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Monitoring Spatio-Temporal Changes in Vegetation Cover, Soil Salinity and Waterlogging in Siwa Oasis, Egypt Using Remote Sensing Data and Techniques

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ABSTRACT

The availability of groundwater resources makes Siwa Oasis a potential region for agricultural projects in the western-desert of Egypt. This region, however, faces serious environmental problems such as water-logging and consequently soil salinization. Accordingly, the primary objectives of this research were to monitor and evaluate spatio-temporal changes in vegetation cover, water-logging and soil salinity in Siwa Oasis using remote sensing (RS) data and techniques. Therefore, Landsat images were acquired at four different periods (1986, 2000, 2013 and 2019), pre-processed and analyzed. Three spectral indices were used for studying the spatio-temporal changes in the mentioned land covers. These indices are the Optimized Soil Adjusted Vegetation Index (OSAVI), the Normalized Difference Water Index (NDWI) and the Salinity Index (SI). The obtained results indicated that the studied land covers were predicted at higher accuracy. Vegetated lands were increased from 19.64 km^2 in 1986 to 94.58 km^2 in 2019. Water-logging areas also increased from 19.42 to 57.00 km2 during the same period. However, sabkha areas decreased from 32.96 to 28.32 km^2. The increase in water-logging areas could be attributed to the increase in vegetated lands, use of inefficient irrigation systems and poor drainage in the closed depression. This, in turn, affects the residential buildings in the Old City as well as the agricultural lands in the low-lying areas of the Oasis .In conclusion, Siwa Oasis is in urgent need for developing an effective land management program, which should be taken into account using more effective irrigation systems and enhancing agricultural drainage in the area.

Keywords: Siwa Oasis, remote sensing, soil-salinity, water-logging, vegetation cover.

INTRODUCTION

Siwa Oasis is a great natural depression in the western-desert of Egypt. It represents a promising area for agricultural projects due to the availability of ground water resources. However, this area is facing serious land degradation problems such as water-logging and consequently soil salinity. Estimates of salt-affected soils vary widely, however they represent about one billion hectares (about 7% of the earth's continental extent) as reported by Ghassemi *et al*. (1995). Soil salinity represents one of the major land degradation problems under arid and semi-arid environments. It is either human-induced or naturally occurred. It causes negative impacts on plant growth and sustainability of agricultural lands (Ghassemi *et al*., 1995; Hanson *et al*., 1999; Toparkngarm, 2006). Consequently, it is imperative to monitor and map soil-salinity at a beginning phase so as to build up a successful soil reclamation plan that could help in the remediation of currently salt-affected soils and preventing future increase in soil salinity.

Currently, remote sensing data have proven their ability in providing reliable and at real time information about changes in land-cover dynamics. These data can help in detecting changes in vegetation covers, water-logging areas and soil salinity. Spectral indices have been widely used to highlight certain features such as vegetation, soil salinity, water features and so on. Vegetation indices such as the normalized difference vegetation index (NDVI) (Rouse *et al*., 1973), the soil adjusted vegetation index (SAVI) (Huete, 1988) and the optimized SAVI (Rondeaux *et al*., 1996) have been used in studying vegetation cover and heath. Vegetation heath could be used as indirect indicator of soil salinity. The normalized difference water index (NDWI), has likewise been utilized as indirect indicator of poor-drainage and subsequently soil-salinity (Mcfeeters, 1996).

Many others spectral indices have been developed for detecting soil-salinity (Khan *et al*., 2001; Douaoui *et al*., 2006). These indices have been used in monitoring the spatio-temporal changes in soil salinity and in developing salinity hazard maps over large areas (Elnaggar and Noller, 2010; Rashed, 2016). However most of these indices work well in the visible range of spectrum and under bare highly saline soils, where salt efflorescence is evident. In general, monitoring soil salinity needs first to identify the places where salt-accumulates and second on detecting the spatio-temporal changes in its occurrence. This depends mainly on the way in which salts distribute at the soil surface and within the soil profile and on the remote sensing capability of identifying salts (Zinck, 2001, Elnaggar and Noller, 2010).

Developing a system for managing land resources in Siwa Oasis requires obtaining more accurate and updated information about these resources. This is in order to face any problem that could lead to the degradation of these resources. Therefore, the primary objectives of this research work were to monitor and evaluate spatio-temporal changes in vegetation cover, soil-salinity and water-logging in Siwa Oasis, Egypt using remotely sensed data and techniques.

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MATERIALS AND METHODS

Study area

The studied area in Siwa Oasis is located between these coordinates 29º 6' 10.14"- 29º 18' 36.24" N and 25º 16' 2.36" to 25º 51' 3.04" E as illustrated in Fig. 1. It covers an area of about 606 km^2. This area has an arid to semi-arid cimate. The average monthly maximum temperature is 39.6 ºC in August, whereas the average monthly minimum temperature is 7 ºC in January. Mean annual precipitation is 13 mm and evaporation varied from 5.2 mm/day in December to 17 mm/day in June. Relative humidity ranged between 29% in May and 60% in December (Rashed, 2016).

The majority of soils in Siwa Oasis are sandy-textured soils (Elnaggar *et al*., 2017). They are low in soil organic matter (about 0.43%) and low in total porosity (about 41%) and CEC (13 Cmol kg^{-1}). Additionally, these soils are higher in soil salinity (about 77 dSm^{-1}), exchangeable magnesium percentage (about 45%) and total carbonates (about 27%). Soils in the Oasis are classified as *torripsamments* and *aquisalids* (Omar, 2005).

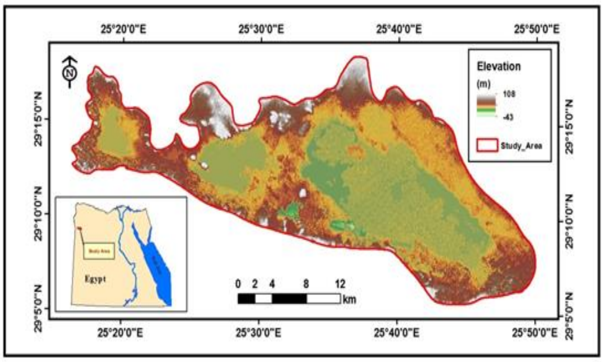

Fig.1. Location map of study area and its topography.

Remote sensing data

In this work, Landsat data were used to evaluate changes in vegetation cover, water logging and soil salinity within Siwa Oasis, Egypt. These data were acquired by the end of the summer season at four different years (1986, 2000, 2013 and 2019). The Oasis is covered by one image (path 180 and row 40) according to the WRS2 system. These Landsat images were downloaded from the United States geological Survey (USCS) web site called earth explorer (http://earthexplorer.usgs.gov/). The types of sensors and acquisition dates of these images are represented in Table 1. Digital image processing was carried out on the collected images using ENVI (ver. 5.3) software package as illustrated in Fig. 2.

Image preprocessing

Radiometric correction was carried out on the collected images. The pixel values were converted from digital numbers (DNs) into top of atmosphere reflectance using ENVI software package (ver. 5.3). Atmospheric correction was also preformed to eliminate the effects of dust, smoke and haze in the images and to get the surface reflectance. The dark object subtraction (DOS) method in ENVI was used in carrying out the atmospheric correction.

Geometric registration was also done based on the 1986 image to align all the studied images to the same reference image. All the studied images were projected using the UTM projection (Zone 35 N and WGS1984 datum) and had the same pixel size (30 m). Fig. 3 shows a false color composite (R=NIR, G= Red and G= Green) of the studied four images.

Table 1. Main characteristics of the studied Landsat images.

Sensor	Acquisition Date	Path	Row
Landsat 8 (OLI)	16/08/2019	180	40
Landsat 8 (OLI)	15/08/2013	180	40
Landsat 7 (ETM+)	19/08/2000	180	40
Landsat 5 (TM)	21/08/1986	180	40

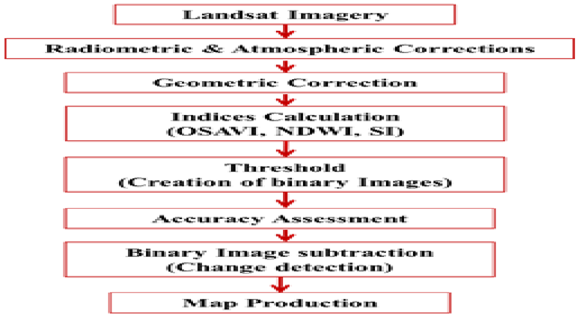

Fig. 2. Flowchart of image analysis and map production.

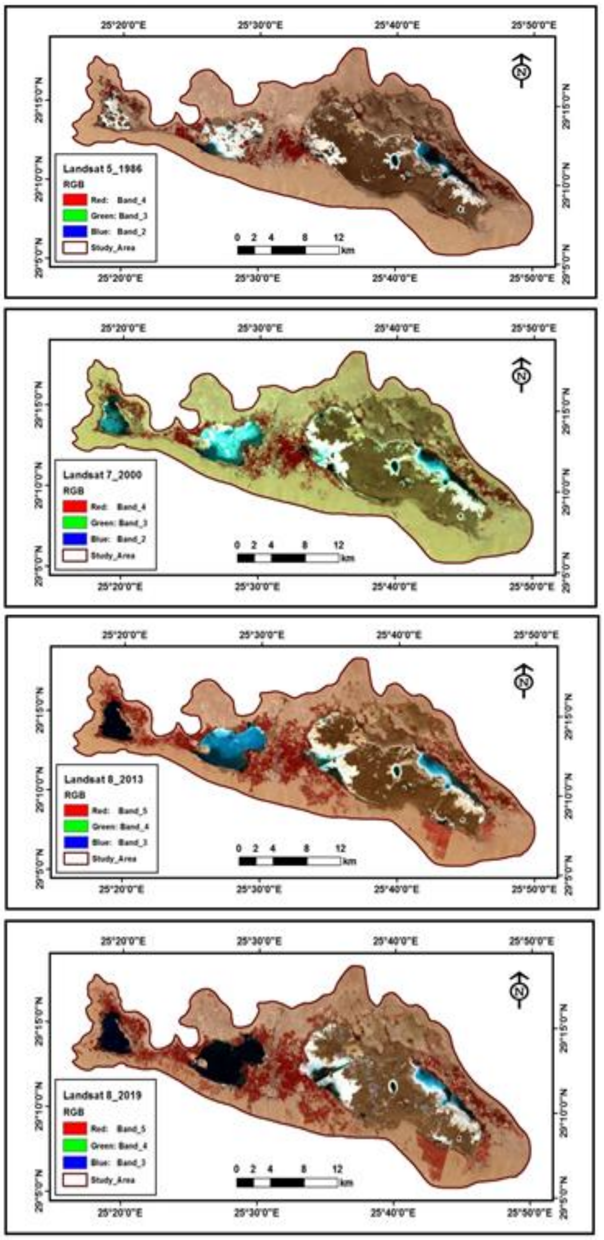

Fig. 3. Landsat images for Siwa Oasis in 1986, 2000, 2013 and 2019.

Studied Spectral Indices

The Optimized Soil-Adjusted Vegetation Index (OSAVI) was applied in this work to study the spatio-temporal changes in vegetation cover within the Oasis. The OSAVI is a modification of the Soil Adjusted Vegetation Index (SAVI) developed by Huete (1988). The OSAVI uses a standard value of 0.16 as a canopy background adjustment factor. According to Rondeaux *et al.* (1996), this value provides greater soil variation than the SAVI for low vegetation cover. It demonstrates an increased in sensitivity to vegetation cover greater than 50%. Accordingly, this index is best used in areas with relatively sparse vegetation where soil background is visible through the canopy. The OSAVI is computed using the following equation (Rondeaux *et al.*, 1996):

$$OSAVI = \frac{1.5 * (NIR - Red)}{(NIR + Red + 0.16)} \quad (1)$$

Where, NIR is the reflectance in the near-infrared part of spectrum and R is the reflectance in the visible red.

The vegetation cover and its health are also used as indirect indictor of soil salinity. Generally, saline soils are characterized by less dense and unhealthy vegetation. The Salinity Index (SI) developed by Douaoui *et al.* (2006) was applied in this work to study the spatial variability in Sabkha within Siwa Oasis. This salinity index showed a highly significant correlation with salinity, especially in sparsely vegetated and bare lands. This index is calculated as follow:

$$SI = \sqrt{Green^2 * Red^2} \quad (2)$$

Where, B and R are the spectral-reflectance in the visible blue and red bands, respectively.

The Normalized Difference Water Index (NDWI) developed by McFeeters's was used in this study to evaluate the spatial-changes in water-logged areas within Siwa Oasis. This index is calculated using the following equation (Mcfeeters, 1996):

$$NDWI = \frac{(\rho\ Green - \rho\ NIR)}{(\rho\ Green + \rho\ NIR)} \quad (3)$$

Where; ρ Green is the spectral-reflectance in the visible green band, whereas ρ NIR is the spectral-reflectance in the near infrared band.

Evaluation of the studied land covers

In order to evaluate of the studied land covers, a threshold value for each of the investigated OSAVI, SI, and NDWI indices. It is used to distinguish vegetated from non-vegetated areas, water-logged from dry lands and saline form non-saline soils. This threshold value was used to convert the continuous data in each image to a binary or a two class image (0 and 1). This image has only two-classes (i.e., vegetated and non-vegetated land, water-logged and dry land and sabkha and non-sabkha). The area under each class was computed by multiplying the number of pixels in that class by the pixel size.

Detecting changes in the investigated land-covers

Spatio-temporal changes in each of the investigated land-covers within Siwa Oasis were achieved through binary-image subtraction for two consecutive years. In this case, a new triple class image (+1, 0 and -1) will be obtained. The first class (+1) reveals positive change toward the studied land cover (i.e., vegetated land, sabkha and water-logging), the second class (0) indicates no-change in land cover, and the third class (-1) points out an opposite change in the investigated land-cover to another activity.

RESULTS AND DISCUSSIONS

Evaluation of vegetated areas in Siwa Oasis

Data in Table 2 show the temporal changes in vegetated areas within Siwa Oasis depending on the OSAVI index from 1986 to 2019. These vegetated areas were about 19.64, 38.17, 97.22 and 94.58 km^2 in 1986, 2000, 2013 and 2019; respectively. They represent about 3.24, 6.29, 16.03 and 15.59% of the studied area, respectively. Fig. 4 illustrates the spatio-temporal changes of these areas within the Oasis. The vegetated areas increased over the time in the Oasis; however, the significant increase was observed in the last decade. This is mainly due to the increase in land reclamation and cultivation activities, especially in the southern and northwestern parts of the Oasis. Soils in these areas are sandy-textured soils, which are easier in their reclamation when compared with other calcareous soils in the area.

On the other hand, the non-vegetated areas represent the majority of the Oasis. These areas were about 586.83, 568.29, 509.24 and 511.89 km^2 in 1986, 2000, 2013 and 2019; respectively. Their percentages were about 96.76, 93.71, 83.97 and 84.41%; respectively.

Table 2. Calculation of the vegetated-areas in Siwa Oasis from 1986 to 2019.

Land-cover	1986		2000		2013		2019	
	Area km^2	%	Area km^2	%	Area km^2	%	Area km^2	%
Non-Veg.	586.83	96.76	568.29	93.71	509.24	83.97	511.89	84.41
Veg. land	19.64	3.24	38.17	6.29	97.22	16.03	94.58	15.59
Total	606.47	100	606.47	100	606.47	100	606.47	100

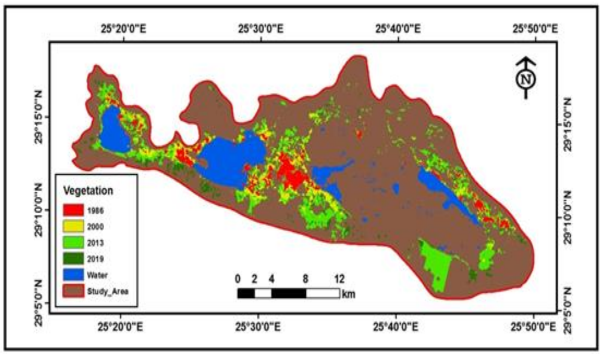

Fig. 4. Spatio-temporal changes in vegetated lands within Siwa Oasis from 1986 to 2019.

Evaluation of Sabkha in Siwa Oasis

Data in Table 3 represent changes in sabkha within Siwa Oasis depending on the SI index from 1986 to 2019. Sabkha areas were about 32.96, 36.39, 26.23 and 28.32 km^2 in 1986, 2000, 2013 and 2019; respectively. Their percentages were about 5.43, 6.00, 4.32 and 4.67%, respectively. Fig. 5 demonstrates the spatiao-temporal changes in shabka area within the Oasis. Sabkha was decreased over the time in the Oasis. The significant increase was observed during the period from 1986 to 2000. This is mainly due to the increases in vegetated areas within the Oasis, the use of conventional irrigation systems and poor drainage. This results in the conversion of some sabkha areas into permanent lakes.

It is also noticed that the used salinity index only detected highly saline soils (sabkha) in the Oasis, where it works in the visible range of spectrum (green and red). These soils generally have higher reflectance due to salt-efflorescence on their surface. Accordingly, there is need to integrate remotely sensed data with lab data in order to accurately map soil salinity at lower and moderate levels, where salt-efflorescence is not evident.

Table 3. Shabka area in Siwa Oasis from 1986 to 2019.

Land-cover	1986		2000		2013		2019	
	Area km^2	%	Area km^2	%	Area km^2	%	Area km^2	%
Non-sabkha	573.53	94.57	570.10	94.00	580.26	95.68	578.17	95.33
Sabkha	32.96	5.43	36.39	6.00	26.23	4.32	28.32	4.67
Total	606.49	100.00	606.49	100.00	606.49	100.00	606.49	100.00

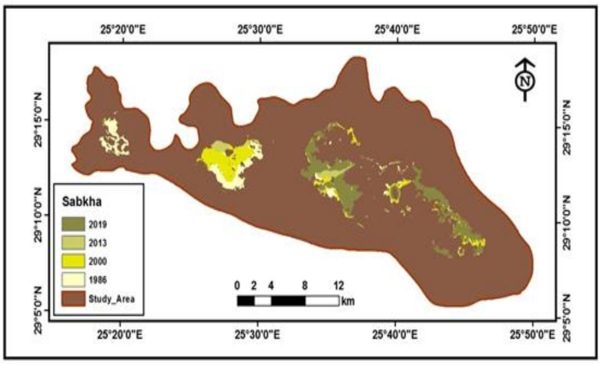

Fig. 5. Spatio-temporal changes in sabkha within Siwa Oasis from 1986 to 2019.

Evaluation of water-logging in Siwa Oasis

The estimated values of water-logged areas in Siwa Oasis depending on the NDWI from 1986 to 2019 are shown in Table 4. Water-logged areas were about 19.42, 48.47, 55.32 and 57.00 km^2 in 1986, 2000, 2013 and 2019; respectively. They represent about 3.20, 7.99, 9.12 and 9.40% of the studied area; respectively. These results reveal a significant increase in water-logged areas in Siwa Oasis from 1986 to 2019. This could be attributed to the increase in agricultural areas, use of inefficient irrigation systems and poor drainage. Similar results were obtained by (Misal *et al*., 1997; Masoud and Koike, 2006; El-Bastawesy *et al*., 2013; El-Said, 2017). Fig. 6 illustrates the spatial variability in water-logged areas within the Oasis.

In contrast, the dry areas were about 549.46, 557.99, 551.14 and 587.04 km^2 in 1986, 2000, 2013 and 2019; respectively. Their percentages were about 96.80, 92.01, 90.88 and 90.60%; respectively. Fig. 7 illustrates the estimated values of vegetated lands, water-logging areas, sabkha in Siwa Oasis during the four studied periods of time from 1986 to 2019.

Table 4. Water-logged areas in Siwa Oasis from 1986 to 2019.

Land-cover	1986		2000		2013		2019	
	Area km^2	%	Area km^2	%	Area km^2	%	Area km^2	%
Dry-land	587.04	96.80	557.99	92.01	551.14	90.88	549.46	90.60
Water body	19.42	3.20	48.47	7.99	55.32	9.12	57.00	9.40
Total	606.47	100	606.47	100	606.47	100	606.47	100

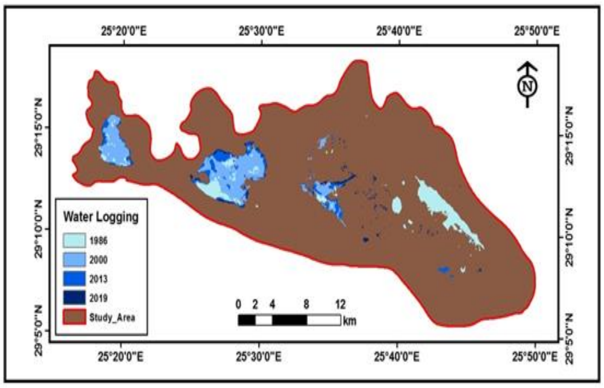

Fig. 6. Spatio-temporal changes in water-logging areas within Siwa Oasis from 1986 to 2019.

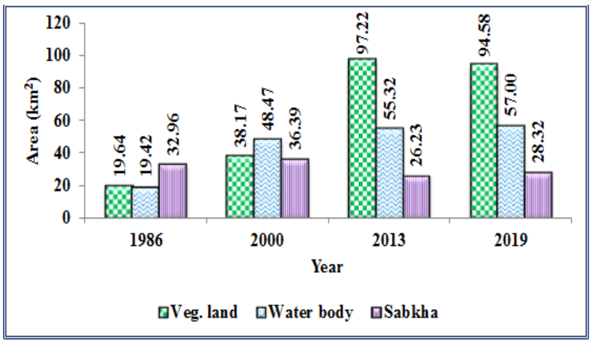

Fig. 7. Estimated values of vegetated lands, water-logging areas, sabkha in Siwa Oasis from 1986 to 2019.

Spatio-temporal changes in vegetated areas, saline soils and water logged areas

Table 5 shows the temporal changes in vegetated versus non-vegetated areas in studied are between each two successive periods of time, based on the OSAVI. The shifts from vegetated to non-vegetated areas were approximately 1.20 km^2 (0.20 percent) over the entire examined period of time from 1986 to 2019. On the other hand the shifts towards vegetated areas were approximately 76.14 km^2 (12.55 percent) during the same period (Fig. 8). These results indicate a general trend towards land cultivation projects.

Table 5. Temporal changes in vegetated versus non-vegetated areas between consecutive years from 1986 to 2019.

Type of change	1986 - 2000		1986 - 2013		1986 - 2019	
	Area km^2	%	Area km^2	%	Area km^2	%
To non-veg.	0.89	0.15	0.60	0.10	1.20	0.20
No change	586.15	96.65	527.69	87.01	529.13	87.25
To veg. land	19.43	3.20	78.18	12.89	76.14	12.55
Total	606.47	100	606.47	100	606.47	100
Type of change	2000 - 2013		2000 - 2019		2013- 2019	
	Area km^2	%	Area km^2	%	Area km^2	%
To non-veg.	0.82	0.13	2.04	0.34	15.34	2.53
No change	545.79	89.99	545.98	90.03	578.44	95.38
To veg. land	59.87	9.87	58.44	9.64	12.69	2.09
Total	606.47	100	606.47	100	606.47	100

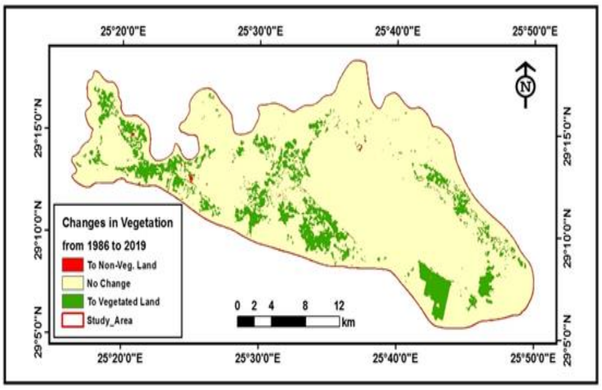

Fig. 8. Spatio-temporal changes in vegetation cover within Siwa Oasis from 1986 to 2019.

Table 6 represents temporal changes in sabkha and non-sabkha areas within Siwa Oasis between each two successive periods of time from 1986 to 2019 based on the studied SI index. Changes from sabkha to non-sabkha areas were about 24.59 km^2 (4.06 percent) from 1986 to 2019, whereas changes to sabkha areas were about 19.95 km^2 (3.29 percent) during the same period of time. The spatial distribution of these changes in sabkha areas within Siwa Oasis from 1986 to 2019 is illustrated in Fig. 9.

Table 6. Temporal changes in Sabka versus non-Sabkha areas within Siwa Oasis between consecutive years from 1986 to 2019.

Type of change	1986 - 2000		1986 - 2013		1986 - 2019	
	Area km^2	%	Area km^2	%	Area km^2	%
To non-sabkha	14.1	2.32	23.8	3.92	24.59	4.06
No change	574.84	94.78	565.61	93.26	561.92	92.65
To sabkha	17.53	2.89	17.06	2.81	19.95	3.29
Total	606.47	100	606.47	100	606.47	100
Type of change	2000 - 2013		2000 - 2019		2013 - 2019	
	Area km^2	%	Area km^2	%	Area km^2	%
To non-sabkha	17.2	2.84	20	3.3	6.39	1.05
No change	582.24	96.01	574.55	94.74	591.59	97.55
To sabkha	7.03	1.16	11.92	1.97	8.49	1.4
Total	606.47	100	606.47	100	606.47	100

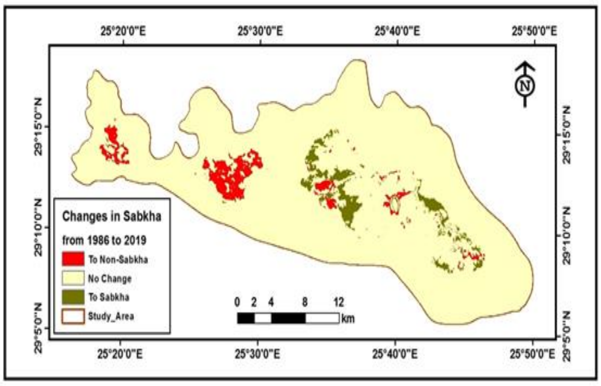

Fig. 9. Spatio-temporal changes in sabkha within Siwa Oasis from 1986 to 2019.

Table 7 shows the temporal changes in water-logged versus dry land areas within Siwa Oasis between each two consecutive periods of from 1986 to 2019 based on the studied NDWI index. The total changes from water-logged to dry land areas were about 3.66 km^2 (0.60 percent) from 1986 to 2019, whereas changes to water-logged areas were about 41.24 km^2 (6.80 percent) at the same period. The spatio-temporal changes in water-logged areas within Siwa Oasis from 1986 to 2019 are illustrated in Fig. 10.

Table 7. Temporal changes in water-logging versus dry-land areas between consecutive years from 1986 to 2019.

Type of change	1986 - 2000		1986 - 2013		1986 - 2019	
	Area km^2	%	Area km^2	%	Area km^2	%
To dry-land	0.96	0.16	2.21	0.36	3.66	0.60
No-change	575.50	94.89	566.14	93.35	561.58	92.60
To water body	30.01	4.95	38.12	6.28	41.24	6.80
Total	606.47	100	606.47	100	606.47	100
Type of change	2000 - 2013		2000 - 2019		2013 - 2019	
	Area km^2	%	Area km^2	%	Area km^2	%
To dry-land	2.54	0.42	4.20	0.69	3.15	0.52
No change	594.54	98.03	589.53	97.21	598.50	98.69
To water body	9.39	1.55	12.73	2.10	4.83	0.80
Total	606.47	100	606.47	100	606.47	100

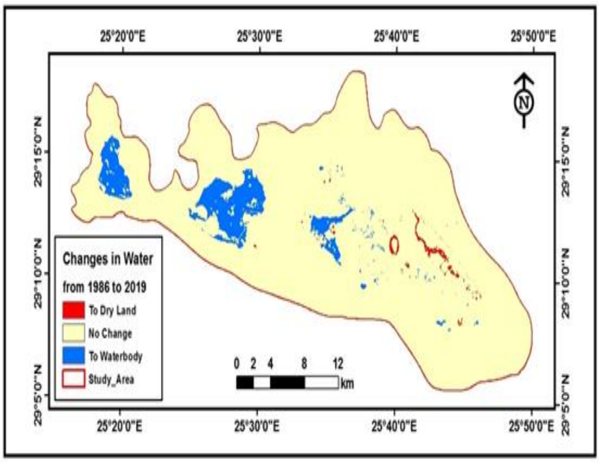

Fig. 10. Spatio-temporal changes in water-logging area within Siwa Oasis from 1986 to 2019.

CONCLUSION

It can be concluded that remote sensing data can provide reliable and at real time data that help in mapping and monitoring spatio-temporal changes in vegetation cover, water-logging areas and soil salinity within Siwa Oasis. There is an interchangeable relationship between vegetation cover, sabkha and water logged areas in the Oasis. The increase in vegetation areas due to land reclamation and cultivation projects, as well as the use of conventional irrigation systems and poor drainage, resulted in increased in water-logged areas. The increase in water-logged areas resulted in the decrease of sabkha, were old sabkha was converted into some permanent lakes. It is also noticed that remotely sensing data only detects highly saline-soils (Sabkha) in the Oasis, where salt-efflorescence is evident. Consequently, there is a need to integrate both remotely sensed data and laboratory data in order to map soil salinity at lower and moderate levels with higher accuracy.

In conclusion, Siwa Oasis is suffering from a poor drainage problem due to the closed depression, increase in vegetated lands and use of inefficient irrigation systems. Consequently, there is an urgent need for developing an effective land management program that takes into account using more effective irrigation systems and enhancing agricultural drainage in the area.

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رصد التغيرات المكانية والزمانية في الغطاء النباتي وملوحة التربة والغدق بالمياه في واحة سيوة ، مصر باستخدام بيانات وتقنيات الاستشعار عن بعد

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يجعل توافر موارد المياه الجوفية واحة سيوة من اولى المناطق المحتملة للمشاريع الزراعية في الصحراء الغربية لمصر. ومع ذلك ، تواجه هذه المنطقة مشاكل بيئية خطيرة مثل الغدق بالمياة وبالتالي تملح التربة. وبناءً على ذلك ، كانت الأهداف الأساسية لهذا البحث هي رصد وتقييم التغيرات المكانية والزمانية في الغطاء النباتي والغدق بالمياه وملوحة التربة في واحة سيوة باستخدام بيانات وتقنيات الاستشعار عن بعد (RS). لذلك ، تم الحصول على صور لاندسات في أربع فترات مختلفة (1986 ، 2000 ، 2013 و 2019). حيث تمت معالجة هذه الصور وتحليلها. كما تم استخدام ثلاثة مؤشرات طيفية لدراسة التغيرات المكانية والزمانية في الأغطية الأرضية المذكورة. هذه المؤشرات هي مؤشر الغطاء النباتي المحسن للتربة (OSAVI) ، ومؤشر اختلاف الماء المعياري (NDWI) ومؤشر الملوحة (SI). أوضحت النتائج التي تم الحصول عليها أن أغطية الأرض المدروسة تم تقييما بدقة عالية باستخدام المؤشرات المدروسة. حيث زادت مساحة الغطاء النباتى فى واحة سيوة من 19.64 إلى 94.58 كيلومتر مربع في 1986 و 2019 على التوالي. كما زادت مناطق الغدق بالمياة من 19.42 إلى 57.00 كيلومتر مربع. ومع ذلك ، انخفضت مساحة السبخة من 32.96 إلى 28.32 كيلومتر مربع. وهذه الزيادة في مناطق الغدق بالمياة يمكن أرجاعها الى الزيادة في مساحة الغطاء النباتى واستخدام أنظمة الري منخفضة الكفاءة وسوء الصرف في هذا المنخفض المغلق. والذى يؤثر بدورة على المبانى السكنية فى البلدة القديمة وكذلك الأراضى الزراعية الموجودة فى المناطق المنخفضة من الواحة. ويرجع الانخفاض في مساحة السبخة إلى تحويل السبخات الجافة إلى بعض البحيرات الدائمة. في الختام ، فإن واحة سيوة بحاجة ماسة إلى تطوير برنامج فعال لإدارة الأراضي والذى يجب أن يأخذ في الاعتبار استخدام أنظمة ري عالية الكفاءة وتحسين الصرف الزراعي في المنطقة.