Soil-Quality Status in the Reclaimed Land of Arid Region

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Abstract

From the reclaimed land W-the western desert road, W-Mallawi district, El Minya Governorate of Egypt, sixteen soil samples were taken. The samples were physically and chemically analyzed in the USA, to evaluate the purity of the soil and its extracts using a variety of indices, including the soil quality index (SQI), sodium absorption ratio (SAR), base saturation percentage (BS%), summation pollution indexes ($P_{\text{sum}}$), and the comprehensive ecological risk index (RI), which was also compared with guidelines from the food and agriculture organization (FAO). The findings indicate that (1) the pH changed from weakly to moderately alkaline, controlling the adsorption and heavy metal (HM) immobilization. (2) Soils are classified as calcareous if their CaCO3% content is greater than 5%, with salinities varying from non-saline to moderately salty. (3) texture of 75% of the soil samples was clay, 25% was clay loam, Kaolinite minerals represented 25% of soil samples, and 75% of samples were montmorillonite minerals, depending on the relation of cation exchange capacity (CEC) with soils. (4) The predominance of SO4, Cl, & Ca is due to the degradation of carbonate and evaporite minerals in soil extracts. (5) exceeding N & P-compounds in extracts indicated the role of phosphate fertilizers, which added to the improvement of soil fertility. (6) Based on SQI readings, soil quality varied from poor to marginal, SAR revealed that there was no risk associated with sodium levels in soils, and according to BS percentages, soil fertility is low. (7) HM Contents had a low influence in soil extracts based on $P_{\text{sum}}$ & IR values. (8) Agriculture was more extensive in 2018 and 2020 than in 2022, which could mean that there was no farming throughout this growing season or harvest. (9) Due to the low fertility of the soil in the research location, it was advised not to apply phosphate fertilizers, which causes HM contamination in those soils that affect both animal and human health.

Capsule: The soil in the research sites were newly reclaimed as its quality is pivotal for agriculture.

1. Introduction

In arid regions, agriculture is growing to satisfy soaring food-seeking access (Lim et al., 2020). To effectively manage lands, especially regarding soil quality and Agroecosystem production, thorough and exact salinity monitoring are vital. Some repercussions caused by accumulations of salts on the surface and within the rhizosphere were salt crusts, soil fissures, stunted plants, narrowed leaflets, shrinking, and plant demise (Sumner, 1993; Oster et al., 1999).

Electrical conductivity (EC), which is quantified in saturated soil paste samples, is the most frequent way of estimating soil salinity (Bower and Wilcox, 1965; Salinity Laboratory, 1954). The soil’s EC is a dynamic feature that is influenced by aspects as temperature, texture, and moisture content (Zhang et al., 2021). Because its extract reflects a known natural phase of the soil extracts and may be linked to the response of plants, it is the international method and variable for improving soil salinity (Khorsandi & Yazdi, 2011; Salinity Laboratory, 1954).

The mechanisms of salt concentrations on soil chemistry, nutrient uptake, contamination with heavy metals (HM), and pedogenetic cycles all rely on comprehending the constitution of the soil liquid, also termed the soil extracts (Hossain et al., 2020; Bockmann et al., 2021). Three major techniques for extracting soil-based extracts are centrifugation, water extraction, and saturated soil paste (Richards, 1954; Hossain et al., 2020). Saturated soil paste is the accepted and still most widely applied approach (Aboukila & Norton, 2017).

Many experts, analyzed the condition of the soil including Asmoay (2017), Aboukila & Norton (2017), Asmoay et al. (2019), Hossain et al. (2020), Bockmann et al. (2021), Alves et al. (2022), Moldovan et al. (2022), Seo et al. (2022), Yan et al., (2022), Zhang et al., (2022), and Wang et al., (2023).
The primary purpose of this research was to assess the soil quality and its conditions in terms of salinity, HM pollution, and state of agricultural extent over the preceding 12 years. Desert zones in Egypt represent the most potentially for agricultural reclamation, and the research area considers one of these sites.

1.1. Location

The study area, which embraced in the southwest portion of the El Minya governorate, was between the latitudes of 27° 42' and 27° 50' N and the longitudes of 30° 14' and 30° 35' E (Fig. 1). According to geomorphology, it represents the recently reclaimed area of the alluvial plain on the Eastern margin of the western Eocene plateau (Said, 1981; Fig. 1). Minia Formation, Samalut Formation, Moghra Formation, Gebel Qatrani, gravel, and Quaternary sediments (conglomerate, sand dunes, Nile silt, and wadi deposits) comprised the stratigraphic column's rock unit from bottom to top (Said, 1990; Fig. 2).

2. Materials And Methods

From the research area, sixteen soil samples were taken, sieved through a 2-mm mesh, and allowed to air dry before being examined physically and chemically. The saturated soil pastes extracts were analyzed at Stukenholtz Laboratory, Inc., 2924 Addison Ave. E., P.O. Box 353 Twin Falls, USA, using method WCC-103 according to Gavlak et al. (2005).

To evaluate the soil quality for agriculture, the soil quality index (SQI) can apply (CCME, 2001). Each SQI value falls into one of five categories: poor quality (0–45), marginal quality (45–65), fair quality (65–80), good quality (80–95), and excellent quality (95–100; Marvin et al., 2004).

The following equation (Eq. 1), which uses ions’ contents defined in epm, is applied to clarify the sodium risk on soil (Richards, 1954):

\[
SAR = \frac{Na}{\sqrt{Ca + Mg/2}}
\] ..................................................(1)

According to Joshua & Musgrave (2017), SAR values are defined as no risk (> 3), moderate risk (3–6), high risk (18–26), and severe risk (> 26).

According to Sonon et al. (2022), CEC values can be used to define the sort of soil texture, with number 5 indicating sand, 5–10 fine sandy loam, 10–15 loam, 15–30 clay loam, and > 30 clay. It can identify the clay minerals as Kaolinite (3–15), illite (15–40), and montmorillonite (40–120; Sonon et al., 2022).

Base saturation percentage (BS%) measures the fertility of the soil, it is calculated using the following formula (Eq. 2) where concentrations represented in meq/100g (Sonon et al., 2022).

\[
BS\% = \left(\frac{Ca + Mg + K}{CEC}\right) \times 100
\] ..............................................(2)

The impacts of different contaminants on soil extracts are reflected in the pollution index (Pi). The following equation (Eq. 3) yields the pollution index, according to Hakanson (1980), Gao et al. (2013), and Ming (2014).

\[
Pi = \frac{Ci}{Si}
\] .....................................................(3)

Ci is the metal content in the soil extracts with ppm, and Si is the reference content of this metal in the soil extracts, according to Hooda (2010).
The following formula (Eq. 4) is applied to determine the total pollution indices ($P_{\text{sum}}$), according to Hakanson (1980), Gao et al. (2013), and Ming (2014).

\[ P_{\text{sum}} = \sqrt{((\text{Ave} \, P_i)^2 + (\text{Max} \, P_i)^2)/2} \]  

Eq. (4)

$P_{\text{sum}}$ numbers were categorized into five grades are clean (< 1), slight pollution (1–2), mild pollution (2–3), moderate pollution (3–5), and high pollution (> 5; Gao et al., 2013; Ming, 2014).

The consequences of different pollution levels were evaluated using the possible ecological risk assessment procedure. The overall effects of several pollutants are reflected in the comprehensive index of potential ecological risk (RI), (Hakanson, 1980). RI was computed from this following formula (Eq. 5; Hakanson, 1980; Zhang et al., 2022):

\[ RI = \frac{\sum_{i=1}^{n} E_i^r}{n} \]

Eq. (5)

$E_i^r$ indicates the consequence of a single contaminant on the environment in soils (Hakanson, 1980; Zhang et al., 2022), which is calculated from this equation (Eq. 6):

\[ E_i^r = T_i^r x C_i^l \]

Eq. (6)

$T_i^r$ is the metal's toxicity reactivity value, which was identified by Yan et al. (2022). $C_i^l$ is the pollution coefficient for a metal, which is estimated from this formula (Eq. 7):

\[ C_i^l = \frac{c_i}{c_i^f} \]

Eq. (7)

$c_i$ is the measured metal content in soil extracts, $c_i^f$ is the reference concentration of this metal in the soil extracts (according to Hooda, 2010). RI magnitudes were divided into four rates are slight ecological risk (< 50), moderate ecological risk (50–100), considerable ecological risk (100–200), and high ecological risk (> 200) according to Ma et al. (2011).

3. Result And Discussion

Egypt's population density is growing, which is ramping up food consumption, whereas the fertility of the Nile Valley’s lands is deteriorating due to building invasion. The quality of its soils is more urgent since the government encourages enterprises to make reclamations to expand agriculture in areas where the research area views it as a potential zone.
3.1. Physicochemical Variables

The pH of the studied soil extracts ranged from weakly (7.9) to moderately alkaline (8.2), which is more effect on the availability of plant nutrients and microbial activity, as well as the adsorption and immobilization of heavy metals (Table 1; Denny, 2002; Kabata-Pendias, 2011). According to Richards (1954), EC values ranged from 1720 to 8700µS/cm, referring that the salinity of soils ranged between non-saline and moderately saline, which were higher than the standard limits established by FAO (1994, Table 1) in the majority of samples. CaCO3% fluctuated in the examined samples between 5.3 and 14.5% (Table 1), with its content rising over 5% to refer that the soils are calcareous (Lindsay, 1979).
Table 1
Physicochemical variables in the studied soil’s extracts.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Min.</th>
<th>Max.</th>
<th>Average</th>
<th>Median</th>
<th>Q1</th>
<th>Q3</th>
<th>FAO, 1994</th>
<th>Hooda, 2010</th>
<th>Samples exceeded the reference limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.9</td>
<td>8.2</td>
<td>8.03</td>
<td>8</td>
<td>8</td>
<td>8.1</td>
<td>6-8.5</td>
<td></td>
<td>All samples except 1, 4 &amp; 16</td>
</tr>
<tr>
<td>EC (µS/cm)</td>
<td>1720</td>
<td>8700</td>
<td>5934</td>
<td>6200</td>
<td>4785</td>
<td>7900</td>
<td>3000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaCO₃%</td>
<td>5.3</td>
<td>14.5</td>
<td>10.7</td>
<td>11.05</td>
<td>8.2</td>
<td>13.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OM %</td>
<td>0.31</td>
<td>1.15</td>
<td>0.56</td>
<td>0.51</td>
<td>0.45</td>
<td>0.58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEC (meq/100g)</td>
<td>20</td>
<td>73.5</td>
<td>48.7</td>
<td>51.9</td>
<td>24.5</td>
<td>68.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca (ppm)</td>
<td>318</td>
<td>1370</td>
<td>833</td>
<td>792</td>
<td>419</td>
<td>1236</td>
<td>401</td>
<td></td>
<td>All samples except 1, 4, 6 &amp; 8</td>
</tr>
<tr>
<td>Mg (ppm)</td>
<td>16</td>
<td>34</td>
<td>25</td>
<td>27</td>
<td>21</td>
<td>29</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na (ppm)</td>
<td>16</td>
<td>418</td>
<td>91</td>
<td>32</td>
<td>23</td>
<td>90</td>
<td>920</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K (ppm)</td>
<td>172</td>
<td>655</td>
<td>340</td>
<td>355</td>
<td>265</td>
<td>405</td>
<td>78</td>
<td></td>
<td>All samples</td>
</tr>
<tr>
<td>Cl (ppm)</td>
<td>98</td>
<td>4338</td>
<td>864</td>
<td>229</td>
<td>128</td>
<td>634</td>
<td>1063</td>
<td></td>
<td>5, 11 &amp; 16</td>
</tr>
<tr>
<td>SO₄ (ppm)</td>
<td>999</td>
<td>999</td>
<td>999</td>
<td>999</td>
<td>999</td>
<td>999</td>
<td>960</td>
<td></td>
<td>All samples</td>
</tr>
<tr>
<td>NO₃ (ppm)</td>
<td>4</td>
<td>88</td>
<td>18</td>
<td>7.5</td>
<td>5.5</td>
<td>19</td>
<td>10</td>
<td></td>
<td>1, 4, 5, 10, 11 &amp; 16</td>
</tr>
<tr>
<td>N (ppm)</td>
<td>25</td>
<td>50</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>30</td>
<td>5</td>
<td></td>
<td>All samples</td>
</tr>
<tr>
<td>NH₃ (ppm)</td>
<td>3.3</td>
<td>13</td>
<td>6.7</td>
<td>5.8</td>
<td>5.4</td>
<td>7.3</td>
<td>5</td>
<td></td>
<td>All samples</td>
</tr>
<tr>
<td>P (ppm)</td>
<td>7</td>
<td>14</td>
<td>9.7</td>
<td>9.5</td>
<td>8.8</td>
<td>11</td>
<td>2</td>
<td></td>
<td>All samples except 1, 4 &amp; 6</td>
</tr>
<tr>
<td>Fe (ppm)</td>
<td>2.8</td>
<td>6.3</td>
<td>4.2</td>
<td>4.3</td>
<td>3.3</td>
<td>4.8</td>
<td>5</td>
<td>5</td>
<td>1, 4 &amp; 7</td>
</tr>
<tr>
<td>MN (ppm)</td>
<td>3.1</td>
<td>4.6</td>
<td>3.6</td>
<td>3.5</td>
<td>3.2</td>
<td>3.9</td>
<td>0.2</td>
<td>5</td>
<td>All samples</td>
</tr>
<tr>
<td>Cu (ppm)</td>
<td>0.0</td>
<td>0.2</td>
<td>0.11</td>
<td>0.10</td>
<td>0.10</td>
<td>0.2</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 3.2. Heavy Metals (HM)

If HM concentrations surpass the reference limits in soils, pollution ensues. This contamination can get into foods and water, which causes harmful effects on human health (Asmoay et al., 2019). Fe levels in most samples ranged from 2.8 to 6.3 ppm, not outpacing the FAO & Hooda (2010) reference limits (Table 1). In all samples, Mn values varied between 3.1 and 4.6 to rise above the FAO limit (Table 1). It can originate from phosphate fertilizers and minerals such as augite and hornblende in sediments (Omer, 2003; Asmoay, 2017). Cu concentrations in soil extracts ranged from 0 to 0.2 ppm (Table 1), which can observe in both human and animal waste and is a crucial element of plant and animal metabolism (ATSDR, 2002). Zn is necessary for all biota, can emanate from igneous rocks and phosphate fertilizers, and its content changed between 0.3 and 0.9 ppm in the examined samples (Table 1; Friberg et al., 1986; Asmoay, 2017). In most samples, B ranged from 1.1 to 17 ppm, above the FAO &
Hooda (2010) standard limits, can release from rocks and sewage, and can cause damage if present in an elevated amount (WHO, 2022).

### 3.3. Soil Quality

Because of an increase in the concentration of the dissolving elements above FAO limits, soil quality for agriculture varied from bad in 75% of samples to marginal in 25% of samples, according to SQI values (Table 1 & Fig. 3). No risk in 88% of the examined soil extracts was reflected by SAR values which changed between 0.17 and 4.1. (Table 1 & Fig. 4; Joshua & Musgrave, 2017). BS values ranged from 8.38 to 12.83% in the analyzed soils that were less fertile to be amended with lime or fertilizers, which are one sources of the toxic metals in soils and groundwater (Table 1 and Fig. 5; ALCL., 2013; Sonon et al., 2022).

### 3.4. HM Content Evaluation in Soil Extracts

Simulation of HM concentrations by indices can show how HM accumulation in soils and water can impair plant, human, and animal health (Asmoay, 2017, Asmoay et al., 2019; Zhang et al., 2022). $P_{sum}$ levels differed between 0.43 and 4.43 (Table 1 & Fig. 6), which stated that the HM concentrations in the soil extracts had no harmful impact on health (Hakanson, 1980; Hooda, 2010; Gao et al., 2013; Ming, 2014; Moldovan et al., 2022). RI values varied from 2.02 to 9.66 (Table 1 and Fig. 7), showing a minimal ecological risk associated with the concentrations of HM in soil extracts (Hakanson, 1980; Hooda, 2010; Yan et al., 2022). HM component in the soil extracts consequently had barely acute effect.

### 3.5. Land use-land cover (LU-LC) changes

Through the use of Landsat imagery, land feature changes year over year can have qualitative and quantitative impacts on the aquatic system (Verma et al., 2020). Due to intense irrigation, the water table can be reduced by 42 m, as observed in UAE (Elmahdy and Mohamed, 2012; Ghebreyesus et al., 2016; Khan et al., 2019). In Egypt, elevated population density on the fertile Nile Valley lands has led to the curtailment of the areas in use for agriculture. Population growth led to diminishing food, causing seek new sources of it. Reclaiming the desert and drilling fresh groundwater wells to irrigate such areas are the solves. As shown by Landsat images which were processed using the Arc Map tools, the lands have changed because of the previously mentioned reasons. In the research area, agriculture spaces grew in 2018 and 2020 before declining in 2022 (Fig. 8). This decline may result from agricultural harvesting or no farming occurring this season.

### 4. Conclusions

Soil extracts’ pH values alternated from weakly to moderately alkaline, which adjusts nutrient availability, adsorption, and HM immobility. The soil’s salinity fluctuated from non-saline to moderately saline; however, over 5% of CaCO3% suggested that the soil samples were calcareous. Relation of CEC to soil texture depicted that clay characterized 75% of samples and clay loam is 25%. It also revealed that kalinite and montmorillonite of clay minerals in soils were 25 & 75%, respectively. Due to the dissolution of the carbonate and evaporite minerals, $SO_4$, $Cl$, & $Ca$ ions are more prevalent in soil extracts. Excess of $N$ & $P$-compounds above FAO-referenced limits in extracts, reflecting the contribution of human activity. Except for $Fe$, $Mn$, & $B$, the level of HM metals in soil extracts didn’t exceed the guideline values. According to SQI, soil quality differed from poor to marginal, since some of its elements were above FAO-recommended limits. SAR established that sodium levels in soils didn't pose any harm. BS values revealed the soils are less fertile and lack a treatment with lime and fertilizers, which can cause pollution with HM. $P_{sum}$ & RI indices demonstrated the low risk of HM in extracts in soils. The extent of agriculture in the
research area expanded in 2018 and 2020, and then declined in 2022 because of specific conditions like no farming or agricultural harvesting, according to Landsat imagery processed using arc map software.

Declarations

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**Figures**

**Figure 1**

Location map of the study area.
Figure 2

Geologic map of the study area (After Conco, 1987).
Figure 3

SQI values classification for the examined samples.
Figure 4

SAR values classification for the studied samples.
Figure 5

BS values classification for the investigated samples.
Figure 6

$P_{\text{sum}}$ values classification for the studied samples.
Figure 7

RI values classification for the examined samples.
Figure 8

LU-LC changes in agricultural extent of the study area.