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Mapping Soil Salinity and Evaluation of Water Quality in Siwa Oasis Using GIS

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ABSTRACT

Siwa Oasis represents a promising area for agricultural expansion projects in the western desert of Egypt due to the availability of water resources. However, these areas are suffering from land degradation problems, especially soil salinity. Accordingly, the main objectives of this work were to evaluate and map soil salinity as well as groundwater quality in Siwa Oasis. Therefore, twenty representative soil profiles were randomly distributed throughout the studied area. These profiles were sampled based on the development of soil horizons. A total of 46 soil-samples were collected and these samples were analyzed for their physical and chemical properties. Groundwater samples were collected from irrigation-wells and they were analyzed for their chemical parameters. Landsat images were also acquired at three different periods to monitor the changes in vegetation cover, soil salinity and water logging. The obtained results indicated a wide variability within soil physical and chemical properties in the Oasis. Most of the suited soils were very saline, non-sodic based on the EC and ESP values (EC= 77 dSm^{-1} and ESP= 14.62 in average). Agricultural areas were increased from 22 km^2 in 1992 to 81 km^2 in 2015. On the other hand, saline soils were increased from 35 km^2 to 64 km^2 and water logged areas were also increased from 19 to 51 km^2 from 1992 to 2015, respectively. These results could be due to the expansion in reclamation-projects, increase in crop irrigation and poor drainage. The salinity of groundwater varied from 2.28 to 5.45 dSm^{-1} (3.76 in average), which indicates a degradation in its quality. In summary, soils in Siwa Oasis are salt-affected and they need a proper land reclamation program and development of effective irrigation and drainage systems.

Keywords: Siwa Oasis, salinity, water quality, water logging, vegetation, GIS.

INTRODUCTION

Soil salinity is a serious environmental problem especially in arid and semi-arid areas. It either occurs naturally or human-induced. High levels of soil salinity have serious negative impacts on various aspects of agriculture and environmental sustainability (Singer and Munns, 1996; El-Swaify, 1997; Toparkngarm, 2006). Soil salinity don't only inhibit plant growth and subsequent agricultural output but it also result in land degradation phenomena such as dispersion of fine particles and increase in soil erosion (Metternicht and Zinck, 2003). Salt-affected soils cover about 1000 million hectares or about 7% of the earth's continental surface (Ghassemi *et al.*, 1995). Accordingly, it is important to monitor and map soil salinity at an early stage to develop an effective soil reclamation program that could help in reducing or preventing future increase in soil salinity.

Increase in the amount of soluble salts in the root zone restricts plant roots from withdrawing water in the soil solution by the osmotic potential. In other words, high levels of soil salinity reduce the amount plant available water (Hanson *et al.*, 1999; Bauder and Brock, 2001; Attibu, 2014). This leads to reduction in water uptake and increase in plant stress.

The conventional methods used in determining soil salinity depend on collecting soil samples, making soil extracts and measuring electrical connectivity (EC). These methods are expensive, labor-intensive and time-consuming. Nowadays, remote sensing data and GIS techniques have proven to provide reliable and up-to-date information on the recent changes in land cover dynamics. They can provide a great help for monitoring the changes in soil salinity and the expectations for further land degradation (Goossens *et al.*, 1993; Casas, 1995). Spectral indices have been widely used for direct and indirect detection of soil salinity. Vegetation indices such as the normalized difference vegetation index (NDVI) and the soil adjusted vegetation index (SAVI) have been used as indirect indicators for soil salinity (Huete, 1988). Water logging indices as the normalized difference water index (NDWI) and the modified NDWI, have also been used as indirect indicators for poor drainage and consequently soil salinity (Mcfeeters, 1996). On the other hand, the salinity index (SI) and the normalized difference salinity index (NDSI) have been utilized as direct indicators for soil salinity (Tripathi *et al.*, 1997).

Siwa Oasis is a closed depression at the northwest of the western desert of Egypt. It was selected in this study because of its promising capabilities for agricultural development. However, soils in this Oasis are suffering from many environmental problems such as water logging, soil salinity, and wind erosion. These problems result in deterioration of land productivity and reduction in agriculture income.

The main objectives of this work were to evaluate and monitor changes in soil salinity within Siwa Oasis either directly through using salinity indices and soil analyses or indirectly based on changes in vegetation cover and water logging areas.

MATERIALS AND METHODS

1. Description of study area

Siwa Oasis is a natural depression in the western desert of Egypt. It lies between 25^o 16' 2.36" to 25^o 51' 3.04" E and 29^o 6' 10.14"- 29^o 18' 36.24" N as shown in Fig. 1. The studied area is approximately 613 km^2. The Oasis is about 23 m below-sea-level (BSL). Its mean-annual-temperature (MAT) ranges between 5.81 ^oC and 37.83 ^oC in January and July; respectively. The maximum soil-mean-temperature is 32.8 °C in July and August, where the minimum soil-mean-temperature is 13.3 °C in January as recorded by Abd El-Samie (2000). The mean- annual-precipitation (MAP) is 9.51 mm, where it took a variable pattern. Evaporation rates vary from 4.81 to 13.52 mm per day. The higher values were documented in June, whereas the lower rates were recorded in December. The mean annual relative humidity (RH) is about 41.2%, where it varies from 30% in May and June to 56% in December. Wind erosion is very evident in April.

Abu Al-Izz (1971) reported that the most obvious geomorphologic-features in the Oasis are: hills, mountains, lakes and the sea of sand. Agriculture lands represent about 88 km^2, where agriculture is the main activity in the Oasis. This is mainly due to the availability of groundwater resources (Samy, 2010).

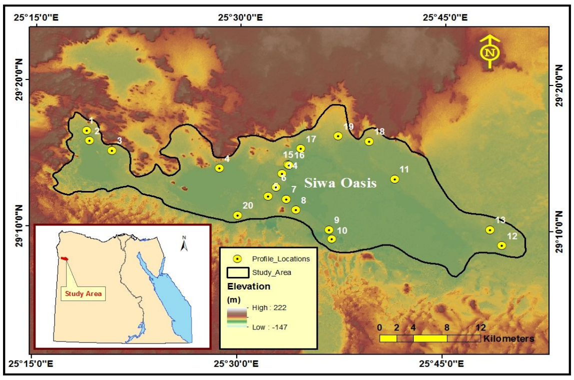

Fig.1. Location map of study area and soil profiles in Siwa Oasis.

2. Soil sampling and analyses:

Twenty representative soil-profiles were dug within the studied area in Siwa Oasis and their locations were recorded using the GPS (Garmin legend) as represented in Figure 1. Samples were collected from these soil-profiles based on the maturity of their horizons. These samples were analyzed for their physical and chemical properties as described by the Soil Survey Staff (2010).

3. Groundwater sampling and analyses:

In this work, groundwater samples were collected from some private irrigation-wells. These samples were analyzed for their chemical properties using the same procedures as in soils analyses.

4. Geo-statistical analyses

The ordinary Kriging was used to study the spatial distribution of the studied soils parameters throughout the studied area. It is working under the geostatistical analyst extension in ArcGIS desktop software (version 10.3).

5. Satellite data and their analyses

Landsat Data

Landsat imagery was used in this work to evaluate vegetated, salt-affected and water logging areas. The studied area is covered by one image (path 180 and row 40). The studied images were acquired at three different dates (1992, 2002, and 2015). These images were downloaded for free from the earth explorer website (http://earthexplorer.usgs.gov/), which is developed by the United States Geological Survey (USGS).

Atmospheric and radiometric corrections

Both atmospheric and radiometric corrections were carried out on the collected images to get rid of the effects of haze, dust and smoke in these images. The digital numbers DNs were also converted at atmosphere reflectance using ERDAS imagine software (version 2014).

Geometric Correction

Geometric correction was also carried out to align all the studied images. It preformed using the polynomial projection tool under ERDAS imagine, were 12 grounded control points were used in this process and the RMS error was less than one. They were projected using the UTM projection, zone 35N, and datum WGS1984.

Vegetation Indices

The soil adjusted vegetation index (SAVI) was used to study the spatial distribution of vegetation in the studied area. The SAVI is a modification of the NDVI. It corrects the influence of soil brightness in areas with low vegetative cover. The NDVI works effectively in these areas with > 30% of plant-cover, while the SAVI works better in areas with <15% of plant-cover (Xu, 2008). The SAVI is computed according to the following formula (Huete, 1988):

$$\mathbf{SAVI = (NIR - R) \times (1 + L) / (NIR + R + L)} \qquad \mathbf{(1)}$$

Where, NIR is the near infrared reflectance and R is the reflectance of the red band. L is the soil brightness correction factor, which ranges between 0 and 1 based on the density of vegetation cover. In this study, a value of 0.5 was utilized.

Salinity Indices

The above mentioned vegetation indices were used as indirect indictors of salt-affected soils (SASs). This is mainly because SASs are usually characterized by poorly-developed vegetation covers. The Salinity Index (SI) was used to study the spatial distribution of saline soils in Siwa Oasis. This index illustrated a highly significant-correlation with soil-salinity in less-densely vegetated areas and bare soils (Douaoui *et al.*, 2006; Elnaggar and Noller, 2010).The SI is computed according to the following formula (Tripathi *et al.*, 1997):

$$\mathbf{SI = \sqrt{(B * R)}} \qquad \mathbf{(2)}$$

Where, B and R are the reflectance in the blue and red portions of visible spectrum, respectively.

Water Indices

The McFeeters's normalized difference water index (NDWI) was used to evaluate the changes in water logged areas over time. The McFeeters's NDWI is computed using the following equation (Mcfeeters, 1996):

$$\mathbf{NDWI = (\rho\ Green - \rho\ NIR) / (\rho\ Green + \rho\ NIR)} \qquad \mathbf{(3)}$$

Where; ρ Green and ρ NIR are the reflectance of the green and NIR bands; respectively.

Calculation of agricultural lands, saline- soils and water-logged areas

In this work, a threshold value for the studied vegetation index was used to separate agricultural from non-agricultural areas. This threshold was used to convert the SAVI image into a binary-image. This binary image only contains two-classes: non-agricultural and agricultural areas. A similar method was utilized to differentiate non-saline from saline soils and water-logged areas from dry lands. The areas allocated for each class was calculated based on the number of pixels in that class.

Changes in the studied land covers within Siwa Oasis

Changes in the studied land covers in the studied area were carried out through subtracting the binary-images obtained from each of the studied indices for two consecutive years. A new image with three values is obtained as a result of this process. The positive value (+1) indicates positive toward the studied land cover (agricultural lands, saline soil or water logged area), Zero refers to no change in land cover, and the negative value reveals negative change in the studied land cover toward other activities.

RESULTS AND DISCUSSION

1. Soil-physical properties within Siwa Oasis

Data in Table 1 represent the range and average of some soil-physical characteristics in Siwa Oasis. The values of total sand (TS) in the studied area varied from 55.25 to 98.03% (about 85% in average). Silt content ranged between 0.02 and 36.23% (about 8% in average). Clay content varied from 1.34 to 22.40% (about 7% in average). Consequently, sandy soils are most prevalent in the studied area; however there are small patches of clay soils distributed in the area. Saturation percentage (SP) was highly associated with the soil texture and it was ranged between 17 and 59% (about 34% in average). Soil organic matter (SOM) was very low in the studied soils, which could be attributed to the very arid weather and low additions of organic amendments. SOM varied from 0.09 and 1.3% (about 0.43% in average). There was wide variability in the contents of total carbonates in the Oasis based on soil parent-material. Total carbonates, represented as $CaCO_3$ were ranged between 1.71 and 59.72% (about 27% in average). Soil bulk-density varied from 1.00 to 2.08 g cm^{-1} (about 1.58 g cm^{-3} in average) . The greater values were linked with coarse-textured soils but the lower-values were linked with fine-textured ones. Total soil porosity in the studied area was ranged between 21.51 and 67.51% (about 40.70% in average). It took an opposite trend to that of soil bulk density, where the greater values were connected with the fine-textured soils and vise versa.

Table 1. Some soil physical-properties of the studied soils.

Property	Unit	Min.	Max.	Average
Total Sand	(%)	55.25	98.03	85.22
Silt	(%)	0.02	36.23	8.14
Clay	(%)	1.34	22.4	6.64
Soil-Texture		--	--	Loamy Sand
Saturation Percentage	(%)	17.00	59.00	34.02
Soil Organic Matter	(%)	0.09	1.3	0.43
Total Carbonates	(%)	1.71	59.72	27.04
Soil Bulk Density	(g cm^{-3})	1.00	2.08	1.58
Total Porosity	(%)	21.51	67.51	40.70

2. Soil chemical properties within Siwa Oasis

Soil chemical properties of soils in the studied area are represented in Table 2. Sodium was the dominant cation in soil solution of the studied soils. It was followed by calcium, magnesium and potassium; respectively. Na^+ ions varied from 0.51 and 102.77 cmol-kg^{-1} soil (about 17 cmol-kg^{-1} soil in average). Ca^{2+} varied from 0.55 to 15.51 cmol-kg^{-1} soil (about 3.24 cmol-kg^{-1} soil in average). Mg^{2+} ranged between 0.15 and 18.48 cmol-kg^{-1} soil (about 3.50 cmol-kg^{-1} soil in average). K^+ varied from 0.04 and 1.26 cmol-kg^{-1} soil (about 0.23 cmol-kg^{-1} soil in average).

Chlorides were the prevalent anions in the soil solution within the studied soils. It was followed by sulfates and bicarbonates; respectively. Cl^- varied from 0.86 to 110.76 cmol-kg^{-1} soil (about 19.03 cmol-kg^{-1} soil in average). SO_4^{2-} varied from 0.11 and 23.37 cmol-kg^{-1} soil (about 4.24 cmol-kg^{-1} soil in average). HCO_3^- ranged between 0.12 and 3.54 cmo- kg^{-1} soil (about 0.70 cmol-kg^{-1} soil in average). Soil-pH varied from 8.10 to 8.97 (about 8.41 in average). Most of the studied soils in the Oasis were highly-salinity. The EC values ranged between 4.25 to 427 dS m^{-1} (about 77 dS m^{-1} in average).

The exchangeable cations indicated that Mg^{2+} is the prevalent cation on the colloidal-complex. This could be accredited to soils parent materials, where the majority of the soils in the Oasis were developed on lack deposits (Lacustrine-deposits) or in close vicinity from the existing lakes. Exchangeable Mg^{2+} ranged between 3.58 and 41.21 cmol-kg^{-1} soil (about 14.27 cmol-kg^{-1} soil in average). Calcium was the second dominant cation on the colloidal complex followed by sodium. Exchangeable Ca^{2+} varied from 2.18 to 29.88 cmol-kg^{-1} soil (about 11.25 cmol-kg^{-1} soil in average). Exchangeable Na^+ ranged between 0.64 and 15.66 cmol-kg^{-1} soil (about 4.31 cmol-kg^{-1} soil in average). Potassium was the least dominant on the exchange complex, where it was about 1.18 cmol-kg^{-1} soil in average.

There were wide variations in the cation exchange capacity (CEC) within the studied soils. The CEC values were ranged between 9.84 and 70.70 cmol-kg^{-1} (about 13.31 cmol-kg^{-1} soil in average). The lower values were linked with the coarse-textured soils, while the higher values were connected with fine-textured soils. Most soils in the studied area were non-sodic, where the values of exchangeable sodium percentage (ESP) were lower than 15%. The ESP values were ranged between 2.55 and 38.47% (about 14.55% in average). However, soil alkalinity due to exchangeable magnesium should be considered due to its dominancy on the exchange complex, where magnesium also has an influence on the structure of clay soils. Once the exchangeable magnesium percentage (EMP) exceeds 20%, the soil becomes difficult to work, where magnesium results in the dispersion of clay particles (Smith *et al.*, 1949). EMP in the studied soils varied from 7.58 to 71.54% with an average of 45.09%, which indicates a higher soils alkalinity.

Table 2. Soil chemical properties of the studied soils.

Chemical Properties		Min.	Max.	Average
	Na^+	0.51	102.77	17.01
Soluble cations	K^+	0.04	1.26	0.23
(cmol kg^{-1} soil)	Ca^{2+}	0.55	15.51	3.24
	Mg^{2+}	0.15	18.48	3.5
	$CO3^{2-}$	0.00	0.00	0.00
Soluble anions	$HCO3^-$	0.12	3.54	0.70
(cmol kg^{-1} soil)	Cl^-	0.86	110.67	19.03
	$SO4^{2-}$	0.11	23.37	4.24
pH		8.10	8.97	8.41
EC (dSm^{-1})		4.25	427	76.76
	Ca^{2+}	2.18	29.88	11.25
Exchangeable Cations	Mg^{2+}	3.58	41.21	14.27
(cmol kg^{-1} soil)	Na^+	0.64	15.66	4.31
	K^+	0.27	5.03	1.18
CEC (cmol kg^{-1} soil)		9.84	70.70	13.31
ESP (%)		2.55	38.47	14.55
EMP (%)		7.58	71.54	45.09

2. Chemical properties of water samples

There were wide variations in the chemical properties among the collected groundwater samples from Siwa Oasis. Data in Table 3 show that Na^+ was the prevalent cation in the collected groundwater samples, followed by Mg^{2+}, Ca^{2+} and K^+; respectively. The average concentrations of K^+, Ca^{2+}, Mg^{2+}, and Na^+ were 0.65, 8.90, 9.08, and 19.00 meq l^{-1}; respectively. In contrast, the dominant anions were chlorides in water samples followed by sulfates and bicarbonates; respectively. The average concentrations of HCO_{3^-}, SO_4^{2-} and Cl^- were 2.07, 12.18 and 23.38 meq l^{-1}; respectively.

The pH values in groundwater samples ranged between 7.90 and 8.26 (about 8.09 in average). The EC values varied from 2.27 to 5.46 dS m^{-1} (about 3.75 dS m^{-1} in average). The higher EC values could be attributed to the collection of these water samples from the private wells and the poor drainage in the Oasis. In general, private wells have a shallower depth (< 150 m) when compared with the governmental wells (> 600 m). The calculated sodium adsorption ratio (SAR) was ranged between 4.33 and 8.08 (about 6.26 in average). It was also found that the residual sodium carbonates (RSCs) in water sample had negative values (about -16 meq l^{-1} in average), which could be attributed to the prevalence of both Ca^{2+} and Mg^{2+} ions in water-samples. This indicates little possibility for soils in the studied are to be converted into sodic soils when irrigated with this groundwater. These results are in agreement with those obtained by Aly *et al.* (2016), where they stated that groundwater quality in Siwa Oasis is degrading over time.

Table 3. Chemical analyses of groundwater-samples from Siwa Oasis.

Chemical Property		Min.	Max.	Average
	Na^+	11.68	28.71	19.00
Soluble cations	K^+	0.43	1.01	0.65
(cmol kg^{-1} soil)	Ca^{2+}	5.81	12.95	8.90
	Mg^{2+}	4.64	12.25	9.08
	$CO3^{2-}$	--	--	--
Soluble anions	$HCO3^-$	1.13	3.09	2.07
(cmol kg^{-1} soil)	Cl^-	14.51	35.91	23.38
	$SO4^{2-}$	7.20	17.52	12.18
pH		7.90	8.26	8.09
EC (dSm^{-1})		2.27	5.46	3.75
SAR		4.33	8.08	6.26
RSC (meq l^{-1})		-24.09	-9.32	-15.90

3. Vegetated areas in Siwa Oasis Based on the SAVI Index.

Data in Table 4 represent the estimated agricultural areas in Siwa Oasis based on the SAVI index from 1992 to 2015. These areas were about 22.22, 38.20 and 81.17 km^2 in 1992, 2002 and 2015; respectively. Their percentages were about 3.62, 6.23 and 13.24%, respectively. The spatial distribution of these areas is represented in Figure 2. In contrast, the estimated areas of non-agricultural lands were about 591, 575 and 532 km^2 in 1992, 2002 and 2015; respectively. Their percentages were about 96.38, 94 and 87%; respectively. These results reveal a significant increase in agricultural areas from 1992 to 2015. However, the highest increase in these areas was observed in the last decade.

Table 4. Estimated agricultural area in Siwa Oasis from 1992 to 2015 based in the SAVI index.

Agric. Cover	1992		2002		2015	
	Area (km^2)	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**
Non-Agric.	590.78	96.38	574.80	93.77	531.83	86.76
Agric.	22.22	3.62	38.20	6.23	81.17	13.24
Total	613	100	613	100	613	100

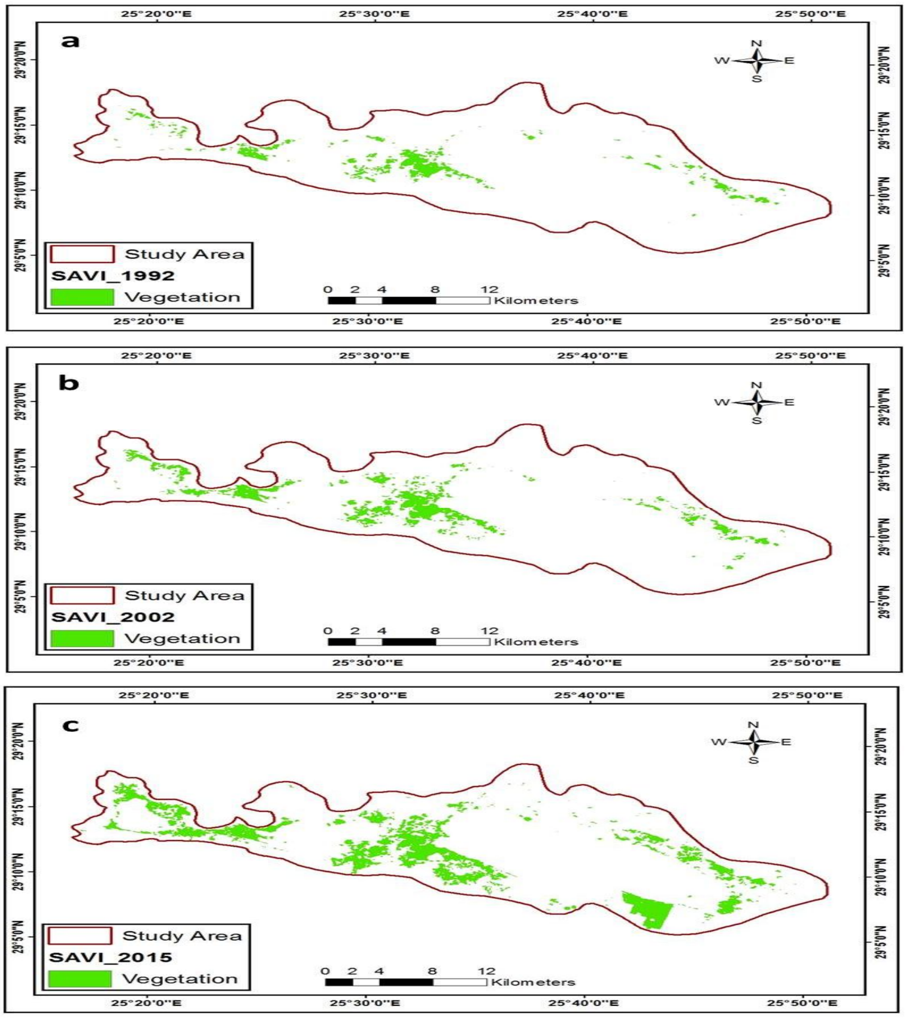

Figure 2. Spatial distribution of agricultural areas in Siwa Oasis based on the SAVI index in: a) 1992, b) 2002, and c) 2015.

4. Salt-affected areas in Siwa Oasis Based on the SI Index.

The assessment values of salt-affected areas in Siwa Oasis from 1992 to 2015 based on the salinity Index are represented in Table 5. Salt-affected areas were about 35, 40 and 64 km^2 in 1992, 2002 and 2015, respectively. As a percentage, they represented about 5.74, 6.49 and 10.46%, respectively. The spatial variability within these areas is represented in Figure 3. In the contrary, non-saline areas were about 578, 573 and 549 km^2 in 1992, 2002 and 2015, respectively. As a percentage, they represented about 94.26, 93.51 and 89.54%; respectively. These data indicate an increase in salt affected areas within the Oasis. However, the SI index only included areas of wet sabkhas, which have a higher reflectance in the visible range. This could be linked with the increase in agricultural areas, where most of these areas are irrigated using the conventional irrigation systems and they are poorly drained.

Table 5. Estimated salt-affected areas in Siwa Oasis from 2002 to 2015 based on the salinity index (SI).

Land Cover	1992		2002		2015	
	Area km^2	**%**	**Area km^2**	**%**	**Area km^2**	**%**
Non-Saline	577.82	94.26	573.19	93.51	548.91	89.54
Saline	35.18	5.74	39.81	6.49	64.09	10.46
Total	613	100	613	100	613	100

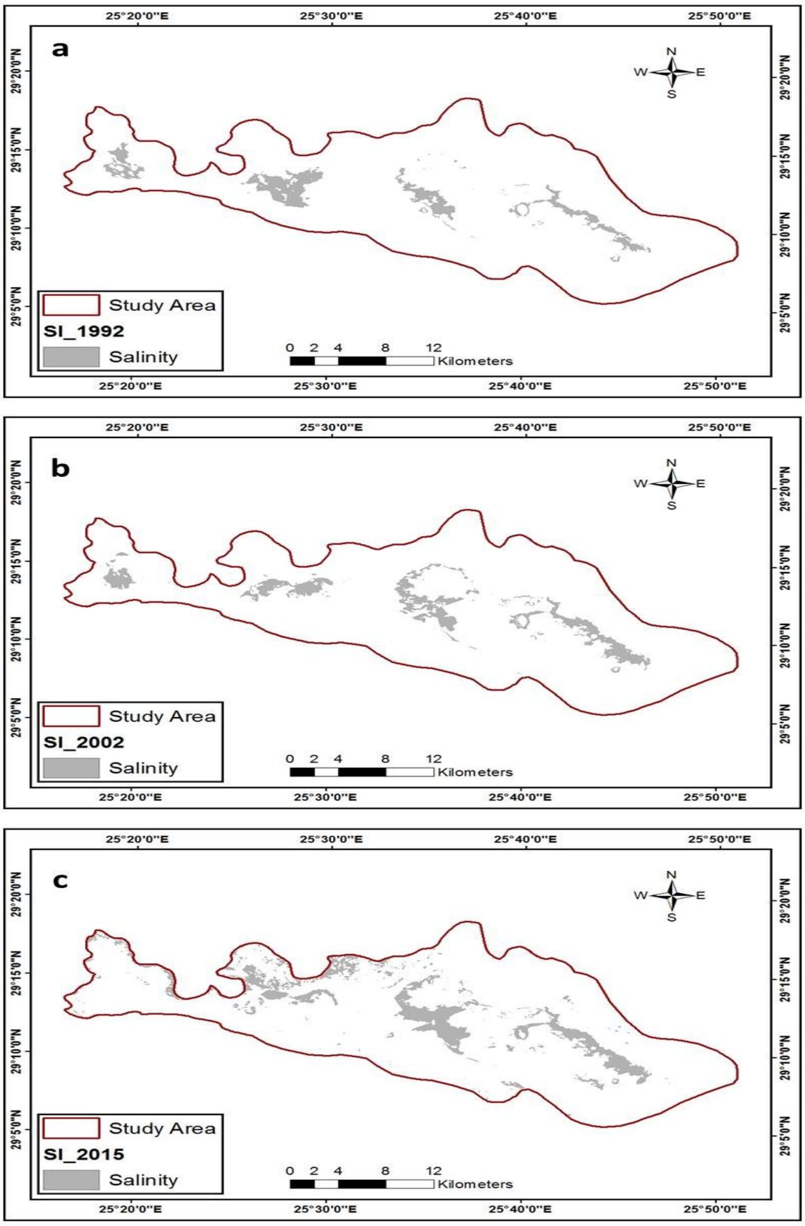

Figure 3. Spatial distribution of salt-affected areas in Siwa Oasis based on the SI index in: a) 1992, b) 2002, and c) 2015.

5. Water features in Siwa Oasis Based on the NDWI Index.

Table 6 show that the estimated water features in Siwa Oasis based on the NDWI from 1992 to 2015. Water features were about 19, 48 and 51 km^2 in 1992, 2002 and 2015; respectively. As a percentage, they represent about 3.09, 7.84 and 8.32%, respectively. The spatial variability within water-logged areas is represented in Figure 4. On the other hand, the dry areas were about 594, 565 and 562 km^2 in 1992, 2002 and 2015, respectively. As a percentage, they represent about 96.91, 92.16 and 91.68%; respectively. These values indicate an increase in water features within the studied area, which could be attributed to the increase in agricultural areas and poor drainage. These results could be enhanced with those obtained by Masoud and Koike (2006).

Table 6. Estimated water features in Siwa Oasis from 1992 to 2015 depending on the NDWI index.

Land Cover	1992		2002		2015	
	Area (km^2)	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**
Dry Land	594.08	96.91	564.94	92.16	562	91.68
Water Features	18.92	3.09	48.06	7.84	51	8.32
Total	613	100	613	100	613	100

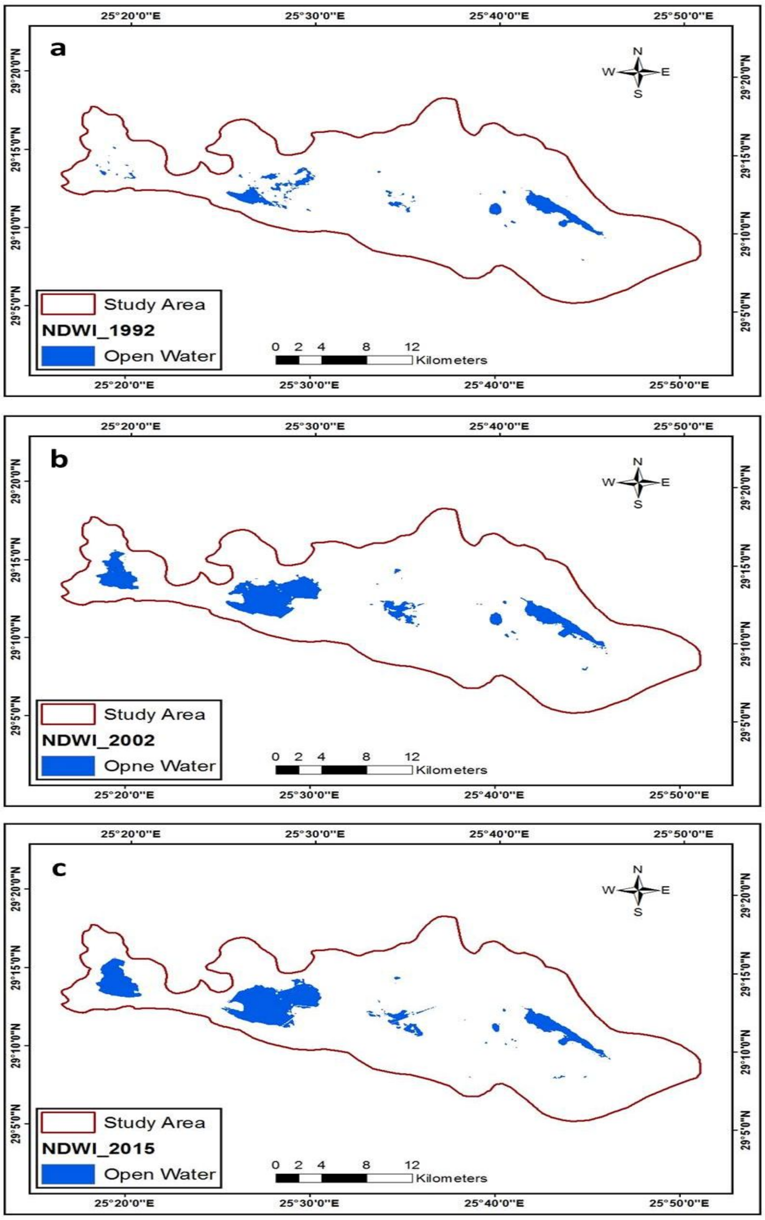

Figure 4. Spatial distribution of water features in Siwa Oasis based on the NDWI index in: a) 1992, b) 2002, and c) 2015.

6. Changes in vegetated areas, saline soils and water logged areas

Changes in non-agricultural versus agricultural-areas in Siwa Oasis from 1992 to 2015 were determined based on the SAVI data. Changes within each two successive years are shown in Table 7 and Figure 5. About 1.83 km^2 were The changed from agricultural to non-agricultural areas from 1992 to 2002, while about 17.82 km^2 were changes to agricultural areas during the same period. Also, about 1.23 km^2 were changes from agricultural to non-agricultural areas from 2002 to 2015, while about 44.20 km^2 were changes to agricultural areas during the same period. The total changes from agricultural to non-agricultural areas were about 1.33 km^2 from 1992 to 2015, whereas changes to agricultural areas were about 60.28 km^2 at the same period. These results reveal that agriculture areas in Siwa Oasis were obviously increased from 1992 to 2015. This could be associated with the development in land reclamation projects.

Table 7. Changes in agricultural versus non- agricultural areas in Siwa Oasis from 1992 to 2015.

SAVI	1992-2002		2002-2015		1992-2015	
	Area (km^2)	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**
To non-veg.	1.83	0.30	1.23	0.20	1.33	0.22
No change	593.35	96.79	567.57	92.59	551.39	89.95
To veg.	17.82	2.91	44.20	7.21	60.28	9.83
Total	613	100	613	100	613	100

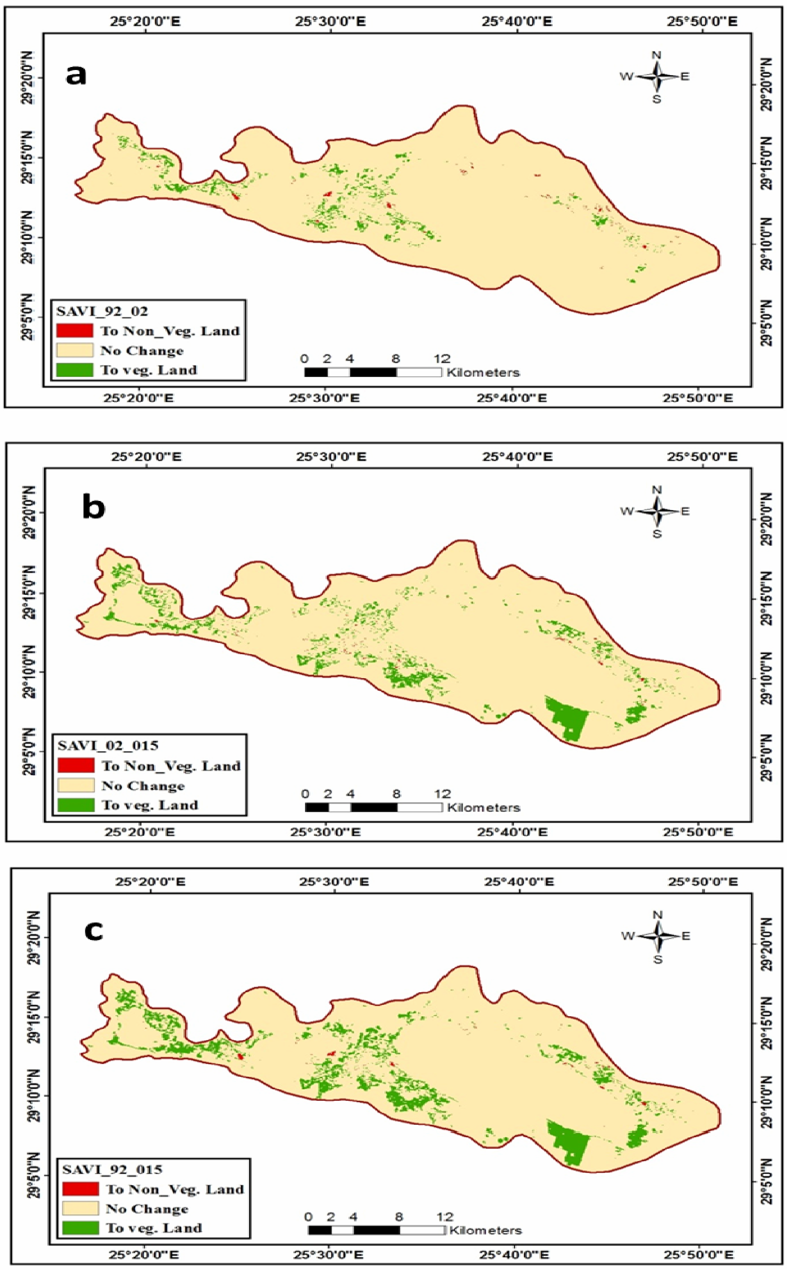

Figure 5. Changes in vegetated areas in Siwa Oasis from 1992 to 2015.

Changes in saline versus non- saline areas in Siwa Oasis from 1992 to 2015 were studied depending on the SI results. Changes between each two successive years are illustrated in Table 8 and Figure 6. Changes from saline to non-saline areas were about 14.81 km^2 from 1992 to 2002, whereas changes to saline areas were 19.44 km^2 during this period. Also, changes from saline to non-saline areas were about 11.16 km^2 from 2002 to 2015, while changes to saline areas were 35.44 km^2 during this period. The total changes from saline to non-saline areas were about 18.86 km^2 from 1992 to 2015, while changes to saline areas were about 47.53 km^2 during this period. These results indicate that saline-areas in Siwa Oasis were also obviously increased from 1992 to 2015. This could be attributed to the increase in crop irrigation associated with the expansion in land reclamation and cultivation projects. This is in addition to the used of conventional irrigation systems, which are low in their efficiency and the poor drainage within the Oasis.

Table 8. Changes in saline versus non- saline areas in Siwa Oasis from 1992 to 2015.

SI	1992-2002		2002-2015		1992-2015	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
To non-saline	14.81	2.42	11.16	1.82	18.86	3.08
No change	578.75	94.41	566.40	92.40	546.61	89.17
To saline	19.44	3.17	35.44	5.78	47.53	7.75
Total	613	100	613	100	613	100

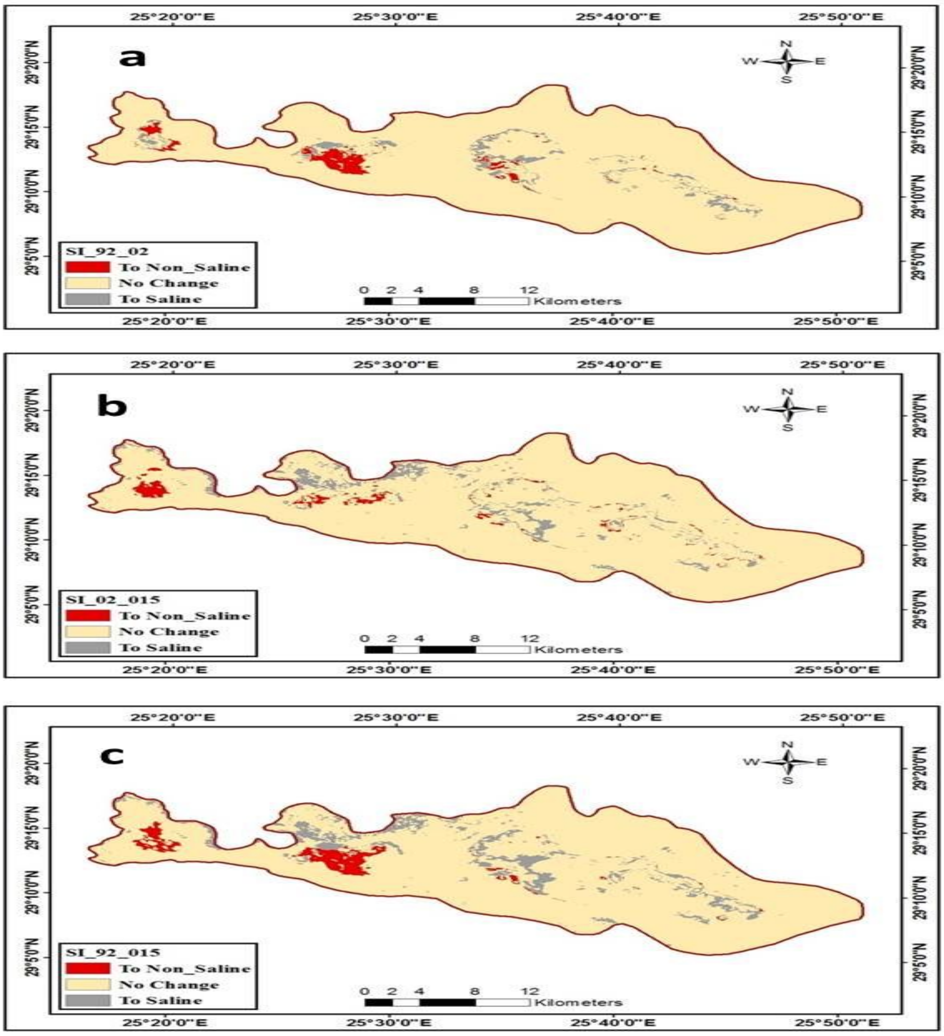

Figure 6. Changes in saline areas in Siwa Oasis from 1992 to 2015.

Changes in water-logged versus dry land areas in Siwa Oasis from 1992 to 2015 were studied based on the NDWI data. Changes between two successive periods are represented in Table 9 and Figure 7. Changes from water-logged to dry land areas were about 0.29 km^2 from 1992 to 2002, while changes to water-logged areas were 29.43 km^2 during this period. Also, changes from water-logged to dry land areas were about 3.90 km^2 from 2002 to 2015, while changes to water-logged areas were 6.82 km^2 during this period. The total changes from water-logged to dry land areas were about 1.29 km^2 during the studied period of time from 1992 to 2015, while changes to water-logged areas were about 33.34 km^2 during this period. These results reveal that water-logged areas in Siwa Oasis were noticeably increased from 1992 to 2015, which agree with the increase in saline soils in Siwa Oasis. It is noticed that some of the salt-affected areas (wet Sabkha) have changed into water-logged areas as shown in the north-western part of the studied area (Siwa Lake). This also could be attributed to the increase in crop irrigation and poor drainage within the Oasis.

Table 9. Changes in water-logged versus dry land areas in Siwa Oasis from 1992 to 2015.

NDWI	1992-2002		2002-2015		1992-2015	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
To dry land	0.29	0.05	3.90	0.64	1.29	0.21
No change	583.28	95.15	602.28	98.25	578.37	94.35
To water-logged	29.43	4.80	6.82	1.11	33.34	5.44
Total	613	100	613	100	613	100

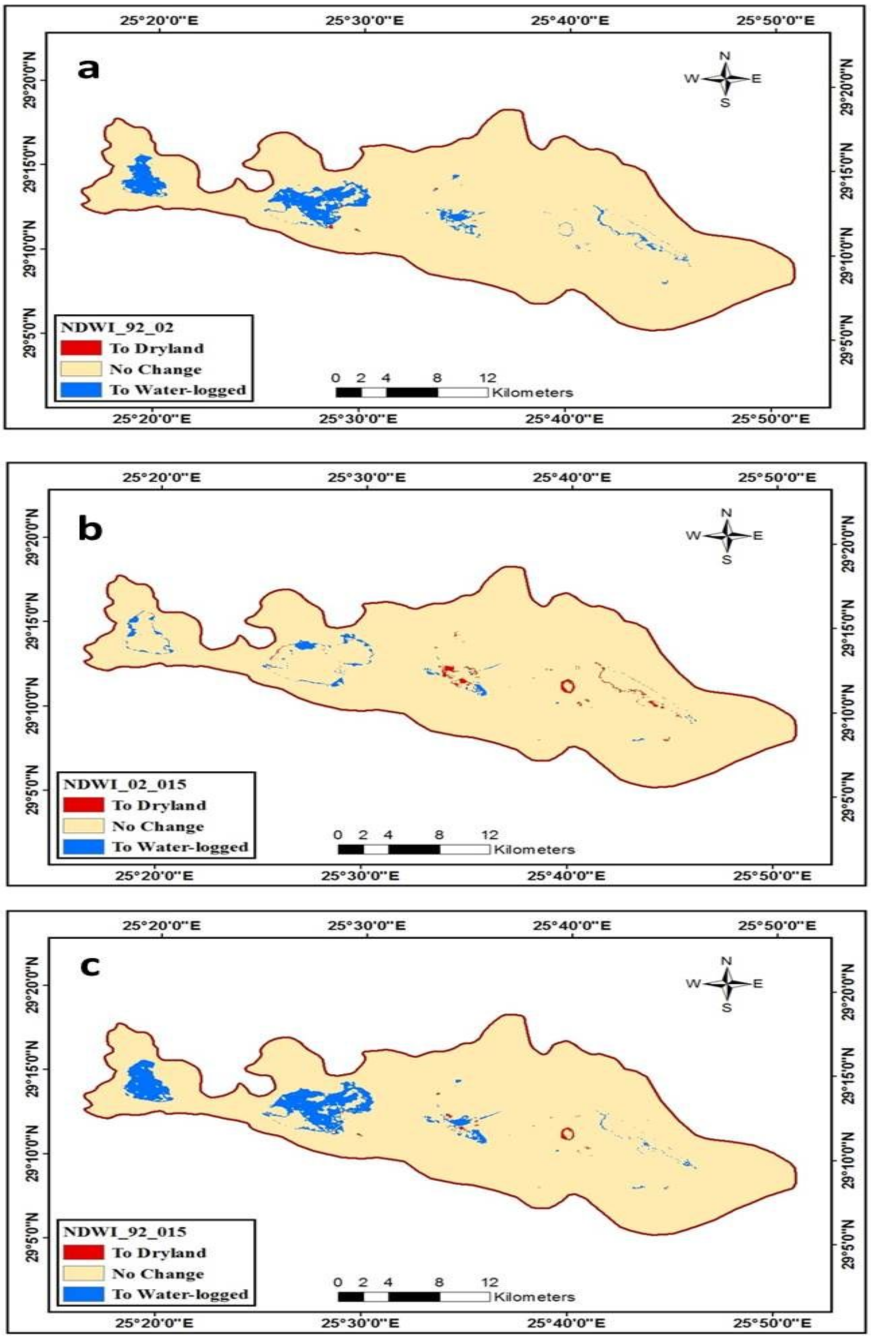

Figure 7. Changes in water-logged areas in Siwa Oasis from 1992 to 2015.

CONCLUSION

It could be concluded that, the integration between field work, laboratory analyses, GIS techniques and remote sensing data, could provide valuable help in evaluating salt-affected soils in Siwa Oasis. However, laboratory analysis provide more accurate information about the degree of soils salinity, whereas RS data only classify salt-affected areas were salt-efflorescence is evident. Most of the suited soils in Siwa Oasis were very saline, non-sodic soils. There was an obvious increase in agricultural areas within the studied area. In contrast, there was an obviously increase in both salt-affected and water-logged areas in Siwa Oasis from 1992 to 2015. This could be accredited to the increase in land reclamation projects, crop irrigation and poor drainage. Moreover, the salinity of groundwater was also high. However, this could be attributed to the collection of water sampler from private wells, which are shallower in depth than the governmental wells.

In conclusion, soils in Siwa oasis are suffering from very high soil salinity problem, which needs to develop an effective land reclamation program with effective irrigation and drainage systems.

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إنتاج خرائط الأراضي الملحية وتقييم جودة المياه في واحة سيوة باستخدام نظم المعلومات الجغرافية

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تعتبر واحة سيوة واحدة من أكثر المناطق الواعدة لمشاريع التوسع الزراعي في الصحراء الغربية بمصر نظرا لتوافر الموارد المائية بها. ومع ذلك، تعاني هذه المناطق من مشاكل تدهور الأراضي وبصفة خاصة ملوحة التربة. وتبعا لذلك، كانت الأهداف الرئيسية لهذا العمل هى تقييم وإنتاج خرائط ملوحة التربة وتقييم جودة المياه الجوفية في واحة سيوة. لذلك، تم توزيع عشرون قطاعا أرضيا بشكل عشوائي في جميع أنحاء منطقة الدراسة. وأخذت عينات من هذه القطاعات تبعا لدرجة تطوير آفاق التربة. وتم جمع 46 عينة تربة وتحليلها للتعرف على خصائصها الفيزيائية والكيميائية. كما تم أيضا جمع عينات مياه من كل من آبار الري. وتم تحليل هذه العينات للتعرف على خصائصها الكيميائية. كما تم الحصول على صور لاندسات خلال ثلاث فترات زمنية مختلفة لرصد التغيرات في الغطاء النباتي وملوحة وغدق التربة. وأشارت النتائج التي تم الحصول الى وجود تباينا كبيرا في خواص التربة الفيزيائية والكيميائية بالواحة. وكان معظم الأراضى عالية الملوحة جدا وغير صودية وذلك على أساس قيم الـ EC و الـ ESP (EC = 77 ديسيسيمنز/ متر و ESP =14.62% في المتوسط). وقد زادت مساحة المناطق الزراعية من 22 كم^2 في 1992 الى 81 كم^2 في 2015. ومن ناحية أخرى، زادت مساحة الأراضى الملحية من 35 إلى 64 كم^2 وزادت أيضا مساحة المناطق الغدقة من 19 الى 51 كم^2 فى الفترة من 1992 الى 2015، على التوالي. ويمكن أن يعزى ذلك إلى التوسع في مشاريع استصلاح الأراضي والزيادة في ري المحاصيل وسوء الصرف. وتراوحت ملوحة المياه الجوفية بين 2.28 الى 5.45 ديسيسيمنز/ متر (3.76 ديسيسيمنز/ متر في المتوسط)، مما يشير إلى وجود تدهور في جودتها. ويمكن تلخيص ذلك فى أن الأراضى في واحة سيوة تعاني من مشكلة الملوحة ولذلك فهى فى حاجة الى برنامج مناسب لإستصلاح الأراضي بالأضافة الى تطوير نظم فعالة للري والصرف.