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Detecting Soil Productivity Changes and Degradation Processes in the Irrigated Agriculture East of the Nile Delta, Egypt

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ABSTRACT

This study aims to detect the changes of soil productivity and soil degradation processes in the irrigated agriculture east of the Nile Delta. The study area extends between longitudes 31º20` and 32º 15` E & latitudes 29º 54` and 31º 12` N. The main landforms of the area were delineated by using remote sensing and land surveying data. The recognized landforms include flood plain, fluvio-lacustrine and Aeolian deposits. A semi detailed survey was carried out in order to verify landform units and collecting soil samples. The historical data of the soils has been extracted from the available studies of the year 1975. Results indicate that the degradation processes are sweeping the investigated soils, where 69.73 % of the area has been degraded during the period of 1975 - 2011. The soil productivity was shifted from low to high grade only in 30.27 % of the total area. Soil Salinity, alkalinity, water logging and compaction are the main degradation process prevail the area. The agriculture development in the area requires improved drainage network through governmental support and proper land management by farmers themselves.

Key words: *Remote sensing, Landforms, Soil productivity, Soil degradation, East Nile Delta, Egypt.*

INTRODUCTION

Soils are limited resource and could be considered non-renewable (Blum, 2006); it is continuously exposed to degradation processes (Bai et al. 2008). The cultivated land represents about 40 - 50 % of the global (Smith et al., 2007), 20 % of them are severely degraded (Adams & Eswaran, 2000; and Davis & Masten, 2003). In irrigated agriculture under the arid climate, water logging and salinization are the major land degradation processes (Dwivedi et al., 1999). Most of these processes are directly affected by human activities (Singh, 1995). Land degradation leads to a gradual decrease in soil productivity (Hillel, 2009); hindering sustainable development (Lal, 2008; Bockstaller et al., 2009) and consequently food gap (Cassman et al., 2003). In Egypt, the alluvial soils being degraded drastically due to water logging and soil salinity (Darwish & Abdel Kawy, 2008; Wahab et al., 2010); these problems have already emerged after the construction of the High Dam (Waterbnty, 1979). Salinization and water logging lead to yield reduction by 17 % in the Nile valley and by 25 % in the irrigated lands east and west of the Delta; these problems are serious in the future if remedied measures are not taken (Dregne, 1986; Mohamedin et al. 2010). In terms of productivity loss land degradation is a result of mismatch between land use and land quality (Tekwa et al., 2001). The estimation of the changes in the soil productivity is one of the most common relations used to assess the land degradation (Van Lynden & Kuhlman, 2003). The current study aims to detect the soil productivity changes land degradation hazard in some irrigated soils east of the Nile Delta through, 1) Mapping the main landforms and soils of the study area, 2) Assessing the soil degradation hazard 3) Monitoring of soil productivity changes during the last 36 years in the different landforms, and 4) Setting the correlation between productivity index and soil degradation processes.

MATERIALS AND METHODS

The study area

The studied area incorporates approximately 4577.86 km^2, It is bounded by longitudes 31º20` and 32º 15` E & latitudes 29º 54` and 31º 12` N (Fig. 1). The area belongs to the late Pleistocene which is represented by the deposits of the Neonile which lowering its course at a rate of 1m/1000 years (Said, 1993). According to Egyptian

Meteorological Authority (1996), the studied area is affected by the arid climate conditions.

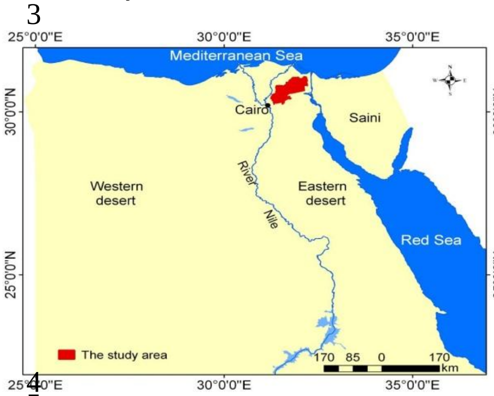

Figure 1. Location of the study area

Satellite data processing

The Scan Line Corrector (SLC) of the Landsat 7 was failed in May 31, 2003. The Landsat 7 still to gain data generating images of about 22% missed data (Storey et al., 2005). To recover the capability of the image, the SLC-off data is exchanged with calculated values using ENVI 4.7 software. Landsat ETM+ image (Fig. 2) acquired during the year 2010 (pass 176 /row 39) was used. to improve the contrast and enhancing the edges, the image was stretched, smoothly filtered, and their histograms were matched according to Lillesand and Kiefer (2007). The atmospheric correction was done to reduce the noise effect using FLAASH module. 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 (ITT, 2009). The digital elevation model (DEM) of the study area (Fig. 3) was extracted from the Shuttle Radar Topography Mission (SRTM). This data could be combined with multispectral images to realize better view of the landscape.

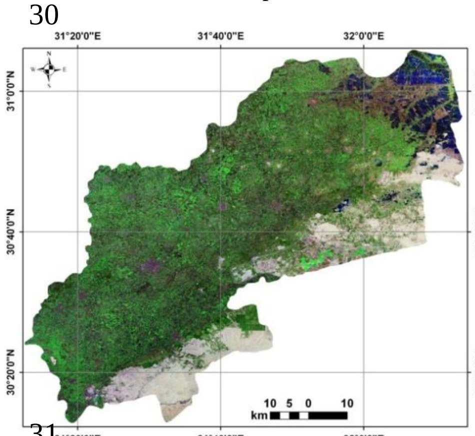

Figure 2. Landsat ETM+ image (bands 7, 4, 2)

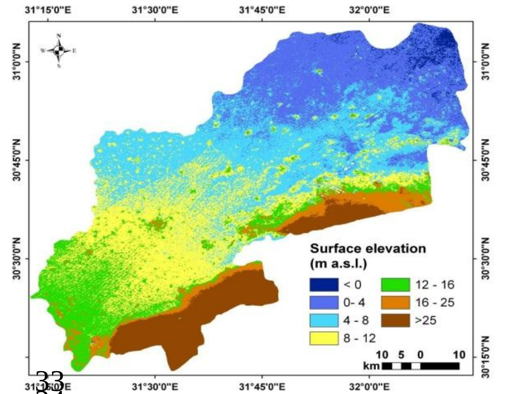

Figure 3. Surface elevation as extracted from SRTM data

Landform and soil mapping

The Landsat ETM+ image and SRTM data were processed in ENVI 4.7 software to identify the different landforms and establish the soil database (Dobos et al., 2002; Zinck & Valenzuala, 1990). A semi-detailed survey was carried out throughout the investigated area in order to gain an appreciation on soil patterns, land forms and the landscape characteristics. A total of 43 ground truth sites were studied in the field, from which thirteen soil profiles and thirty observation points were collected to represent the different preliminary mapping units. The morphological description of the profiles was carried out according to the guidelines outlined by FAO (2006). Sum of 44 disturbed soil samples was collected and prepared for laboratory analyses. Representative soil samples were collected and analyzed according to USDA (2004). The soils were classified to the sub great group level on the basis of the key to soil taxonomy (USDA, 2010). The correlations between physiographic and taxonomic units were carried out in order to produce the physiographic - soil map of the studied area (Elbersen & Catalan, 1986). The obtained data from land survey and laboratory analyses were recorded in the attribute table of the landform map using Arc-GIS 9.2 software.

Assessment of soil degradation

This study is based on comparing between the data extracted from RISW report, (1975) and the data obtained from this study. The severity of degradation processes is characterized by the rate, degree and extent in which the soil is degraded. Rate and degree were defined and described by using the methodology described by FAO (1979) and Oldeman (1988).

Soil productivity index

The Soil Productivity Index (PI) was calculated using the model defined by Riquier et al. (1970), modified by Raji (2000) as: PI=

(H/100*D/100*P/100*T/100*S/100*O/100*A/100 *M/100)*100

Where: (PI) Productivity index, (H) Moisture availability, (D) Drainage, (P) Effective depth, (T) Texture / structure, (S) Soluble salt concentration, (O) Organic matter content, (A) cation exchange capacity / nature of clay, (M) Mineral reserve in B horizon. According to Likhar and Parsad (2011) each factor is rated on a scale from 0 to 100, the actual percentages being multiplied by each other. The resultant index of productivity, also lying between 0 and 100, is set against a scale placing the soil in one or other of five productivity classes as presented in Table 1.

Table 1. Grades and classes of the calculated soil productivity index (PI)

PI (%)	Grade	Class
65 - 100	I	Excellent
35 - 64	II	Good
20 - 34	III	Average
8 - 19	IV	Low
0 - 7	V	Extremely low

RESULTS AND DISCUSSION

Landforms and soil properties

Land surveying and satellite data interpretation indicated that, the investigated area includes three main landscapes: a- Fluvio-lacustrine plain with six landforms i.e., clay flats (high & low elevated), sabkhas (dry & wet), swamps and water bodies; b- Aeolian deposits including sandy remnants (high & low elevated), and c- flood plain containing overflow mantle (relatively high & relatively low elevated), overflow basins (high & low elevated) and decantation basins (high & low elevated), river terraces (relatively high & relatively low) and turtle backs. The main landforms and associated soil sets in the investigated area are represented in Figure 4 and Table 2.

Soils of Fluvio - lacustrine plain

The soil data of fluvio-lacustrine plain indicate that the water table differs from 70 to 90 cm, soil texture is clayey, pH values are slightly alkaline (8.00 - 8.20), EC values ranges between 13.11 and 21.20 dS/m, $CaCO_3$ content is high (8.10 - 11.20 %), OM content is relatively low recording 1.7 to 1.94%, CEC is high (50.00 - 60.00 meq/100g soils), ESP is high, (19.20 and 28.10 %). The soils of clay flats were classified as *Vertic Torrifluvents*. The dry and wet sabkhas were classified as *Gypsic Haplosalids* and *Typic Aquisalids* respectively.

Soils of Aeolian deposits

The analytical data showed that the soil depth ranges between 100 and 120 cm, Soil texture is sandy, pH values range between 7.7 and 8.00, EC values range between 7.40 and 11.30 dS/m, $CaCO_3$ content is low (1.10 - 2.40 %), OM content is low (0.25 to 0.40 %), CEC is very low (4.00 - 8.1 meq/100g) reflecting the low amounts of clay and OM. The ESP is high as it ranges between 17.40 and 24.00%. Soils of this unit were classified as *Typic Torripsamments*.

Soils of flood plain

The obtained data showed that, water table depth of the flood plain soils ranges between 100 and 150 cm. Soil texture is clayey, pH values range between 7.35 and 8.2, EC values are located in the range 1.60 and 9.40 dS/m, $CaCO_3$ content is low (0.30 - 1.10 %), OM records a range of 1.10 and 1.61 %, CEC ranges between 34.18 and 48.16 meq/100 g, The ESP is high (10.10 - 20.20 %). Soils of this unit were classified as *Vertic Torrifluvents* for overflow basins and river terraces, *Typic Torrifluvents* for overflow mantle and decantation basins meanwhile some parts of the overflow basins were classified into *Typic Natrargids*.

Soil degradation

Thirty soil profiles were investigated during 2011, these profiles were collected from the same locations which previously studied by RISW (1975). The analytical data of 1975 and 2011 indicate that the degradation rate is slight to moderate. The annual increases of EC, ESP, and bulk density range from 0.01 to 0.13 dS/m, 0.01 to 0.07%, and from 0.0 to 0.01 g/cm3 respectively, while the water table level is decreased by a rate of 0.6 to 1.0 cm per year. The moderate degradation rates affect 37.56% of the studied area attributing the soils of OM1, OM2, OB1, OB2, CF1, CF2, OS1 and OS2. The degradation hazard is low to high, as the present values (determined in 2011) of EC, ESP, bulk density and the depth of water table differ from 0.7 to 12.4 dS/m, 11.6 to 20.2%, 1.12 to 1.45 g/cm3 and 70 to 150 cm respectively. The data indicate that the high degrees of salinization, Alkalinization, water logging and compaction attribute the CF1 and CF2. The land surveying data indicated that the soil degradation in the studied area is governed by the human activities i. e. over irrigation, improper use of machinery, human intervention in natural drainage and the absence of conservation measurements. The main land characteristics of the studied sites in 1975 and 2011 are shown in Table 3.

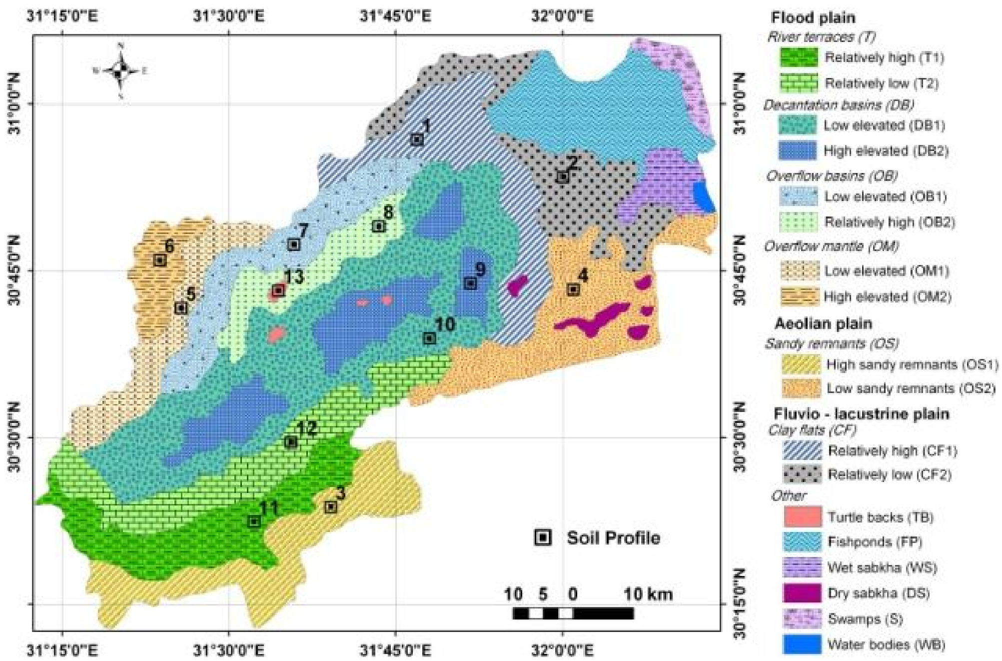

Figure 4. Landforms of the study area overlapped by locations of the studied soil profiles

Table 2. Landforms and Soils of the Investigated Area

Relief	Lithology /Origin	Land form	Mapping unit	Profile No.	Area %	Soil sets
		Relatively high clay flats	CF1	1	8.01	*Vertic Torrifluvents*
		Relatively low clay flats	CF2	2	2.30	*Vertic Torrifluvents*
Almost flat to gently undulating	Fluvio - lacustrine deposits	Dry sabkha	DS	--	0.95	*Gypsic Haplosalids*
		Wet sabkha	WS	--	1.83	*Typic Aquisalids*
		Fishponds	FB	--	5.84	--
		Swamps	S	--	2.74	--
		Water bodies	WB	--	1.39	--
Gently undulating	Aeolian deposits	High sandy remnants	OS1	3	7.96	*Typic Torripsamments*
		Low sandy remnants	OS2	4	8.84	*Typic Torripsamments*
		Over flow Mantle				
		Low elevated	OM_1	5	2.65	*Typic Torrifluvents*
		High elevated	OM_2	6	4.69	*Typic Torrifluvents*
		Over flow basin				
		Low elevated	OB_1	7	6.75	*Vertic Torrifluvents*
Almost flat to gently undulating	Alluvial deposits	High elevated	OB_2	8	3.99	*Typic Natrargids*
		Decantation basin				
		Low elevated	DB_1	9	7.52	*Typic Torrifluvents*
		High elevated	DB_2	10	18.57	*Typic Torrifluvents*
		River terraces				
		Relatively High	T_1	11	6.91	*Vertic Torrifluvents*
		Relatively low	T_2	12	8.74	*Vertic Torrifluvents*
		Turtle backs	TB	13	0.32	*Typic Torripsamments*

Table 3. Changes in the main land characteristics during 1975 and 2011

Profile No.	Mapping unit	Area (km^2)	Water table level (cm)		Bulk density g/cm^3		EC ds/m		ESP %	
			1975	2011	1975	2011	1975	2011	1975	2011
1	CF1	378.21	120	90	1.30	1.35	6.20	13.11	22.40	28.10
2	CF2	108.60	100	70	1.30	1.35	5.10	21.00	15.10	19.20
3	OS1	375.85	150	120	1.10	1.12	3.40	7.40	11.30	17.40
4	OS2	417.40	150	100	1.10	1.13	2.60	11.30	12.50	24.00
5	O.M1	125.13	120	110	1.30	1.33	5.20	8.30	18.30	20.20
6	OM2	221.45	150	135	1.30	1.35	7.30	9.40	16.20	18.40
7	OB1	318.72	150	140	1.20	1.36	0.40	1.90	14.00	14.60
8	OB2	188.40	120	110	1.22	1.36	4.40	7.80	12.20	14.10
9	DB1	355.08	140	150	1.30	1.43	5.10	3.19	11.20	10.60
10	DB2	876.83	130	150	1.30	1.48	6.80	4.80	12.40	11.20
11	T1	326.27	100	130	1.10	1.16	3.90	1.60	11.30	10.10
12	T2	412.68	110	100	1.25	1.30	4.30	5.60	12.60	13.80
13	TB	15.11	110	100	1.30	1.30	1.60	2.80	11.30	12.00

Note: The data of 1975 were extracted from RISW report (1975), the soil characteristics (bulk density, EC, ESP) were calculated to the depth of 100 cm

Changes of soil productivity

The data illustrated in Table 4 indicate that the land degradation process sweeping the study area, where the total area of the extremely low productivity (V) increased from 901.86 km^2 in 1975 to 1692.75 km^2 in 2011. This indicates that the soils of grade V were increased by 19.20 %. The degraded soils are associated to the OM1, OM2, CF1, CF2, OS1, OS2, T1 and T2, representing 69.73 % of the studied area. The soils of TB, DB1 and DB2 were enhanced; these soils represent 30.27 % of the total area. An area of 370.19 km^2 representing the soils of TB and DB2 has been shifted from grade II in 1975 to grade I in 2011.

The changes of soil productivity index (PI) during 1975 and 2011 in the different landforms are illustrated in Tables 5 and 6. The results indicate that the soils of clay flats are naturally degraded as they located near to Lake El Manzala. In the CF1 unit the soil PI is very low, it was changed from 7.74 (IV) in 1975 to 1.96 (V) in 2011. For the CF2 the grade of PI still V, while the PI value was decreased from 6.63 to 1.23. The changes of soil PI in the CF1 and CF2 are mainly related to the decreased effective depth and the increment of soluble salts. The PI of Aeolian deposits were classified as extremely low due to the original low quality of the soil properties. The low changes of PI in 1975 and 2011 are mainly related to the few changes in effective depth and soil salinity. The cultivation practices were started recently (2003) in these landforms; this can explain the stability of PI at grade (V). For the landforms of the flood plain the soil PI was changed from class II to class III in the soils of overflow mantle. The PI of OM1 was shifted from 38.88 in 1975 to 20.82 in 2011, while turned from 35.08 (1975) to 22.04 (2011) in the OM2. The main factors reduced the PI in the overflow mantle are salinity, compaction, alkalinity and the effective soil depth. Values of soil PI in the OB1 landform were decreased from 41.15 to 24.72, while they turned from 31.25 to 17.24 in the OB2 unit. The reduction of soil PI in these units is related to soil depth, drainage condition, soil salinity, and alkalinity. The soils of DB1 were enhanced as the PI value increased from 37.28 (II) to 78.16 (I). Also the PI of the DB2 was increased from 31.36 (III) to 62.50 (II) in 1975 and 2011 respectively. The soils of river terraces were degraded due to water logging and salinization. The productivity index in T1 unit was decreased by 14.53%, while it decreased by 13.05 % in the T2. The soils of turtle backs were enhanced as the estimated PI was increased from 35.69 in 1975 to 69.44 in 2011 due to the high efficiency of subsurface drainage in these landforms. These data indicate that the PI is mainly affected by soil salinity, alkalinity, water logging and compaction (Figures 5, 6, 7 & 8). The statistical analyses indicate the high correlation between productivity index and degradation factors i.e. soil salinity (- 0.607**), alkalinity (- 0.709**), water logging (0.842**) and compaction (0.555**).

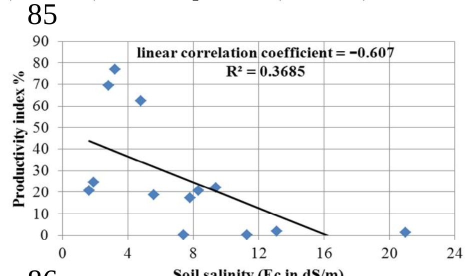

Figure 5. The correlation between productivity index and soil salinity

Table 4. Areas of soil productivity grades in 1975 and 2011

1975				2011			
PI %	**G**	**Area Km^2**	**Mapping Unit**	**PI %**	**G**	**Area Km^2**	**Mapping Unit**
0-7	V	901.86	CF2, OS1 and OS2	0-7	V	1692.75	CF1, CF2, OS1, OS2 and T2
8-19	IV	378.21	CF1	8-19	IV	188.40	OB2
20-34	III	1391.51	OB2, DB2 and T1	20-34	III	991.57	OM1, OM2, OB1 and T1
35-64	II	1448.16	OM1, OM2, OB1, DB1, TB and T2	35-64	II	876.83	DB2
65-100	I	0.00	-----	65-100	I	370.19	TB and DB1

PI= productivity index, G= productivity grade

Table 5. Calculated productivity index for the year 1975

Site No.	**Mapping unit**	1975 Rating of soil characteristics								**PI**	**G**
		H	**D**	**P**	**T**	**S**	**O**	**A**	**M**		
1	CF1	100	60	60	80	60	80	80	70	7.74	IV
2	CF2	100	60	60	80	60	80	80	60	6.63	V
3	OS1	60	90	80	50	70	40	30	30	0.54	V
4	OS2	60	90	80	50	60	40	30	30	0.47	V
5	OM1	100	100	100	60	100	80	90	90	38.88	II
5	OM2	100	95	95	60	100	80	90	90	35.08	II
7	OB1	100	100	95	60	100	80	95	95	41.15	II
8	OB2	100	95	95	60	95	75	90	90	31.25	III
9	DB1	100	80	85	90	75	90	90	90	37.28	II
10	DB2	100	75	85	90	75	90	90	90	31.36	III
11	T1	100	90	95	60	100	85	90	90	35.32	II
12	T2	90	90	95	60	100	85	90	90	31.78	II
13	TB	100	80	85	90	80	90	90	90	35.69	II

Moisture availability (H), Drainage (D), Effective depth (P), Texture / structure (T), Soluble salt concentration(S), Organic matter content (O), Cation exchange capacity / nature of clay (A) , Mineral reserve (M) , Productivity index (PI) and Productivity Grades (G)

Table 6. Calculated productivity index for the year 2011

Site No.	**Mapping unit**	2011 Rating of soil characteristics								**PI**	**G**
		H	**D**	**P**	**T**	**S**	**O**	**A**	**M**		
1	CF1	100	40	40	80	40	80	80	60	1.96	V
2	CF2	100	40	40	80	30	80	80	50	1.23	V
3	OS1	60	90	60	50	60	40	30	30	0.34	V
4	OS2	60	90	60	50	40	40	30	30	0.23	V
5	OM1	100	90	85	60	80	70	90	90	20.82	III
5	OM2	100	90	90	60	80	70	90	90	22.04	III
7	OB1	100	95	90	60	85	70	90	90	24.72	III
8	OB2	100	90	85	60	80	65	85	85	17.24	IV
9	DB1	100	100	100	95	95	95	95	90	77.16	I
10	DB2	100	100	95	95	95	90	90	90	62.50	II
11	T1	100	85	90	60	80	70	90	90	20.82	III
12	T2	90	85	90	60	80	70	90	90	18.73	V
13	TB	100	100	100	95	95	95	90	90	69.44	I

Moisture availability (H), Drainage (D), Effective depth (P), Texture / structure (T), Soluble salt concentration(S), Organic matter content (O), Cation exchange capacity / nature of clay (A) , Mineral reserve (M) , Productivity index (PI) and Productivity Grades (G)

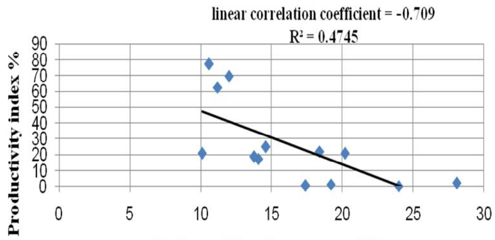

Figure 6. The correlation between productivity index and ESP

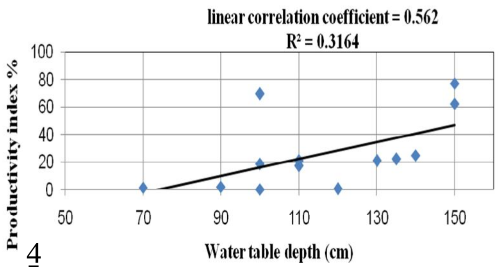

Figure 7. The correlation between productivity index and water table depth

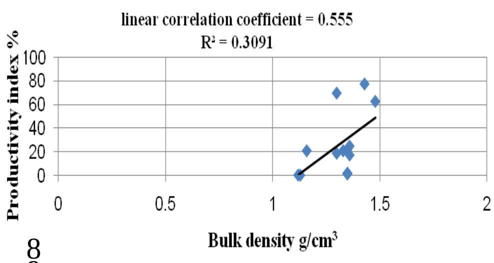

Figure 8. The correlation between productivity index and soil bulk density

CONCLUSION

The area under investigation is dominated by degradation process of salinization and water logging. The study indicates that the productivity index was decreased in 69.73 % of the area between 1975 and 2011, while increased in the rest of the area (30.27 %). Vast areas in Aeolian deposits, fluvio- lacustrine and flood plain were degraded due to the poor land management. The calculated productivity index represent a high correlation with the dominant soil degradation factors i.e. salinization and water logging. The increased soil salinity and water logging process indicate the low efficiency of the recently established drainage networks. Consequently, the agriculture development in the area requires the governmental support to improve the drainage networks and proper land management that can be performed by the farmers.

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