Review Article

GIS-based land degradation risk assessment of Damietta governorate, Egypt

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Abstract

This study aims to assess the land degradation risk in the governorate by using Geographical Information System (GIS) technique. The preliminary landforms of the area were defined by using remote sensing data. The area includes flood plain, lacustrine plain, and marine plain. A total of 18 soil profiles representing different mapping units were studied. Thirty six soil samples were collected for laboratory analysis. The soil properties of bulk density and electrical conductivity (EC) were attached to the different landforms. The thematic layers of these properties were created in Arc-GIS 10.2 software using the spatial analysis function and then these layers were matched together to assess the soil degradation. The obtained results revealed that the high risk of physical (i.e. soil compaction) and chemical vulnerability (i.e. salinization) covered an area of 86.02 km² (12.83%) and 2.28 km² (0.34%), respectively in the surface soil layers. The land degradation hazard in the surface layers due to soil compaction was moderate to very high, whereas the degree of salinization was low to high. Regarding to the subsurface soil layers, the high risk of physical degradation and chemical degradation covered an area of 127.8 km² (19.06%) and 10.6 km² (1.58%), respectively. The land degradation hazard due to soil compaction in the subsurface layers was moderate to high, whereas the degree of salinization was low to very high.

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1. Introduction

Land is the most valuable natural resource for production of food, fuel and many other essential goods that are required to meet human and animal needs [1]. Soils are limited resource and could be considered nonrenewable [2]; it is continuously exposed to degradation processes [3]. Land degradation, defined as a reduction in the biological productivity of land arising from climate change and human activities, is a serious environmental problem [4]. The cultivated land represents about 40–50 % of the global [5], 20% of them are severely degraded [6,7]. In irrigated agriculture lands under the arid climate, water logging and salinization are the major land...
degradation processes [8]. Most of these processes are directly affected by human activities [9,10]. Land degradation leads to a gradual decrease in soil productivity [11], hindering sustainable development [12,13] and consequently food gap are expected [14]. The main types of land degradation identified in Egypt are salinity, sodicity, compaction and water logging [15]. The alarming losses in economic revenues and agro-ecosystem services have revealed an acute need for monitoring of land degradation and analyses of its causes in order to advise decision makers on spatial targeting of land rehabilitation measures [16]. This study aims to address the land degradation risk of Damietta governorate. Land surveying data, laboratory analyses, remote sensing and GIS were the main tools used to fulfill this objective.

2. Materials and methods

2.1. The study area

Damietta governorate is located at the northeast of the Nile Delta between longitudes 31° 28’ & 32° 04’ and latitude 31° 10’ & 31° 30’ (Fig. 1). The governorate covers an area of 227,575.32 acres, representing 0.1% of the Republic’s area, and encompasses 4 districts, 10 cities, 47 rural units and 85 villages. According to the preliminary results of 2006 census, population is about 1.1 million people; 38.4% of them live in urban areas and 61.6% in rural areas. The governorate cultivated area covers 108.8 thousand acres and is famous for growing wheat, maize, cotton, rice, potatoes, lemons, grapes, and tomatoes [17].

2.2. Digital image processing

- In this study Landsat-8 image (path 176, row 038) acquired during the year 2013 was used. Image was radiometrically and geometrically corrected to accurate the irregular sensor response over the image and to correct the geometric distortion due to Earth’s rotation [18].
- Using the satellite data and the digital elevation model (extracted from the available contour maps at scale 1:25,000) the landform map of the area was produced by Ali and Shalaby [19]. Following the methodology developed by Dobos et al. [20], the different landform units were checked and updated during the field work.

2.3. Field work and laboratory analyses

- A semi detailed survey was carried out throughout the investigated area in order to gain an appreciation on soil patterns. A total of 18 ground truth sites were studied in the field, from which 18 soil profiles and 36 soil samples were collected to represent the different landform units (Fig. 2).
- Soils samples were analyzed following the procedure detailed by USDA [21] and Klute [22].
- The land surveying and laboratory analyses data were recorded in the attribute table of the landform map using Arc-GIS 10.2 software.

2.4. Spatial distribution of soil properties

Spatial interpolation is commonly used for producing continuous information when data are collected at distinct
locations (e.g. soil profiles). The inverse distance weighted (IDW) is an interpolation method, which weighs the surrounding known values to derive estimations for an unmeasured location. However, the weights are based not only on the distance between the known points and the unmeasured point but also on the overall geostatistical relationships among the known points [23]. Arc-GIS 10.2 software has been used to interpolate the soil properties i.e. electrical conductivity (EC); soils pH; and bulk density using the IDW method.

2.5. Soil degradation assessment

Land degradation risk was assessed following the methodology developed by FAO [24] and UNEP [25]. Table 1 illustrates the risk of land degradation which depends on the EC and bulk density values.

3. Results and discussion

3.1. Landforms

Three landscapes were recognizing in the study area i.e. flood plain, lacustrine plain and marine plain. The flood plain dominates the southern parts including low elevated river terraces, high elevated river terraces, river levee, overflow mantle, decantation basin and overflow basin. Marine plain exhibit the northern parts, comprises the units of high elevated sand sheet, low elevated sand sheet, sandy beach,
wetlands and hammock. The landforms of fish ponds and water bodies of the lacustrine plain dominate the north-eastern parts of the governorate.

### 3.2. Spatial distribution of soil properties

#### 3.2.1. Surface soil layer

Table 2 represents some physical and chemical analyses of the soils in the different landform units and Table 3 represents summary statistics of some soil properties. In this study, the data indicated that the soil texture was clayey to sandy; the fine texture attributed the flood plain. Values of soil pH were slightly alkaline, ranging between 7.4 and 8.63 in the different soils; the highest value characterized the overflow basin. The average pH value in the surface layers was 8.06. The spatial distribution of EC in the study area indicated that the EC values ranged from 1.8 to 11.39 (dS/m) in the surface layer. The average EC value in the surface layers was 3.78 (dS/m). The highest value dominated the topsoils of high elevated sand sheet. The high values of EC may be attributed to the origin of parent material and as a result of high water table [15]. According to FAI [26], the soils with EC value of below 0.80 (dS/m) are considered normal and suitable for all crop types. The spatial distribution of bulk density (BD) showed that the BD values ranged from 1.22 to 1.65 (g/cm³); the highest value occupying the surface layers of high elevated sand sheet. The average BD value in the surface layers was 1.34 (g/cm³). The high values of bulk density may be due to the effect of using heavy machinery on the surface layer [27,28]. These results are similar to those of other relevant studies [e.g. [15,29,30]] who studied the spatial distribution of soil properties in soils north of the Nile Delta. Fig. 3 represents the spatial distribution of EC and Fig. 4 represents the spatial distribution of bulk density in the topsoil layers over the study area.

#### 3.2.2. Subsurface soil layer

The data indicated that the soil texture was clayey to sandy; the fine texture attributed the flood plain. Values of soil pH were slightly alkaline, ranging between 7.5 and 8.7 in the different soils; the lowest value characterized the overflow basin. The average pH value in the subsurface layers was 8.07. The spatial distribution of EC in the study area indicated that the EC values ranged from 1.35 to 20.58 (dS/m) in the subsurface layer. The results showed that the lowest value of soil EC (1.35) was in low elevated sand sheet, while the highest one (20.58) was observed in the high elevated sand sheet. The average EC value in the subsurface layers was 4.23 (dS/m). This is in an agreement with Berhe et al. [31] who found that the average EC value in the subsurface layers was higher than the average EC value in the surface layers. The high values of EC may be attributed to over-irrigation and other forms of poor agricultural and soil management practices [32]. The spatial distribution of bulk density (BD) showed that the BD values...
ranged from 1.21 to 1.60 (g/cm³); the high values occupying the subsurface layers of hammock and the high elevated sand sheet. The average BD value in the subsurface layers was 1.35(g/cm³). Similar results were obtained by Singh et al. [33] who found that the average of BD values in the subsurface layers was higher than the average BD values in the surface layers. The increase in bulk density with depth is due to migration of silt and clay from upper layers to this layer, which resulted in firm packing (consolidation) of soil [34]. Fig. 5 represents the spatial distribution of EC and Fig. 6 represents the spatial distribution of bulk density in the subsurface layers over the study area.

3.3. Classes of soil degradation risk

3.3.1. Surface layer

Table 4 represents types, classes and areas of degradation risk affected the surface soil layer. The obtained data revealed that the soils had a moderate to very high risk of soil compaction and low to high risk of salinity. The high risk of soil compaction and salinity covered an area of 86.02 km² (12.83%) and 2.28 km² (0.34%), respectively. Human-induced salinization can result from two causes: poor management of irrigation schemes, and high salt content of the irrigation water or too little attention given to the drainage of irrigated fields. A second type occurs where human activities lead to an increase in evapo-transpiration of soil moisture in areas of high salt containing parent materials or with saline ground water [35]. A similar finding was obtained by El-Nahry [36], who found that the main types of land degradation identified in an area located between northern Isamillia and southern Port Said Governorates were salinity and compaction as a result of human activities, inadequate soil management, using heavy machinery and human intervention in natural drainage systems. Fig. 7 represents classes of soil salinity risk in the surface soil layer and Fig. 8 represents classes of soil compaction risk in the surface soil layers of the study area.

3.3.2. Subsurface layer

Table 5 represents types, classes and areas of degradation risk affected subsurface soil layers of the study area. The obtained data revealed that the subsurface soils were subjected to a moderate to high risk of physical degradation (soil compaction) and a low to very high risk of chemical degradation (salinization). The high risk of physical degradation (soil compaction) and chemical degradation (salinization) covered an area of 127.8 km² (19.06%) and 10.6 km² (1.58%),

| Type       | Risk class | Area (Km²) | Area (%) |
|------------|------------|------------|----------|
| Salinization| Low        | 467.34     | 69.70    |
|            | Moderate   | 200.88     | 29.96    |
|            | High       | 2.28       | 0.34     |
|            | Very high  | –          | –        |
|            | Low        | –          | –        |
|            | Moderate   | 584.47     | 87.17    |
|            | High       | 85.35      | 12.73    |
|            | Very high  | 0.67       | 0.1      |
| Total      |            | 670.5      | 100      |

Fig. 6 – Spatial distribution of bulk density in the subsurface soil layer.

Fig. 7 – Classes of soil salinity risk in the surface soil layer.

Fig. 8 – Classes of soil compaction risk in the surface soil layer.
respectively. Same results were obtained by Wahab et al. [29] who found that the human induced land degradation hazards due to soil compaction and salinization was slight to high in soils north of Nile Delta. Fig. 9 represent classes of soil salinity risk in the subsurface soil layers and Fig. 10 represent classes of soil compaction risk in the subsurface soil layers of the study area.

### 4. Conclusion and recommendations

Understanding the spatial distribution of soil properties and their relation with the landforms is the key to setting the appropriate land management. Distribution of the soil properties over the landforms of Damietta governorate had been investigated by using spatial analyses techniques. The area includes various landforms i.e. flood plain, lacustrine plain and marine plain. The distribution of the soil properties i.e. EC and bulk density (BD) represented a wide variation over these landforms. It can be concluded that a significant area in the governorate is subjected to a high risk of soil compaction and salinity. Moreover, processes of compaction and salinization changes from low to high in different land units. GIS is very helpful tool to store, manipulate and quantitatively evaluate soil degradation.

In addition, the following recommendations suggested for reducing land degradation in the city:

- Establish methods to remedy any degraded land prior to agricultural or residential use (i.e. salinity, erosion, leaching, stagnation, chemical composition, etc.).
- Reducing soil compaction could be realized through avoiding field practices that have the potential to damage the soil structure. So, conducting field operations with heavy machines on wet soils should be minimized.
- Governments should form committees to promote sustainable land use practices.
- Introduce the concept of a controlled environmental greenhouse as an option/alternative to farms whose land easily suffers from land degradation.
- Revert to such agricultural practices as crop rotation in order to preserve soil quality.
- Move to drip irrigation methods as crop rotation in order to preserve soil quality.
- Use minimum/conservation tillage methods.
- Use precision agricultural methods.
- Promoting land-use systems that provide permanent vegetative cover to protect the soil, increase fertility and optimize water penetration.
- Identifying the causes of land degradation before prescribing solutions for it.
- Before developing land, a clear evaluation procedure should be established and implemented.
- The government should pass legislation that protects land against practices that lead to degradation.
- Establish community environmental awareness programs.
- Decisions regarding land use should be based on continual research and monitoring on the condition and stability of the land.
- Informational meetings regarding the impact of land use on the environment should be held periodically within the community.
- Educate the people about respecting the land and use of sustainable land practices.
- Using techniques that provide economic benefits for land users in the short as well as the long term.

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| Type          | Risk class | Area (Km²) | Area (%) |
|---------------|------------|------------|----------|
| Salinization  | Low        | 474.85     | 70.82    |
|               | Moderate   | 185.06     | 27.60    |
|               | High       | 9.39       | 1.4      |
|               | Very high  | 1.2        | 0.18     |
|               | Low        | —          | —        |
|               | Moderate   | 542.7      | 80.94    |
|               | High       | 127.8      | 19.06    |
|               | Very high  | —          | —        |
| Total         | —          | 670.5      | 100      |

Fig. 9 – Classes of salinity risk in the subsurface soil layer.

Fig. 10 – Classes of compaction risk in the subsurface soil layer.
• Develop a long-term land conservation plan.
• Provide data on land resources — including soils, climate, vegetation and topography if land-use and conservation policies are to be developed.
• Evaluating land resources and identifying the causes of land misuse.

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