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Physical and chemical characteristics of soils in newly-reclaimed areas of western El-Minya, EGYPT

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THE AIM of this study is to evaluate the physical and chemical properties of soils in newly reclaimed areas west of El-Minya. Soil physical and chemical properties are critical for understanding soil health, fertility and its suitability for agriculture or other uses. Soil samples were collected aseptically in sterile poly-bags from fifty (50) profile locations and were analysed for physical and chemical properties. ArcGIS was applied in the geospatial mapping of the studied area. Surface interpolation of soil properties was done using ordinary kriging under the geostatistical analyst-extension in ArcGIS desktop (ver. 10.5). Soil physical and chemical analyses illustrated that the investigated soils were extremely drained, from shallow-deep in depth, strongly to very strongly alkaline (pH 8.08–9.82), and non-saline to moderately saline (EC 0.13–12.38 $dS.m^{-1}$). Furthermore, the soils were low in organic matter content (0.9–6.3g kg^{-1}), cation exchange capacity (CEC) that ranged from 10.00–57.65 $cmolkg^{-1}$ and a high range of calcium carbonates (44–426.2 g kg^{-1}). Results also revealed that soils were low in available nutrients: nitrogen (10.05–27.96 mg kg^{-1}), phosphorus (0.06–4.13 mg kg^{-1}), whereas potassium was from low to high (126.03–699.16 mg kg^{-1}). The potential and major constraints for plant growth in the studied area include: (i) bioclimatic factors (rainfall, coldness or warmness), (ii) soil factors (depth, texture, stoniness and salinity) and (iii) other physical indices (soil structure, surface cover, infiltration depth and root depth). In essence, investigated soils could be improved through the adequate management practices including provision of adequate drainage system, application of organic manures, mulching to reduce evaporation and improve water storage, maintenance of cover crop, strip cropping and crop rotation, subsoiling to break the cemented gypsic subsoil for better root penetration, and utilization of mineral fertilizers, especially nitrogen and phosphorus for cereal crops. This is to support policy making framework for stakeholders, decision-makers, and resource managers in future planning of the studied area.

Keywords: Arid soils, Characterization, Reclamation projects**,** GIS mapping.

1. Introduction

Soil is among the most valuable natural resources for the future planning and development worldwide (Place *et al*. 2021). In this regard, the production of food, fodder, fuel, and feed to satisfy the desires of humans and animals is mostly dependent on agriculture and related fields that rely on soil resources. Sandy soils are mainly distributed in arid and semi-arid regions (approximately 900 million ha worldwide) (Yost and Hartemink, 2019). These soils are marked with low water and nutrient supply potentials given their low colloidal content (clay and organic carbon) (Abdel-Motaleb *et al.*, 2025). The world's soil resources are finite, readily degraded by misuse and mismanagement, non-renewable over human time frames, and diminishing due to degradation and conversion to non-agricultural uses (El-Ramady *et al.*, 2024).

Sustainable cultivation of newly-reclaimed soils in arid and semi-arid regions requires an accurate monitoring of soil physical and chemical characteristics to relieve the pressure on food supplies for the fast-growing population in such vulnerable areas (Abdullahi *et al.*, 2023)**.** For decades, the biggest concern for sustainable soil productivity is the population explosion in relation to production of food crops worldwide.

This problem progresses as a result of the ongoing loss of fertile land caused by the fast urbanization (Elsaid Saeed *et al.*, 2024). In view of this, about 74, 600 hectares of most fertile agricultural soils in the Nile Delta were lost from 1992 and 2015 under the continuous threat by urbanization and it is expected to increase to 87,000 hectares under “business as usual scenario” by 2030 (Abd El-kawy *et al.*, 2019) thereby threatening agricultural production and food security in Egypt. Hence, projects involving meaningful control of land reclamation and cultivation are now of utmost importance to compensate these arable soil losses. These projects require

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additional authentic information about soil resources that will be used. The application of these techniques has not been used only to surface soil properties but also to map them at different depth intervals (Hinge et al., 2018). Furthermore, there is no clear consensus about the optimum technique suited on reflecting capabilities of different soil types/depths, which usually varies depending on the specific scenario. In some research, for example, inverse distance weighing (IDW) appears to be an appropriate method for mapping variables such as P, K, or SOM in subsoil (Caloiero et al., 2021), but in others, the kriging methodology works well for topsoil (Zhang et al., 2023). In certain circumstances, radial basis function (RBF) produced superior results than IDW or Kriging approaches (Zandi et al., 2011).

The main goal of this study is to evaluate the physical and chemical characteristics of soil resources in newly reclaimed areas west of El-Minya, Egypt and to provide data necessarily for evaluating soil health, fertility status and physical and chemical characteristic maps of their spatial distribution for agricultural purposes. This research is in tandem with the deliverables in helping planners and policymakers to build a decision-making framework for long-term use of reclaimed soil resources of the studied area.

2. Materials and Methods

2.1. The study area

The study area is located on 27º 52′ 00"; 27º 55′ 00″ N and 29º 55′ 00″; 30º 1′ 00″ E, covering an area of 3676 hectares in the western River Nile (Fig. 1) out of the total area of 13471.65 hectares as a pilot plot. The 40 years (1981 to 2022) metrological records were obtained from National Aeronautic Space Administration (NASA) Langley research centre (LaRC; https://www.nasa.gov/langley/). These data indicated that the mean, minimum and maximum temperatures ranged from 3.36 to 24.55°C in winter and 19.42 to 41.99°C in summer. Mean annual rainfall ranged from 12.07 mm in winter to 0.02 mm in summer. Average relative humidity was 60.25% in winter and 32.58% in summer and wind speed ranges from 2.54 m/s in winter to 3.46 m/s summer. According to the American Soil Taxonomy (USDA, 2004), the soil is aridic moisture regime and hyperthermic temperature regime.

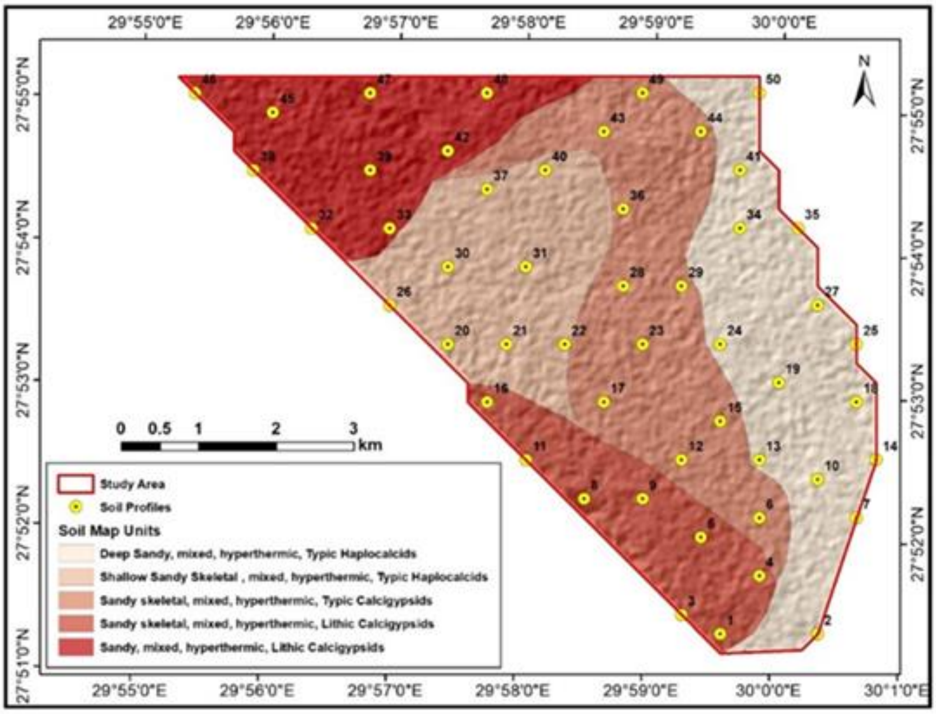

Fig. 1. Soil profile locations and physiographic units of the study area.

2.2. Soil samples collection and analyses

Soil samples were collected aseptically in sterile poly-bags from fifty (50) profile locations in a grid sampling format, the area was divided into grids collecting the samples at regular intervals (50m x 50m grid) and transported to the laboratory for analyses. The samples were analysed for particle size distribution, pH (in deionized water suspension 1:2.5 w:v), ECe (in the soil paste extract), Exchangeable Sodium Percent (ESP),

$CaCO_3$ % and $CaSO_4.2H_2O$% according to the certified methods (Jackson, 2005; Sparks *et al.*, 2020; Piper, 2019; Hesse and Hesse, 1971). The pH/mV/Temperature Meter (Jenway 3505 model) was used for the measurement of soil pH in deionised (DI) water suspension (1:2.5 w:v). Soil salinity (ECe) was measured in soil water extract. Total carbonate was estimated volumetrically using Collins Calcimeter and calculated as calcium carbonate. Gypsum content was determined through acetone precipitation. Cation Exchange Capacity (CEC) was determined after soil saturation with ammonium acetate (1.0 M) and the Exchangeable sodium percentage (ESP) was calculated using the equation 1.

$$\boldsymbol{ESP = [Na - soil] * 100/CEC} \qquad \textbf{(eq1)}$$

Water-soluble cations and anions were determined in DI water extract (1:2.5): cations of Na^+, K^+ using flame photometer, Ca^{2+} and Mg^{2+} by titration with EDTA, anions of CO_3^{2-} and HCO_3^- by titrating with H_2SO_4 and anions of Cl^- by titrating with $AgNO_3$. Organic matter was determined by Walkley and Black oxidation process. Available N was determined using Kjeldahl method after extraction with 2.0 M KCl. Available P was determined spectrophotometrically following extraction by 0.5 M $NaHCO_3$ extraction (pH 8.5). Available K was measured in 1.0 M $NH_4CH_3CO_2$ extraction (pH 7.0) by Sherwood flame photometer (MODEL 360). Soil colour was defined by Munssel Colour Charts. Ordinary kriging (OK) was used to conduct the spatial distribution of the soil parameters in ArcGIS (version 10.5) under the geostatistical analyst.

2.3. Geospatial mapping

ArcGIS was applied in the geospatial mapping of the studied area. Surface interpolation of soil properties was done using ordinary kriging under the geostatistical analyst-extension in ArcGIS desktop (ver. 10.5) (El-naggar 2020). Kriging formula predict an unmeasured location using a weighted sum of measured values equation 2 (Barrena-González et al. 2022).

$$\boldsymbol{Z(S0) = \sum_{i=1}^{n} \lambda i \, Z(Si)} \qquad \textbf{(eq2)}$$

Note: Z(S0) = Is the prediction location, λi = is an unknown weight for the measured value at the ith location, n = number of measured values, Z(Si) is the measured value at the ith location

3. Results

3.1. Spatial distribution of soil physical properties

Total sand (TS) ranged from 68.28% to 98.59%, with an average abundance of 83.31%. The wide variation in total sand content could be attributed to the type of soil parent material. Similarly, silt percentage ranged from 1.37% to 26.73%, with an average value of 15.01%, whereas clay value ranged from no detected concentration up to 9.00%, with an average abundance of 1.68%. Based on these findings, the common soil texture in the study area is sandy.

Values of soil bulk density in the studied area ranged from 1.09 to 1.78 g cm^{-3} with an average value of 1.18 g cm^{-3}. This finding highlights the urgent need to improve the micro pores formation of soil by sufficient additions of organic matter to stimulate microbial colonization and water movement within soil matrix (El-Ramady *et al.*, 2019). Soil water measurement including available water content (AW), field capacity (FC) and saturation percentage (SP) ranged as 4.47-11.67%, 8.94-23.35% and 17.88-46.70% with an average value of 6.18, 12.38 and 24.75%, respectively (Fig. 2). These values suggested the need to maximize water supply potential of the soil *via* addition of organic amendments (Mosa *et al.*, 2020b).

The soil colour is influenced by the mineral composition as well as water and organic matter content of the study area. The colour range between yellowish brown (10YR 5/8) moist: yellow (10YR 7/8) dry; Brownish yellow (10YR 6/8) moist: yellow (10YR 7/6) dry; Strong brown (7.5YR 5/8) moist: reddish yellow (7.5YR 6/8) dry; Brownish yellow (10YR 6/6) moist: very pale brown (10YR 8/4) dry; and Yellow (10YR 7/6) moist: very pale brown (10YR 8/2) dry.

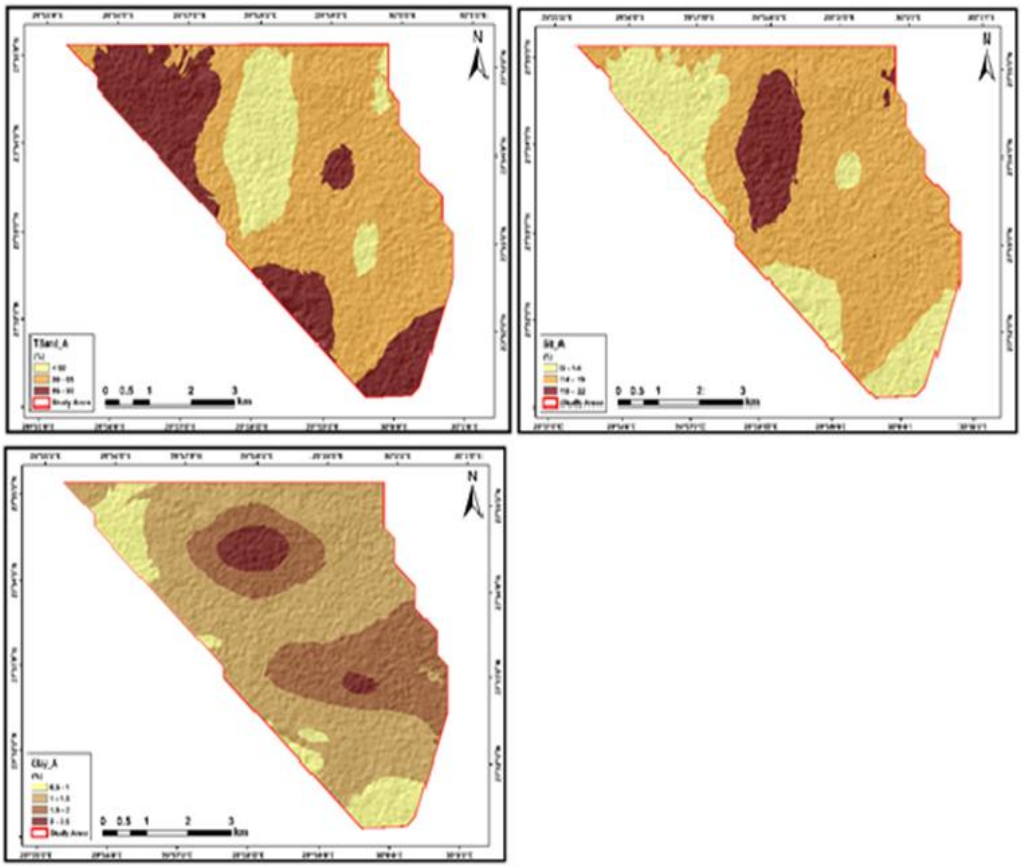

Fig. 2. Spatial variability of sand, silt and clay of the study area.

3.2. Spatial distribution of soil chemical properties

3.2.1. Soil EC, pH, OM and $CaCO_3$

In general, the pH value of soils in the studied area has a range value of 8.08-9.82, demonstrating the common alkaline nature of most Egyptian soils. Meanwhile, ECe ranges from 0.13 dSm^{-1} (nonsaline) to 12.38 dS m^{-1} (very strongly saline), with an average of 3.95 dS m^{-1} as indicated in Table 2 (Vargas *et al.*, 2018). Calcium carbonate ($CaCO_3$) levels in soils ranged from 44 to 426.2g kg^{-1}, with a mean value of 13.91g kg^{-1}. According to the classification of calcium carbonate reaction in the soil matrix, approximately 39.24% of the studied soils were classified as slightly calcareous, 52.60% were moderately calcareous, 6.90% were strongly calcareous, and 1.26% were extremely calcareous soils in the surface layer (A) (Jahn *et al.*, 2006). Regarding the subsurface layer (B), 45.55% were slightly calcareous, 42.96% were moderately calcareous, 10.47% were strongly calcareous, and (1.02%) were extremely calcareous (Fig. 3). In this regard, it is well known that total calcium carbonate content and its distribution within soil profile influences soil productivity in terms of its fertility, supply potentials of water and nutrients (Abou El-Anwar *et al.*, 2019).

The organic matter content of the studied area was very low, ranging between 0.9 and 6.3g kg^{-1}, with an average of 3.5g kg^{-1}. This low organic matter content could be attributed to the low precipitation, high temperature, low activity of living organisms (Ibraheem *et al.*, 2022). Organic matter is an important indicator for soil health since it enhances the physical, chemical, and biological quality indicators of soils**.** Furthermore, it was proposed that higher soil organic matter levels led to better soil productivity given the improvement of water retention, soil structure, and nutrient availability (Alshaal *et al.*, 2017) (Fig. 3).

The cationic configuration of the soil saturation extract demonstrates that Na^+ dominates the majority of the soil layers, followed by Ca^{2+} and Mg^{2+}, with K^+ having the lowest concentration. The anionic composition is characterized by the dominance of SO_4^{2-}, Cl^-, and HCO_3^-, which is consistent with the findings of (Gameh *et al.*, 2020)**.** The Soil gypsum content in the studied area varies from 0.44 to 10.76%, with an average value of 5.62%. Gypsum content ranges from low to high, which correlates with soil chemical properties of the parent materials.

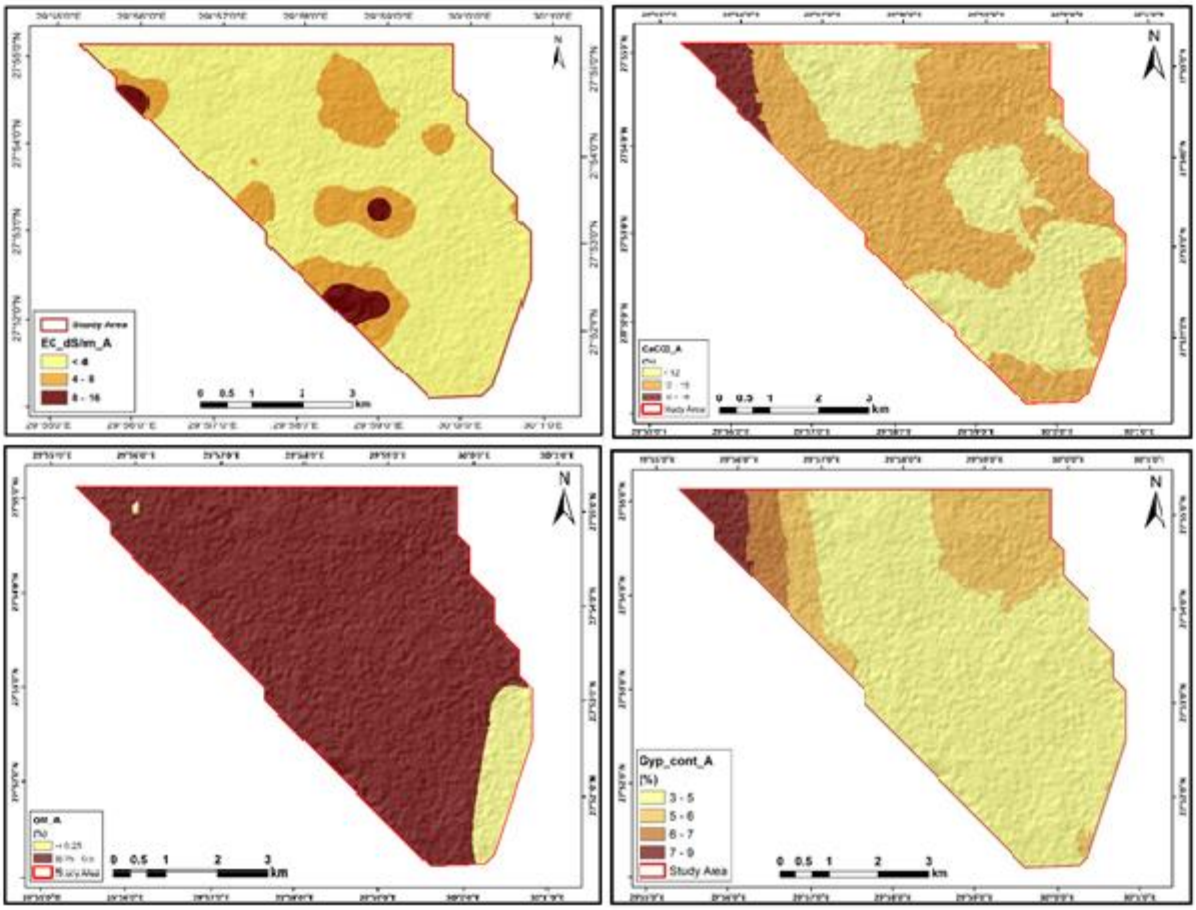

Fig .3. Spatial distribution of some chemical properties in soil layer of the study area.

3.2.2. ESP and CEC of the soil profiles

The exchangeable sodium percentage (ESP) in the study area ranges from 0.30 to 24.04%, with an average value of 7.19% (Fig. 4). The highest ESP values are connected with the subsurface and deepest layers of profiles. A low exchangeable sodium percentage (ESP) for most soil profiles, suggests a low sodicity hazard, whereas high ESP values were associated with high salinity and soluble sodium dominance in soil solution. However, the majority of the soil profiles in the study area were "loamy sand", indicating that the exchangeable sodium percentage (ESP) may drop if an efficient drainage system is implemented. The CEC values of soil samples ranged from 10.00 to 57.65 cmol kg^{-1}, with an average value of 22.38 cmol kg^{-1}, (Fig. 4). The cation exchange capacity of most investigated soils was very poor. This could be explained by the fact that the soil in the study location contains a large sand percentage, resulting in a low nutrient retention capacity, and thus low fertility.

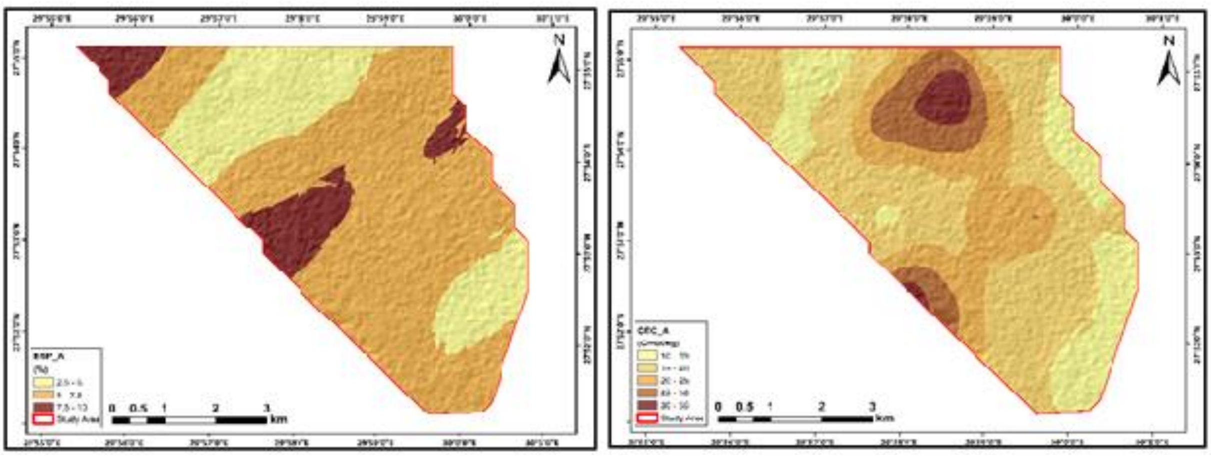

Fig. 4. Spatial distribution of ESP and CEC in soil layer of the study area.

3.2.3. Spatial distribution of available nutrients

The available nitrogen levels ranged from 10.05 to 27.96 mg kg^{-1}, with an average of 18.00 mg kg^{-1} (Fig. 5). The nitrogen distribution in surface layer (A) and subsurface layer (B) ranged from very low to low, with low fertility status being the most common. This finding suggest the need for supplemental nitrogen application to sustain the urgent needs of plant requirements (El-Ghamry *et al.*, 2021). Phosphorus, the second most limiting nutrient after nitrogen, has a negative influence on crop yield when inadequate levels are existed in soil. The available phosphorus levels in surface and subsurface layers ranged from 0.06 to 4.15 mg kg^{-1}, with an average value of 0.55 mg kg^{-1} (Fig. 5). The low available phosphorus content in the studied area could be attributable to high calcium concentration resulting in phosphorus precipitation into insoluble phosphates (Mosa *et al.*, 2020a). The available potassium content ranged from 126.03 to 1541.7 mg kg^{-1}, with an average value of 437.34 mg kg^{-1} (Fig. 5). The available potassium distribution in layers (A) and (B) ranged from medium to high, with high values being more prevalent. This relatively high content of potassium in soil matrix could be attributed to the presence of K-containing minerals (e.g. glauconite) (Hegab and Abd El-Wahed, 2016).

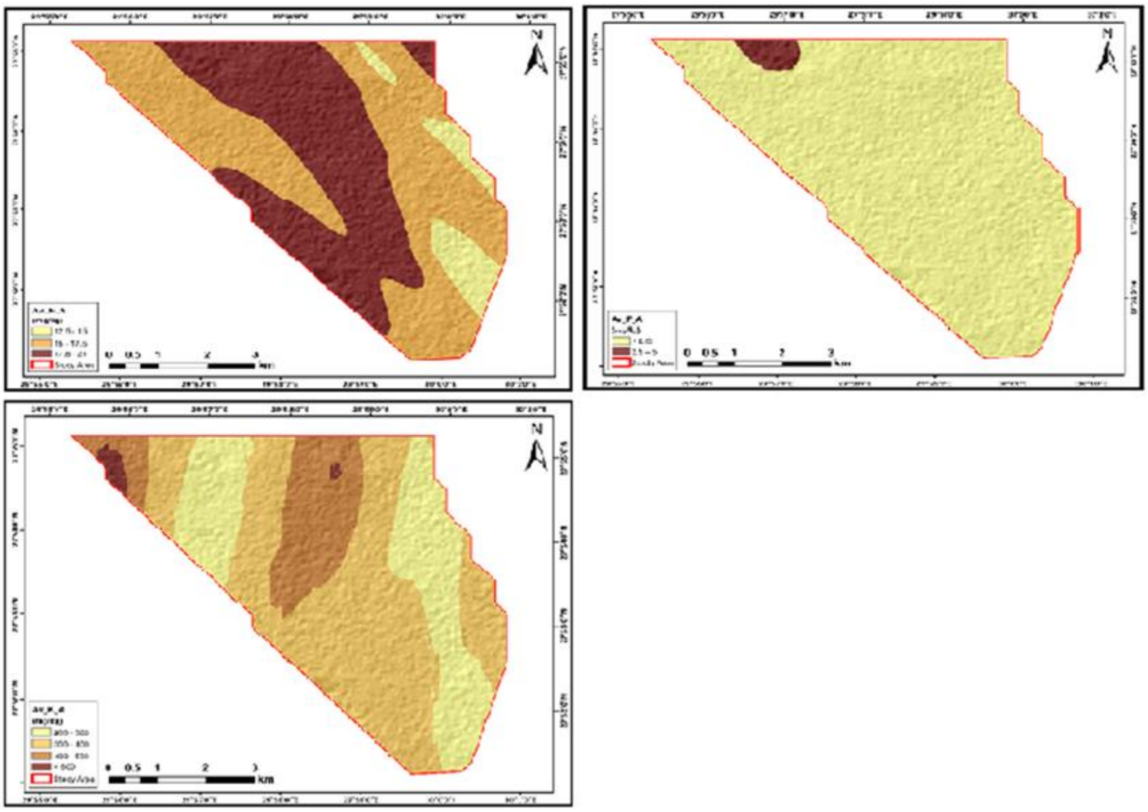

Fig. 5. Spatial distribution of available nutrients in soil layer of the study area

4. Salt-affected soils of the study area

Spatial distribution of salt-affected soils according to their surface and subsurface layers were19.96 and 35.60%, respectively (Table 1). However, the non-salt affected soils were 78.87 and 62.66% based on their surface and subsurface layers, respectively. Based on spatial interpolation of ESP values, the area of sodic soils was approximately 0.16 and 0.17% in the surface and subsurface layers, respectively. Saline-sodic soils cover about 0.70% of the surface layer and approximately 1.57% of the subsurface layer. The overall area of SASs rose with soil depth. It covered approximately 7.77 km^2 (21.13%) at the surface layer (A) (Fig. 6). This could be due to parent materials of soils in the studied area.

Table 1. Areas and percentages of salt-affected soils in layers (A) and (B) of the study area.

Salt-affected soils	Layer A		Layer B	
	Area (km^2)	%	Area (km^2)	%
Normal Soil	28.99	78.87	23.03	62.66
Saline Soil	7.34	19.96	13.09	35.6
Saline-Sodic Soil	0.26	0.7	0.58	1.57
Sodic Soil	0.17	0.47	0.06	0.17

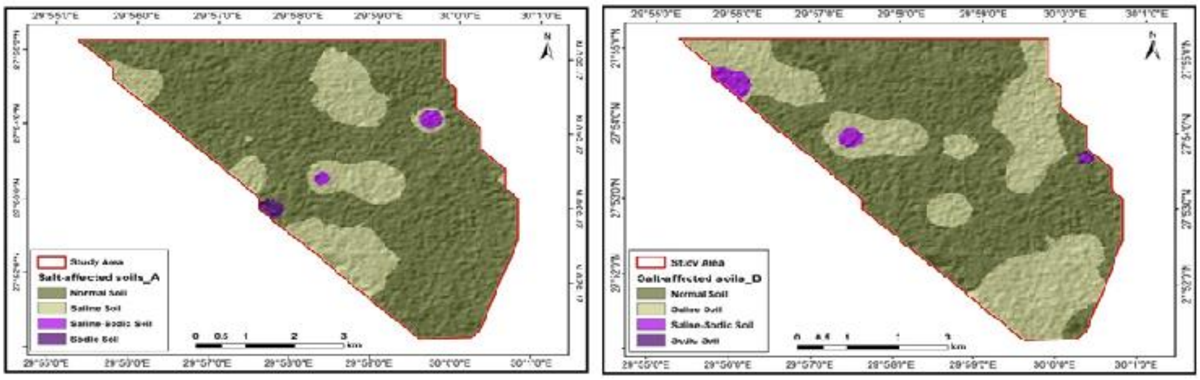

Fig. 6. Spatial distribution of salt-affected soil in the study area.

5. Discussion

The physical and chemical properties of soils in newly reclaimed areas west of Minya were evaluated. Soil physicochemical characteristics analysed illustrated that the investigated soils were extremely drained, from shallow-deep in depth. Based on the soil content variability, total sand (TS) ranged from 68.28% to 98.59%, with an average abundance of 83.31%. The wide variation in total sand content could be attributed to the type of soil parent material. Similarly, silt percentage ranged from 1.37% to 26.73%, with an average value of 15.01%, whereas clay value ranged from no detected concentration up to 9.00%, with an average abundance of 1.68%. Based on these findings, the common soil texture of the study area is sandy.

The average value of bulk density of soil in the studied area was 1.18 g cm^{-3}. Soil water measurement including available water content (AW), field capacity (FC) and saturation percentage (SP) ranged as 4.47-11.67%, 8.94-23.35% and 17.88-46.70% with an average value of 6.18, 12.38 and 24.75% respectively. This finding highlights the urgent need to improve the micro pores formation of soil by sufficient additions of organic matter to stimulate microbial colonization and water movement within soil matrix and the need to take full advantage of water supply potential of the soil through the addition of organic amendments.

In general, the soil pH ranged from 8.08-9.82 strongly to very strongly alkaline, indicating the alkaline nature of most Egyptian soils. Meanwhile, ECe ranges from 0.13 dS m^{-1} (non-saline) to 12.38 dS m^{-1} (moderately saline), with an average of 3.95 dS m^{-1}**.** Concentration of calcium carbonate ranged from 4.40 to 42.62%, with a mean value of 13.91%. Based on the reaction of calcium carbonate reaction in the soil matrix, approximately 39.24% of the studied soils were classified as slightly calcareous, 52.60% were moderately calcareous, 6.90% were strongly calcareous, and 1.26% were extremely calcareous. Due to calcium carbonate content distribution within soil profile, it is presumed that soil productivity such as: fertility levels, water and nutrients supply potentials may be hindered.

The organic matter content was observed to be very low, ranging between 0.09 and 0.63%, with an average of 0.35%. This low organic matter content could be attributed to low precipitation, high temperature, low activity of living organisms. The presence of organic matter in soil enhances the physical, chemical, and biological quality**.** Furthermore, higher soil organic matter levels led to better soil productivity given the improvement of water retention, soil structure, and nutrient availability.

The cationic configuration of the soil saturation extract demonstrates that Na^{+} dominates majority of the soil layers, followed by Ca^{2+} and Mg^{2+}, with K^{+} having the lowest concentration. The anionic composition is characterized by the dominance of SO_4^{2-}, Cl^{-}, and HCO_3^{-}. Soil gypsum content varies from 0.44 to 10.76%, with an average value of 5.62%. Gypsum content ranges from low to high, which correlates with soil chemical properties of the parent materials.

The value of exchangeable sodium percentage (ESP) ranges from 0.30 to 24.04%, with an average value of 7.19%. Low exchangeable sodium percentage (ESP) for most soil profiles, suggests a low sodicity hazard, whereas high ESP values were associated with high salinity and soluble sodium dominance in soil solution. However, majority of the soil profiles in the study area were “loamy sand”, indicating that the exchangeable sodium percentage (ESP) may drop if an efficient drainage system is implemented. The CEC values ranged from 10.00 to 57.65 cmol kg^{-1}, with an average value of 22.38 cmol kg^{-1}. The cation exchange capacity of most investigated soils was very poor. This could be explained by the fact that the soil in the study location contains a large sand percentage, resulting in a low nutrient retention capacity, and thus low fertility.

Available nitrogen ranged from 10.05 to 27.96 mg kg^{-1}, with an average of 18.00 mg kg^{-1}. Nitrogen distribution in the soil ranged from very low to low, with low fertility status being the most common. This finding suggests the need for supplemental nitrogen application to sustain the urgent needs of plant requirements. Phosphorus, the second most limiting nutrient after nitrogen, has a negative influence on crop yield when inadequate in soil. The available phosphorus ranged from 0.06 to 4.15 mg kg^{-1}, with an average value of 0.55 mg kg^{-1}. The low available phosphorus content could be attributable to high calcium concentration resulting in phosphorus precipitation into insoluble phosphates. The available potassium content ranged from 126.03 to 699.16 mg kg^{-1}, with an average value of 437.34 mg kg^{-1}. The available potassium distribution ranged from medium to high, with high values being more prevalent. This relatively high content of potassium in soil matrix could be attributed to the presence of K-containing minerals (e.g. glauconite).

Spatial distribution of salt-affected soils was 19.96%, non-salt affected soils 78.87%. Based on spatial interpolation of ESP values, the area of sodic soils was approximately 0.16%. Saline-sodic soils cover about 0.70%. The overall area of SASs rose with soil depth. It covered approximately 7.77 km^2 (21.13%). This could be due to soil parent materials. The potential and major constraints observed for plant growth in the area include: (i) bioclimatic factors, (ii) soil factors and (iii) other physical indices. In essence, investigated soils could be improved through adequate management practices including provision of adequate drainage system, application of organic manures, mulching to reduce evaporation and improve water storage, maintenance of cover crop, strip cropping and crop rotation, subsoiling to break the cemented gypsic subsoil for better root penetration, and utilization of mineral fertilizers, especially nitrogen and phosphorus for cereal crops. This is to support policy making framework for stakeholders, decision-makers, and resource managers in future planning of the studied area.

Generally, the profile is nearly level in slope, with desert plain landform, uncultivated vegetation and surface covered with desert pavement. The soil colour range between yellowish brown (10YR 5/8) moist: yellow (10YR 7/8) dry; Brownish yellow (10YR 6/8) moist: yellow (10YR 7/6) dry; Strong brown (7.5YR 5/8) moist: reddish yellow (7.5YR 6/8) dry; Brownish yellow (10YR 6/6) moist: very pale brown (10YR 8/4) dry; and Yellow (10YR 7/6) moist: very pale brown (10YR 8/2) dry. More so, the mineral composition as well as organic matter and water content of the study area have great influence in the soil colour of the study area.

6. Conclusions

According to this study, the soils of the study area were found to be poor in both physical and chemical properties which in turn influenced the fertility component of the soil. Furthermore, the soils are characterized with low water and nutrients supply capacity, which can be attributed to soil textural class, cation exchange capacity, alkaline nature of the soil (soil pH) and low organic matter content. The soil could be enhanced by changing and modifying the unfavourable features, such as increasing the texture with River Nile clay particles from the reserves behind the High Dam. This would help to change the soil's nitrogen content, increase cation exchange capacity, and reduce salinity. The quality of groundwater in the study area is of good quality that can support agricultural production for a long term. Therefore, the data generated in this study can help decision makers and policy planners in developing adequate and appropriate sustainable land management practices through effective land use planning for the studied area under the soil and environmental conditions.

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