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MONITORING CHEMICAL AND PHYSICAL SOIL DEGRADATION IN DAMANHOUR DISTRICT, AL-BEHEIRA GOVERNORATE, EGYPT

Abdrabelnabi Mohamed Abdelhady, Emad Fawzy Abdelaty[1], Hadeer Mahmoud Mardy, and Ebrahim Ahmed Shehata

Natural Resources and Agricultural Engineering Department, Faculty of Agriculture, Damanhour University, Egypt.
* emad.fawzy@agr.dmu.edu.eg (Emad F. Abdelaty)

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ABSTRACT

Different soil parameters are widely used in soil quality evaluation. This study aimed to determine the soil quality index in agricultural soils using integrated soil parameters and consider it as an indicator of chemical soil degradation in the study area and using satellite images for physical soil degradation monitoring. The study was carried out in Damanhour District, Al-Beheira Governorate, Egypt, in 2023, compared with a previous study in 2017. Soil samples collected from the surface and subsurface layers were analyzed to determine soil characteristics. The results showed that soil pH increased from 7.57 in 2017 to 8.65 in 2023, the electrical conductivity (EC) decreased slightly from 3.45 dS/m to 3.15 dS/m, the sodium adsorption ratio (SAR) increased from 5.33% to 7.21%, total carbonate ($CaCO_3$) increased from 0.60% to 3.19%, and finally, organic matter (OM) increased from 0.14% to 1.02%. The soil quality index (SQI) in the study area decreased from 57.14% in 2017 to 48.57% in 2023. Although the comparison period is very short in such cases, it became clear that the soil suffers from chemical degradation - even if to a small degree - which makes it need good management to address this problem by paying attention to the suitability of irrigation water and the optimal use of chemical fertilizers. Also, 12% of the agricultural land was exposed to physical

degradation between 2010 and 2030 because of urban expansion, which requires decision-makers to take the necessary measures to address this issue.

Keywords: Soil Quality Index, Chemical Soil Degradation, Physical Soil Degradation, Damanhour District.

INTRODUCTION

Agricultural production and providing food to people are one of the most important issues in the world. Given that land is agriculture's primary resource, therefore, the study of its level and condition is necessary. Measures to preserve and improve soil productivity are based on an investigation of the spatial distribution of soil fertility properties **(Bobomurodov *et al.*, 2023)**. Agricultural soils are Egypt's most important resource for the population **(Abdelrahman *et al.*, 2019)**. In the Nile Delta, improper land use and management affect agro-ecosystems and food production causes land degradation **(Abdelrahman *et al.*, 2018; Abdelrahman *et al.*, 2022)**.

Knowledge-based soil management has become important for agricultural productivity and sustainability, and accurate soil information helps farmers make decisions at the farm level **(Ball *et al.*, 2018)**. Soil maps are the representation of soil types and their properties. Many people use soil maps, including professors, students, agriculturists, and decision makers **(Khatri and Suman, 2019)**.

The land is the main resource for agriculture, and therefore soil information is very important. This makes the use of geographic information systems (GIS) an essential tool in this sector. The application of GIS technologies is also so important in the study of soils **(Islam *et al.*, 2017)**. ArcGIS is software used for working with maps and geographical data **(Khatri and Suman, 2019; Eljamassi, 2013)**.

A precise evaluation and monitoring of soil quality (SQ) is important for sustainable land-use planning **(Abuzaid and Bassouny,**

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2018) and soil degradation detection. Soil quality is not measured directly but inferred from measurable and specific indicators. These indicators should be integrated into a soil quality index. There is a need to monitor soil quality and take it as an indicator of soil degradation rate **(Elbasiouny *et al.*, 2017)**.

Impacts of land degradation on livelihoods, environment, economic growth and migration are becoming more apparent throughout the worldwide **(Zdruli, 2014)**. Land degradation is also a natural and human-induced process that leads to a decline in land productivity, therefore soil is central for realizing eight of the seventeen sustainable development goals (SDGs) **(Ziadat *et al.*, 2022)**.

The objectives of this article are to: 1) identify appropriate indicators to assess the quality of Egyptian Delta soils, 2) identify threshold values of indicators, 3) assess and monitor chemical soil quality and link it with the soil degradation rate in the study area (2017-2023) compared to a previous study **(Abdellatif *et al.*, 2017),** and 4) using satellite images for physical soil degradation monitoring.

MATERIALS AND METHODS

Study Area

El-Beheira Governorate is located in the western part of the Delta and bounded between longitudes 30° 17' 54.42" and 30° 36' 27.96" East and latitudes 30° 54' 51.10" and 31° 7' 59.34" North (Figure 1).

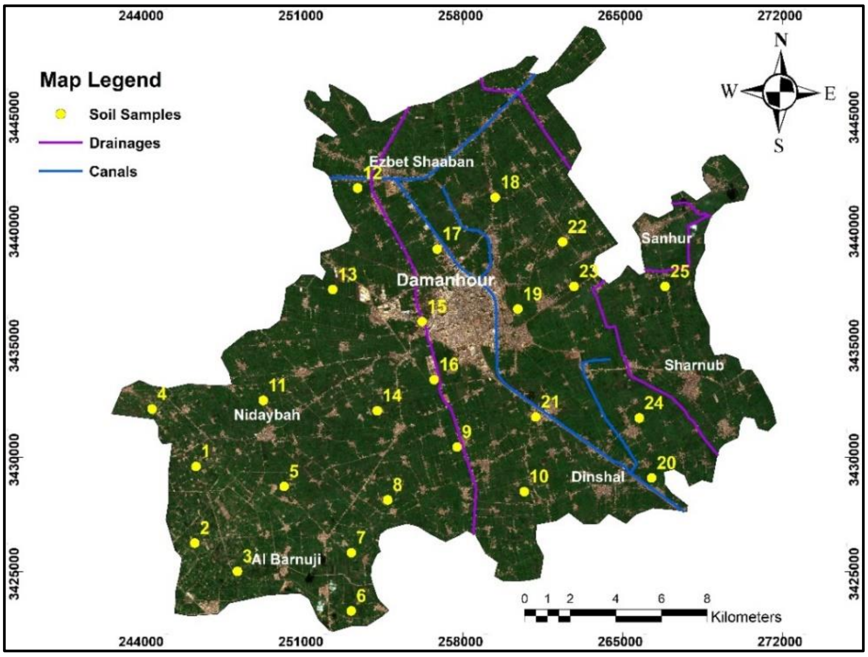

Figure 1: Soil sampling map (From: Earth Explorer, 2022)

Climate

The region is characterized by high temperatures in summer and warm temperatures in winter. The mean minimum and maximum annual temperatures in the study area are 14.2 °C and 26.6 °C, respectively **(EMA, 1996; Abdellatif *et al.*, 2017)**. The annual precipitation is 83.7 mm. Evaporation rates reach their maximum in the summer months, especially in June, 6.8 mm, and their lowest in the winter, in January, 2.5 mm, while the annual average of evaporation reaches 4.6 mm **(USDA, 2006)**.

Soil Sampling

The geographical distribution of twenty-five locations for soil surface (0–30 cm) and subsurface (30–60 cm) samples were chosen based on the geographical distribution of soil samples in study of Abdellatif, et al., 2017 (which we are comparing with).The Global Position System (GPS) guided the field trip to locate soil samples with a locational accuracy of (± 5 m). The soil samples' geo-coordinates were expressed by the Universe Transverse Micrometer (UTM) system, zone 36N.

Soil Samples Analysis

Each sample was air-dried, sieved through a 2-mm sieve, and stored in plastic jars for routine soil physical and chemical analysis. Soil pH was measured in a 1:2.5 soil-water suspension, and the electric conductivity (EC) of soil paste extract was measured. Soluble cations (Ca, Mg) were determined by titration, while sodium (Na) was determined by the flame photometer. Total carbonate was measured, and sodium adsorption ratio (SAR) were calculated. All analyses were elaborated according to **(Page *et al.,* 1982)**. Organic matter content (OM %) was determined by the dichromate oxidation method **(Walkley and Black, 1934)**.

Soil Quality Index (SQI)

Soil quality index was calculated according to **Amacher *et al.* (2007)** using the following equations:

SQI % = (Total SQI / maximum possible total SQI for properties measured) x 100) (Eq. 1).

Whereas Total SQI = Σ individual soil property index values (measured values only) (Eq. 2).

This index was calculated according to the approach of **(Amacher *et al.*, 2007; Triantafyllidis *et al.*, 2018)** whereas each soil parameter was assigned with a unit score ranging from 0 to 1 as shown in (Table 1).

Table 1: Soil quality index values and associated soil property threshold values and interpretations.

N0.	Soil Parameter	Range	Score	Reference
1	pH	< 3.0	- 1	Amacher *et al.*, 2007
		3.0 – 4.0	0	
		4.0 – 5.5	1	
		5.5 – 6.8	2	
		6.8 – 7.2	2	
		7.2 – 7.5	1	
		7.5 – 8.5	1	
		> 8.5	0	
2	EC (dS/m)	< 16.0	1	Triantafyllidis *et al.*, 2018
		> 16.0	0	
3	SAR (%)	< 13.0	1	Amacher *et al.*, 2007
		> 13.0	0	
4	$CaCO_3$ (%)	< 40.0	1	Triantafyllidis *et al.*, 2018
		> 40.0	0	
5	O.M. (%)	< 1.0	0	Amacher *et al.*, 2007
		1.0 – 5.0	1	
		> 5.0	2	

The SQI is rated between 0 – 100. This index expresses the degree of soil quality as a percentage of the measured indicators as shown in Table 2 **(Elbasiouny *et al.*, 2017)**.

Table 2: The rating of soil quality Index.

No.	Degree	Range (%)	Reference
1	Excellent	> 86.96	**Elbasiouny *et al.*, 2017**
2	Very Good	73.91 – 86.96	
3	Good	65.22 – 73.91	
4	Moderate	47.83 – 65.22	
5	Low	< 47.83	

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GIS-Data Processing

Mapping of soil characteristics was obtained by interpolating individual soil properties using ArcMap software **(ESRI, 2011)**. The inverse distance weighted (IDW) technique was applied to map the spatial distribution pattern of the soil properties.

Mapping of Land Use Land Cover

Supervised classification was done for land use land cover classification using ArcGIS 10.8 software **(ESRI, 2011)**.

Remotely Sensed Change Detection of Land Use Land Cover

Change detection is the process of identifying differences in the state of an object by observing it at different times. We used supervised classification comparison for doing change detection **(ESRI, 2011)**.

RESULTS AND DISCUSSION

Descriptive statistics for some chemical soil characteristics of the study area

Some soil chemical characteristics were determined, and the descriptive statistics of these properties, such as minimum, maximum, average, standard deviation (SD), and coefficient of variation (CV), were calculated for the dates 2017 and 2023, as shown in (Table 3).

Table 3: Descriptive Statistics (2023).

Property	Descriptive Statistics									
	2017					2023				
	Min	Max	Aver.	SD	CV%	Min	Max	Aver.	SD	CV %
pH	7.10	7.90	7.57	1.40	18.50	8.35	9.05	8.65	0.18	2.13
E.C (dS/m)	1.20	10.83	3.45	2.30	66.66	0.85	14.12	3.15	3.37	106.96
SAR (%)	0.92	11.55	5.33	2.68	50.24	0.76	17.72	7.21	5.30	73.51
$CaCO_3$ (%)	0.16	3.04	0.60	0.68	113.46	0.5	7.75	3.19	1.89	59.34
O.M (%)	0.03	0.25	0.14	0.07	48.63	0.25	1.65	1.02	0.33	32.83

The data showed that the soil is moving to be alkaline soil with a change from 7.57 to 8.65 in pH value. According to the electrical conductivity, the soil was slightly saline in the two periods, but the average sodium adsorption ratio increased from 5.33% in 2017 to 7.21% in 2023. The study area soils are facing sodicity problems. The study area soils have a low content of total calcium carbonate and organic matter. The low values of the coefficient of variation (CV) indicate that the samples did not have extreme values except in total calcium carbonate in 2017 and electrical conductivity in 2023.

GIS-Mapping Soil Properties

Soil Alkalinity

Soil pH is a very important factor in plant nutrition as it controls the validity of the nutrients in the soil for uptake by the plant **(Mustafa *et al.*, 2011)**. The chemically neutral soil has a pH value equal to 7, higher than that is considered alkaline soil, and less than that is considered acidic soil **(Halder, 2013)**. The data in Table (4) and the alkaline map in 2017 (Figure 3) show that 8945 ha (23%) of the study area are very slightly alkaline and have pH values from 7.1 to 7.5. 30184 ha of the study area (77%) have pH values from 7.5 to 8.1 (slightly alkaline soil). The present results of 2023 (Table 4 and Figure 3) show that moderately alkaline soil covers 8370 ha (21%) of the study area with pH values ranging from 8.3 to 8.6. While 30795 ha (79%) are alkaline soil with pH values ranging from 8.6 to 8.9. Thus, there was a change and an increase in pH values in all parts of the study area in the period from 2017 to 2023, This increase in pH value may be due to the application of irrigation water containing a relatively high proportion of sodium bicarbonates (Reuse drainage water) (Figures 2 and 3).

Table 4: Soil pH Classes of the Study Area.

Soil pH		**Year**				**Areal change (2017– 2023)**	
		2017		**2023**			
		Area					
Thresholds	**Class**	**ha**	**%**	**ha**	**%**	**ha**	**%**
7.1-7.5	Very Slightly Alkaline Soil	8945	23	0	0	- 8945	-23
7.5-8.1	Slightly Alkaline Soil	30184	77	0	0	- 30184	-77
8.3-8.6	Moderately Alkaline Soil	0	0	8370	21	+ 8370	21
8.6-8.9	Alkaline Soil	0	0	30759	79	+ 30759	79
	Total	39129	100	39129	100	----	----

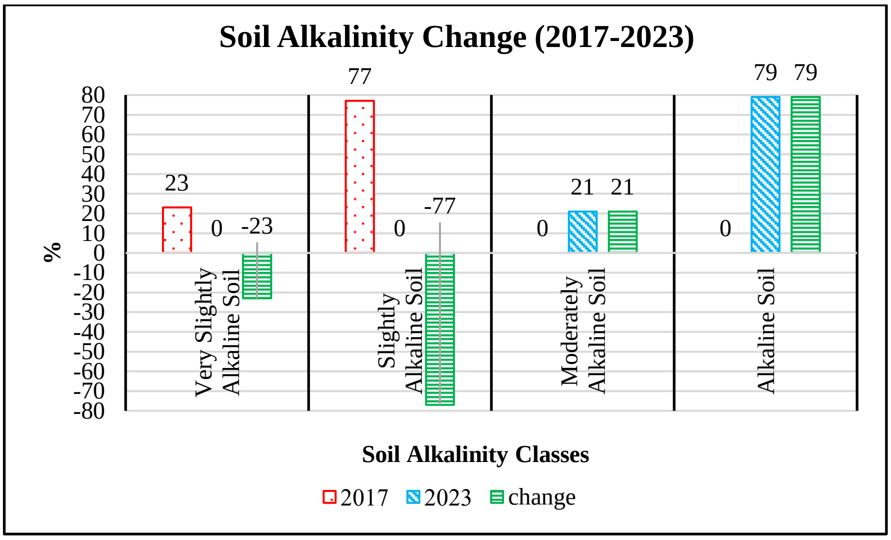

Figure 2: Soil alkalinity change rate between 2017 and 2023.

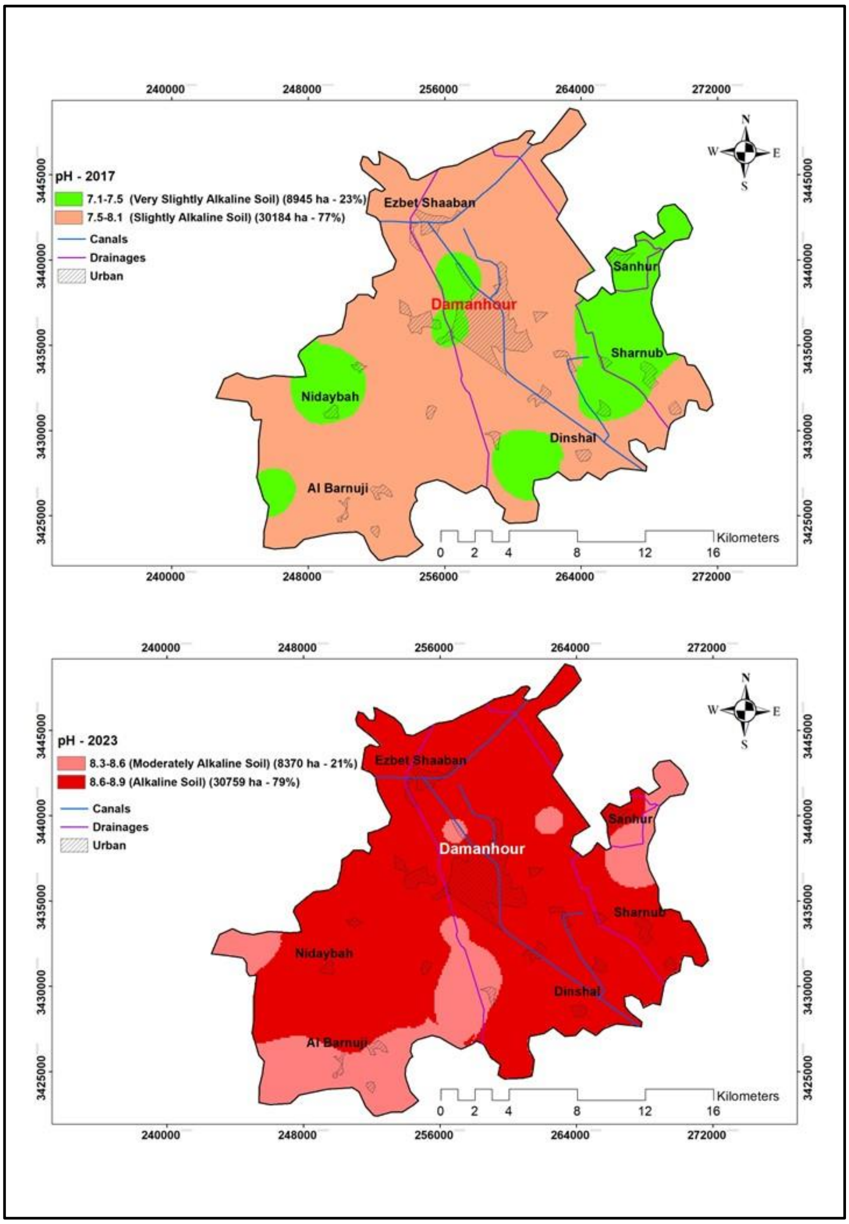

Figure 3: Alkalinity maps of study area (2017 and 2023).

Electrical Conductivity (EC)

It is generally accepted that one of the primary elements that adversely affects soil fertility is soil salinity. The development of crops is negatively impacted by soil salinity, which also considerably reduces harvest **(Sonmez *et al.*, 2008)**. In 2017, the results of EC were non-soil saline 2733 ha (7%). Slightly saline soil covers an area of 29694 ha (76%). Moderately saline soil affected 5966 ha (15%) and strongly saline soil 736 ha (2%) (Figure 5). In general, soil salinity status between 2017 and 2023 slightly decreased (Figure 4). The present results of 2023 (Table 5) indicated that the areas of non-saline soil with EC less than 2 dS/m affected 7379 ha, 19% of the total study area. Most of the area is slightly saline soil that has an EC value from 2-4 ds/m covering an area of 28730 ha (73%). Soil has moderately saline soil from 4-8 ds/m affected on 2463 ha (6%). Strongly saline soil EC value from 8-16 dS/m occurred in 557 ha (1%) from the study area (Figure 5).

Table 5: Changes soil salinity classes of the study area (2017-2023).

Soil Salinity		Year				Areal change (2017– 2023)	
		2017		2023			
		Area					
Thresholds (dS/m)	Class	ha	%	ha	%	ha	%
0-2	Non-Saline Soil	2733	7	7379	19	+ 4646	+ 12
2-4	Slightly Saline Soil	29694	76	28730	73	- 964	- 3
4-8	Moderately Saline Soil	5966	15	2463	6	- 3503	- 9
8-16	Strongly Saline Soil	736	2	557	1	- 179	- 1
Total		39129	100	39129	100	----	----

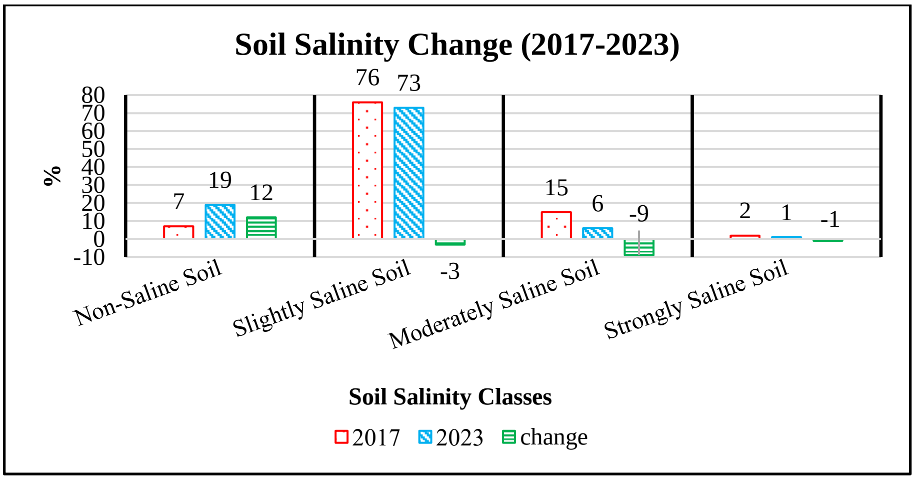

Figure 4: Soil salinity change rate between 2017 and 2023.

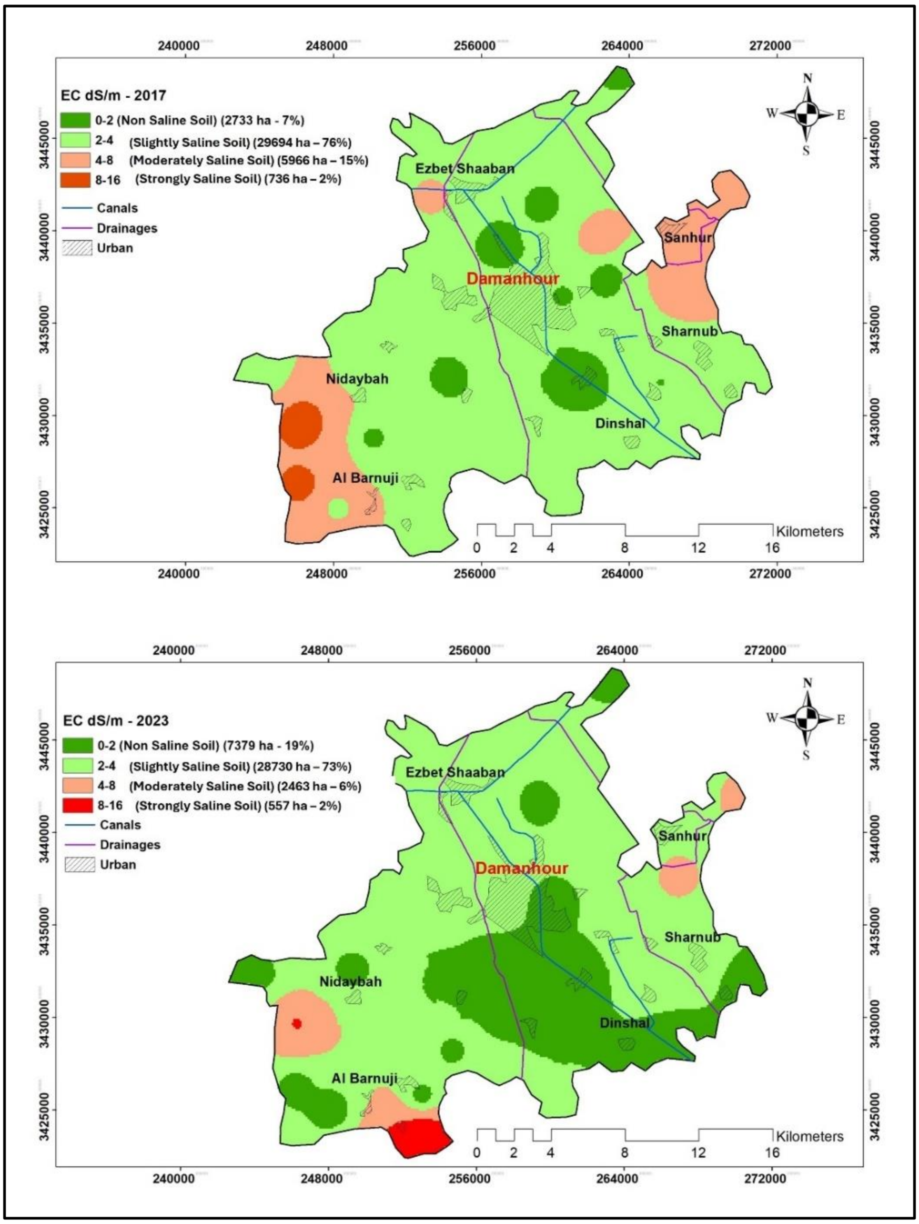

Figure 5: Soil salinity maps of study area (2017 and 2023).

Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio (SAR) of soil solution extracts has been an important tool for predicting the equilibrium exchangeable sodium percentage (ESP) in salt-affected soils **(Gharaibeh *et al.*, 2021)**. When comparing the results of SAR between 2017 and 2023 (Figure 7) we found that about 1466 ha (4%) from the study area became sodic soil and had an SAR value of more than 13% (Table 6 and Figure 6).

Table 6: Soil SAR classes of the study area.

Soil SAR		Year				Areal change (2017– 2023)	
Thresholds (%)	Class	2017		2023			
		Area					
		ha	%	ha	%	ha	%
0.9-4	**Non-Sodic Soil**	39129	100	37993	96	- 1466	- 4
13-17.7	**Sodic Soil**	0	0	1466	4	+ 1466	+ 4
Total		39129	100	39129	100	----	----

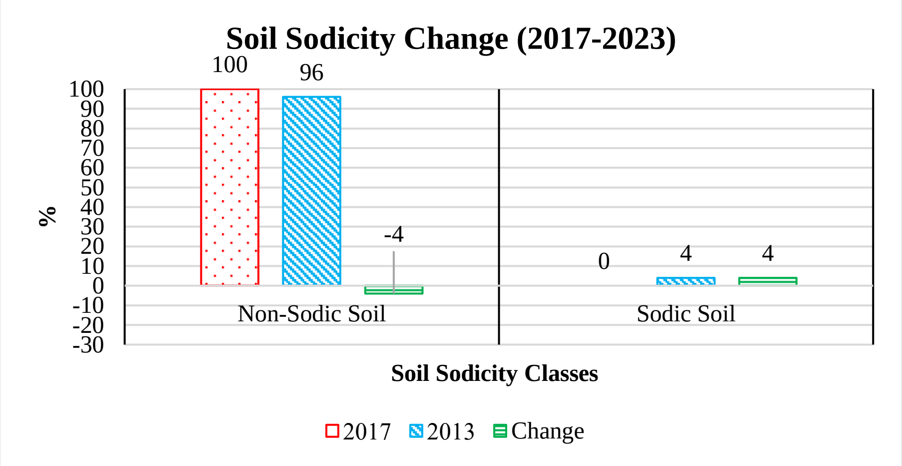

Figure 6: Soil sodicity change rate between 2017 and 2023.

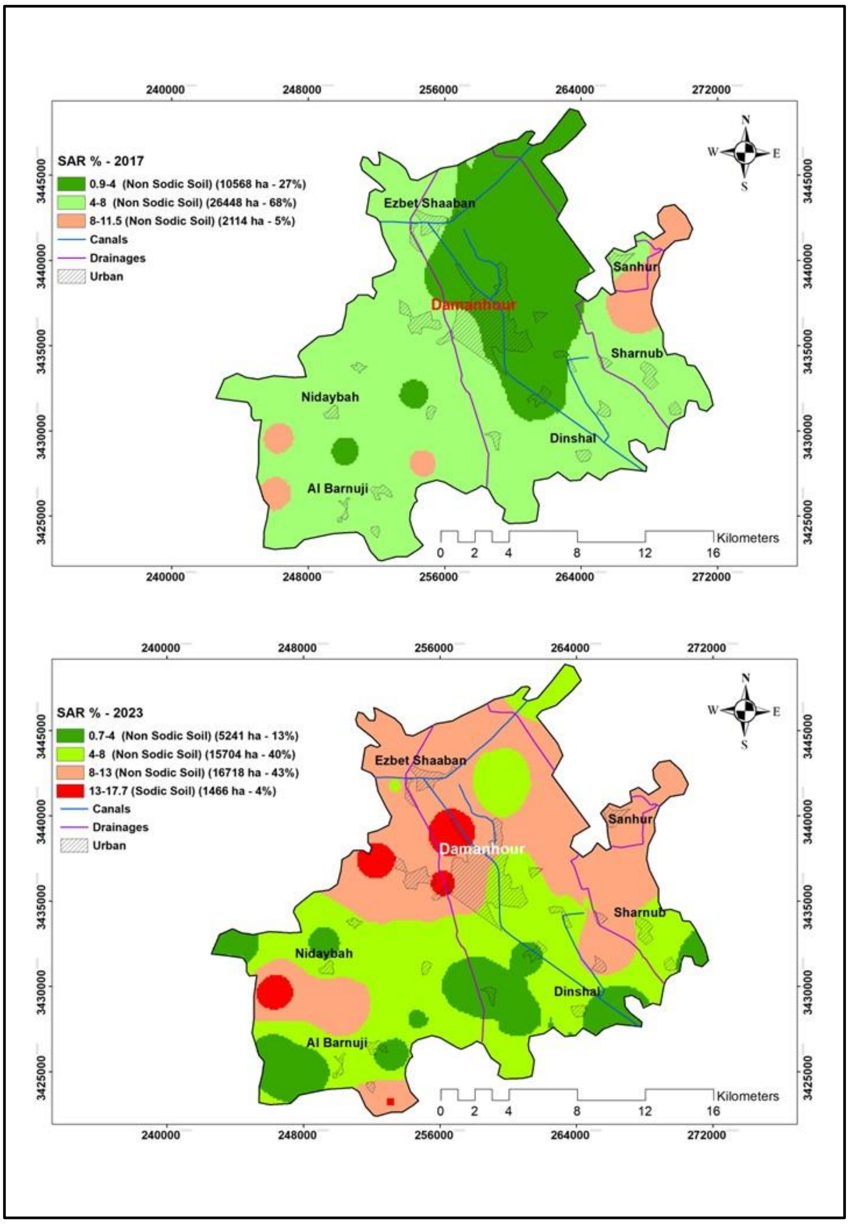

Figure 7: SAR maps of study area (2017 and 2023).

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Total Carbonate

The total carbonate influences soil properties and all soil processes. The high content of total carbonate causes increased soil pH and reduced availability of N, P, K, S, Fe, Zn, and B **(Umer *et al.*, 2020; Singare *et al.*, 2022)**. As shown in Figure (9), the results of $CaCO_3$ in 2017 were around (100%) of the study area, less than 4% (weakly calcareous). Soil analysis results for study area samples in 2023 show that there is an increase in the percentage of total carbonate, and moderately calcareous soil in 20% of the study area (Table 7, Figure 8).

Table 7: Soil $CaCO_3$ classes of the study area.

Soil $CaCO_3$		Year				Areal change (2017– 2023)	
Thresholds (%)	Class	2017		2023			
		Area					
		ha	%	ha	%	Ha	%
0-4	**Weakly Calcareous**	39149	100	31636	80	- 7513	- 20
4-8.85	**Moderately Calcareous**	0	0	7513	20	+ 7513	+ 20
Total		39129	100	39129	100	----	----

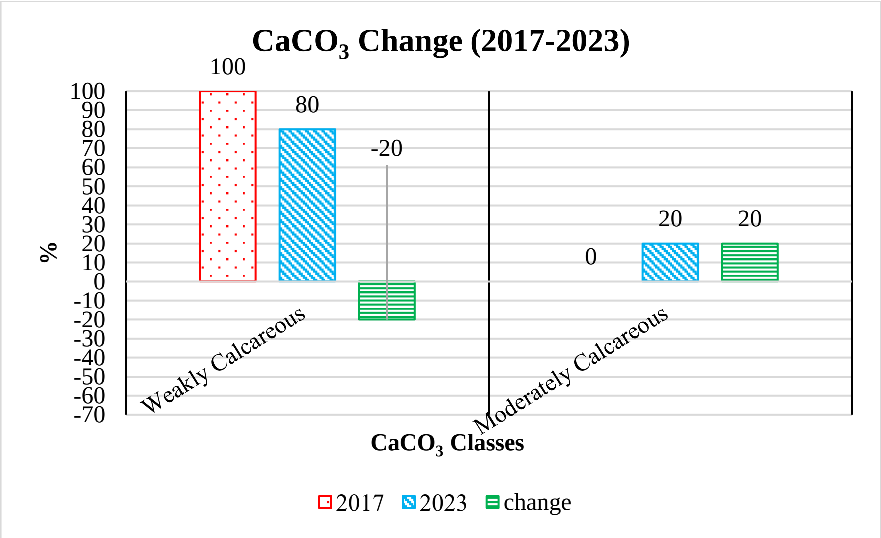

Figure 8: Soil $CaCO_3$ change rate between 2017 and 2023.

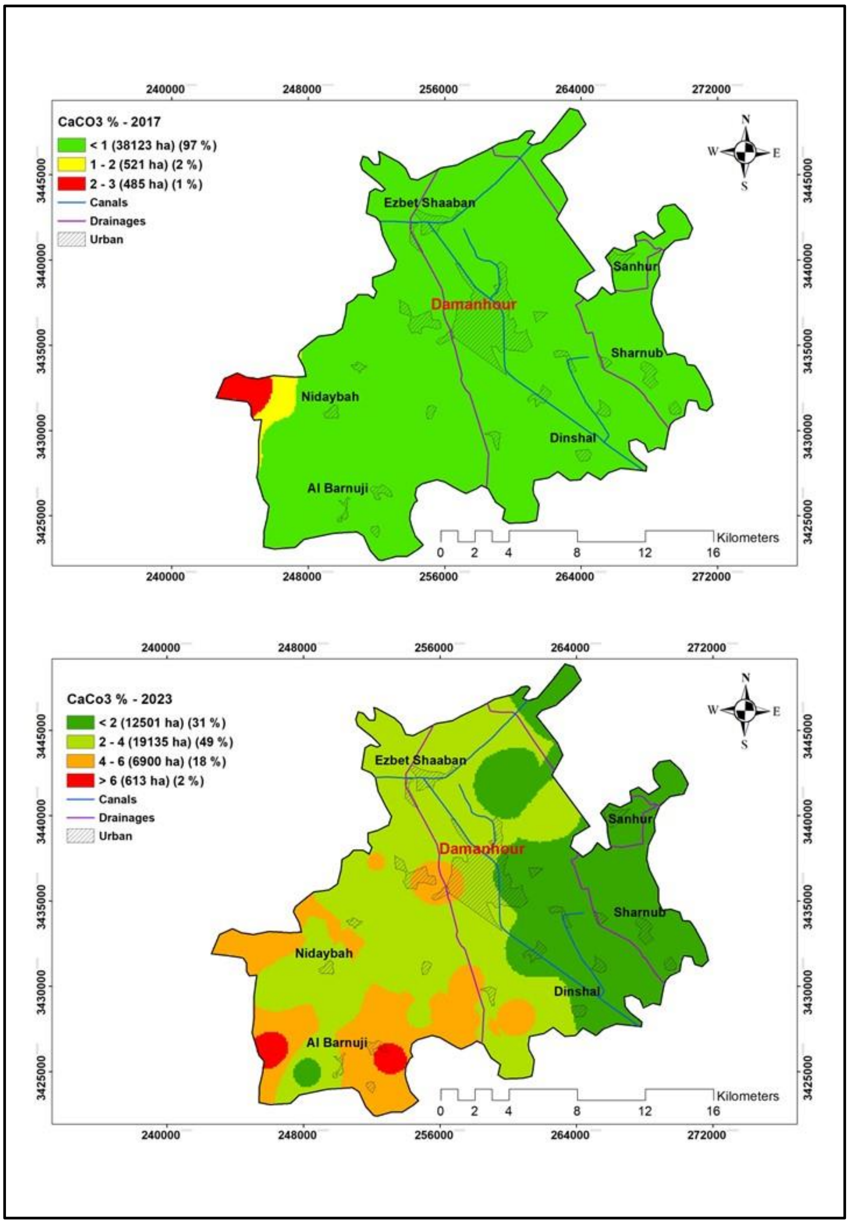

Figure 9: $CaCO_3$ maps of study area (2017 – 2023).

Organic Matter

Organic matter plays a significant role in crop production and soil health by improving physical, chemical and biological properties in the soil **(Voltr *et al.*, 2021)**. When comparing the results of the organic matter of the soil in the study area from the period of 2017 to 2023 (Table 8 and Figure 10), we found that the percentage of organic matter in 2023 (1.7%) is slightly higher than it was in 2017 (0.2%), but the soil is still poor in organic matter (Figure 11).

Table 8: Soil organic matter classes of the study area.

Soil Organic Matter		**Year**				**Areal change (2017– 2023)**	
Thresholds (%)	**Class**	**2017**			**2023**		
		Area					
		ha	**%**	**ha**	**%**	**ha**	**%**
0.0-1.0	**Very Low**	39129	100	17216	44	- 21913	- 56
1.0-1.7	**Low**	0	0	21913	56	+ 21913	+ 56
Total		39129	100	39129	100	----	----

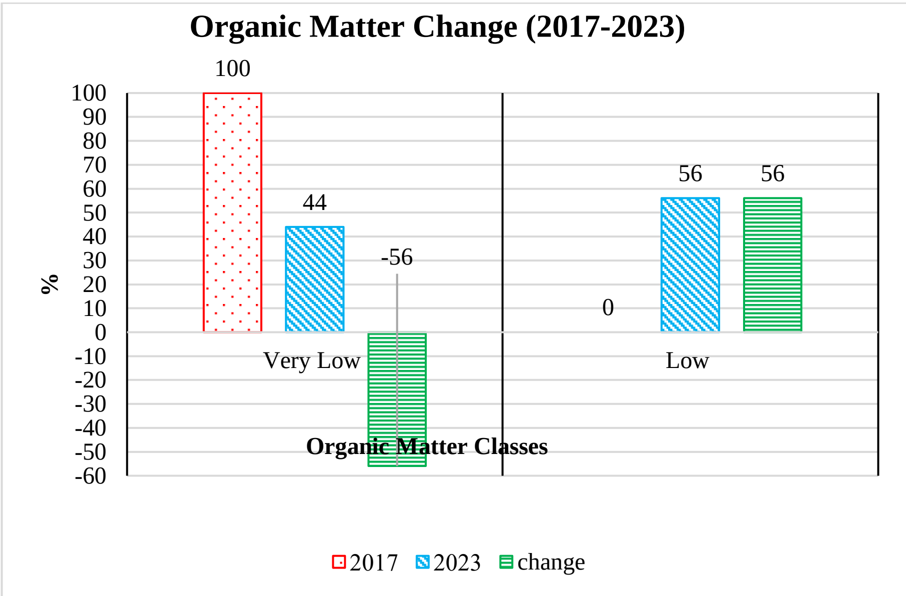

Figure 10: Soil organic matter change rate between 2017 and 2023.

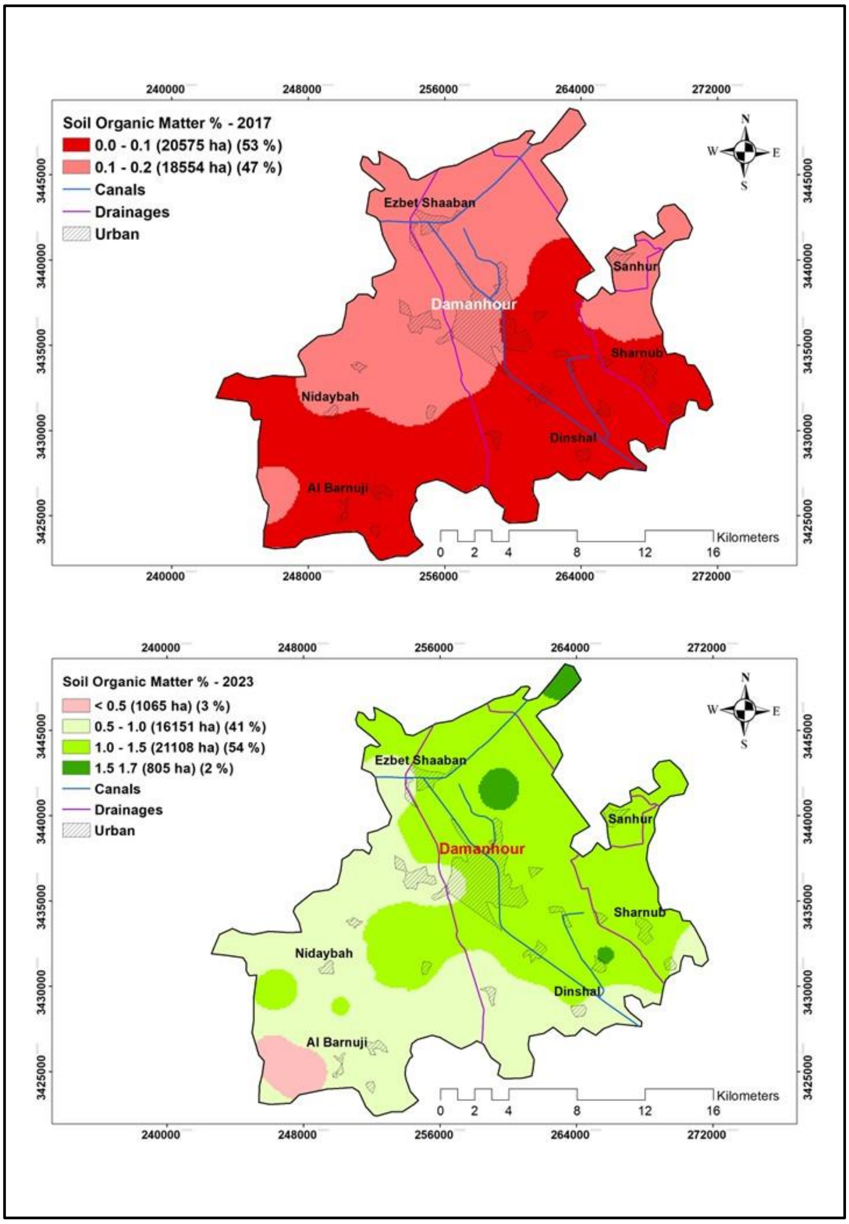
Soil Organic Matter % - 2017
0.0 - 0.1 (20575 ha) (53 %)
0.1 - 0.2 (18554 ha) (47 %)
Canals
Drainages
Urban
Ezbet Shaaban
Damanhour
Sanhur
Sharnub
Nidaybah
Dinshal
Al Barnuji
Kilometers
Soil Organic Matter % - 2023
< 0.5 (1065 ha) (3 %)
0.5 - 1.0 (16151 ha) (41 %)
1.0 - 1.5 (21108 ha) (54 %)
1.5 1.7 (805 ha) (2 %)

Figure 11: Organic matter maps of study area (2017 – 2023).

Soil Quality Index

The indicators used in SQI evaluation are EC, pH, SAR, $CaCO_3$, and organic matter. The parameters selected for the minimum data set were independent of each other, and after the assignment of a score value, they were integrated into SQI. The soil quality index in the study area is still under a moderate degree, although its value decreased from 57.14% in 2017 to 48.57% in 2023 (Table 9), which means that the soil is suffering from chemical degradation - although the comparison period is very short in such cases - and needs good management to address this problem.

Table 9: Soil quality index (2017 and 2023).

Year	Average of total SQI for Soil Parameters	Maximum possible total SQI for properties measured	SQI (%)	SQI Degree
2017	4.00	7.00	57.14	Moderate
2023	3.40	7.00	48.57	

Physical Soil Degradation

Satellite images – Land Cover Mapping

The supervised classification of multitemporal Aster (2010) and Sentinel-2 (2023) data mapped the land cover of the studied regions that compose two types of land covers (urban area, and agricultural land) (Figure 12). ArcMap 10.8 software has allowed calculating the area and the percentage of each class (Table 10). Aster (2010) data mapping determined quantitatively these covers; urban area covers 4153 ha (11%) of the total area of the study area in 2010, and agricultural land cover 34976 ha (89%). While in Sentinel-2 (2023) data, urban area represents 8825 ha (23%), and agricultural land area represents 30303 ha (77%) of the total area (Figure 13).

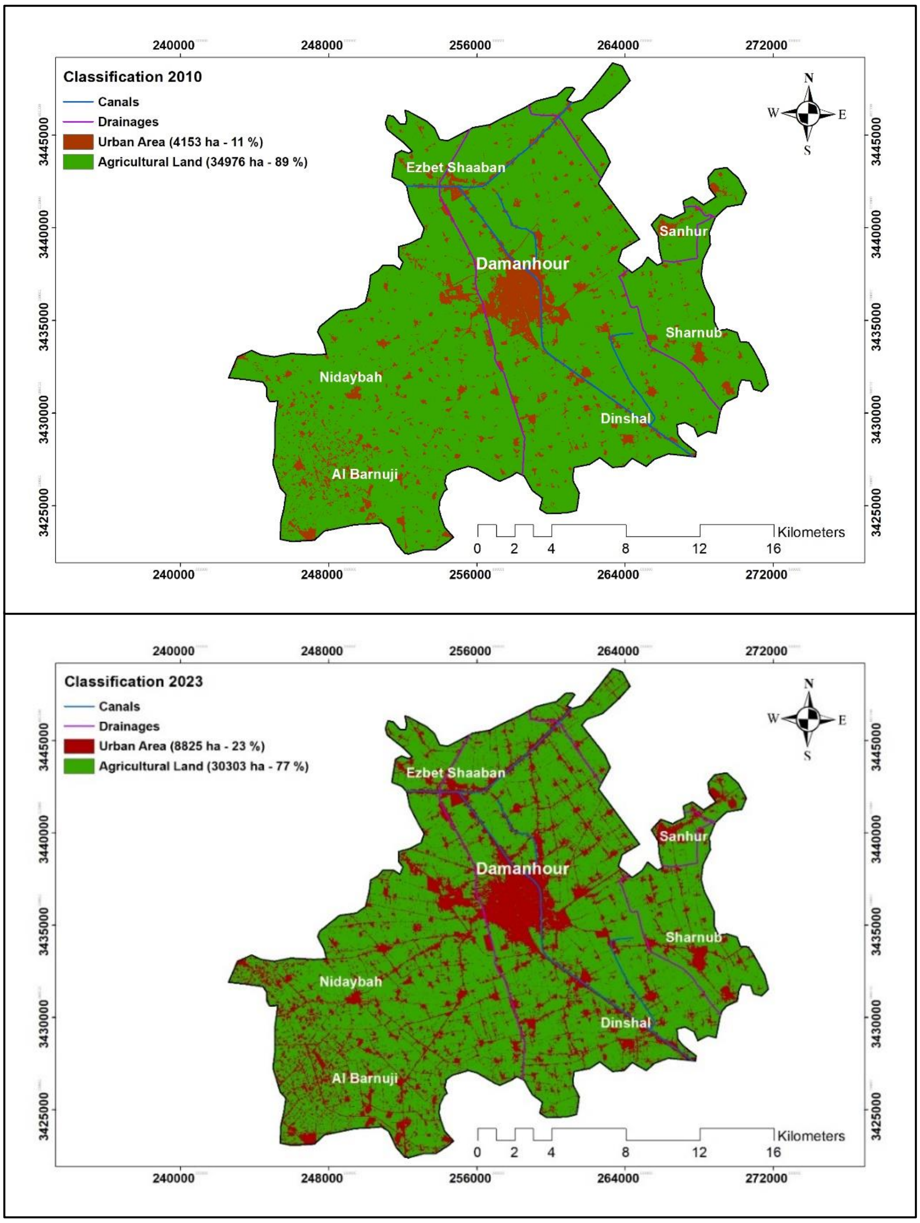

Figure 12: Remotely sensed map of land cover for studied area (2010 – 2023).

Table 10: ASTER (2010) and Sentinel-2 (2023) mapped of land cover.

Land Cover Classes	Satellite Data			
	ASTER (2010)		Sentinel-2 (2023)	
	Area		Area	
	ha	%	ha	%
Urban Area	4153	11	8825	23
Agricultural Land	34976	89	30304	77
Total	39129	100	39129	100

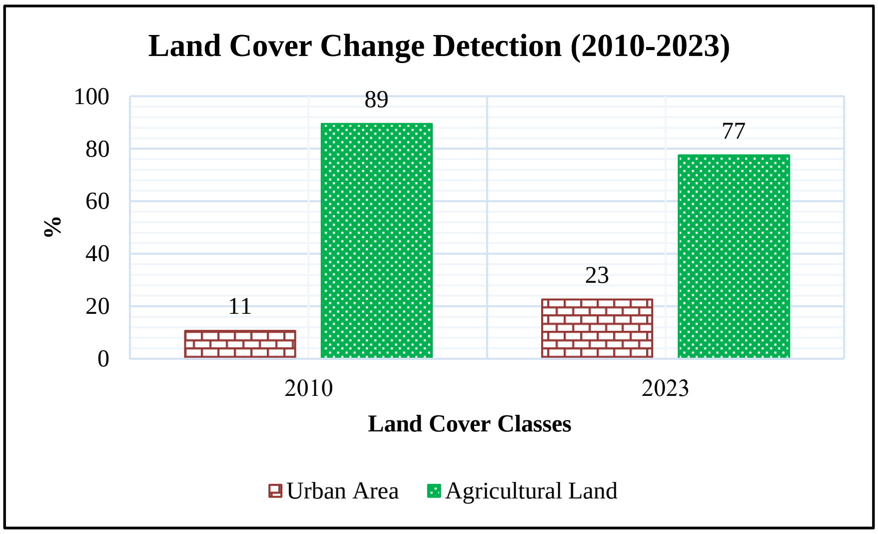

Figure 13: Comparison of land cover classes mapped by ASTER (2010), and Sentinel-2 (2023) satellite data.

Remotely sensed change in detection of land cover

Regardless of the type of satellite data, the comparison between Aster (2010) and Sentinel-2 (2023) maps enabled us to detect thirteen-year changes of land cover (Table 11). The results of this study indicate increasing changes in urban area, where the rate of urban ratio increased in the period 2010-2023 by (12%). This increase in urban area is met by a decrease in the area of agricultural land, where agricultural land decrease in the period 2010-2023 by (12%). Consequently, 12% of the land area was exposed to physical degradation between 2010 and 2030 due to urban expansion, which requires decision-makers to take the necessary measures to address this issue.

Table 11: Changes of land cover by ASTER (2010) and Sentinel-2 (2023) data.

Land Cover Classes	Satellite Data				Detected Change	
	ASTER (2010)		Sentinel-2 (2023)			
	Area		Area		Area	
	ha	%	ha	%	ha	%
Urban Area	4152	10	8825	22	4672	12
Agricultural Land	34976	89	30304	77	-4672	-12
Total	39129	100	39129	100	0	0

CONCLUSION

The SQI was developed to integrate measured soil properties into a single index number, which can be used to assess trends in soil quality. There is an urgent need to monitor and assess soil quality as an indicator of soil degradation, especially in the Egyptian Delta, because these soils are vital resources for national food security. This study suggested some soil properties that affect soil quality and degradation, such as pH, EC, SAR, $CaCO_3$, and organic matter. Then, threshold values for the selected parameters were established for this purpose based on published studies. The index used in this research is flexible and accurate because it excludes unmeasured soil properties. Based on the case study, the soil alkalinity, exchangeable sodium, and total carbonate values increased in 2023 compared to 2017, resulting in a decrease in the soil quality index from 57.14% in 2017 to 48.57% in 2023. Although the comparison period is very short in such cases, it became clear that the soil suffers from chemical degradation - even if to a small degree - which makes it need good management to address this problem by paying attention to the suitability of irrigation water and the optimal use of chemical fertilizers. Also, 12% of the agricultural land was exposed to physical degradation between 2010 and 2030 because of urban expansion, which requires decision-makers to take the necessary measures to address this issue.

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الملخص العربي

رصد التدهور الكيميائي والفيزيائي للتربة (مركز دمنهور، محافظة البحيرة، مصر).

عبدرب النبي محمد عبدالهادي – *عماد فوزي عبد العاطي – هدير محمود مرضي – إبراهيم أحمد شحاته

[1]قسم الموارد الطبيعية والهندسة الزراعية، كلية الزراعة، جامعة دمنهور، دمنهور، مصر

تُستخدم معايير التربة الفردية المختلفة على نطاق واسع في تقييم جودة التربة. هدفت هذه الدراسة إلى تحديد مؤشر جودة التربة في الترب الزراعية باستخدام خصائص التربة المتكاملة واعتباره مؤشر لتدهور التربة في منطقة الدراسة، واستخدام صور الأقمار الصناعية لرصد التدهور الفيزيائي للتربة. تم حساب مؤشر جودة التربة من خلال اختيار الخصائص المناسبة، وتعيين النقاط للخصائص المختارة، ومن ثم دمج الخصائص المختلفة في مؤشر واحد. أجريت الدراسة في مركز دمنهور، محافظة البحيرة، مصر، في عام 2023، مقارنة بدراسة سابقة في عام 2017. تم تحليل عينات التربة التي تم جمعها من الطبقات السطحية (0-30 سم) وتحت السطحية (30-60 سم) لتحديد خصائص التربة (الرقم الهيدروجيني، والتوصيل الكهربائي، ونسبة الصوديوم المدمص، وكربونات الكالسيوم، والمادة العضوية). أظهرت النتائج أن درجة الرقم الهيدروجيني للتربة ارتفع من 7.57 عام 2017 إلى 8.65 عام 2023، وانخفضت قيمة التوصيل الكهربائي بشكل طفيف من 3.45 ديسيسيمنز/م إلى 3.15 ديسيسيمنز/م، وارتفعت نسبة الصوديوم المدمص من 5.33% إلى 7.21%، وارتفعت نسبة الكربونات الكلية من 0.60% إلى 3.19%، وأخيراً ارتفعت نسبة المادة العضوية من 0.14% إلى 1.02%. وفي المجمل انخفض مؤشر جودة التربة في منطقة الدراسة من 57.14% عام 2017 إلى 48.57% عام 2023، مما يعني أن التربة تعاني من التدهور وتحتاج إلى إدارة جيدة لمعالجة هذه المشكلة. على الرغم من قصر فترة المقارنة في مثل هذه الحالات، فقد اتضح أن التربة تعاني من التدهور الكيميائي - وإن كان بدرجة ضئيلة - مما يتطلب إدارة جيدة لمعالجة هذه المشكلة من خلال الاهتمام بملاءمة مياه الري والاستخدام الأمثل للأسمدة الكيميائية. كما أن 12% من الأراضي الزراعية تعرضت للتدهور المادي بين عامي 2010 و2030 بسبب التوسع العمراني، مما يتطلب من صانعي القرار اتخاذ الإجراءات اللازمة لمواجهة هذه المشكلة.

الكلمات الإفتتاحية: مؤشر جودة التربة، تدهور التربة الكيميائي، تدهور التربة الفيزيائي، مركز دمنهور.