were the key factors driving soil total N, but clay content was the most important one (Figure 6b). Based on Pearson's correlation (Table 5), SOC was negatively associated with soil bulk density ($p < 0.001$), EC ($p < 0.001$), ESP ($p < 0.01$), soil pH ($p < 0.01$), and soil Fe content ($p < 0.05$), but it was enhanced with increasing CEC ($p < 0.001$), available P ($p < 0.001$), available K ($p < 0.001$), available N ($p < 0.001$), total N ($p < 0.001$), C/N ratio ($p < 0.05$), soil Mn content ($p < 0.05$), and soil Cu content ($p < 0.001$). Soil total N content was negatively correlated with soil bulk density ($p < 0.001$), soil pH ($p < 0.05$), and soil Fe content ($p < 0.01$) and positively correlated with clay content ($p < 0.001$), CEC ($p < 0.001$), and available P ($p < 0.05$), available K ($p < 0.05$), available N ($p < 0.05$), SOC ($p < 0.001$), and soil Cu content ($p < 0.05$).

Table 4. The chemical properties of the studied sediments (Bulk density/Soil organic).

Profile	Bulk Density (g cm^{-1})	CEC (cmol$_c$ kg^{-1})	CaCO$_3$ (g kg^{-1})	EC (dS m^{-1})	pH	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Total N (g kg^{-1})	Soil Organic C (g kg^{-1})
P1	1.67 ± 0.10	26.8 ± 1.27	336 ± 9.24	1.31 ± 0.06	8.40 ± 0.08	20.2 ± 0.44	12.2 ± 0.64	72.2 ± 1.85	0.87 ± 0.04	3.00 ± 0.02
P2	1.44 ± 0.15	24.2 ± 0.69	428 ± 6.81	3.35 ± 0.08	8.21 ± 0.00	16.8 ± 0.14	6.39 ± 0.18	67.1 ± 1.56	0.83 ± 0.10	3.70 ± 0.06
P3	1.30 ± 0.13	33.5 ± 1.10	4.90 ± 0.68	0.79 ± 0.12	7.83 ± 0.01	45.7 ± 1.79	19.8 ± 0.40	287 ± 7.16	1.67 ± 0.12	5.50 ± 0.08
P4	1.30 ± 0.13	32.1 ± 1.10	4.40 ± 0.87	0.77 ± 0.11	7.80 ± 0.01	43.2 ± 1.79	20.7 ± 0.40	298 ± 8.78	1.69 ± 0.09	4.80 ± 0.06
P5	1.38 ± 0.17	32.0 ± 1.04	36.7 ± 2.34	32.0 ± 2.34	8.50 ± 0.12	25.8 ± 0.64	6.70 ± 0.12	155 ± 4.16	1.02 ± 0.01	1.50 ± 0.06
P6	1.40 ± 0.17	31.0 ± 1.04	36.9 ± 2.34	29.0 ± 2.34	8.40 ± 0.12	23.8 ± 0.64	6.10 ± 0.12	150 ± 4.16	1.02 ± 0.01	1.40 ± 0.06
P7	1.80 ± 0.11	3.80 ± 0.27	820 ± 12.4	22.1 ± 1.73	8.07 ± 0.00	11.1 ± 0.28	4.60 ± 0.45	62.6 ± 1.56	0.34 ± 0.02	0.80 ± 0.03
P8	1.70 ± 0.16	3.97 ± 0.36	149 ± 5.20	8.90 ± 0.96	8.16 ± 0.02	10.3 ± 0.86	4.80 ± 0.52	60.9 ± 1.21	0.33 ± 0.02	1.00 ± 0.03

Table 5. Correlation coefficients between different soil properties for the studied sediments.

	Clay	BD	CEC	EC	ESP	pH	CaCO$_3$	AP	AK	AN	TN	SOC	C/N	Fe	Zn	Mn
BD	−0.70 ***															
CEC	0.85 ***	−0.77 ***														
EC	0.27 ^{ns}	0.22 ^{ns}	−0.24 ^{ns}													
ESP	0.73 ***	−0.17 ^{ns}	0.32 ^{ns}	0.75 ***												
pH	0.23 ^{ns}	0.39 ^{ns}	−0.03 ^{ns}	0.52 *	0.71 ***											
CaCO$_3$	−0.31 ^{ns}	0.31 ^{ns}	−0.11 ^{ns}	−0.32 ^{ns}	−0.14 ^{ns}	0.46 *										
AP	0.37 ^{ns}	−0.60 **	0.70 ***	−0.60 **	−0.31 ^{ns}	−0.61 **	−0.40 ^{ns}									
AK	0.56 **	−0.75 ***	0.69 ***	−0.28 ^{ns}	−0.07 ^{ns}	−0.62 **	−0.67 ***	0.89 ***								
AN	0.61 **	−0.77 ***	0.80 ***	−0.36 ^{ns}	−0.06 ^{ns}	−0.54 *	−0.54 *	0.93 ***	0.98 ***							
TN	0.65 **	−0.77 ***	0.87 ***	−0.40 ^{ns}	−0.02 ^{ns}	−0.46 *	−0.39 ^{ns}	0.92 ***	0.93 ***	0.98 ***						
SOC	0.35 ^{ns}	−0.70 ***	0.75 ***	−0.73 ***	−0.60 **	−0.56 **	−0.06 ^{ns}	0.88 ***	0.76 ***	0.84 ***	0.88 ***					
C/N	−0.33 ^{ns}	−0.004 ^{ns}	0.08 ^{ns}	−0.79 ***	−0.36 ^{ns}	−0.17 ^{ns}	0.71 ***	0.16 ^{ns}	−0.12 ^{ns}	−0.01 ^{ns}	0.10 ^{ns}	0.50 *				
Fe	−0.80 ***	0.67 ***	−0.89 ***	0.05 ^{ns}	−0.45 *	−0.18 ^{ns}	−0.12 ^{ns}	−0.40 ^{ns}	−0.39 ^{ns}	−0.52 *	−0.62 **	−0.54 *	−0.06 ^{ns}			
Zn	−0.28 ^{ns}	−0.022 ^{ns}	−0.12 ^{ns}	−0.24 ^{ns}	−0.62 **	−0.82 ***	−0.60 **	0.51 *	0.55 **	0.44 *	0.35 ^{ns}	0.32 ^{ns}	−0.04 ^{ns}	0.37 ^{ns}		
Mn	−0.33 ^{ns}	0.21 ^{ns}	0.11 ^{ns}	−0.63 **	−0.65 **	−0.34 ^{ns}	0.17 ^{ns}	0.49 *	0.17 ^{ns}	0.27 ^{ns}	0.29 ^{ns}	0.49 *	0.54 *	0.05 ^{ns}	0.44 *	
Cu	−0.18 ^{ns}	−0.25 ^{ns}	0.33 ^{ns}	−0.93 ***	−0.75 ***	−0.57 **	0.24 ^{ns}	0.67 ***	0.40 ^{ns}	0.49 *	0.53 *	0.83 ***	0.80 ***	−0.13 ^{ns}	0.41 ^{ns}	0.73 ***

Notes: BD, CEC, EC, ESP, AP, AK, AN, TN, SOC, and C/N refer to bulk density, cation exchange capacity, electric conductivity, exchangeable sodium percentage, available phosphorus, available potassium, available nitrogen, total nitrogen, soil organic carbon, and carbon-to-nitrogen ratio, respectively. * Correlation is significant at $p < 0.05$, ** Correlation is significant at $p < 0.01$, *** Correlation is significant at $p < 0.001$, ^{ns} refers to non-significant relationship.

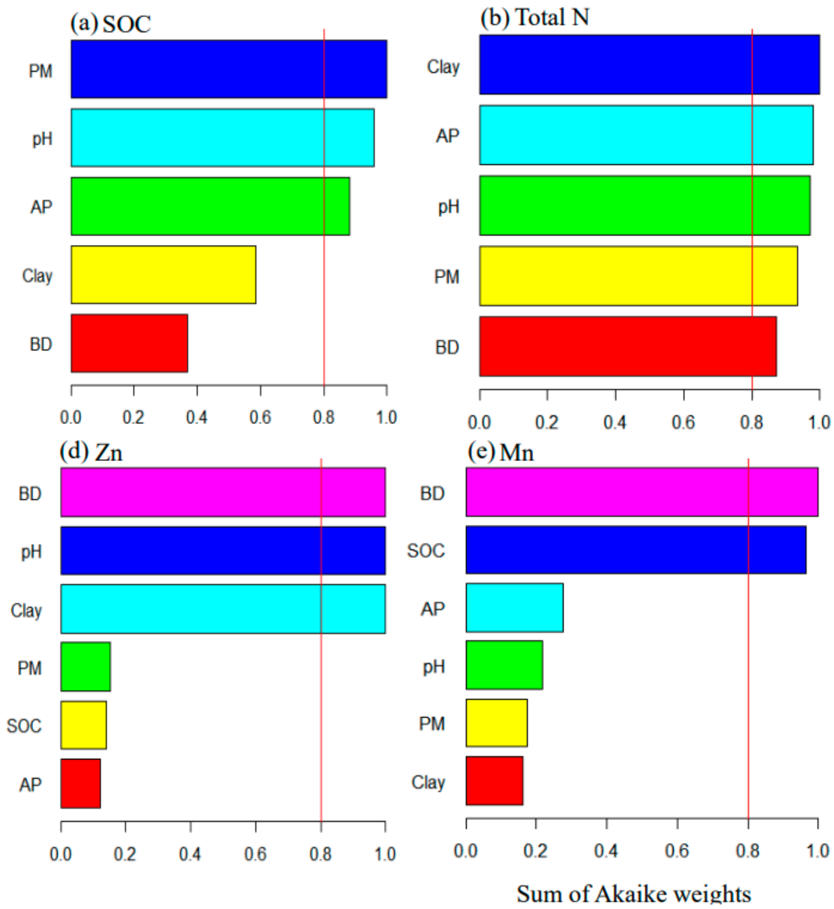

Figure 6. Model-averaged importance of the predictors of the impact of the factors on soil substrates and heavy metal content: (**a**) soil organic C; (**b**) total N stocks; (**c**) soil Fe content; (**d**) soil Zn content; (**e**) soil Mn content; (**f**) soil Cu content. The importance is based on the sum of Akaike weights derived from the model selection process using Akaike's information criterion corrected for small samples. The cut-off is set at 0.8 (red line) to differentiate between unimportant and important factors [39]. PM, parent materials; AP, available phosphorus; BD, soil bulk density; SOC, soil organic carbon.

3.5. Patterns and Controlling Factors of Heavy Metal Availability in Arid Regions

The soil content of heavy metals (mg kg^{-1}) varied, with deposits ranging from 0.99 to 5.17, from 0.44 to 0.86, from 0.41 to 0.72, and from 0.33 to 0.70, with an average of 2.38 ± 0.29, 0.64 ± 0.03, 0.56 ± 0.02, and 0.57 ± 0.03 for Fe, Zn, MN, and Cu, respectively (Figure 5b). The average content of Fe in aeolian deposits was greater than those in marine, alluvial, and lacustrine deposits ($p < 0.001$), without any significant differences between alluvial and marine deposits. The highest average content of Zn, Mn, and Cu was recorded in alluvial deposits, with significant differences between other deposits (Figure 5b). Parent material, clay content, soil pH, and SOC were the primary impact factors on the amount of soil-available Fe (Figure 6c). Bulk density, soil pH, and clay content had the most effects on the amount of soil-accessible Zn, while parent material, SOC, and available P had little impact (Figure 6d). Only bulk density and SOC had an impact on the amount of soil-available Mn; the other parameters had no significance (Figure 6e). The major factors that determined soil availability of Cu were SOC, clay content, and soil pH, with little or no impact from bulk density, parent material, or available P (Figure 6f). Based on Pearson's correlation (Table 5), soil Fe content was negatively associated with clay content ($p < 0.001$), CEC ($p < 0.001$), ESP ($p < 0.05$), total available N ($p < 0.05$), soil total N ($p < 0.01$), and SOC ($p < 0.05$), but it increased ($p < 0.001$) with increasing soil bulk density. Soil Zn content was negatively correlated with ESP ($p < 0.01$), soil pH ($p < 0.001$), and $CaCO_3$ ($p < 0.001$), while it was positively correlated with available P ($p < 0.05$), available K ($p < 0.01$), and available

N ($p < 0.05$). Soil Mn content increased with increasing available P ($p < 0.05$), SOC ($p < 0.05$), C/N ratio ($p < 0.05$), and soil Zn content ($p < 0.05$), but it decreased with increasing EC ($p < 0.01$) and ESP ($p < 0.01$). Soil Cu content was negatively correlated with EC ($p < 0.001$), ESP ($p < 0.001$), and soil pH ($p < 0.001$) and positively correlated with available P ($p < 0.001$), available N ($p < 0.05$), and total N ($p < 0.05$), SOC ($p < 0.001$), C/N ratio ($p < 0.001$), and soil Mn content ($p < 0.001$).

4. Discussion

Parent material, time, climate, relief, and organisms are the five main variables that combine to form soil [40]. The sixth factor is human activity (anthropogenic activities), which influences soil formation [41]. These activities refer to a group of geomorphic and pedological processes, including irrigation, extensive ploughing, the burning of natural vegetation, and the production of genetically modified crops [42]. Each soil factor's proportional weight varies from place to place, but the totality of all factors frequently determines the type of soil that forms in any particular region [43]. Parent material, which might include organic materials or mineral rock, is the basis for the majority of soil formation processes [44]. Soil formation occurs when parent rock material is exposed to the atmosphere or when organic matter, minerals, or both are put on the Earth's surface [45]. Here, we offer four cases of some of the most significant effects of parent material influences on soil parameters [46]. Providing a straightforward quantification of all the soil components that affect soil formation is difficult in practice [43].

Parent material, which affects soil physical, chemical, and biological aspects, is one of the most important variables governing soil development and genesis [47]. It also supplies macro and micronutrients for plant growth as well as a habitat for soil microbes [47]. Thus, the ability of parent material to shape these qualities plays a significant role in the structure and communities of soil microorganisms [48]. The impact of parent material on the soil microbial population and structure is well understood [48]. However, there have been few investigations on the effects of parent materials on soil substrate (SOC and total N) and heavy metal (Fe, Zn, Mn, and Cu) availability [17,49]. Here, we discuss the impact of soil parent materials and soil physical (e.g., bulk density and clay content) and chemical (e.g., pH and available P) properties on SOC, soil total N, and soil heavy metal (Fe, Zn, Mn, and Cu) availability.

4.1. The Role of Parent Material in Controlling Soil Substrate Availability in Arid Regions

One of the purposes of this study was to assess the impact of soils derived from four different parent material categories (fluvio-marine, Nile alluvial, lacustrine, and aeolian) on soil substrate availability. SOC is gaining popularity, since it is the largest terrestrial carbon store and plays an important role in the global carbon cycle [50]. In the present study, SOC content was slightly higher in the soils developed from alluvial deposits compared to the soils formed from other deposits. The high content was most likely connected with continuous vegetation forms and dense cover [51]. The aggregation of soils from alluvial deposits enhances the stability of SOC contained within organo-mineral associations, resulting in increased resistance to soil erosion [52]. In addition, organic matter improves soil physical qualities, increases water infiltration, and improves soil structure. Thus, it appears that these sediments are ideal for a methodological case study to demonstrate how the lithological facies might change in response to river sedimentation dynamics. Manure application is a common source of SOM [52]. Furthermore, alluvial soils had higher CEC values than the other deposits, indicating their high clay and SOC content. The low SOC content in soils developed from lacustrine deposits can be attributed to long arid periods and poor vegetation [53]. One of the main issues with calcareous soils derived from marine deposits is a lack of organic matter. On the other hand, there are extensive areas of sandy soils that are being farmed, but the soil fertility is frequently low and depends on the SOC levels [54]. The pedons that were selected from aeolian deposits had the lowest SOC. Aeolian soils are typically characterized by having limited organic matter content, a sandy or loamy sand texture, and very weak structural stability [55]. Because sand is inert and has minimal surface bonding on its particles, these soils also have relatively poor CEC [56]. Moreover, sand contains significant macropores, which are pores with a large particle size and typically contain air rather than water [56]. They are rather simple to manage without any compacting from mechanical cultivation [57]. Sandy soils are sensitive to slumping, mainly when there is a deficiency in organic matter [58]. More siliceous parent materials, such as illite and kaolinite, create clay minerals with a lower CEC than less siliceous parent materials, such as montmorillonite and vermiculite [59]; therefore, boosting the clay fraction's content could benefit SOC stocks in two different ways, thus playing a relatively greater role in the CEC [60]. Moreover, the predominance of quartz for soils inherent from aeolian and marine deposits would facilitate leaching due to its low surface area and charges [61]. Parent material has an impact on the nutrients in the soil [62], which may then change how much root exudation occurs and how the rooting system develops. In the present study, the low available NPK level of aeolian deposits was due to the low organic matter and clay content. In addition, nutrients generally increase as the parent material becomes less siliceous. Owing to low nutrient retention, additional supplies of fertilizers are used to keep nutrient levels at their ideal levels [61,63]. Liming is important, but it should only be performed little and often. Because it serves to store water and plant nutrients in the soil and to enhance soil structure and biological activity, organic matter, especially as humus, is very advantageous [64]. Many different crops can be grown successfully in sandy soils, including carrot, beetroot, cucumber, muskmelon, watermelon, fenugreek, radish, etc. [65]. However, alluvial deposits had the highest available NPK content as a result of their high content of clay and organic matter, cultivation management processes, and vegetation; consequently, the majority of the biological activities occurred there [66]. Soil microbial biomass, soil substrate availability, and soil bulk density drive soil gross N mineralization [67,68]. Soil substrate availability is a main factor controlling soil dissimilatory nitrate reduction to ammonium. In addition, clay minerals in the old alluvial plain were generated by subsequent Nile floods from Pleistocene deposits [69]. We found that montmorillonite, vermiculite, and illite are the clay minerals identified in alluvial soils, in decreasing order of abundance [70]. They have the capacity to store irrigation water and adsorb more exchangeable cations in aqueous media, providing plant nutrients [70]. In the current study, parent materials affected soil chemical aspects; thus, soils formed from lacustrine and marine deposits had the highest pH values, which were attributed to shell fragments, the accumulation of $CaCO_3$, and a high value of ESP [23]. In addition, these soils were classified as saline soils due to the great quantities of soluble salts in Lake Manzala [71,72]. It is essential to cultivate such soils with crops suitable for the local climate, topography, and water availability, which includes halophyte plants, as well as growing crops with high economic yields that can resist salt [73]. Soil conditioners may be used to improve the chemical and physical properties of such soils [74]. On the other hand, soils representing alluvial River Nile sediments (the old deltaic plain) had the lowest values of soil pH, EC, $CaCO_3$, and ESP, as well as advanced cultivation processes, for a long time [7]. Rice, corn, cotton, wheat, oranges, and potatoes are the most common crops grown in these soils [75]. The northern Mediterranean zone's arid or semiarid soils are primarily calcareous [76]. The amount of $CaCO_3$ in the soil is an accurate indicator of how the marine parent material has affected the soil [76]. The limestone and calcarenite ridges that eroded into the surface layer of Egypt's northern coastline resulted in the majority of the sand being formed by the combination of $CaCO_3$ [77]. As a result of the exceptionally low acidity of carbonic acid, calcareous soils are often alkaline in character [78]. They may contain a calcic horizon, a layer of secondary carbonate deposits (typically calcium or magnesium), more carbonate than an underlying layer by at least 5%, and more carbonate than the horizon, so they are identified by the parent material's $CaCO_3$ content [78]. Acid-forming fertilizers, such as ammonium sulphate and urea fertilizers, sulfur compounds, organic manures, and green manures, are considered effective ways of reducing the pH of soil to a neutral value [20]. Wheat, alfalfa, sunflower, barley, date palm, cotton, and olive were the optimum crops for land use in this unit [79]. In aeolian soils, carbonates and soluble salts may be carried by the wind; nevertheless, their endurance in the soil is caused by limited leaching [80]. Poor drainage and the use of saline water for irrigating agricultural crops is reflected in the high salinity of these soils [81].

4.2. Drivers of Heavy Metal Availability in Arid Regions

Understanding the variables affecting the distribution of heavy metals in agricultural soil is crucial [82]. A number of factors, including intrinsic soil properties (such as pH and soil P content), environmental conditions (such as climate and topographic moisture), land use characteristics, and soil type, can influence the availability and mobility of heavy metals in the soil [83]. Moreover, soil heavy metal levels decrease with increasing distance from the source due to topography and water flow [84]. The most critical factor among them is soil pH, since it regulates nearly all physical, chemical, and biological processes in soil that affect metal availability, such as metal solid phase dissolution and the precipitation, complexation, and acid–base interactions of metal species [85]. The rivalry between free metal ions and other cations in solution increases when pH decreases metal ion sorption on soil particles, leading to increased metal concentrations in the soil solution [86]. Alkaline soils require particular management strategies, such as the addition of acidifying minerals, organic matter, and gypsum, to raise pH levels [87]. Growing legumes can help maintain a lower pH. Using alkalinity-tolerant crops and pastures can also help mitigate the effects of high pH levels [88]. This conclusion suggests that when developing models to predict soil heavy metals in response to parent materials and soil pH, these factors should be taken into account. In our study, the SOM content had a significant impact on the heavy metal availability in the soil because it adsorbs metals through complexation processes [89]. In addition, the availability of heavy metals was found to be highly correlated with EC, where higher EC values are typically associated with greater metal release rates [90]. The amount of heavy metals in their soluble forms, such as Ni, Cu, Zn, and Pb, is often increased in soil that has been fertilized with NPK and manure.

5. Conclusions

Eight soil profiles derived from four different parent materials—fluvio-marine, Nile alluvial, lacustrine, and aeolian deposits—were meticulously set out in the current study so that their effects on soil substrate and heavy metal availability could be assessed. The soil parent material clearly differed in the contents of SOC and total N through its impact on the soil chemical and physical properties, mainly clay content. The major factor that determined soil Fe availability was the soil parent material type, whereas soil bulk density was the driver of soil Zn and Mn contents. Clay content was the most important factor affecting soil Cu content. The findings of this study could deepen our understanding of the effect of soil parent materials on soil substrates (SOC and total N), which are the main factors controlling soil nutrients availability, and could also deepen our understanding of micronutrient management in alkaline soils. This study is useful for agricultural authorities to help farmers understand their soil and how to manage it. Both anthropogenic activities and agricultural land use should be considered when assessing the impact of parent material change on different soil aspects.

Author Contributions: Conceived and designed the experiments: M.A.A. and A.S.E.; Performed the experiments: M.A.A. and A.-R.M.M.; Contributed reagents/materials/analysis tools: M.A.A. and A.-R.M.M.; Analyzed the data: M.A.A., A.-R.M.M. and A.S.E.; Wrote the paper: M.A.A., A.S.E., M.Z. and K.P.-U.; Revised the paper: M.A.A. and A.S.E. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data sets generated and analyzed during the current study are available on the request from the corresponding author.

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References

1. Wilson, M. The importance of parent material in soil classification: A review in a historical context. *Catena* **2019**, *182*, 104131. [CrossRef]
2. Wysocki, D.A.; Lietzke, D.; Zelazny, L. Effects of parent material weathering on chemical and mineralogical properties of selected Hapludults in the Virginia Piedmont. *Soil Sci. Soc. Am. J.* **1988**, *52*, 196–203. [CrossRef]
3. Suther, B.E.; Leigh, D.S.; West, L.T. Soil Chemistry and Clay Mineralogy of an Alluvial Chronosequence from the North Carolina Sandhills of the Upper Coastal Plain, USA. *Soil Syst.* **2021**, *6*, 1. [CrossRef]
4. Irmak, S.; Surucu, A.; Aydogdu, I. Effects of different parent material on the mineral characteristics of soils in the arid region of Turkey. *Pak. J. Biol. Sci. PJBS* **2007**, *10*, 528–536. [CrossRef] [PubMed]
5. Gray, J.; Murphy, B. Parent material and world soil distribution. In Proceedings of the 17th World Congress of Soil Science, Bangkok, Thailand, 14–21 August 2002; pp. 1–2215.
6. Khorasani, M.; Ghorbani, R.R. Evaluation of carbon sequestration potential in corn fields with different management systems. *Soil Tillage Res.* **2013**, *133*, 2531.
7. Alnaimy, M.A.; Shahin, S.A.; Afifi, A.A.; Ewees, A.A.; Junakova, N.; Balintova, M.; Abd Elaziz, M. Spatio Prediction of Soil Capability Modeled with Modified RVFL Using Aptenodytes Forsteri Optimization and Digital Soil Assessment Technique. *Sustainability* **2022**, *14*, 14996. [CrossRef]
8. Al-Kaisi, M.M.; Yin, X.; Licht, M.A. Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils. *Agric. Ecosyst. Environ.* **2005**, *105*, 635–647. [CrossRef]
9. Angst, G.; Messinger, J.; Greiner, M.; Häusler, W.; Hertel, D.; Kirfel, K.; Kögel-Knabner, I.; Leuschner, C.; Rethemeyer, J.; Mueller, C.W. Soil organic carbon stocks in topsoil and subsoil controlled by parent material, carbon input in the rhizosphere, and microbial-derived compounds. *Soil Biol. Biochem.* **2018**, *122*, 19–30. [CrossRef]
10. Gray, J.M.; Bishop, T.F. Change in soil organic carbon stocks under 12 climate change projections over New South Wales, Australia. *Soil Sci. Soc. Am. J.* **2016**, *80*, 1296–1307. [CrossRef]
11. Xue, Z.; An, S. Changes in soil organic carbon and total nitrogen at a small watershed scale as the result of land use conversion on the loess plateau. *Sustainability* **2018**, *10*, 4757. [CrossRef]
12. Elrys, A.S.; Desoky, E.-S.M.; Alnaimy, M.A.; Zhang, H.; Zhang, J.-B.; Cai, Z.-C.; Cheng, Y. The food nitrogen footprint for African countries under fertilized and unfertilized farms. *J. Environ. Manag.* **2021**, *279*, 111599. [CrossRef] [PubMed]
13. Zhang, X.; Li, M.-J.; Yang, C.; Zhan, L.-Q.; Wu, W.; Liu, H.-B. The stratification of soil organic carbon and total nitrogen affected by parent material and cropping system. *Catena* **2022**, *210*, 105898. [CrossRef]
14. Van Eynde, E.; Groenenberg, J.E.; Hoffland, E.; Comans, R.N. Solid-solution partitioning of micronutrients Zn, Cu and B in tropical soils: Mechanistic and empirical models. *Geoderma* **2022**, *414*, 115773. [CrossRef]
15. Elrys, A.S.; Merwad, A.-R.M.; Abdo, A.I.; Abdel-Fatah, M.K.; Desoky, E.-S.M. Does the application of silicon and Moringa seed extract reduce heavy metals toxicity in potato tubers treated with phosphate fertilizers? *Environ. Sci. Pollut. Res.* **2018**, *25*, 16776–16787. [CrossRef]
16. Anderson, D. The effect of parent material and soil development on nutrient cycling in temperate ecosystems. *Biogeochemistry* **1988**, *5*, 71–97. [CrossRef]
17. Zinn, Y.L.; de Faria, J.A.; de Araujo, M.A.; Skorupa, A.L.A. Soil parent material is the main control on heavy metal concentrations in tropical highlands of Brazil. *Catena* **2020**, *185*, 104319. [CrossRef]
18. Zhenghu, D.; Honglang, X.; Zhibao, D.; Gang, W.; Drake, S. Morphological, physical and chemical properties of aeolian sandy soils in northern China. *J. Arid. Environ.* **2007**, *68*, 66–76. [CrossRef]
19. Ugolini, F.; Hillier, S.; Certini, G.; Wilson, M. The contribution of aeolian material to an Aridisol from southern Jordan as revealed by mineralogical analysis. *J. Arid. Environ.* **2008**, *72*, 1431–1447. [CrossRef]
20. Alnaimy, M.; Zelenakova, M.; Vranayova, Z.; Abu-Hashim, M. Effects of Temporal Variation in Long-Term Cultivation on Organic Carbon Sequestration in Calcareous Soils: Nile Delta, Egypt. *Sustainability* **2020**, *12*, 4514. [CrossRef]
21. Ibrahim, A.; Gemail, K.S.; Bedair, S.; Saada, S.A.; Koch, M.; Nosair, A. An Integrated Approach to Unravel the Structural Controls on Groundwater Potentialities in Hyper-arid Regions Using Satellite and Land-Based Geophysics: A Case Study in Southwestern Desert of Egypt. *Surv. Geophys.* **2022**, *44*, 783–819. [CrossRef]
22. Ferreira, E.P.; Anjos, L.H.C.d.; Pereira, M.G.; Valladares, G.S.; Cipriano-Silva, R.; Azevedo, A.C.d. Genesis and classification of soils containing carbonate on the Apodi Plateau, Brazil. *Rev. Bras. Cienc. Solo* **2016**, *40*, 1–20. [CrossRef]
23. Wilford, J.; De Caritat, P.; Bui, E. Modelling the abundance of soil calcium carbonate across Australia using geochemical survey data and environmental predictors. *Geoderma* **2015**, *259*, 81–92. [CrossRef]

24. Ismail, A. Soil properties and moisture characteristics and their relationship with crop mid-day stress in the Sudan Gezira. *Geo J.* **1991**, *23*, 233–237. [CrossRef]
25. Caicedo, B.; Mendoza, C.; Lizcano, A.; Lopez-Caballero, F. Some contributions to mechanical behaviors of lacustrine deposit in Bogotá, Colombia. *J. Rock Mech. Geotech. Eng.* **2019**, *11*, 837–849. [CrossRef]
26. Shaheen, S.M.; Abo-Waly, M.E.; Ali, R.A. Classification, characterization, and management of some agricultural soils in the North of Egypt. In *Developments in Soil Classification, Land Use Planning and Policy Implications: Innovative Thinking of Soil Inventory for Land Use Planning and Management of Land Resources*; Springer: Berlin/Heidelberg, Germany, 2013; pp. 417–448.
27. Elewa, H.H.; Nosair, A.M.; Zelenakova, M.; Mikita, V.; Abdel Moneam, N.A.; Ramadan, E.M. Environmental Sustainability of Water Resources in Coastal Aquifers, Case Study: El-Qaa Plain, South Sinai, Egypt. *Water* **2023**, *15*, 1118. [CrossRef]
28. Omran, E.-S.E.; Negm, A.M. Adaptive management zones of Egyptian coastal lakes. In *Egyptian Coastal Lakes and Wetlands: Part I: Characteristics and Hydrodynamics*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 37–60.
29. US Department of Agriculture. *Soil Survey Manual*; US Department of Agriculture: Washington, DC, USA, 1993.
30. Conoco, C. *Geological Map of Egypt, Scale 1:500,000-NF 36 NE-Bernice, Egypt*; The Egyptian General Petroleum Corporation: Cairo, Egypt, 1987.
31. Klute, A. *Water Retention: Laboratory Methods*; SSSA Book Series; Soil Science Society of America, American Society of Agronomy: Madison, WI, USA, 2018; pp. 635–662.
32. Tedesco, M.; Gianello, G.; Bissani, C.; Bohnen, H.; Volkweiss, S. *Análises de Solo, Plantas e Outros Materiais. Rev. e Ampliada*; Departamento de Solos, Universidade Federal do Rio Grande do Sul-UFRGS: Porto Alegre, Brazil, 1995; Volume 174.
33. van Reeuwijk, L.P. *Procedures for Soil Analysis*; No. 9; International Soil Reference and Information Center, Food and Agriculture Organization of the United Nations: Wageningen, The Netherlands, 1986; ISSN 0923-3792.
34. Tan, Z.; Lal, R. Carbon sequestration potential with changes in land use and management in Ohio. *Agric. Ecosyst. Environ.* **2005**, *110*, 140–152. [CrossRef]
35. Baruah, T.; Barthakur, H. Determination of available Potassium, Sulphur, Particle density and textural properties. In *A Text Book of Soil Analysis*; Vikas Publishing House Private Lim: New Delhi, India, 1997.
36. Lindsay, W.; Norvell, W. Development of DTPA soils test for Zinc Cu, Fe and Mn. *Soil Sci. Am. J.* **1978**, *42*, 421–428. [CrossRef]
37. Brown, G. *Crystal Structures of Clay Minerals and Their X-ray Identification*; The Mineralogical Society of Great Britain and Ireland: London, UK, 1982; Volume 5.
38. Dietrich, F.; Diaz, N.; Deschamps, P.; Ngatcha, B.N.; Sebag, D.; Verrecchia, E.P. Origin of calcium in pedogenic carbonate nodules from silicate watersheds in the Far North Region of Cameroon: Respective contribution of in situ weathering source and dust input. *Chem. Geol.* **2017**, *460*, 54–69. [CrossRef]
39. Elrys, A.S.; Uwiragiye, Y.; Zhang, Y.; Abdel-Fattah, M.K.; Chen, Z.-X.; Zhang, H.-M.; Meng, L.; Wang, J.; Zhu, T.-B.; Cheng, Y. Expanding agroforestry can increase nitrate retention and mitigate the global impact of a leaky nitrogen cycle in croplands. *Nat. Food* **2023**, *4*, 109–121. [CrossRef]
40. Huggett, R. Soil landscape systems: A model of soil genesis. *Geoderma* **1975**, *13*, 1–22. [CrossRef]
41. Chen, B.; Zhang, X.; Tao, J.; Wu, J.; Wang, J.; Shi, P.; Zhang, Y.; Yu, C. The impact of climate change and anthropogenic activities on alpine grassland over the Qinghai-Tibet Plateau. *Agric. For. Meteorol.* **2014**, *189*, 11–18. [CrossRef]
42. Lal, R. Global potential of soil carbon sequestration to mitigate the greenhouse effect. *Crit. Rev. Plant Sci.* **2003**, *22*, 151–184. [CrossRef]
43. Jenny, H. *Factors of Soil Formation: A System of Quantitative Pedology*; Courier Corporation: Chelmsford, NC, USA, 1994.
44. Wagai, R.; Mayer, L.M.; Kitayama, K.; Knicker, H. Climate and parent material controls on organic matter storage in surface soils: A three-pool, density-separation approach. *Geoderma* **2008**, *147*, 23–33. [CrossRef]
45. Chesworth, W. The parent rock effect in the genesis of soil. *Geoderma* **1973**, *10*, 215–225. [CrossRef]
46. Babur, E. Effects of parent material on soil microbial biomass carbon and basal respiration within young afforested areas. *Scand. J. For. Res.* **2019**, *34*, 94–101. [CrossRef]
47. Wilding, L. Factors of soil formation: Contributions to pedology. *Factors Soil Form. A Fiftieth Anniv. Retrosp.* **1994**, *33*, 15–30.
48. Company, J.; Valiente, N.; Fortesa, J.; García-Comendador, J.; Lucas-Borja, M.E.; Ortega, R.; Miralles, I.; Estrany, J. Secondary succession and parent material drive soil bacterial community composition in terraced abandoned olive groves from a Mediterranean hyper-humid mountainous area. *Agric. Ecosyst. Environ.* **2022**, *332*, 107932. [CrossRef]
49. Massas, I.; Kalivas, D.; Ehaliotis, C.; Gasparatos, D. Total and available heavy metal concentrations in soils of the Thriassio plain (Greece) and assessment of soil pollution indexes. *Environ. Monit. Assess.* **2013**, *185*, 6751–6766. [CrossRef]
50. Horwath, W. Carbon cycling and formation of soil organic matter. In *Soil Microbiology, Ecology and Biochemistry*; Elsevier: Amsterdam, The Netherlands, 2007; pp. 303–339.
51. John, K.; Abraham Isong, I.; Michael Kebonye, N.; Okon Ayito, E.; Chapman Agyeman, P.; Marcus Afu, S. Using machine learning algorithms to estimate soil organic carbon variability with environmental variables and soil nutrient indicators in an alluvial soil. *Land* **2020**, *9*, 487. [CrossRef]
52. Song, K.; Zheng, X.; Lv, W.; Qin, Q.; Sun, L.; Zhang, H.; Xue, Y. Effects of tillage and straw return on water-stable aggregates, carbon stabilization and crop yield in an estuarine alluvial soil. *Sci. Rep.* **2019**, *9*, 4586. [CrossRef]
53. Paul, E.; Collins, H.; Leavitt, S. Dynamics of resistant soil carbon of Midwestern agricultural soils measured by naturally occurring 14C abundance. *Geoderma* **2001**, *104*, 239–256. [CrossRef]

54. Azam, S. Collapse and compressibility behaviour of arid calcareous soil formations. *Bull. Eng. Geol. Environ.* **2000**, *59*, 211–217. [CrossRef]
55. Dickson, B.L.; Scott, K.M. Recognition of aeolian soils of the Blayney district, NSW: Implications for mineral exploration. *J. Geochem. Explor.* **1998**, *63*, 237–251. [CrossRef]
56. McTainsh, G.; Strong, C. The role of aeolian dust in ecosystems. *Geomorphology* **2007**, *89*, 39–54. [CrossRef]
57. Ravi, S.; D'Odorico, P.; Breshears, D.D.; Field, J.P.; Goudie, A.S.; Huxman, T.E.; Li, J.; Okin, G.S.; Swap, R.J.; Thomas, A.D. Aeolian processes and the biosphere. *Rev. Geophys.* **2011**, *49*, RG3001. [CrossRef]
58. Bröder, L.; Keskitalo, K.; Zolkos, S.; Shakil, S.; Tank, S.E.; Kokelj, S.V.; Tesi, T.; Van Dongen, B.E.; Haghipour, N.; Eglinton, T.I. Preferential export of permafrost-derived organic matter as retrogressive thaw slumping intensifies. *Environ. Res. Lett.* **2021**, *16*, 054059. [CrossRef]
59. Croffie, M.E.; Williams, P.N.; Fenton, O.; Fenelon, A.; Daly, K. Rubidium measured by XRF as a predictor of soil particle size in limestone and siliceous parent materials. *J. Soils Sediments* **2022**, *22*, 818–830. [CrossRef]
60. Saiz, G.; Bird, M.I.; Domingues, T.; Schrodt, F.; Schwarz, M.; Feldpausch, T.R.; Veenendaal, E.; Djagbletey, G.; Hien, F.; Compaore, H. Variation in soil carbon stocks and their determinants across a precipitation gradient in W est A frica. *Glob. Chang. Biol.* **2012**, *18*, 1670–1683. [CrossRef]
61. Pincus, L.; Ryan, P.; Huertas, F.; Alvarado, G. The influence of soil age and regional climate on clay mineralogy and cation exchange capacity of moist tropical soils: A case study from Late Quaternary chronosequences in Costa Rica. *Geoderma* **2017**, *308*, 130–148. [CrossRef]
62. Torn, M.S.; Swanston, C.; Castanha, C.; Trumbore, S. Storage and turnover of organic matter in soil. In *Biophysico-Chemical Processes Involving Natural Nonliving Organic Matter in Environmental Systems*; John Wiley & Sons: Hoboken, NJ, USA, 2009; pp. 219–272.
63. Elnaggar, A. Spatial variability of soil physiochemical properties in Bahariya Oasis, Egypt. *Egypt. J. Soil Sci.* **2017**, *57*, 313–328.
64. Vandenberghe, J.; Sun, Y.; Wang, X.; Abels, H.; Liu, X. Grain-size characterization of reworked fine-grained aeolian deposits. *Earth Sci. Rev.* **2018**, *177*, 43–52. [CrossRef]
65. Ouda, S.; Sayed, M.; El-Afandi, G.; Khalil, F. Developing an adaptation strategy to reduce climate change risks on wheat grown in sandy soil in Egypt. In *Meeting the Challenge of Sustainable Development in Drylands under Changing Climate-Moving from Global to Local, Proceedings of the Tenth International Conference on Development of Drylands, Cairo, Egypt, 12–15 December 2010*; International Dryland Development Commission (IDDC): Cairo, Egypt, 2011; pp. 346–356.
66. Kumar, A.; Yadav, D. Long-term effects of fertilizers on the soil fertility and productivity of a rice–wheat system. *J. Agron. Crop Sci.* **2001**, *186*, 47–54. [CrossRef]
67. Elrys, A.S.; Wang, J.; Metwally, M.A.; Cheng, Y.; Zhang, J.B.; Cai, Z.C.; Chang, S.X.; Müller, C. Global gross nitrification rates are dominantly driven by soil carbon-to-nitrogen stoichiometry and total nitrogen. *Glob. Chang. Biol.* **2021**, *27*, 6512–6524. [CrossRef] [PubMed]
68. Abdo, A.I.; Deng, Y.; Sun, D.; Chen, X.; Alnaimy, M.A.; El-Sobky, E.-S.E.; Wei, H.; Zhang, J. Maintaining higher grain production with less reactive nitrogen losses in China: A meta-analysis study. *J. Environ. Manag.* **2022**, *322*, 116018. [CrossRef] [PubMed]
69. Afify, A.; Arafat, S.; Ghar, M.A.; Khader, M. Physiographic soil map delineation for the Nile alluvium and desert outskirts in middle Egypt using remote sensing data of EgyptSat-1. *Egypt. J. Remote Sens. Space Sci.* **2010**, *13*, 129–135. [CrossRef]
70. Yoothong, K.; Pukamphol, M.; Hutspardol, A. Distribution of Clay Minerals–Kaolinite, Illite and Montmorillonite in the Coarse and the Fine Clay Fractions in Some Alluvial Soils. *Agric. Nat. Resour.* **1986**, *20*, 285–299.
71. Nosair, A.M.; Shams, M.Y.; AbouElmagd, L.M.; Hassanein, A.E.; Fryar, A.E.; Abu Salem, H.S. Predictive model for progressive salinization in a coastal aquifer using artificial intelligence and hydrogeochemical techniques: A case study of the Nile Delta aquifer, Egypt. *Environ. Sci. Pollut. Res.* **2022**, *29*, 9318–9340. [CrossRef]
72. Abu Salem, H.S.; Gemail, K.S.; Junakova, N.; Ibrahim, A.; Nosair, A.M. An Integrated Approach for Deciphering Hydrogeochemical Processes during Seawater Intrusion in Coastal Aquifers. *Water* **2022**, *14*, 1165. [CrossRef]
73. Youghly, N.A.; Elbous, M.M.; Elbanna, M.A.; Taher, H.S.; Hegazi, N.A.; Youssef, H.A.; Fouad, M.F. Assessment of heavy metal contamination and tolerant bacteria associated with halophyte Arthrocnemum Macrostachyum in Lake Manzala, Egypt. *Alfarama J. Basic Appl. Sci.* **2021**, *2*, 263–284. [CrossRef]
74. Ali, S.; Ahmed, H.R. Comparative effects of different soil conditioners on wheat growth and yield grown in saline-sodic soils. *Sains Malays.* **2016**, *45*, 339–346.
75. Abdel Monem, M.A.; Radojevic, B. Agricultural production in Egypt: Assessing vulnerability and enhancing adaptive capacity and resilience to climate change. In *Climate Change Impacts on Agriculture and Food Security in Egypt: Land and Water Resources—Smart Farming—Livestock, Fishery, and Aquaculture*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 205–222.
76. González-Ubierna, S.; Jorge-Mardomingo, I.; Carrero-González, B.; de la Cruz, M.T.; Casermeiro, M.Á. Soil organic matter evolution after the application of high doses of organic amendments in a Mediterranean calcareous soil. *J. Soils Sediments* **2012**, *12*, 1257–1268. [CrossRef]
77. Ata, A.; Salem, T.N.; Hassan, R. Geotechnical characterization of the calcareous sand in northern coast of Egypt. *Ain Shams Eng. J.* **2018**, *9*, 3381–3390. [CrossRef]
78. Lucena, J.J. Effects of bicarbonate, nitrate and other environmental factors on iron deficiency chlorosis. A review. *J. Plant Nutr.* **2000**, *23*, 1591–1606. [CrossRef]

79. Ayyad, M. Vegetation and environment of the Western Mediterranean coastal land of Egypt: IV. The habitat of non-saline depressions. *J. Ecol.* **1976**, *64*, 713–722. [CrossRef]
80. Mohamed, E.S.; Belal, A.; Saleh, A. Assessment of land degradation east of the Nile Delta, Egypt using remote sensing and GIS techniques. *Arab. J. Geosci.* **2013**, *6*, 2843–2853. [CrossRef]
81. El Shinawi, A.; Zeleňáková, M.; Nosair, A.M.; Abd-Elaty, I. Geo-spatial mapping and simulation of the sea level rise influence on groundwater head and upward land subsidence at the rosetta coastal zone, nile delta, Egypt. *J. King Saud Univ. Sci.* **2022**, *34*, 102145. [CrossRef]
82. Wu, Q.; Hu, W.; Wang, H.; Liu, P.; Wang, X.; Huang, B. Spatial distribution, ecological risk and sources of heavy metals in soils from a typical economic development area, Southeastern China. *Sci. Total Environ.* **2021**, *780*, 146557. [CrossRef]
83. Ramadan, E.M.; Badr, A.M.; Abdelradi, F.; Negm, A.; Nosair, A.M. Detection of Groundwater Quality Changes in Minia Governorate, West Nile River. *Sustainability* **2023**, *15*, 4076. [CrossRef]
84. Zechmeister, H.G. Correlation between altitude and heavy metal deposition in the Alps. *Environ. Pollut.* **1995**, *89*, 73–80. [CrossRef]
85. Fairbrother, A.; Wenstel, R.; Sappington, K.; Wood, W. Framework for metals risk assessment. *Ecotoxicol. Environ. Saf.* **2007**, *68*, 145–227. [CrossRef]
86. Nahmani, J.; Hodson, M.E.; Black, S. A review of studies performed to assess metal uptake by earthworms. *Environ. Pollut.* **2007**, *145*, 402–424. [CrossRef]
87. Soltanpour, P.; Schwab, A. A new soil test for simultaneous extraction of macro- and micro-nutrients in alkaline soils. *Commun. Soil Sci. Plant Anal.* **1977**, *8*, 195–207. [CrossRef]
88. Msimbira, L.A.; Smith, D.L. The roles of plant growth promoting microbes in enhancing plant tolerance to acidity and alkalinity stresses. *Front. Sustain. Food Syst.* **2020**, *4*, 106. [CrossRef]
89. Zeng, F.; Ali, S.; Zhang, H.; Ouyang, Y.; Qiu, B.; Wu, F.; Zhang, G. The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. *Environ. Pollut.* **2011**, *159*, 84–91. [CrossRef] [PubMed]
90. Wierzbowska, J.; Kovačik, P.; Sienkiewicz, S.; Krzebietke, S.; Bowszys, T. Determination of heavy metals and their availability to plants in soil fertilized with different waste substances. *Environ. Monit. Assess.* **2018**, *190*, 567. [CrossRef] [PubMed]