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Monitoring land use/land cover spatiotemporal changes and its implications on the productivity of Idku Lake, Egypt

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ABSTRACT

Lakes are considered one of the most important components of the land cover which is exposed to environmental changes threatening their sustainability. Idku is one of the most radical coastal lakes in Egypt. Thus, the current study focused its aim on setting a database for LULC spatiotemporal changes of Idku Lake that can be relied on for the management and the comprehensive study of its productivity and related economics. Satellite images of CORONA, Landsat TM, ETM, and OLI-TIRS and Sentinel-2A were used throughout the period from 1967 to 2021. Different processing techniques were applied to extract different features in the study area such as hydrophytes, water bodies, islands and urban. Results indicate that there is a great diminution in Idku Lake's total area of about 58% from 136.5 km^2 in 1967 to 56 km^2 in 2021, with vegetation covering of about twice the open water area and a depth range between 0.18-3.03m. These phenomena are attributed to anthropogenic unregulated activities of land use in which aquaculture represented 80.5% of the reduced area. The problem can be defined in terms of sustainability in general and productivity in particular. Based on the results and according to CAPMAS, fish production of Idku Lake and its related economy have witnessed a change over the past two decades. The period from 1994 to 2004 reflected an increasing trend and the period from 2004 to 2019 reflected a dramatically decreasing production trend. Idku Lake recorded a 30% of fish production loss from 2004 to 2019 and a 46% of economic return loss of about 8.2 million$ yearly. Lake change and pollution are key factors in production detraction and quality alteration rather than health and economic effect, and thus there should be monitoring and control mechanisms for those changes.

INTRODUCTION

Land use and land cover are important factors in global environmental change and sustainability **(Hegazy & Kaloop 2015)**. To ensure the sustainable management of natural resources, it is important to monitor and control the processes of change in land use and land cover **(Petit *et al.*, 2001)**. The spatial distribution of land use and land cover using satellite images is a key factor to understand and explain the phenomenon of global environmental change. Remote sensing and satellite data are used on a large scale to achieve an effective way in terms of cost reduction to detect the changes in land use and land cover over wide geographic areas **(Lunetta & Worthy 2006)** and study the place at different times **(Singh,**

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1989). Change detection in land use and land cover is an important factor to comprehend the interaction and the relationship between human activities and environment.

To understand how land use and land cover impact ecosystems, it is necessary to develop a classification system for the entire region and provide information on what changes occur, where and when they occur, the rates at which they occur, and the physical and social forces that drive these changes **(Lambin *et al*., 2003)**.

The Mediterranean basin in Egypt includes five northern lakes, they are arranged from the west to the east as follows: Mariout - Idku - Burullus - Manzala - Bardawil; these lakes ar significantly important in terms of fish production that amounts about 40% of the total fish production in Egypt **(El Kafrawy *et al.*, 2019)**. The lakes are encountered with a range of challenges, including the diminution of its area and problems resulting from the expansion of agricultural, industrial activities and fishfarms. Idku Lake is one of the most threatened aquatic wetlands in Egypt due to anthropogenic activities and pollution. It receives huge amounts of drainage water that mostly give rise to water movement through the lagoon from both the east and the south to the north **(Khalil & Rifaat, 2013)**. Unfortunately, Idku Lake lost about 77% of its surface area between 1957 and 2012 **(Moufaddal *et al.*, 2008; Shalaby, 2012)**. Heavy vegetation cover the largest area of the lake **(Shawer & Ibrahim, 2010)**.

Available data on surface area of Idku Lake is out of date and sometimes not accurate **(Moufaddal *et al.*, 2008)** thus it is important to focus on performing a reliable database for LULC spatiotemporal changes of Idku Lake for its management and to apply a comprehensive study for the available data of Idku Lake productivity and related economics to stand on their alterations as a secondary consequence of lake change.

MATERIALS AND METHODS

1. Study area

Idku Lake located in the Northwest of the Nile delta and parallel to the Mediterranean Sea at about 36 km east of Alexandria with an area of about 62.7 km^2, of which 22 km^2 of the total surface area is open water whereas, the rest is covered by aquatic vegetation and islands **(Moufaddal *et al.*, 2008)**. In 2017, the lake's water surface area reached 16.8 km^2 (about 4000 feddan) **(EEAA, 2017)**. It is located between latitudes °31 ´10 and °31 ´18 N and longitudes °30 ´23 and °30 ´8 E **(Fig. 1)**. It receives saline water from the sea through Boughaz El-Maadyah at the northe**rani *et al.*, 2001)** and receives drainage freshwater from two main drains namely Kom-Belag and Barsik drain. **Figure (2)** shows drains of Idku Lake.

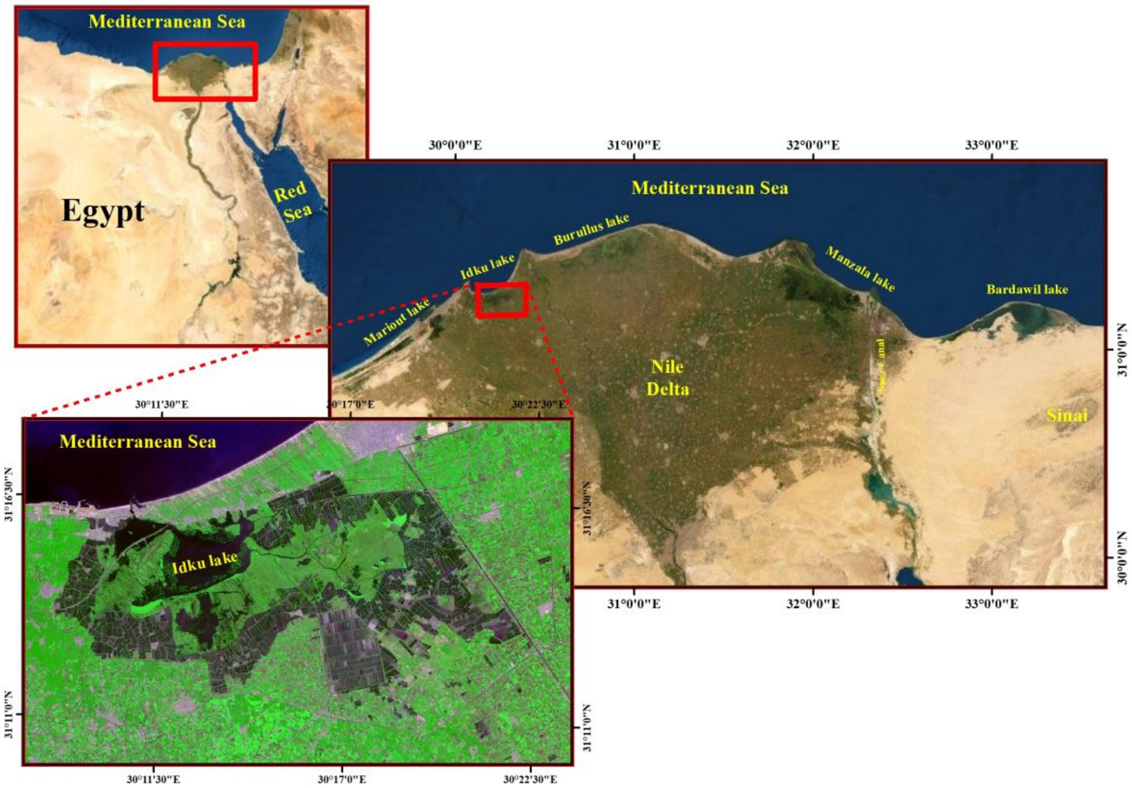

Fig. (1). Location map of study area; Idku lake, Egypt

2. Field trip and survey

Field survey in the study area was done during November 2021 to help interpret the remotely sensed data and for bathymetric measurements at thouthands of points covering the whole sector of the lake using Echosounder equipment with integrated positioning system (GPS), the equipment was tested and verified at two different points before and after the survey.

3. Remote sensing data and GIS analysis

3.1. Satellite images

Satellite data is required for achieving the objectives of the current study to evaluate Idku Lake data during time period from 1985 to 2021, seven satellite images were selected with nearly 0% cloud covering and then downloaded using the United States Geological Survey site (USGS) as follow: (1) Landsat 1985, 1990, 1996, 2001, 2013, (2) Sentinel 2018 and 2021. Details of Satellite images are shown in **Table (1)**. Moreover, CORONA high-resolution satellite imagery of November 1967 was downloaded. Lake boundary was extracted from this image to compare lake area with the more recent ones.

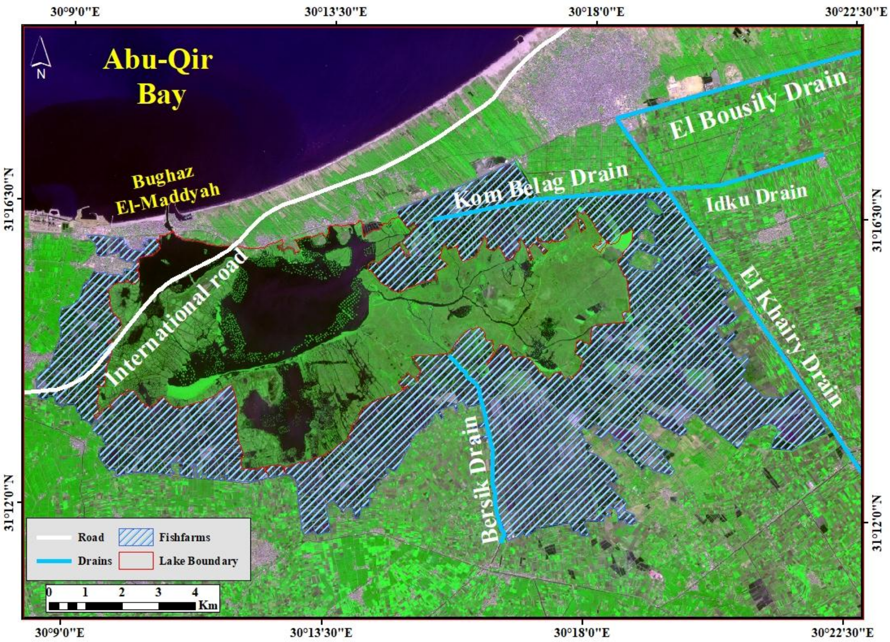

Fig. (2). Idku lake drains

4. Remote sensing data and GIS analysis

4.1. Satellite images

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Table (1). Details of downloaded satellite images

No.	Date	Path / Row or Tile No.	Satellite	Spatial Resolution
1	11/1967	-------	CORONA	1.8 m
2	7/1985	176/38	Landsat-5 TM	30 m
3	6/1990	176/38	Landsat-5 TM	30 m
4	6/1996	176/38	Landsat-5 TM	30 m
5	5/2001	176/38	Landsat-7 ETM	30 m
6	11/2013	176/38	Landsat-8 OLI-TIRS	30 m
7	4/2018	T36RTV	Sentinel-2A	10 m
8	6/2021	T36RTV	Sentinel-2A	10 m

4.2. Image preprocessing

Layer stacking, radiometric and geometric corrections were done for downloaded images using ArcGIS package for further processing.

4.3. Image processing

4.3.1. Image enhancement

Images to be more effective for display for subsequent visual interpretation, and for more information to be extracted, they are enhanced by amplifying the slight differences to make them readily observable using ArcGIS package.

4.3.2. On-Screen Digitizing

Idku Lake's boundary was digitized (extracted) at 1:5,000 scale using On-screen digitizing method. Extraction of land covering, drains, urban and fish-farms were also performed.

4.3.3. NDVI

Normalized Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs) by using its formula (NDVI = NIR - RED / NIR + RED). NDVI is applied to identify and extract hydrophytes and agriculture from other features in the studied images.

4.3.4. NDWI

Normalized Difference Water Index (NDWI) quantifies water **(Xu, 2006)**, was calculated using its formula (NDWI = Green – NIR / Green + NIR). The Green and NIR are the reflection in the green and infrared bands of the Landsat images. NDWI is applied to identify and extract water from other features in the studied images.

4.3.5. Interpolation

Interpolation uses vector points with known values to estimate values at unknown locations to create a raster surface covering an entire area. Spatial interpolation is therefore a mean of creating surface data from sample points. Topo to raster method of interpolation process is applied to bathymetric data along the whole area of Idku Lake for production of bathymetric map.

4.3.6. Change detection analysis

Change detection determines the place and the amount of change in a certain feature at different time. In this study, comparison techniques of analyses and observations were applied to detect morphometric changes in Idku Lake within the period from 1985 to 2021.

5. Statistical analysis

The study used Microsoft Excel software version 2010 to determine the descriptive statistics (mean, standard error, median, standard deviation, minimum and maximum, and range) and to draw comparison graphs of available and extracted data.

RESULTS AND DISSCUTION

I. LULC spatiotemporal changes

Figures (3, 4, 5, 11a) and **table 2** illustrate Idku Lake area change. Change detection in total area in the period from 1967 to 2021 revealed that there is great decline about 58% from 136.5 km^2 in 1967 to 56 km^2 in 2021. This increased change in land cover is a result of quantitative and qualitative changes in land use. Due to the high rates of poverty and unemployment, some residents infringed of on large areas of the lake's edges converting them into houses and agricultural lands for their own account **(Moufaddal *et al.*, 2008; Emam *et al.*, 2021)**, in addition, expansion in aquacultures in which large areas were transformed from free fishing areas to fishfarms without any regulations.

Figures (6, 7, 11b, c) and **Table (3, 4)** illustrate change in geographical distribution of free water covering, hydrophytes covering and islands of Idku Lake along years, in addition to aquaculture creeping. It is clearly seen that along the entire period from 1985 to 2021, the total hydrophytes covering is decreased by about 48km^2 (57%) and aquaculture is increased by about 62 km^2 (661%) while it was only 0.84km^2 losses in open water area. So, the expansion of fishfarms was on account for apart of the lake area that is covered by hydrophytes **(Fig. 11b)**. Hence, aquaculture decreased the total lake area in addition to hydrophytes covering and had a slight effect on open water area. In general, and concerning lake area in 1967, aquaculture represented 80.5% of total surface area deducted from the lake **(Fig. 8, Table 12)** followed by 19% of agriculture and 0.5% of coastal areas transformed into land due to highly sedimentation rate and increasing shallowness. So, aquaculture has the large contribution in Idku Lake area decline.

Moreover, it is important to note that the highest increase in vegetation covering was in 1985, and then decreased dramatically. The highest increase in 1985 can be attributed to drainage water effect. According to **Emam *et al.*, (2021)**, Idku Lake was of 205.07 km^2 total surface area in 1957 and decreased about 50% in 1985 due to reclamation by the governorate and infringement by residents before that date, in addition, the governorate constructed a drainage system to afford job opportunities for youth **(Emam *et al.*, 2021)**. The drainage system from industrial, agricultural and domestic discharge increased the organic content of Idku Lake water and hence heavy growth of hydrophytes to the extent that natural vegetation had covered about 80% the area of the lake in 1985 **(Fig. 6, 11b, Table 3)**. The hydrophytes covering have been decreased by about 7% in 1990, this cover exposing is clearly seen at middle of the lake and its edges. Exposing at the edges is due to starting in aquaculture expanding along the lake edges especially at the Eastern-Southern part. Exposing vegetation at the middle of the lake could be due to clearing works by the governorate at this time. After 1990, nearly the free water area has been remained constant with decreasing vegetation covering at the expense of agriculture and aquaculture expansion. It also noted that land covering (islands) has been diminished dramatically along the whole investigated period that can be due to vegetation creeping and/or resident's infringement.

Although, open water area seems not to be largely changed along the whole period but now in 2021, it still in inadequate proportion to vegetation covering **(Fig. 11c),** that bring up unsustainable lake ecosystem (vegetation is about twice open water area). **Figures (9, 11d)** and **Table 5** illustrate increased activity around Idku Lake. Expansion in agricultures, aquacultures, drainage discharge and other anthropogenic activities especially factories constructions increase population density and vice versa. So, the problem aggravates from merely area reduction or spatial regression to quality change and degraded ecosystem creation. The problem can be defined in terms of sustainability in general and productivity in particular, and in how to recover and conserve both in a planned and executable manner.

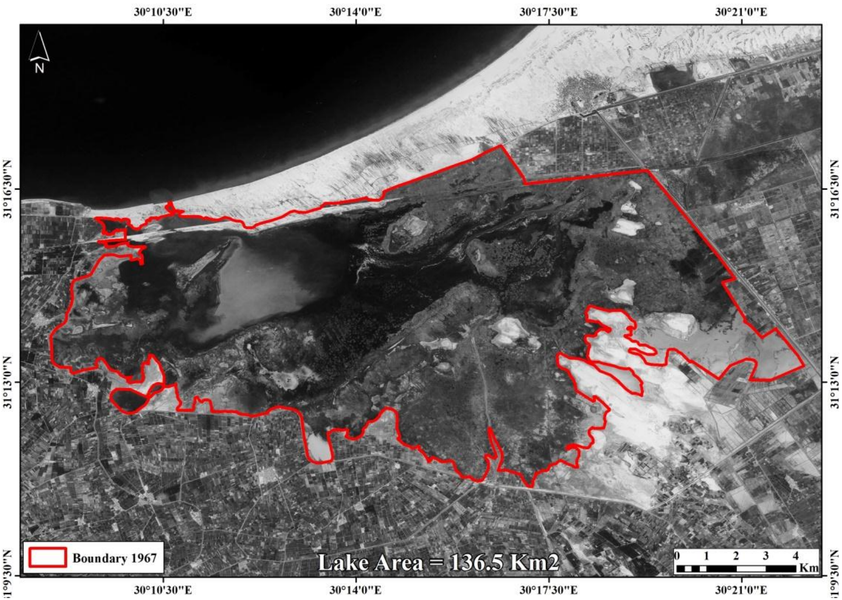
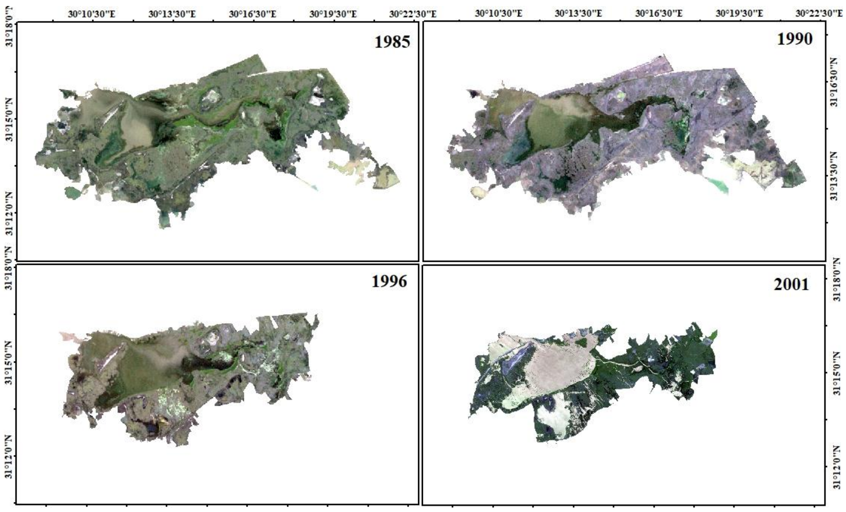


Fig. (3). Satellite image of Idku Lake during 1967



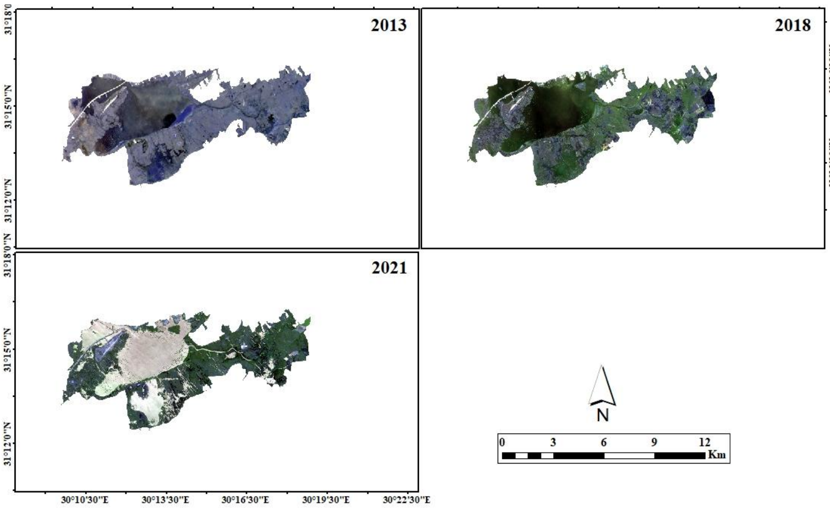


Fig. (4). Satellite images of Idku Lake from 1985 to 2021

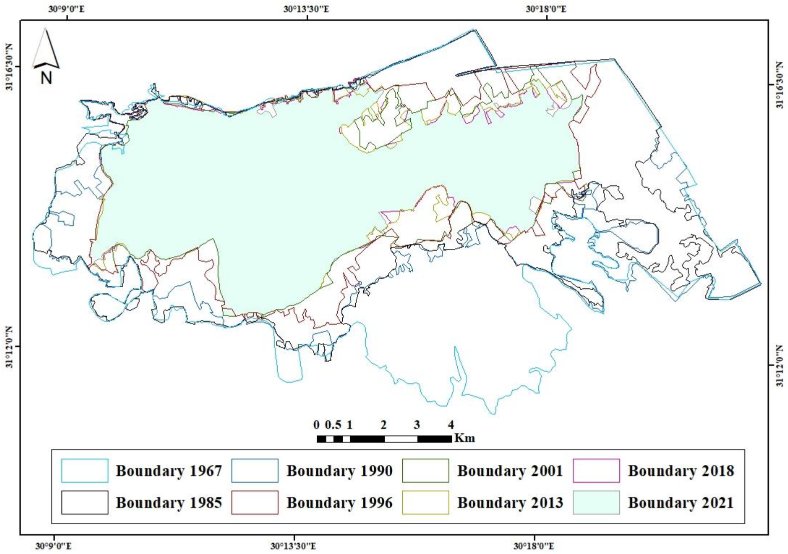


Fig. (5). Superimposed boundaries of Idku Lake from 1967 to 2021

Table (2). Idku Lake area change during period 1967-2021

Year	1967	1985	1990	1996	2001	2013	2018	2021
Lake area	136.5	106.27	108.36	72.152	63.018	58.311	57.125	56.114
change %	----	-30	+1	- 33	- 41	- 45	- 46	- 47

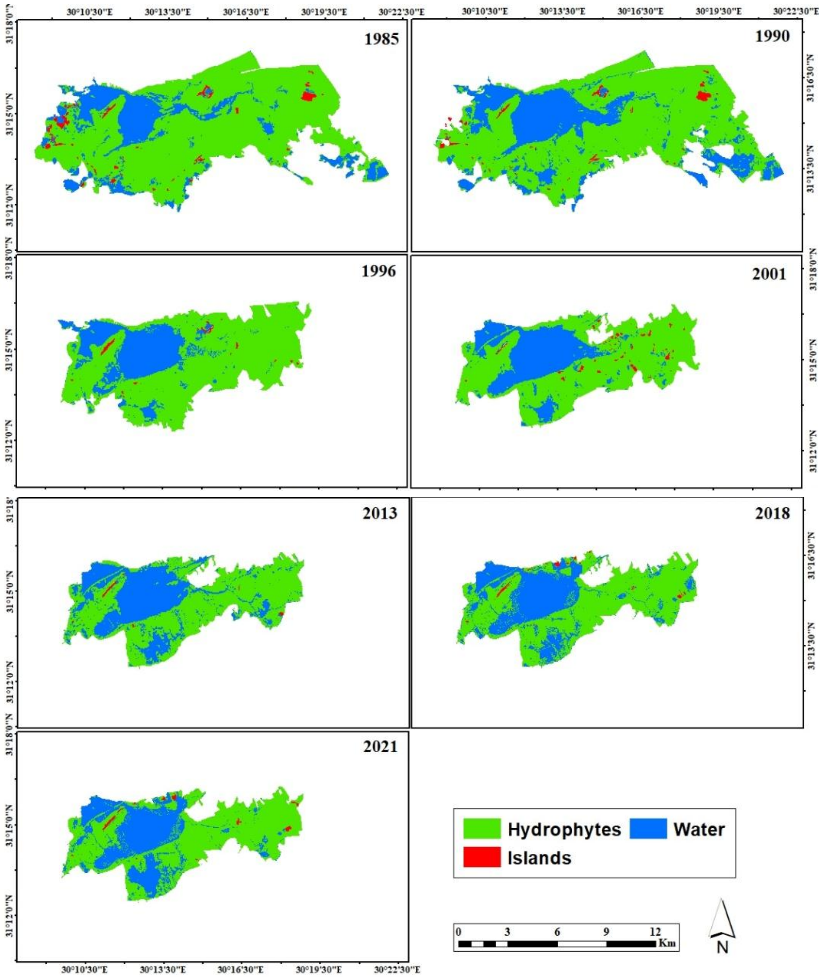


Fig. (6). Geographic classes distribution of Idku Lake during period 1985-2021

Table (3). Percentage of open water area to hydrophytes of Idku Lake during 1985 and 2021

	Open water (W)	Hydrophytes (H)	Total area (T)	W:H	W:T
1985	18%	74%	100%	1:4	1:5
2021	36%	63%	100%	1:2	1:3

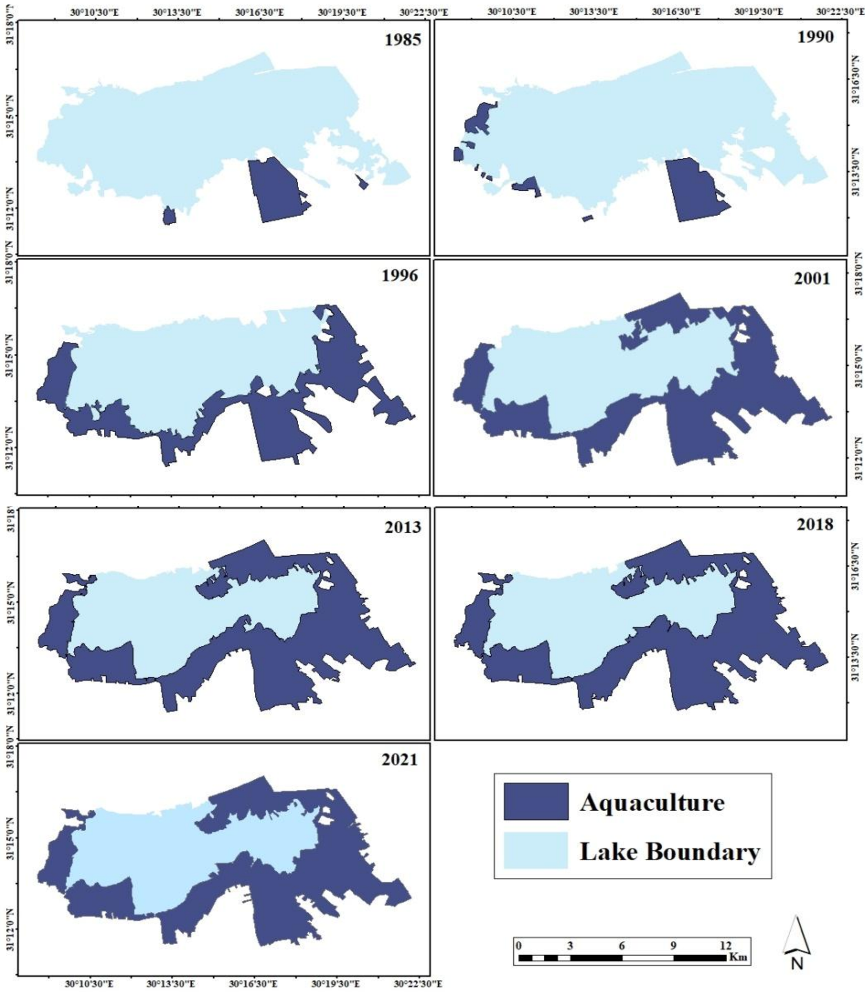


Fig. (7). Aquaculture distribution of Idku Lake during period 1985-2021

Table (4). Areas in (km^2) of different geographic classes of Idku Lake

Year	Water	change %	Hydrophytes	Change %	Islands	change %	Aquaculture	Change %
1985	20.89		83.38		1.99		9.45	
1990	29.09	+39	77.90	-7	1.36	-35	12.01	+27
1996	18.24	-12	53.43	-36	0.46	-77	45.26	+379
2001	19.09	-9	43.12	-48	0.79	-60	64.25	+580
2013	21.94	-5	36.12	-56	0.24	-88	71.26	+654
2018	20.17	-3	36.48	-56	0.47	-76	71.51	+656
2021	20.05	-4	35.54	-57	0.51	-74	71.99	+661

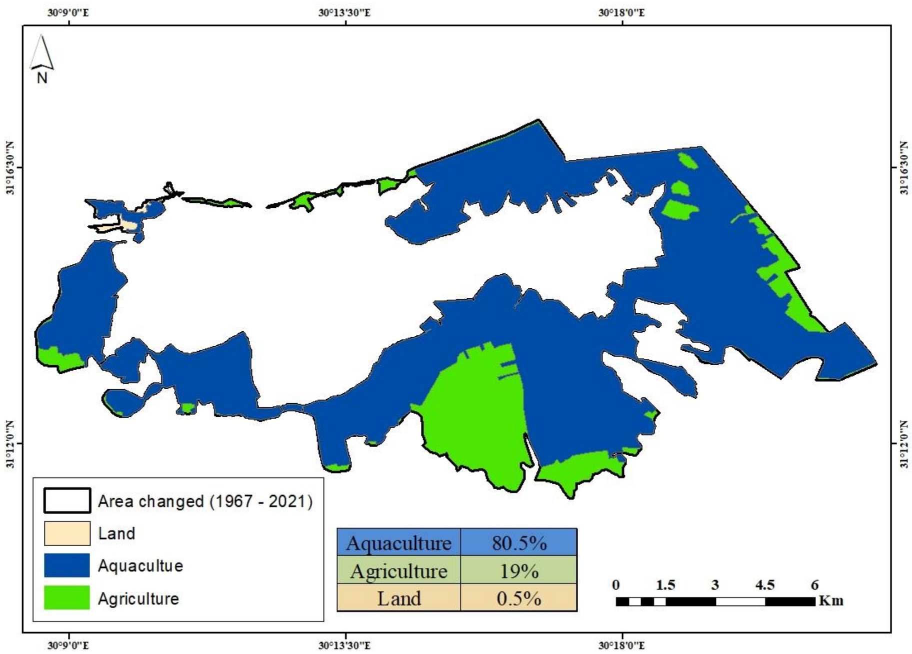


Fig. (8). Land use distribution of total declined area of Idku Lake in 2021

Table (5). Land use around Idku Lake area during 1985 and 2021

	Free land	Urban	Aquaculture	Agriculture	Total
2021 Area km^2	0	20.21	71.99	251.04	343.24
	0%	5.9%	21.0%	73.1%	100%

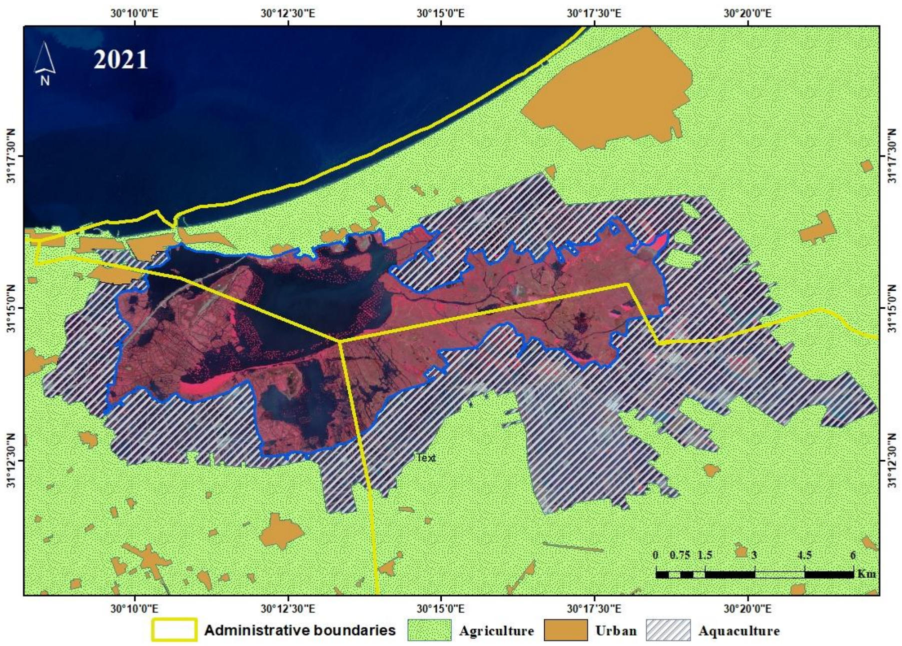


Fig. (9). Land use around Idku Lake during 2021

Previous studies were confirmed progressive reduction of the size of Idku Lake and responsibility of anthropogenic activities for this decline **(Table 6)**. The rate of reduction in the last few years as compared to the second half of the last century have been decrease, that may refer to issuing a new environmental legislation in Egypt and/or reaching erosion to its climax. Inaccuracy of estimates on surface area of Idku Lake and volume of reduction throughout years as given by these previous studies can be referred to the difference in accuracy of methods applied or/and quality of materials or source data utilized e.g. published maps vs. satellite images, conventional survey vs. remote sensing, planimeter vs. computer digitization **(Moufaddal *et al.*, 2008)**. As for the present study, it relied on processing and analysis of satellite imagery of medium to high spatial resolution which is considered good for purposes of mapping and change detection of wetland habitats. Results of remote sensing analysis were supported by field check, knowledge of the area and interviews with local fishermen and residents. Based on this, we believe that figures and estimates provided here on Idku Lake are accurate and trustworthy.

Table (6). Total surface area (km^2) of Idku Lake of some previous studies

Year	Area	Author	Year	Area	Author
1977	126	Samaan	1994	115	Moussa *et al.*
1988	126	Saad	1995	120	Shakweer
1985	100	Dunn	1997	115	Abdel Moati and El Samak
1986	120	Keramburn	2000	126	Shata
1993	115	El Sayed	2001	71	Abbas *et al.*
1994	126	El Khatib	2008	62	Moufaddal

2. Bathymetry

Figure 10 illustrates the bathymetric map of Idku Lake during 2021 based on spatial data analysis which revealed that Idku Lake depth hit the maximum depth (3m) at the middle of the lake (open water area), northern part and near El Boughaz region. While hit the minimum (0.18) at the western part which increase gradually toward the southern and eastern parts.

The maximum lake depth has been decreased from 6.5m **(Moufaddal *et al.*, 2008)** near El Boughaz to 3m at the middle of open water in the present study. **El Kafrawy *et al.* (2019)** stated that the lake depth range between 0.1 and 1.40 m with the maximum depths lie in the middle and the eastern regions, the depth increase in our results can be due to the state's efforts in dredging and cleansing of the lake that started earlier. Deeper lakes have greater water volume and longer retention time, which mitigate the severity of temporal changes to the environment. Furthermore, the hypoliminion serves as a detritus sink, which benefits littoral fishes by allowing organic material to respire without depleting oxygen levels in the epilimnion **(Miranda *et al.*, 2001)**. Depth is also important in controlling vegetation, so the largest side of the lake is heavily vegetated and less than 1 m depth.

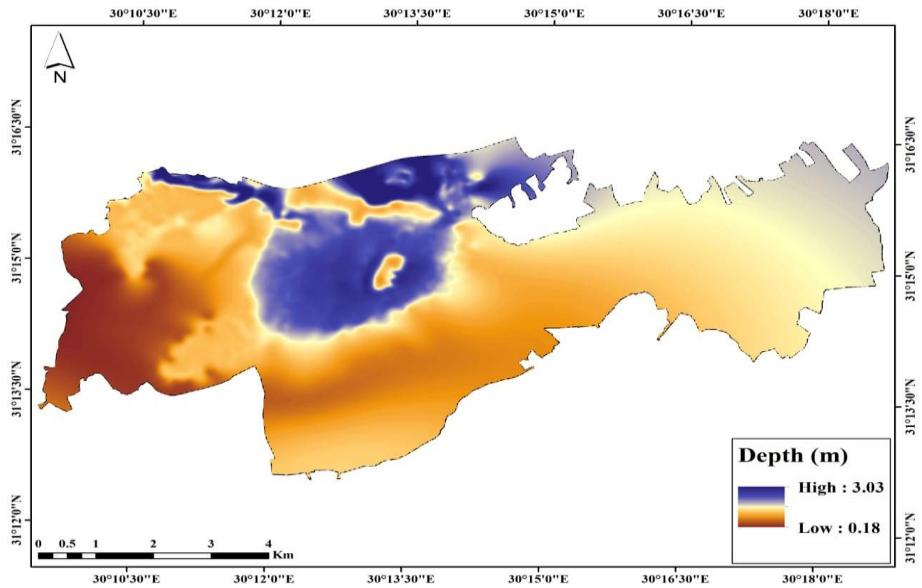


Fig. (10): Spatial distribution map of bathymetry of Idku Lake, Egypt

3. Productivity and related economics

In the last two decades several studies has been carried out on the lake Idku concerning with the technical component of it as toxicity and effect on biological conditions. Nevertheless, a very few studies has concerned with the effect of such components on the socio-economic aspects of the fisheries. The historical data on production is graphically represented in Table (7). To elevate accuracy in productivity data assessment, the data can be distinguished into five time periods as seen in Table (8). The first from 1994 to 1999 reflects a high trend of production as a base period. The second from 2000 to 2004 reflecting to some extent the same rate of production with 1% increase. The two periods from 2005 to 2009 and from 2010 to 2014 reflect a dramatically decreasing production trend with (24 and 36% loss respectively). The last period from 2015 to 2019 reflects a slight recovery of about 5% from the previous period.

In addition, Productivity is one of the measurements of efficiency which affects profitability. Other factors can affect profitability are Land, Area, Capital...etc, and amount of production can be the final output which directly affect profitability. Taking the first period as a base economic rate (average of 17.86m$), it is noticed the declining in economic return at the next four periods of about (21, 54, 47, 38 %) respectively. The income per year was calculated based on the corresponding dollar price at the same year.

If distinguished productivity into two time periods (**Table 8**). The period from 1994 to 2004 is reflecting an increasing trend and the period from 2004 to 2019 reflects a dramatically decreasing production trend. Idku Lake recorded 30% fish production loss from 2004 to 2019 and 46% economic return loss of about 8.2 million$ yearly. The productivity and subsequent economic loss can be attributed mainly to loss in lake area, pollution and water quality deterioration in addition to unregulated fishing or overfishing. The period of 2016 to 2019 experienced partially production recovery could be due to the recent state's efforts in dredging and cleansing of the lake.

It is clearly seen the relation between productivity loss and economic return (**Fig. 11e, 11f**), only in the period from 2005 to 2009, the economy losses amounted to 54% with average of 9.70 million dollar yearly in this period, and production is lost an average of 2310 tons (24%) yearly at the same period. The issue not only in the total production amount, economic return based on production quality and species diverse is also of great concern. *Tilapia species* (Bolti) ranked first followed by *Clarias gariepineus* (Karmot) in the fish production of the Lake with more than 99% percent. On the other hand, species of high economic value as Shrimp, Crab, *Gilthed seabream* (Dennies), *European seabass* (Karros) and Sole common (Moussa) are nearly disappeared and have negligible production contribution, however those species are recorded with good contribution extent in other lakes as Bardawil, Burullus, Manzala and other lakes. This can lower the economic return even in the same production rate from the lake. In 1998 the economic return was about twice that in 2003; however, the two years have roughly the same production amount of 10280, 10230 tons respectively. In 2019, Idku and Bardawil lakes contributed with 8005 and 3125 tons fish production respectively, with higher economic return for Bardawil Lake**.** Productivity loss have also an adverse effect on labor, as in other coastal lagoons, fishing in Idku Lake is artisanal with small fishing boats. The number of fishing boats operating in the lake has also decreased by about 30% during the past decade, from 1,041 in 2004 to 734 in 2013 **(GAFRD, 2015)**.

Table (7). Fish production and corresponding income of Idku Lake, Egypt

Year	Production (ton)	Income (million$)	Year	Production (ton)	Income (million$)
1995	8209	11.76	2008	5886	7.86
1996	10125	18.02	2009	6206	8.95
1997	10784	21.92	2010	6493	8.99
1998	10280	21.29	2011	6387	9.52
1999	9494	16.33	2012	6576	10.38
2000	8922	14.68	2013	6169	8.91
2001	10910	17.44	2014	5855	9.46
2002	10336	15.38	2015	5228	8.58
2003	10230	11.41	2016	5083	8.73
2004	9056	11.07	2017	7200	15.57
2005	9619	12.49	2018	7972	11.98
2006	8986	12.32	2019	8005	10.68
2007	6645	11.48			
*According to CAPMAS					

Table (8). Statistical data of main five periods of productivity

	Period	P_1	P_2	P_3	P_4	P_5
Production	**Year**	**1995-1999**	**2000-2004**	**2005-2009**	**2010-2014**	**2015-2019**
	Av. (tons)	9778	9891	7468	6296	6698
	Productivity change in (tons)	------	+113	-2310	-3482	-3080
	Loss /Increase %	------	+1.1%	-23.6%	-35.6%	-31.4%
	Productivity change in (tons)	--------		-2957		
	Loss /Increase %	--------		-30.2%		
	Sum (tons)	48892	49454	37342	31480	33488
	Max. (tons)	10784	10910	9619	6576	8005
	Min. (tons)	8209	8922	5886	5855	5083
Economy	Av. (million$)	17.86	14.00	8.16	9.45	11.11
	Economic loss in million$	-----	3.86	9.7	8.41	6.75
	Loss %	-----	21.6%	54.2%	47%	37.7%
	Economic loss in million$	--------		8.28		
	Loss %	--------		46.3%		
	Sum (million$)	89.34	70.00	40.81	47.28	55.57
	Max. (million$)	21.92	17.44	12.49	10.38	15.57
	Min. (million$)	11.76	11.07	12.32	8.91	85.86

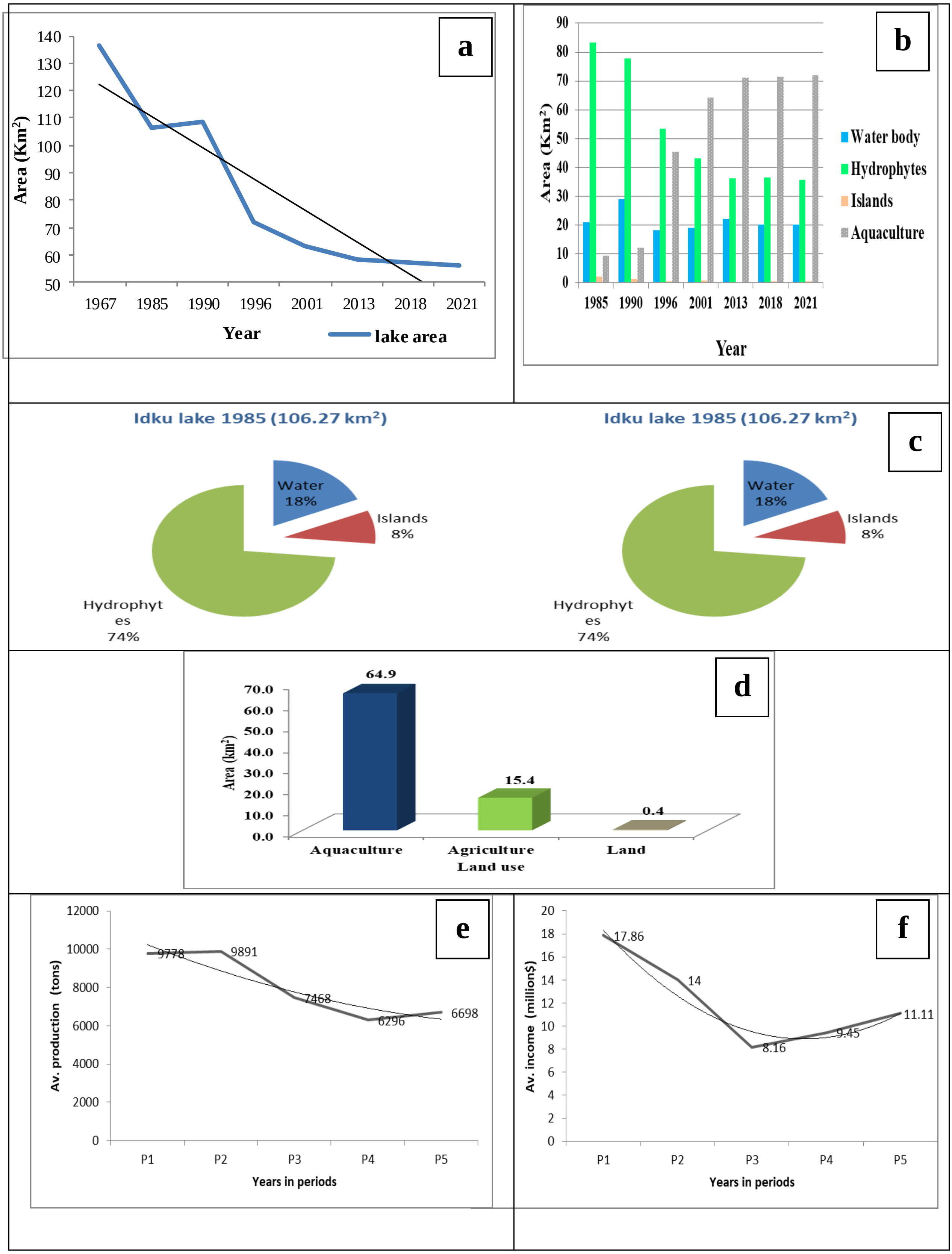


Fig. (11). a: Idku Lake area change during period 1967-2021; **b**: Area change of geographical classes of Idku Lake during period 1985-2021; **c**: Comparison of percentage of geographical classes of Idku Lake from 1985 and 2021; **d**: Land use of total declined area of Idku Lake in 2021; **e**: Production loss of Idku lake from 1994 to 2019; **f**: Economic loss of Idku lake from 1994 to 2019

CONCLUSION

Change detection study of Idku Lake in the period from 1985 to 2021 indicates that there is great decrease in total area of about 47% from 106 km^2 in 1985 to 56 km^2 in 2021 with vegetation is about twice open water area, that is due to anthropogenic unregulated activities of land use. The problem can be defined in terms of sustainability in general and productivity in particular and in how to recover, and then conserve both in a planned and executable manner. According to **CAPMAS**, fish production of Idku Lake and its related economy have been changed along the past two decades. Lake change and pollution are key factor in production detraction and quality alteration rather than health and economic effect.

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