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Monitoring and Assessment of Environmental Changes in Siwa Oasis, Egypt

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Anthropogenic activities were and will remain one of the most influential factors driving environmental changes. Human induced changes can reflect political, social, economic and ecological conditions prevailing an area in general or over a certain period of time. Three remotely sensed satellite images with a time lapse of fourteen years period of time (2003 – 2017) were obtained and investigated to detect changes that took place during that period and the ecological implications of these transformations. Satellite images were atmospherically and geometrically corrected. Normalized difference vegetation index (NDVI) was calculated for all images. Unsupervised and supervised classifications were applied to identify different environments. Change detection techniques were used to detect alterations in different surfaces. Results were combined and compared to previous studies of the same study area. Six classes were recognized and the overall changes showed that vegetation, water bodies and urban are increasing while salt marshes, sabkhas and barren soils are decreasing. However, changes are unequally distributed all over the whole oasis. Anthropogenic activities are the major trigger of all detected changes where the irrational use of water, lack of drainage system is intensively affecting all environments of Siwa Oasis. The present study expects the further expansion of the current water bodies which may escalate salinity problem with accumulating more salts in the soils of Siwa Oasis. Vegetation cover is also increasing and according to the results it is going to increase more in parallel with water bodies. Combination of our results and previous results during the period from 1987 to 2003 have

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confirmed our results and showed a clearer trends for the changing course in the major environments. Water management and raise of awareness should solve the problem of water bodies expansion and restrain the intensification of many of Siwa Oasis ecological problems.

Keywords: Environmental monitoring; change detection; anthropogenic activities; Siwa Oasis.

1. INTRODUCTION

For long time, it was a challenge to detect spatial and temporal changes in any environment and understand its dynamics to draw future scenarios, without exerting a lot of efforts and spending a lot of money. Since the seventies and the development of Geographic Information System (GIS) and Remote Sensing (RS) applications and techniques, it became a much easier job to extract and analyze data from satellite images. Remote sensing is focused on the acquisition of information about an object or phenomena without any physical contact, while GIS is a system that can manage, analyze and store almost all sorts of data and link it to geographical locations. Satellite images have developed much and more resources became available for public and more advanced applications and methods have been established to better deal with different aircrafts and satellite images [1–5].

Remote sensing and GIS techniques became very useful tools in processing and analyzing data for a large number of specialties in almost all disciplines [6–9]. Change detection is one of the most used applications of remote sensing [10–12]. It is a process, in which alterations in land use/cover over time is identified [13]. Advantages of using remote sensing for spotting and monitoring of changes over time may include the cost effectiveness and the highly productive results obtained by such techniques [2]. Change detection techniques have been applied in the fields of water and soil quality, land degradation, vegetation change, deforestation, desertification, soil erosion, coastal changes and habitat changes and all fields related to land use/cover changes [14–23].

Siwa Oasis is one of the five major oases of the western desert of Egypt. It lies between 29°10' to 29°16' N and 25°27' to 25°35' E (Fig. 1). Climate of Siwa is typical arid to semi-arid with a negligible rainfall, high evaporation rate and moderate to high humidity [24]. Data obtained from the metrological stations of the Egyptian Meteorological Authority in Siwa Oasis from (1994-2017) showed that Siwa Oasis is characterized by dry climate, relative humidity (40-60%), average temperature (5-40 °C), evaporation rate (5-15mm) and rainfall (0-3 mm), wind velocity (6.8-12.5 km/hour).

El-Saied et al. shed the light on the uniqueness of Siwa Oasis vegetation including the agricultural system as an ancient system with a rich cultural heritage that keeps much of its traditional cultivars. Food and Agriculture Organization of the United Nation (FAO) declared Siwa Oasis in October 2016 to be a Globally Important Agricultural Heritage System (GIAHS). Siwa Oasis agriculture are mainly composed of dates and olives orchards, everything else cultivated in the oasis is mostly for local consumption. Salinity is a major problem as it is affecting the productive soils of Siwa Oasis [25,26]. Salinity in Siwa Oasis is a result of the poor quality underground water, lack of proper drainage systems, flood irrigation scheme and the high evapotranspiration rates especially in summer [27]. Consequences of such problem is clearly expressed by the presence of many sabkhas and salt marshes. Another manifestation of the problem is the existence of the four salt lakes that characterize Siwa Oasis; Birket Al-Maraqi (9 km^2) and Birket Siwa (32 km^2) to the west of Siwa Oasis, while Birket Zaytun (16 km^2) and Birket Azmuri to the east [28].

Masoud and Koike (2006) detected land salinization change in Siwa Oasis since 1987 to 2003 [29]. Results showed a notable increase of salinity problem over time. The present work aimed at detecting the land use changes including vegetation and salt affected soils in Siwa Oasis over a fourteen year period of time since 2003 till 2017 using remote sensing and geographic information system techniques. Comparing our results to the previous results is to be achieved and discussed.

2. MATERIALS AND METHODS

Many field trips were conducted to the study area, in order to identify different characteristic features and habitats of Siwa Oasis in addition to a 100 ground truth points to support the accuracy assessment of the image classifications. Image processing techniques have been applied to detect land cover/use changes over the fourteen year period of time (2003 - 2017) using ENVI 5.2 software [30] and ArcGIS 10.2.2. [31]. A flow chart describing the methodology applied is shown in (Fig. 2).

Three Satellite images of Siwa Oasis were obtained to investigate land cover changes (2003, 2013 and 2017). At path 180 and row 40, Landsat 7 ETM image was obtained at 24-05-2003 and another Landsat 8 OLI images were obtained at 11-05-2013 and 22-05-2017 from U.S. Geological Survey (USGS) website (https://earthexplorer.usgs.gov), band designations of both satellites is provided in (Table 1). Images' bands 1-7 have been resampled and stacked except for the thermal bands because of its different resolution. Bands were resampled using the nearest neighbor algorithm. Images were registered after the same coordination system. Images were atmospherically corrected. Geometric correction to the Universal Transverse Mercator grid (UTM), zone 36, WGS84 were applied to the three satellite images.

Unsupervised classification using ISODATA and KMEANS clustering techniques were applied for all images for exploratory purposes and to increase the overall final classification accuracy. Supervised classification using maximum likelihood algorithm was employed to classify images. Regions of interest (ROI, known as training areas) have been identified before running the supervised classification. Post classification methods were applied and results were converted into vectors. Accuracy of the classification was assessed and corrections were made using ArcGIS 10.2.2 and with the help of the ground truth points.

Thematic maps were prepared for the three time points. Change detection techniques were applied to define changes over time in the defined regions using ENVI ver. 5.2. Normalized Difference Vegetation Index (NDVI) were calculated for the three images to separate vegetation from other regions based on the fact that chlorophyll absorbs red light while the internal leaf structure is reflecting near infrared (NIR) wavelength [32].

Pearson correlation was calculated to detect association of trends among different classes using SPSS ver. 23 [33].

Table 1. Band designations for the Landsat satellites 7 and 8 (after U.S Geological Survey)

Landsat 8 (Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS))			Landsat 7 (Enhanced Thematic Mapper Plus (ETM+))		
Bands	**Wavelength (μ m)**	**Resolution (m)**	**Bands**	**Wavelength (μ m)**	**Resolution (m)**
Band 1 - Ultra Blue (coastal/aerosol)	0.43 - 0.45	30	Band 1 – Blue	0.45-0.52	30
Band 2 – Blue	0.45 - 0.51	30	Band 2 – Green	0.52-0.60	30
Band 3 – Green	0.53 - 0.59	30	Band 3 – Red	0.63-0.69	30
Band 4 – Red	0.64 - 0.67	30	Band 4 - Near Infrared (NIR)	0.77-0.90	30
Band 5 - Near Infrared (NIR)	0.85 - 0.88	30	Band 5 - Shortwave Infrared (SWIR) 1	1.55-1.75	30
Band 6 - Shortwave Infrared (SWIR) 1	1.57 - 1.65	30	Band 6 – Thermal	10.40-12.50	60 * (30)
Band 7 - Shortwave Infrared (SWIR) 2	2.11 - 2.29	30	Band 7 - Shortwave Infrared (SWIR) 2	2.09-2.35	30
Band 8 – Panchromatic	0.50 - 0.68	15	Band 8 – Panchromatic	.52-.90	15
Band 9 – Cirrus	1.36 - 1.38	30			
Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100 * (30)			
Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 * (30)			

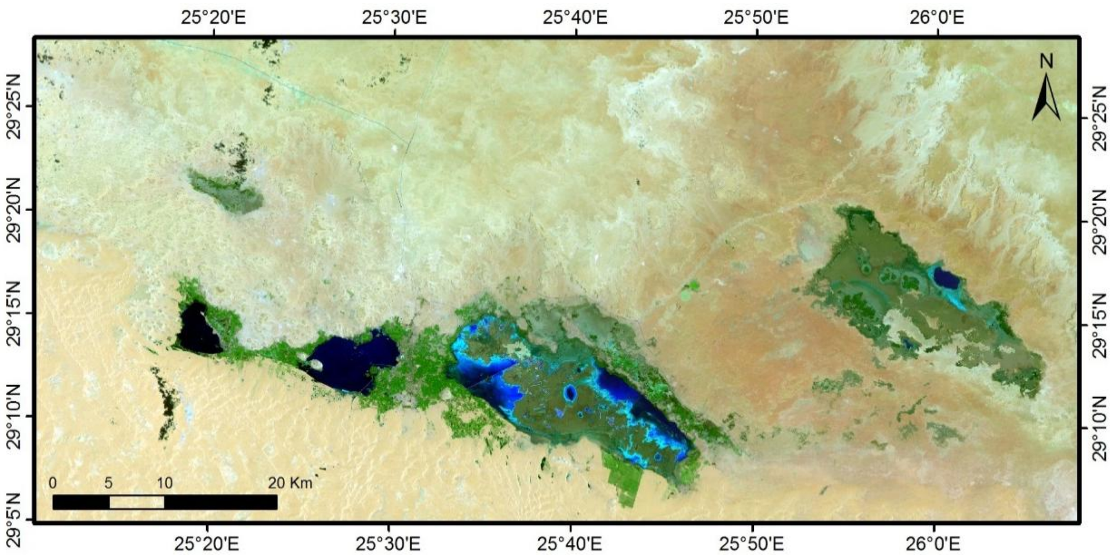

Fig. 1. Study area satellite image acquired at May, 2017 Bands (7, 5 and 3 RGB).

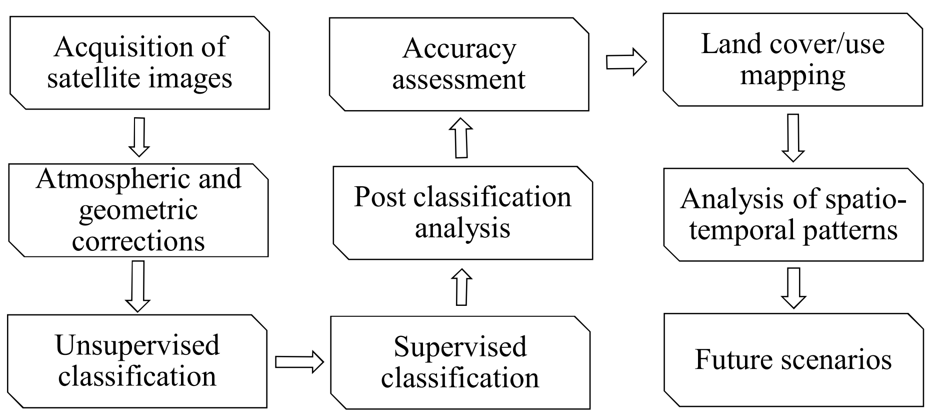

Fig. 2. A Flowchart describing the methodology applied to the studied imageries

3. RESULTS

3.1 Image Classification

Using ISODATA classification technique, the three images of 2003, 2013 and 2017 were classified. Due to the understanding of the study area features, only 5 to 10 classes were allowed to be produced from the classification. Six classes were produced by the classification in the three cases. Results of the unsupervised classification were used for enhancing the identification of the training areas of the supervised classification.

Supervised classification using maximum likelihood algorithm was applied for 2003, 2013 and 2017 images (Fig. 3). Six classes were identified as follows:

1- Vegetation including all sorts of cultivated lands in addition to the natural vegetation of the whole oasis;
2- Sabkhas including all forms of salt affected soils and abandoned lands except for the soil with a salty crust on its surface layer
3- Salt marshes including all regions with a dense surficial salt crust
4- Water bodies

5- Barren soil including all of the non-cultivated regions

6- Urban including all buildings, roads and related objects.

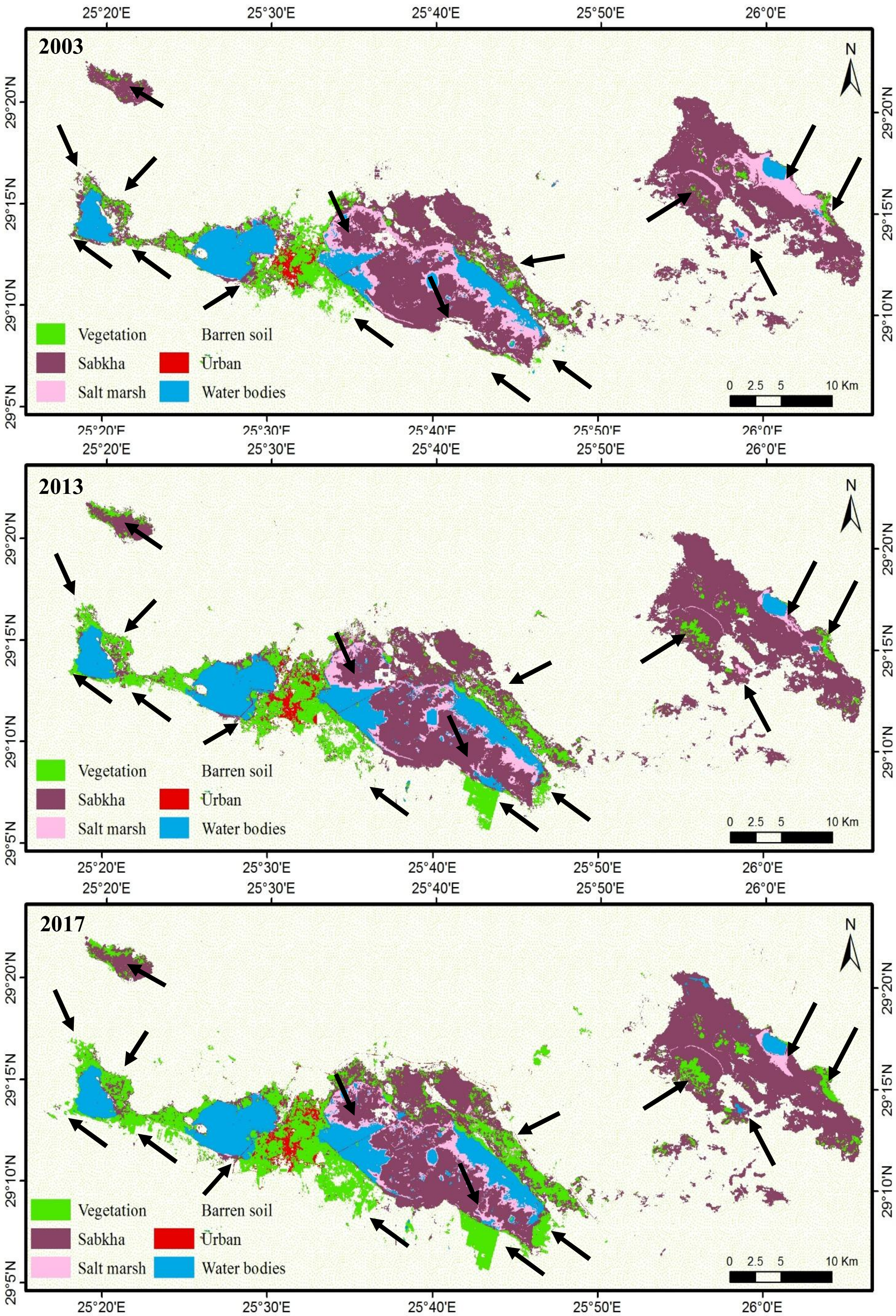

Fig. 3. Supervised classification of the study area showing the six identified classes at 2003, 2013 and 2017. The black arrows are pointing at areas where changes have took place over time whether in the form of shrinkage or expansion

3.2 Normalized Difference Vegetation Index (NDVI)

NDVI is one of the indices that is used for different purposes. It can reflect the healthiness of the vegetation and how dense it is. With the help of different indices as of the LST, it can help in determining a wide range of features including water needs, evaporation and evapotranspiration rates. NDVI ranges between (-1 and 1) and whenever NDVI value is closer to 1, it means more greenness and healthier vegetation and vice versa. Results of 20 randomly selected points showed higher NDVI values in 2017 than in 2013 and 2003 and higher NDVI values in 2013 than in 2003 which indicate dense vegetation cover in 2017 than in 2013 and 2003. Results of NDVI over the three time points is shown in (Fig. 4). Generally cultivated lands NDVI range is between 0.3 and 0.8. Bare soils including the sparse desert vegetation ranges from 0 - 0.3, while negative values of NDVI are marking water bodies.

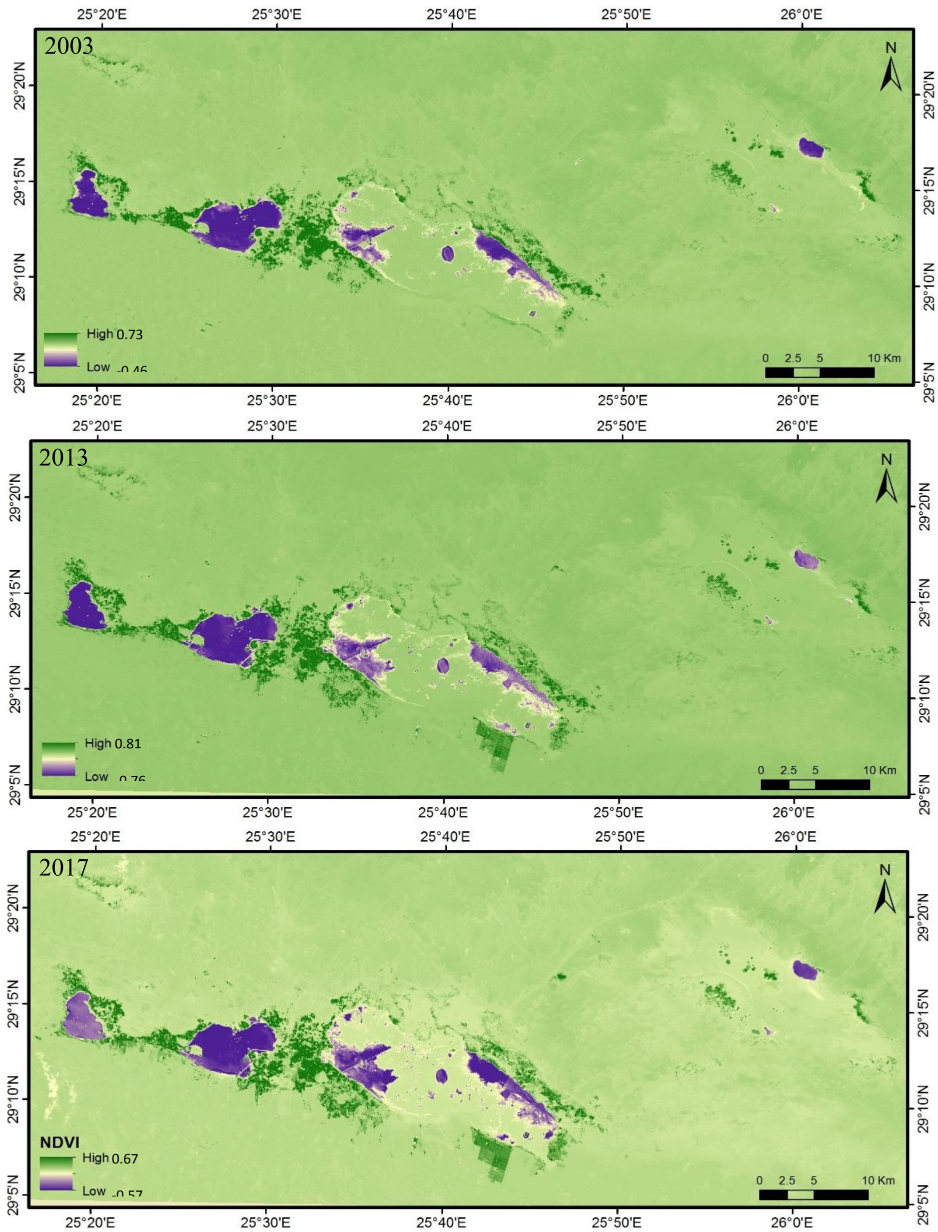

Fig. 4. Normalized difference vegetation index for Siwa Oasis (2003, 2013 and 2017)

3.3 Change Detection

Spatio-temporal changes have been investigated and results showed a significant variation between the three time points (Table 2). Vegetation cover has increased from 52.9 km^2 in 2003 to 88.99 km^2 in 2013 and 135.87 km^2 in 2017 with 156.7 % increase in cover. Water bodies showed similar trend with 23.1% increase from 71.61 km^2 in 2003 to 88.15 km^2 in 2017. Sabkhas area was almost stable with 4.19 km^2 decrease and less than 1.5 % change. Salt marshes area has changed from 55.9 km^2 in 2003 to 30.41 km^2 in 2017 with 45.6 % decrease. Barren soils has also decreased with 74.3 km^2 less in 2017 than in 2003. Urban has increased from 5.82 km^2 to 10.11 km^2 with 73.75 % increase. Percentage of cover change in all regions is shown in (Fig. 5). After excluding barren soils, sabkhas comes on the first place in relation to different classes followed by vegetation, water bodies, salt marshes and urban (Fig. 6).

Land cover changes detected are not evenly distributed all over the study area. Results showed that different changes might be linked to different parts of the Oasis (Fig. 3). To the west of the oasis, water bodies and vegetation has significantly increased by replacing sabkhas, salt marshes and barren soils. In the center of the Oasis, Water has widely replaced salt marshes and some parts of the sabkha while vegetation has replaced some parts of the sabkhas and barren soils. To the east, sabkhas has replaced a large areas of salt marshes while vegetation on the other side has replaced parts of the sabkhas and barren soils. The overall land cover change in vegetation, sabkha, saltmarsh and water bodies is shown in (Fig. 8).

Table 2. Siwa Oasis land cover during the period from 2003 to 2017

Land use pattern	Area km^2 (%) (2003)	Area km^2 (%) (2013)	Area km^2 (%) (2017)	DF km^2 (%) (2003-2013)	DF km^2 (%) (2013-2017)	DF km^2 (%) (2003-2017)
Vegetation	52.92 (1.12)	88.99 (1.88)	135.87 (2.87)	36.07 (68.15)	46.88 (52.68)	82.95 (156.7)
Sabkha	296.14 (6.27)	293.99 (6.23)	291.94 (6.18)	-2.15 (-0.72)	-2.04 (-0.69)	-4.19 (-1.41)
Salt marsh	55.91 (1.18)	29.42 (0.62)	30.412 (0.64)	-26.49 (-47.3)	0.992 (3.374)	-25.4 (-45.6)
Barren soil	4239.81 (89.78)	4214.9 (89.27)	4165.4 (88.2)	-24.92 (-0.58)	-49.4 (-1.17)	-74.3 (-1.75)
Urban	5.82 (0.12)	8.44 (0.18)	10.112 (0.21)	2.62 (45.01)	1.672 (19.81)	4.292 (73.75)
Water bodies	71.61 (1.52)	85.68 (1.81)	88.155 (1.86)	14.07 (19.64)	2.475 (2.888)	16.54 (23.10)

DF: Difference in area between two time points

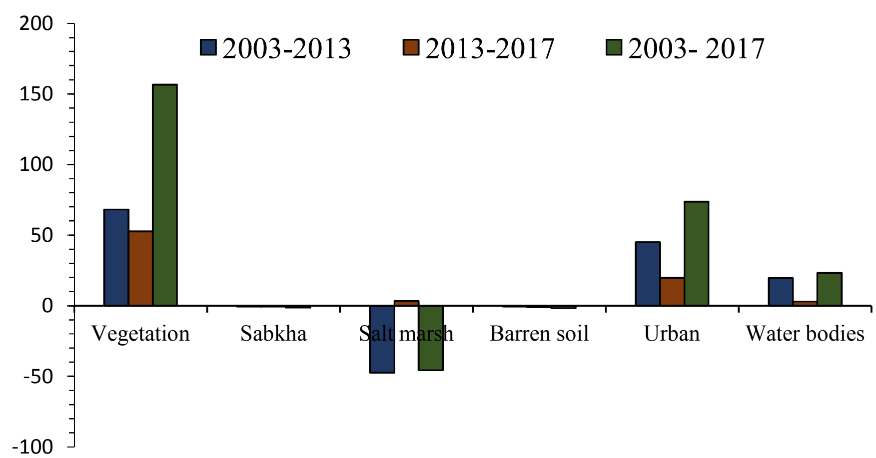

Fig. 5. Percentage (%) of land cover change in Siwa Oasis different classes (2003-2017)

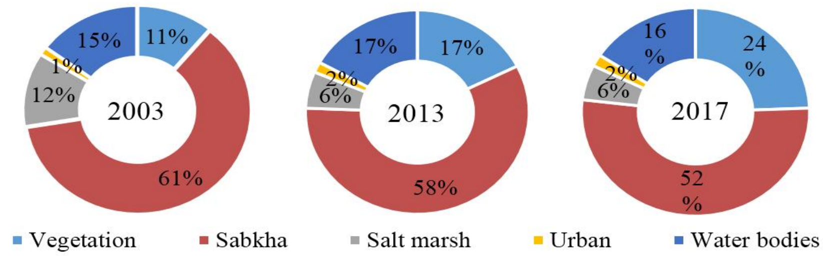

Fig. 6. Percentage (%) of each class cover to the total area after excluding Barren soil

4. DISCUSSION

The present study aimed at detecting the land cover changes that took place in the fourteen years period of time from 2003 to 2017 and to predict the possible ecological implications of these changes on Siwa Oasis future. Three remotely sensed images (2003, 2013 and 2017) were used to achieve the aim of this work. Study area was classified into six classes and changes in each class were detected. Several changes have took place in all classes. Vegetation, water bodies, urban regions have increased while sabkhas, salt marshes, and barren soils have decreased.

Vegetation has increased dramatically in Siwa oasis where around 28,635 feddans were cultivated in 2017 in comparison to less than eight thousand feddans thirty years ago in 1987 [29,34]. Vegetation of both natural and agricultural systems have been estimated in the present study to be 12,599, 21,188 and 32,351 feddans in 2003, 2013 and 2017, respectively. The remarkable increase of vegetation with 156.7% more in 2017 than in 2003 may be due different reasons. First is the state after the Arab Spring that created a necessity for looking after agriculture as a source of income and as a solution for the abrupt high unemployment rate because of the stalled tourism that decreased all over the country from 14.7 million tourists in 2010 to 5.4 million in 2016 [35]. Second is the situation prevailed the last two decades where new comers from some parts of the Nile Valley and Delta, and due to different economic and social reasons have inhabited and cultivated some new areas in Siwa Oasis after selling their small high price territories in their home governorates to buy low price large areas in Siwa Oasis. Large national and international agriculture and dairy corporates have also considered this opportunity to buy large virgin unpolluted terrains for reasonable prices [34]. All of these reasons supports the immense increase in vegetation over the fourteen years period of time. What may also support our point of view is the higher rate of increase in the last four years from 2013 to 2017 with 11161 feddans increase in comparison to only 8588 feddans during the ten years period of time from 2003 to 2013. Population increase is another important reason which might be reflected by the 73.75 % increase in urban regions in 2017 than in 2003.These points not only applies to Siwa Oasis but also to the other oases of the Western Desert of Egypt [36].

Classification results showed that natural vegetation has increased as well which may be due to the fact that these areas are closed against any anthropogenic activities including both touristic as well as for the very usual grazing activities (Egypt has declared this area to be restricted because of the heavy smuggling and weapons trafficking activities through the Libyan borders). Vegetation has replaced parts of all other classes but mainly barren soils with decrease 74.3 km^2 in 2017 than in 2003.

Water bodies have also increased overtime with 23.1 % more in 2017 than in 2003. In the last two decades, the government has dug deep wells in Siwa Oasis and it had a positive effects on the agriculture, however, the irrational use of the precious nonrenewable underground water was one of the negative effects that sources several problems. The large amounts of water produced by the new wells has encouraged the cultivation of wheat, barley, beans, alfalfa, maize and even some highly water consumptive crops such as rice [37]. Gad (2000) reported that around 33 million m^3 of water are wasted every year [38]. El Hossary (2013) stated that the expansion of Siwa Oasis four lakes is inevitable with the overflowing of about 100 million m^3 of waste water every year into these lakes [39]. Scenarios claimed that the wasted water could be used for the cultivation of new 9000 Feddans [39]. Lack of the good drainage system is another problem that escalates the problem of water waste and soil salinity at the same time[29,40]. The massive increase in vegetation during the period from 2013 to 2017 has restrained the expansion of water bodies, as more water is used for irrigation, with only 3% increase to be the minimum increase rate since 1987 (Table 3).

As we are dealing with satellite images with limited resolution (each pixel = 30*30 m^2), some patches were difficult to distinguish. In order to deal with this problem, some regions were grouped under one class. Sabkhas, salt affected soils and abandoned lands were grouped under a class named after the largest member of the group (Sabkhas). Sabkhas has decreased with less than 1.4 % in 2017 than in 2003. Additionally, salt marshes have decreased dramatically with less 45.6 % in cover in 2017 than in 2003. However it might look like that the salinity problem is solved, but three realities are to be considered; First, Water bodies, salt marshes and Sabkhas are temporarily replacing each other all the time especially in winter and summer and under the effect of evaporation and evapotranspiration processes. Second, sabkhas has replaced some parts of the barren soils and salt marshes in the east of Siwa Oasis, while some parts of sabkhas, abandoned lands and salt affected soils have been replaced by water bodies and vegetation in the western part (Fig. 8). Third, salt marshes was replaced mostly by water bodies and sabkhas in the center and the east of Siwa Oasis (Figs. 3 and 8). Previously mentioned facts are indicating that salinity problem is expected to be escalated and with wasting more water, higher concentrations of salts are added to the soils of Siwa Oasis.

In order to better understand the situation on the ground and the expected future of land cover changes in Siwa Oasis, results of Masoud and Koike, 2006 have been combined with our results and reanalyzed (Table 3). Points that increase the reliability of this combination and the outcomes of it are: 1- Both of the present study and Masoud and Koike, 2006 study are sharing a satellite image from the same year (2003) and with only one day difference (23rd and 24th of May 2003); 2- Four classes have been identified in Masoud and Koike, 2006 study (Water, vegetation, wet sabkha/salt crust and dry sabkha) which is in accordance with four of the six identified classes of the present study; 3- Results of both studies is showing similar results in the year 2003 with slight differences except for the salt marsh (wet sabkha/salt crust) class which may be due to different definition of the class. However, a similar time trend of salt marshes is clear throughout both studies. Results of 1987 and 2000 were adopted from Masoud and Koike, 2006 study while 2003, 2013 and 2017 results were adopted from the present study.

Percentage of change in each class in relation to the percentage of other classes throughout the five time points is shown in (Fig. 7A). Trends showed a significant decrease in Sabkhas and salt marshes while water bodies and vegetation increased. These trends are confirming our results. Percentage of change in relation to the same class over the five time points is shown in (Fig. 7B). The line chart showed a great increase in water bodies followed by vegetation while salt marshes and sabkhas decreased. For clearer trends, results of 2003 were excluded as all classes remained almost unchanged during the period from 2000 – 2003 except for water bodies and sabkhas. Trends showed that water bodies have the highest increasing rate followed by vegetation while sabkhas on the other side tend to be stable and salt marshes are significantly decreasing over time (Fig. 7C).

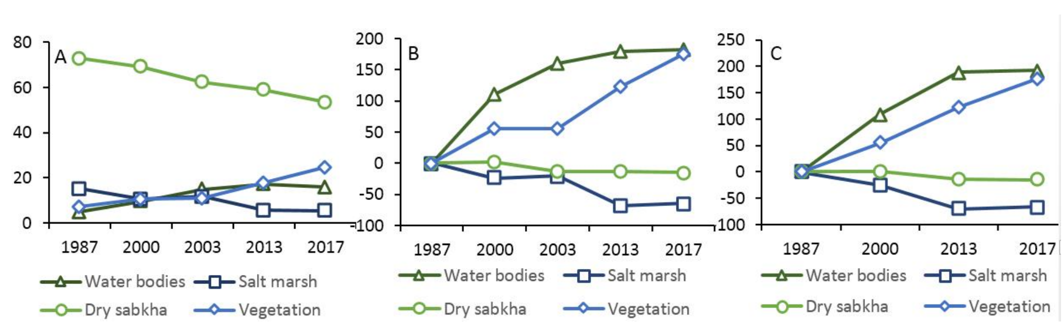

Fig. 7. Percentage of land cover change in relation to the percentage of other classes during the period of 1987 -2017 (A); Cumulative percentage of land cover change in relation to the same class during the period of 1987 -2017 (B); Cumulative percentage of land cover change in relation to the same class during the period of 1987 -2017 after excluding 2003 results (C)

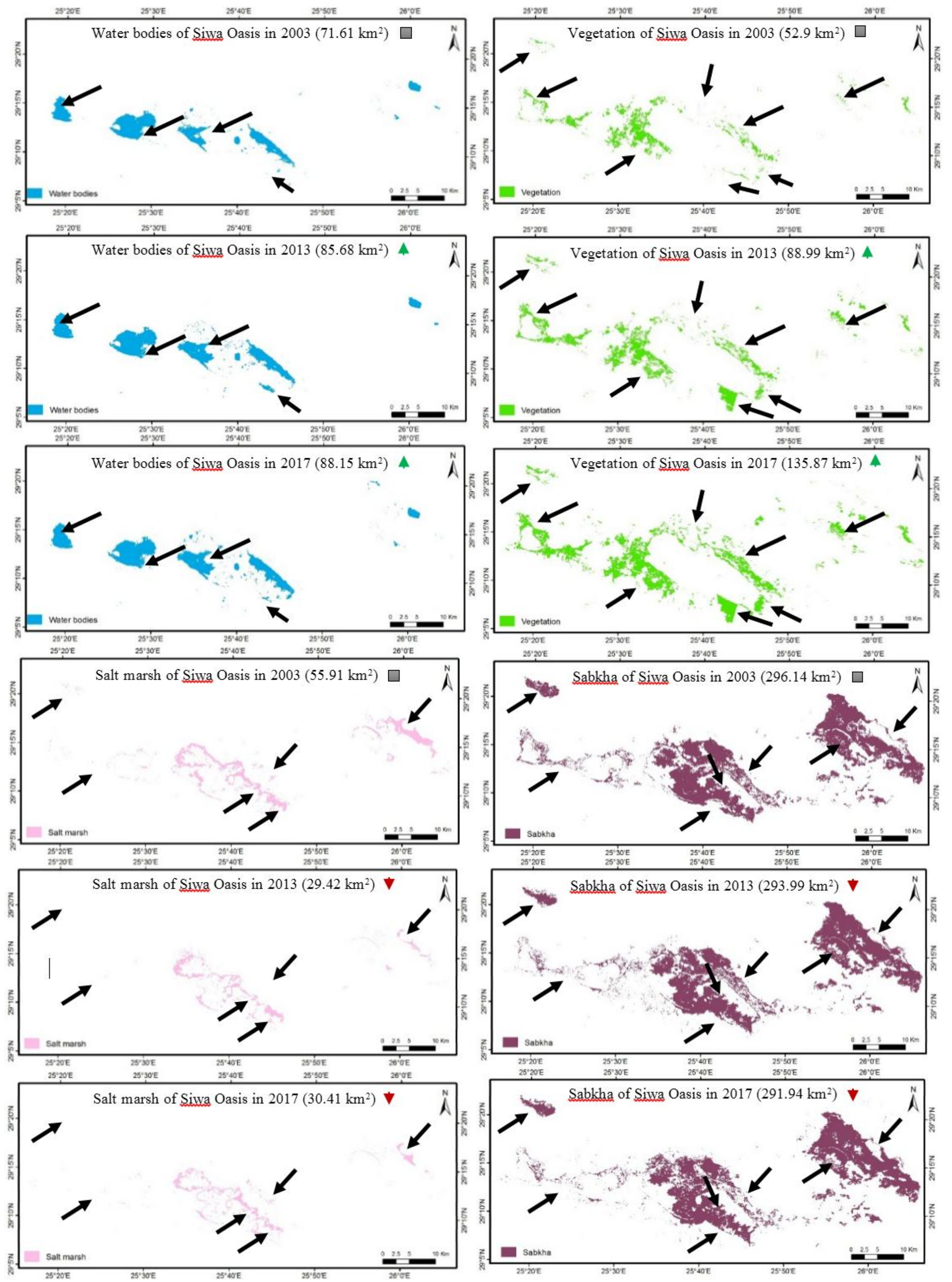

Fig. 8. Overall changes in vegetation, water bodies, sabkhas and salt marshes in 2003, 2013 and 2017. Quadrates are representing the area of different classes in 2003 while green and red arrows are representing the increase or decrease in the areas in 2013 and 2017, respectively

Table 3. Siwa Oasis land cover during the period from 1987 – 2017

Year	Water bodies	% of Change	Salt marsh	% of Change	Sabkha	% of Change	Vegetation	% of Change
1987 (Masoud and Koike, 2006)	22.78	--	71.29	--	342.45	--	34.11	--
2000 (Masoud and Koike, 2006)	47.87	110.14	53.75	-24.6	346.66	1.2293	52.93	55.174
2003 (Masoud and Koike, 2006)	72.64	51.74	78	45.11	306.91	-11.4	48.62	-8.14
2003 (Present work)	71.61	49.59	55.91	4.018	296.14	-14.5	52.92	-0.01
2013 (Present work)	85.68	19.64	29.42	-47.3	293.99	-0.72	88.99	68.15
2017 (Present work)	88.155	2.888	30.412	3.371	291.94	-0.69	135.87	52.68

Table 4. Pearson correlation among different classes of Siwa Oasis land cover

	Water bodies	Salt marshes	Sabkhas	Vegetation
Water bodies	1	-.914*	-.911*	0.813
P-Value		0.03	0.031	0.094
Salt marshes	-.914*	1	0.736	-.889*
P-Value	0.03		0.156	0.043
Sabkhas	-.911*	0.736	1	-0.693
P-Value	0.031	0.156		0.194
Vegetation	0.813	-.889*	-0.693	1
P-Value	0.094	0.043	0.194	

In order to detect the association trends among different classes, Pearson correlation coefficient was calculated. A significant negative correlations were met between water bodies and both salt marshes and sabkhas, while a significant negative correlation was found between vegetation and salt marshes (Table 4). Due to the small number of time points, strong positive correlations between water bodies and vegetation and between salt marshes and sabkha were found non-significant. On the other side strong negative correlations between salt marshes and vegetation and between sabkha and vegetation were also found non-significant.

5. CONCLUSION

The present study has verified the trustworthiness of Geographic Information System and Remote Sensing techniques in detecting, monitoring and predicting land cover changes. The present study showed that the results obtained by such techniques are persistent and could be tested and repeated to bring the same or a very close results with a marginal percentage of error. Calculation of the cultivated area produced from satellite images and its closeness to the number reported by Siwa information center is another prove of reliability and that the application of such techniques would bring the same results of the conventional techniques with much less cost, manpower, effort and time. Combination of image analysis techniques and backing it up with field work is undoubtedly increase the accuracy of the obtained results. Understanding and interpreting results obtained by Remote Sensing techniques is definitely relying on the experience of the researcher in both remote sensing as a science and the nature of the area of interest.

The present study has shed the light on land cover change in Siwa Oasis during the period from 2003 to 2017. Results showed that water is the root of all the changes detected in Siwa Oasis. Pearson correlation results among different classes confirmed that less water means more sabkhas, salt marshes, abandoned lands and salt affected soils and less vegetation. More water means more vegetation and larger water bodies, more salt concentration in soils. Under current circumstances, water bodies is highly suggested to expand and more soils are recommended to be saline. Vegetation is increasing and farmers are facing salinity problem with flooding more water which may restrain their own problem but certainly escalating the problem of the whole oasis. All of the spotted changes are mostly due to anthropogenic activities and merely raise of awareness, regulations and management of natural resources can dismantle the complex situation in Siwa Oasis agro ecosystems. The present study may be used later for further environmental monitoring of land cover/use change patterns in Siwa Oasis. Further studies especially on the natural flora and environmental factors prevailing Siwa Oasis is of great importance.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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