Journal of Coastal Conservation (2024) 28:4
https://doi.org/10.1007/s11852-023-01005-2

CA-Markov chain for simulation and prediction of LULC and assessing the status of water pollution in Manzala Lake after recent development

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Received: 5 November 2023 / Revised: 6 December 2023 / Accepted: 12 December 2023 / Published online: 26 December 2023

Abstract

The Egyptian government recently undertook a large-scale national dredging project to improve the properties and productivity of the northern lakes. Manzala Lake has a distinctive ecological system that offers locals a variety of ecological services. This study was occurred using an integrating approach of remote sensing and Markov modeling to determine the land use/cover (LULC) change of Manzala Lake's components. The physiochemical characteristics of the water were also measured. Six LULC classes namely; water, crops, vegetation, urban areas, bare lands, and, sabkha were detected in and around the lake in three different years (1998, 2010, and 2022). The LULC transition was studied and predicted using the CA-Markov model. The area of surface water, flooded vegetation, sabkha, and urban areas were increased by the year of 2022. The bare lands were declined more comparing with the past periods. The new developments in Manzala Lake made more changes in the LULC of lake ecosystems. Also, it is an indication to exploitation the bare areas around lakes into new urban areas. The obtained results were necessary for the revised management plan. It is essential for managing the lakes' land resources, and vital to carefully consider the development strategies to determine how these projects will influence on the environment and biodiversity. In addition, to what extent this lake productivity will improve and help in the recovery of Egypt's national income.

Keywords Water quality · Development · Dredging project · Manzala Lake · Markov models · Geospatial technique

Introduction

Lakes are considered to be important with reference to climate, travel and trade, recreation, and irrigation. Lakes affect the conditions of the local weather of the area in summer, and winter seasons (Choudhury et al. 2021). They are considered significant sources of both drinking, and irrigation waters. Local and regional factors, such as physiochemical characteristics, landscape, land use/cover, hydrology, climate, and geological features of the region, all have an impact on the water quality of lakes (Read et al. 2015).

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Water quality has deteriorated as a result of anthropogenic activities linked to extensive urbanization, agricultural practices, population growth, and industrialization in numerous regions of the world (El-Zeiny 2022). Additionally, inadequate water resources have made it harder to reduce water pollution and improve water quality (Akhtar et al. 2021). Abd El-Hamid et al. (2017) stated that lake pollution has become one of the most serious environmental issues of recent years with socioeconomic growth and an increase in pollutant discharge from agriculture, industry and domesticity.

Manzala Lake is one of Egypt's largest shallow brackish lakes, with a surface area of about 1275 km^2 (Elbehiry et al. 2018). It is situated in the northeastern region of the Nile River Delta, encompassing the governorates of Damietta, Dakahlia, and Port Said. It borders the Suez Canal on the east, Damietta branch on the west, and Mediterranean Sea on the northern side (Elmorsi et al. 2017). It is characterized by the diversity of its areas with shallow and wide surface areas. The importance of the lake stems from its being a home for migratory birds, breeding, the supply of water and food, socioeconomic importance and remediated value of pollutants such as metal ions (El-Mezayen and Abd El-Hamid 2023; Abd El-Hamid et al. 2023; El-Alfy et al. 2023). It also contains different types of fish, such as tilapia, whiting, grass carp, shrimp, and crabs. In addition, the lake is distinguished by its ability to prevent the entry of seawater and its penetration into agricultural land, which means that it represents a protection wall (Saber 2022).

In Manzala Lake, the most sources of water contamination were either from industrial, domestic, and or agricultural effluents from main drains from urban centers. There are several sources of water feeding the Lake of Manzala, including the old and new Elgamil Boughaz, the Diba Bogaz (Sufara), the Rotma strait, and the Sufara strait. During the last few periods, human activities and climatic changes made many environmental problems and intensive pressure on Lake Manzala that resulted in changing its ecological characteristics (Haroon 2022).

The drainage waters of Bahr El-Baqar and Hadous drains were used in irrigation purposes of agricultural sector (Zahran et al. 2015; Zaghloul et al. 2023). Fariskur, El-Serw, and El-Matria are also classified as agricultural drains south to Manzala Lake. The flow of each drain is nearly about; 4%, 13%, 2%, 49%, and 25% for Fariskur, El-Serw, Matariya, Hadous and Bahr El-Baqar drains, respectively (Elbehiry et al. 2018). The area of Manzala Lake was changed as a result of different anthropogenic activities during the last period for example from 1992 to 2019; the vegetation cover was increased by 19.36–35.18%. Water body areas were decreased from 52.45 to 45.50%, and bare lands were decreased from 28.19 to 19.32% (Hafiz et al. 2019). The lake is experiencing space loss due to erosion, but it also faces other issues and challenges like dredging, soil drying, water pollution from the discharge of industrial and agricultural wastewaters, the growth of macrophytes as the Nile rose and reeds, which impede the movement of water, and effect on the lake's fish stocks (El Kafrawy and Ahmed 2020).

Wetland conservation, wise use, and restoration must be integrated into the planning and execution of the sustainable development goals (SDGs). To achieve the SDGs, it is essential to include wetlands services and benefits in the Nationally Determined Contributions to the Paris Agreement on Climate Change (Choudhury et al. 2021).

The Egyptian Lakes Development Project (ELDP), one of the giant national projects to complete actual development, started by repairing lakes, solving the obstacles and challenges facing them, returning them to the best they were in the past, and becoming global lakes. The Ministry of Environment reviews the factories that dispose industrial wastes in the lakes, and the Ministry of Agriculture provides seed for dumping into the lake after the completion of the development, dredging, and deepening operations. In addition, the housing ministry constructs suitable housing for fishermen who work in the lake to prevent encroachment. It indicates that the process of developing the lake will be completed by 2022 and it will become a tourist destination (Zaghloul et al. 2022). All weeds and thousands of cases of encroachment on the land of the lake were removed from unauthorized nests, buildings, and farms. At the same time, the state combined all official data with the lake's sewage system and implemented a triple treatment plant for sewage water, as well as sediment dredging works, using giant global dredgers from the authority of Suez Canal and significant companies in the world.

The work of the national project to purify and develop Lake Manzala is in progress according to plan. It is an integrated, diversified project that was carefully chosen to be an entry point for the development of lakes and pollutant removal work at an advanced stage in Egypt (Al-Agroudy and Elmorsi 2022). Change processes modeling was made using the Markov chain model (MCM) may be integrated into the temporal data interpolation and short-term studies of change projections. Though, there are two major concerns related to the CA-Markov models for projections of land use/cover change namely; change stationary and the influence of near cells on the change areas (Sinha and Kumar 2013). Whereas, the evaluation of change in land use/cover along the coastal lakes was important for the sustaining process (Abd El-Hamid et al. 2021).

Nowadays, there is a change in the landscape of the lake due to recent developments in the whole lake. So the purpose of this research is to study the land use/cover changes within this development and to evaluate the water pollution status. The present study discusses land use/cover change over three years, which are 1998, 2010, and 2022. We selected these years as the year 2022 represents the study period and that of improvement and development of the lake in comparison with what away of 12 years (in a randomly way to represent the last period only) from this study to highlight the new changes and to some extent the status changed from the past years.

Materials and methods

Study area

One of Egypt's largest lagoons, Manzala Lake has an area of roughly 404.69 km^2. It encompasses three governorates: Port Said, Dakahlia, and Damietta governorates, and is situated in the northeastern region of the Nile River Delta. Its northern border is the Mediterranean Sea, with the Suez Canal sharing its eastern borders with it. It is connected to the Mediterranean Sea by two inlets, Boughaz El-Gamil 1 and Boughaz El-Gamil 2, and is separated from it by a sandy beach bridge, (Redwan and Elhaddad 2022). There are different drains that drain water into the Lake Manzala namely; Hadous, Bahr El-Baqar, El-Serw, El-Matria, and Fariskur drains. The area of Manzala Lake was changed as a result of different anthropogenic activities during the last periods (El-Alfy et al. 2020). The protected area of Ashtoum El-Gamil, which was appointed as a protectorate by Prime Minister's Decree No. 459 of 1988, stands on the northern part of Manzala Lake. Tennis Island is considered an important site in the Lake. It is characterized by the spread of birds in the season of winter (Mohamed 2019).

Number of twelve stations (Bahr El-Baqar- Bahr El-Bashtir- Bahr Legan- Bahr Krmls- Eljanka- Dishidy- Apoat - Tafteish Elserw (Damietta – Elzarqa) - Elhamra – Fatehet Elmosalas- Eltemsah- Elboughaz) was chosen to represent the entire lake area (Table 1; Fig. 1). Water samples were collected from its surface (30 cm to 1 m below, respectively) from January 2022 to December 2022. Different photos taken in the field that represented the land use/coverage during recent development activities are illustrated in Fig. 2.

Table 1 Latitude and longitude of sampling stations in Manzala Lake

No	Station Name	Latitude (N)	Longitude (E)
1	Bahr El-Baqar	31º 19` 99``	32º 20` 56``
2	Bahr El-Bashtir	31º 19` 36``	32º 18` 07``
3	Bahr Legan	31º 19` 67``	32º 15` 08``
4	Bahr Krmls	31º 21` 67``	32º 10` 84``
5	Eljanka	31º 16` 77``	32º 07` 80``
6	Dishidy	31º 22` 69``	32º 02` 49``
7	Apoat	31º 24` 86``	31º 96` 63``
8	Tafteish Elserw (Elzarqa - Damietta)	31º 32` 33``	31º 92` 34``
9	Elhamra	31º 35` 65 ``	31º 95` 28``
10	Fatehet Elmosalas	31º 35` 58``	31º 00` 99``
11	Eltemsah	31º 32` 91``	32º 04` 97``
12	Elboughaz	31º 29` 23``	32º 16` 31``

Surface water samples analyses

Surface water samples were collected from the twelve sites a long Manzala Lake. Clean polypropylene containers were used to store water samples, which were thoroughly filled with water sample, sealed, and prepared for retrieval to the lab. At each site, in situ physiochemical parameters (water depth, transparency, electrical conductivity (EC), temperature, hydrogen ion concentration (pH), and total dissolved solids (TDS) were measured. Temperature, EC, TDS, and salinity were determined using EC/TDS meter (Model: HI98192, Hanna Made in Malaysia) and pH of surface water were determined using (HI8424N, HANNA, USA) pH Meter according to Baird et al. (2012); Hasaballah et al. (2021a). After that, it was checked again in the lab to make sure it was accurate. The water samples were examined as soon as they were brought into the lab. Dissolved oxygen (DO) in water was detected according to Winkler-Azide Modification Method (EPA 1983). The dichromate reflux method was used to analyze chemical oxygen demand (COD), while biological oxygen demand (BOD) was performed using the conventional Winkler method (EPA 1983; Hasaballah et al. 2021b). Furthermore, nitrite (NO_2), phosphate (PO_4), ammonia (NH_4), nitrate (NO_3), and silicates (SiO_4) concentrations in µg/L were determined according

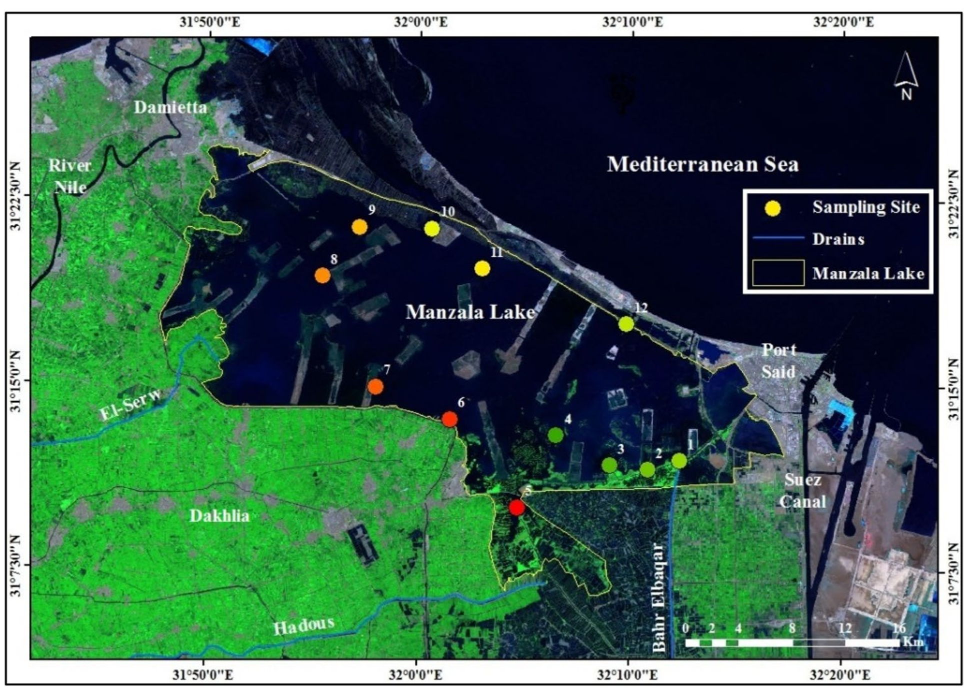

Fig. 1 Sampling sites within Manzala Lake

Fig. 2 Photos were taken by authors in the field through two seasons (winter and summer of 2022) indicating different activities during recent development in Lake Manzala

to Grasshoff et al. (1999). The determination of ammonium occurred by the fixation of samples in the field. For the determination of nutrients NO_3, NO_2, PO_4, SiO_4, and TP, after water samples were filtered through membrane filter papers of 0.45 µm pore size. Chlorophyll-a (Chl-a) was measured according to the methods of Parsons and Strickland (1972) representing the phytoplankton biomass as the following equation:

$$\mathrm{Chl-a} = [(11.64 * \mathrm{E663}) - (2.16 * \mathrm{E645}) + (0.1 * \mathrm{E630})] * 10/\mathrm{V})$$

Data collection and land use/cover analysis in Manzala Lake

The source, acquisition dates, and Landsat sensor types of three images that were collected in three different years (1998, 2010 and 2022) were illustrated in Table 2. The classification of six LULC classes namely; water, crops, vegetation, urban areas, bare lands and sabkha were detected in and around the Lake Manzala in the different years. This was based on the supervised classification characterizing the signal of each class using the maximum likelihood classification algorithm of the ArcGIS 10.5 program (Abd El-Hamid et al. 2021).

Accuracy assessment of LULC map classification in ArcGIS

The accuracy assessment to LULC of three images (1998, 2010, and 2022) was obtained according to Rwanga and Ndambuki (2017). It was applied as steps illustrated in Fig. 3. In accordance with the classification technique of Landis and Koch (1977), the kappa value equal to 1 means perfect agreement but the values that are close to zero mean that the agreement is no better than would be predictable by chance.

LU/LC prediction using the CA–Markov model

Markov and Cellular automata CA-Markov models were adopted using the IDRISI software in the prediction process of the land use/cover of Manzala Lake. The CA-Markov model was able to predict the transition between various categories or

Table 2 Characteristics of the studied Landsat images

Image	Acquisition date	Sensor type	Resolution	Download source
1998	11/9/1998	TM	30 m	https://earthexplorer.usgs.gov/
2010	14/10/2010	TM	30 m	
2022	29/9/2022	OLI	30 m	

- Arc toolbox
- Spatial analyst tools
- Segmentation and classification
- Create accuracy assessment
    - Create accuracy assessment points
    - Number of training random points = 100 points.
    - Conversion from raster to KML layer
    - Google Earth Pro; Landsat images & Field observations
    - Compute confusion matrix

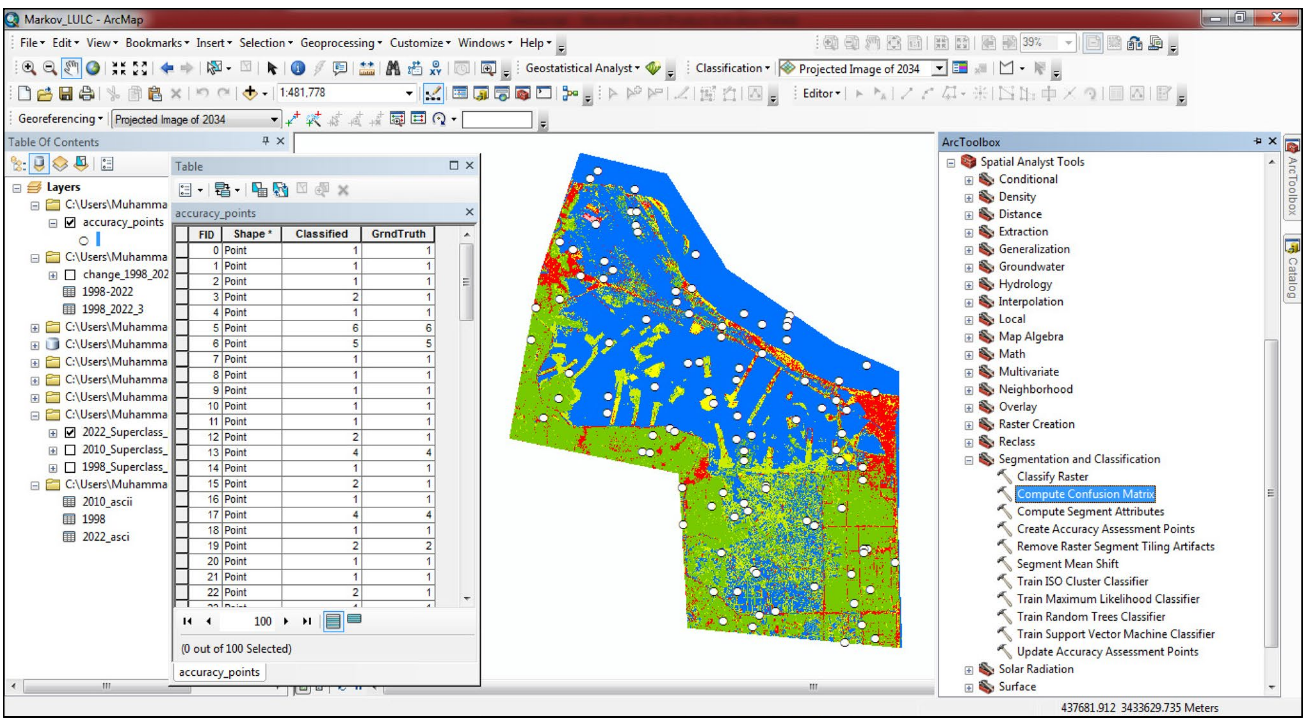

Fig. 3 Chart indicate the procedure of accuracy assessment

classes (Hua 2017; Yang et al. 2020). Markov model guesses the change probability from one state to another, taking into account changes in LU/LC over time (Kumar et al. 2022). The following equations are used to analyse the dynamic change of the studied area based on the previous or current land cover state:

$$S_{(t+1)} = \left(p_{ij} {*} S_{(t)}\right)$$

$$P_{ij} = \begin{pmatrix} p_{11} & p_{12} & p_{1n} \\ p_{21} & p_{22} & p_{2n} \\ p_{n1} & p_{n2} & p_{nn} \end{pmatrix}$$

$$0 \le p_{11} \le 1 \; and \; \sum_{i=1}^{n} p_{ij} = 1, i, j = 1, 2, \ldots \ldots ., n)$$

Where, $S_{(t)}$ is the state of the system at time t, $S_{(t+1)}$ is the value and state of the system at a time $(t+1)$; P_{ij} is the transition probability matrix. By combining two or more simulation techniques and taking advantage of both of their strengths, land use change modeling can become more accurate. It is well known that the CA-Markov model has recently been used in the simulation of dynamic spatial phenomena and the forecasting of future land use change.

Really, the usage of the three based parameters of K_{no}, $K_{location}$ and $K_{quantity}$ in the simulation assessment is highly recommended. These three indicators namely; Kappa for location ($K_{location}$); Kappa for no ability (K_{no}) and Kappa for quantity

($K_{quantity}$) were applied for the CA-Markov model validating for prediction the LULC. The number of iterations of CA-Markov was 10 times and the difference of period of 12 years between the used maps of 2010 and 2022 as illustrated in Fig. 4. The overall accuracy of a simulation run is determined by the Kappa for No Ability (Kno) metric, while the Klocation and Kquantity indices verify the location and quantity on the real and predicted maps, respectively (Bashir et al. 2022; Abd El-Hamid et al. 2021). It was occurred using IDRISI-Selva program ver. 17. The flowchart of methodology was as illustrated in Fig. 5.

Accuracy assessment and validation in prediction process using Kappa coefficient

To have a more perfect construction of this model, accuracy and validation processes were considered. The prediction strength of the model by comparing the simulating ones with the reference map was evaluated using the kappa coefficient of variation of the used IDRISI program (Abbas et al. 2023). The range of the kappa index was observed according to Landis and Koch (1977). According to these values, the calculated Kappa statistic implied that the simulated/predicted values had a considerable agreement within this reference data (Eyoha et al. 2012). The range of kappa statistics interpretation was; [<0 no agreement; 0.0–0.20 slight agreement; 0.21–0.40 fair agreement; 0.41–0.60 moderate agreement; 0.61–0.80 substantial agreement and 0.81–1.00 almost perfect agreement].

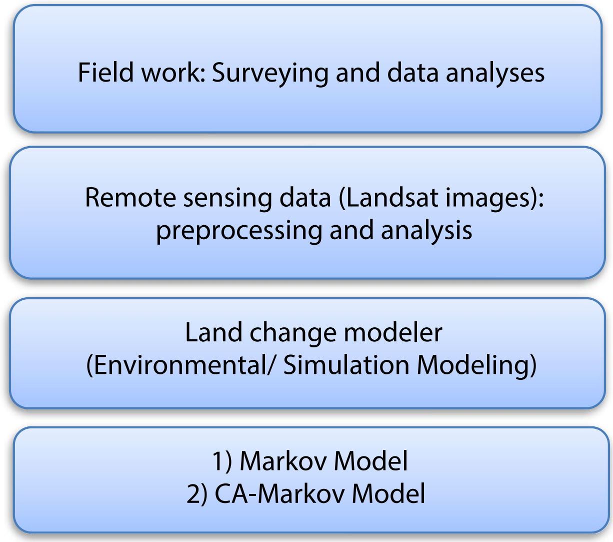

Fig. 5 Flowchart indicate the methodology of study

Statistical analyses

A variety of statistical techniques were used to analyze the data resulted during this study, including analysis of variance (ANOVA), Pearson correlation analysis using SPSS Ver. 26, and principle component analysis (PCA) using the PAST program.

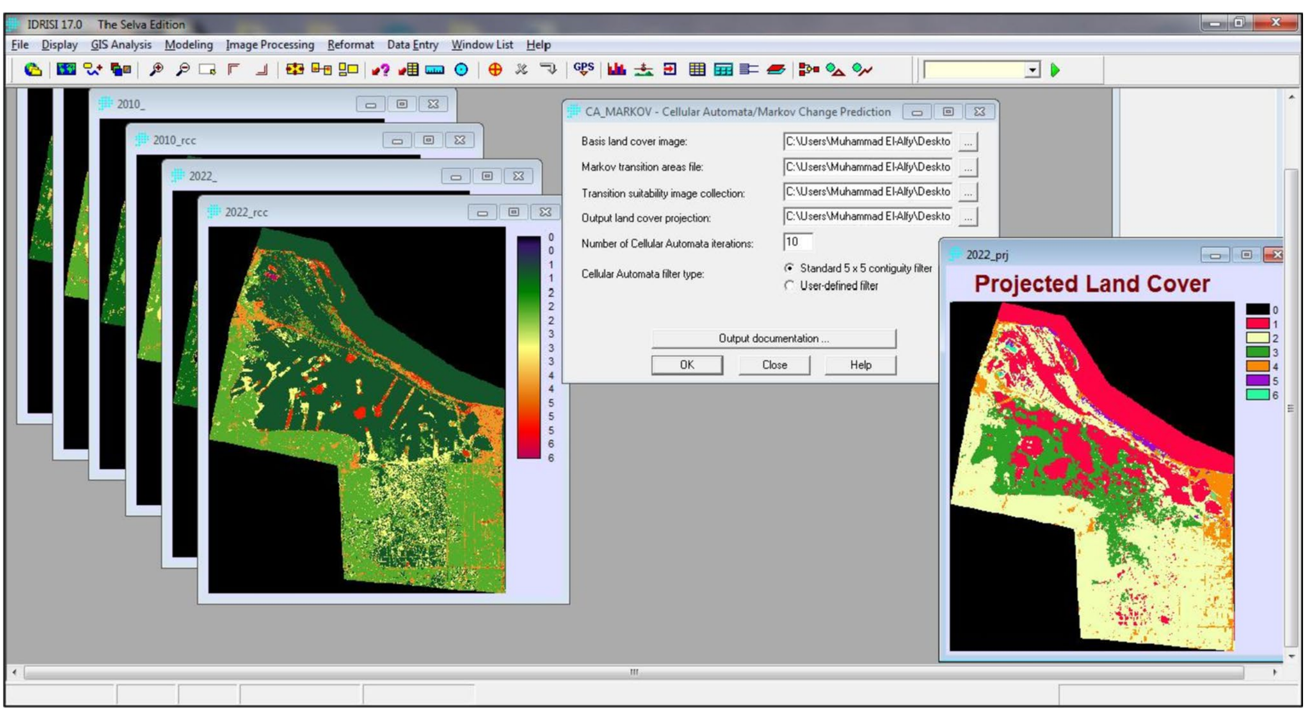

Fig. 4 Processing of CA-Markov Modelling

Results and discussion

Lake water analyses pre and post the ELDP

Water quality parameters and indicators of eutrophication were considered from previously published literature in order to assess the water quality and pollution status of Manzala Lake prior to the ELDP. Badawy and Wahaab (1997) recorded in their study that, the average temperature of lake water was 22ºC with a minimum of 12ºC during winter and a maximum of 30ºC during summer. Hamed et al. (2013) also studied the water characteristics of Manzala Lake from December 2008 to November 2009 and stated that the mean temperature of the water was 22 °C. In addition, Temperature ranging from 14 to 27.5 °C were also recorded by Elmorsi et al. (2017). Soliman et al. (2022), in contrast, confirmed temperature changes ranging from 28 to 33 °C during the study period of 2018. In the present study, the temperature varied between 16 and 19 ºC in winter and 27 and 29 ºC in summer (Table 3) and showed highly significant time variations (P = 0.0001) (Table 4). This manner of temperature variation mirrored the air temperature and matches climate change and the recorded increase in temperature during the last decay (Elshemy and Khadr 2015; Elemam and Eldeeb 2023). In addition, it was also confirmed that the sampling period affected these variations (Soliman et al. 2022). Different lakes around the world reached the same temperature range, such as Lake Heideweiher, which is located in Germany (26.4 °C) (Forner et al. 2023) and Lake Oubeira, which is located in northeast Algeria (22 °C) (Messerer et al. 2019). In contrast with a slight temperature increase the two lakes of Panchkula, Haryana in India recorded 30.7 °C (Vasistha and Ganguly 2022) and Oum Ghellaz Lake northwest of Algeria recorded 32 °C (Aibeche et al. 2022).

There was a noticeable temporal and spatial difference in the visibility of the lake's water, which was generally low and highly turbid ($P < 0.05$). Out of all the sampling locations, Station 6 had the most transparency. There was less transparency in the eastern sector, which is affected by agricultural and domestic drainage water. Water entering a lake through drains, construction sites, suspended particles, and wind generally has an effect on how transparent the water is being.

According to previous studies, for the past forty years, the water has transitioned from being marine state to brackish (Ngugi et al. 2023). According to Khalil (1990), salinity levels were low in the lake's southern region and higher in the region closest to the lake's openings, ranging from 7 to 35‰ on average. Elmorsi et al. (2017) and Deyab et al. (2019) investigated the lake water's salinity and reported that it ranged from 1.8 to 6‰ and 1.7 to 58‰, respectively. In this study, salinity mean values ranged from 4.75 ± 0.3 to 12.35 ± 1.16‰ and the highest value was recorded in summer season at site 8 (28.50 ± 1.16‰). This site also recorded the highest values of EC and TDS (42.6 ± 1.5 µS /cm and 27.40 ± 1.1 g/l, respectively). Lake surface water mean values of EC and TDS varied between 6.84 ± 0.44 to 17.83 ± 1.5 µS /cm, which were recorded in summer, and 4.72 ± 0.29 to 11.93 ± 1.1 g/l, respectively. Salinity, TDS, and EC demonstrated notable temporal and spatial differences ($P < 0.05$). Different factors, including ocean age, depth, stratification, and topographic complexity, have an impact on water nature, salinity and species diversity (Ngugi et al. 2023).

The lake water's pH was measured and varied between natural and slightly alkaline (6.6 ± 0.02 to 8.74 ± 0.05), with mean values of 7.25 ± 0.02 to 8.15 ± 0.05. It displayed significant temporal variation ($P < 0.05$) without any spatial variation. This variation indicates the high productivity of Manzala Lake water. The southern region, ahead of Bahr El-Bashtir, Bahr Krmls, and Bahr El-Baqar Drains, typically obtained the lowest pH values (< 6). Despite the recent development, as a result of organic matter ferments, releasing gases like methane and hydrogen sulphide that decrease pH levels (Ali 2008). However, the pH values for the lake's remaining region are generally higher than 7. It might be related to domestic and/or agricultural wastes mixed into the canal, including soap, detergents, and other organic materials (Deyab et al. 2019). Elmorsi et al. (2017) reported results in agreement with those findings. They claimed that the water's pH was consistently found to be slightly alkaline (7.65 to 8.88). Lake Tonga, in northeastern Algeria, and Lake Oubeira, extremely northeast of Algeria, have also slightly alkaline environments (6.2 < pH < 8.9), (Messerer et al. 2019; Loucif et al. 2020).

Dissolved oxygen measures a water capacity to sustain various aquatic life forms, (Deyab et al. 2019). The DO values changed significantly over time throughout the lake. It demonstrated significant temporal and spatial variability ($P < 0.05$). The DO values ranged from 1.5 ± 0.46 (site 1) to 17.3 ± 0.46 (site 6), with average value of 7.99–10.65 ± 0.5. While DO was not detected at site 1 in the winter season. This is may be due to the development work in the lake, where the present results contradict the results of the previous studies, which were conducted before the development process, so summer values were obviously higher than winter values, except at two sites (5 and 7). It could be comparable with these studies (Deyab et al. 2019; Elmorsi et al. 2017; Khatita et al. 2017; Serag et al. 2022).

On the other hand, the current findings demonstrated that there were numerous variations in BOD and COD between sites, with the lowest mean values (2.9 ± 0.5 mg/l and 26.2 ± 2.6 mg/l) in sites 4 and 5, respectively, as well as average values of 6.28 ± 0.5 mg/l in winter and 31.14 ± 1 mg/l in summer for BOD and 126.67 ± 13.4 mg/l in winter and 58.26 ± 2.6 mg/l in summer for COD, while they recorded their highest mean annual values (48.6 ± 1 mg/l in the summer and 520 ± 13.4 mg/l in the winter) at sites

Table 3 Basic statistics of parameters in surface water of Manzala Lake

Parameter	Season	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Average	Max	Min	STD
NH_4 µg/l	winter	2266.89	2266.89	2274.27	2282.88	2282.88	2100.84	364.08	123.00	255.84	129.15	116.85	209.10	1222.72	2282.88	116.85	107.166
	summer	6808.00	3973.00	1331.00	3071.00	2774.00	197.00	193.00	383.00	108.00	95.00	86.00	103.00	1593.50	6808.00	86.00	214.946
NO_2 µg/l	winter	223.026	186.742	193.936	531.760	243.046	467.949	341.578	186.429	173.604	228.031	205.197	258.998	270.02	531.76	173.60	11.710
	summer	15.014	195.813	155.149	186.742	26.588	105.726	11.574	8.446	8.133	9.384	7.820	11.261	61.80	195.81	7.82	7.634
NO_3 µg/l	winter	2018.40	1942.43	1652.80	2864.78	2002.00	2005.23	3409.83	1924.64	1412.41	2241.52	1373.58	2301.08	2095.73	3409.83	1373.58	57.541
	summer	25.54	287.96	196.09	507.78	84.94	148.47	36.22	21.25	19.39	17.41	18.25	19.88	115.27	507.78	17.41	15.162
SiO_4 µg/l	winter	602.11	525.31	546.82	649.73	665.09	254.98	30.72	70.66	16.90	4.61	43.01	67.58	289.79	665.09	4.61	28.154
	summer	4689.00	3005.00	3939.00	2982.00	4465.00	4151.00	5939.00	4105.00	3865.00	4225.00	3292.00	1301.00	3829.83	5939.00	1301.00	112.903
PO_4 µg/l	winter	230.95	201.85	207.67	163.26	196.34	92.81	18.38	3.06	1.53	1.53	2.14	8.88	94.03	230.95	1.53	9.786
	summer	1.84	95.25	54.82	79.33	15.62	24.20	7.96	5.21	3.06	3.98	3.06	7.66	25.17	95.25	1.84	3.274
TP µg/l	winter	1894.41	1586.27	1683.92	1403.99	1549.38	952.63	410.13	269.1	176	217	178	154	872.90	1894.41	154.00	70.39163
	summer	86.8	151.9	123.69	143.22	125.86	65.1	145.39	182.28	186.62	444.85	345.03	557.69	213.20	557.69	65.10	15.32024
Chl µg/l	winter	86.54	73.75	174.39	97.83	240.38	223.74	341.49	52.65	106.81	72.25	102.41	26.05	133.19	341.49	26.05	9.296
	summer	49.01	204.44	226.67	219.8	137.62	129.96	101.43	71.3	45.33	44.83	61.54	98.44	115.86	226.67	44.83	6.845
DO mg/l	winter	0.00	1.10	2.10	9.60	14.10	11.50	15.30	11.40	8.40	10.50	7.00	4.90	7.99	15.30	0.00	0.505
	summer	1.50	11.20	6.70	13.90	4.80	17.30	10.70	12.10	13.40	11.70	8.00	16.50	10.65	17.30	1.50	0.468
BOD mg/l	winter	4.8	9.6	4.2	2.9	20.9	4.2	6	6	3.6	7.2	3	3	6.28	20.90	2.90	0.502
	summer	48.6	43.8	46.8	24.9	24.9	10.8	31.8	28.7	29.1	29.1	29	26.2	31.14	48.60	10.80	1.064
COD mg/l	winter	120	80	112	120	40	520	192	40	32	56	48	160	126.67	520.00	32.00	13.408
	summer	57.6	115.2	50.4	34.88	26.2	54.5	75.2	77.4	42.5	89.4	37.2	38.6	58.26	115.20	26.20	2.628
pH	winter	7.05	6.98	7.3	6.6	7.44	7.36	7.15	7.2	7.15	7.58	7.75	7.4	7.25	7.75	6.60	0.030
	summer	7.16	7.37	8.09	7.92	7.75	8.39	8.64	8.46	8.64	8.59	8.53	8.74	8.19	8.74	7.16	0.053
TDS g/l	winter	2.43	2.36	2.53	3.15	2.37	2.18	3.76	7.65	8.50	9.26	9.34	3.07	4.72	9.34	2.18	0.299
	summer	2.15	2.40	2.48	1.78	1.62	3.18	15.69	27.40	25.60	26.50	24.40	9.94	11.93	27.40	1.62	1.118
Salinity ‰	winter	2.2	2.3	2.5	3	2.4	2.2	4.1	7.9	8.5	9	9.7	3.2	4.75	9.70	2.20	0.305
	summer	2.00	2.40	2.50	1.80	1.70	3.30	16.30	28.50	26.60	27.50	25.30	10.30	12.35	28.50	1.70	1.164
EC ms/cm	winter	3.47	3.37	3.61	4.49	3.39	3.11	5.36	10.92	12.11	13.20	14.68	4.38	6.84	14.68	3.11	0.447
	summer	3.81	4.71	4.83	3.41	2.99	5.71	24.90	42.60	34.50	35.40	35.70	15.37	17.83	42.60	2.99	1.563
Trans. cm	winter	10.00	10.00	15.00	10.00	15.00	10.00	15.00	10.00	9.00	20.00	10.00	25.00	13.25	25.00	9.00	0.499
	summer	17.00	25.00	20.00	30.00	22.00	32.00	15.00	10.00	26.00	30.00	30.00	20.00	23.08	32.00	10.00	0.693
Depth cm	winter	35	65	90	110	90	130	210	90	100	150	75	35	98.33	210.00	35.00	4.877
	summer	115	70	100	90	105	75	150	25	260	260	280	35	130.42	280.00	25.00	8.879
T°C	winter	18.5	18.5	18.5	17.5	18	18	16	19	19	19	19	19	18.33	19.00	16.00	0.089
	summer	27	27	27	28	29	29	29	29	28.5	29	27.5	28	28.17	29.00	27.00	0.086

T Temperature, *Trans* Transparency, *Max* maximum, *Min* Minimum, *STD* standard deviation

Table 4 Statistical test showing the effect of the main factors (location and time) and their interaction on physiochemical parameters of water

Source	Dependent variable	Type III sum of squares	df	Mean square	F	Sig.
Location	COD	101325.202	11	9211.382	0.974	0.517
	DO	339.515	11	30.865	1.871	0.007
	BOD	744.291	11	67.663	0.957	0.029
	Chl	85960.895	11	7814.627	1.418	0.286
	TP	169865866.228	11	1179613.21	0.325	0.520
	SiO_4	7436659.441	11	676059.949	0.997	0.502
	PO_4	79720.908	11	7247.355	2.130	0.113
	NO_3	2207758.452	11	200705.314	1.309	0.332
	NO_2	146050.412	11	13277.310	2.120	0.114
	pH	2.865	11	0.260	2.328	0.088
	NH_4	49759101.972	11	4523554.725	3.633	0.021
	TDS	1084.528	11	98.593	2.797	0.051
	Salinity	1169.270	11	106.297	2.761	0.053
	EC	2155.411	11	195.946	2.864	0.048
	Temperature	6.250	11	0.568	0.591	0.802
	Transparency	360.333	11	32.758	0.814	0.031
Time	COD	28079.569	1	28079.569	2.970	0.113
	DO	42.400	1	42.400	2.571	0.037
	BOD	3707.620	1	3707.620	52.415	0.000
	Chl	1801.280	1	1801.280	0.327	0.579
	TP	480977.762	1	4801077.762	21.901	0.000
	SiO_4	75191299.210	1	75191299.210	110.916	0.000
	PO_4	28456.395	1	28456.395	8.365	0.015
	NO_3	23533330.870	1	23533330.870	153.433	0.000
	NO_2	260134.660	1	260134.660	41.536	0.000
	pH	5.339	1	5.339	47.729	0.000
	NH_4	824855.727	1	824855.727	0.662	0.433
	TDS	312.049	1	312.049	8.853	0.013
	Salinity	346.560	1	346.560	9.003	0.012
	EC	724.241	1	724.241	10.585	0.008
	Temperature	580.167	1	580.167	603.008	0.000
	Transparency	580.167	1	580.167	14.411	0.003
	Temperature	597.000	23			
	Transparency	1383.333	23			

1 and 6. Unlike COD, which did not exhibit any spatial or temporal variations, BOD showed a significant temporal and spatial variation ($P < 0.05$). (Beheary et al. 2019) recorded results lower than these results for BOD and COD (8.2 ± 1.4 mg/l and 13.2 ± 10.8 mg/l, respectively). This may suggest a simultaneous increase in the aerobic and anaerobic decomposition of ammonia and organic materials in municipal and industrial effluents as well as the production of organic material in the lake itself concurrently with development work. In contrast, in 2015, BOD and COD mean values were higher than the present results (Elmorsi et al. 2019). These results confirmed the quality of the lake's water compared to other lakes that recorded higher levels of COD and BOD, and lower values of DO, such as Poyang Lake in China (Xu et al. 2022); Haryana lakes in India (Vasistha and Ganguly 2022) and Oum Ghellaz Lake in Algeria (Aibeche et al. 2022).

Phosphates, nitrites, ammonia, nitrates, and silicate concentrations were found in high values near the outlets of drains (sites 4, 5, 1 and 2, gradually (in the southern region of the lake and chlorophyll-a in sites 7,6,4,3. All nutrients presented significant temporal variation ($P < 0.05$) without any spatial variation, except for ammonia, which demonstrated significant spatial differences ($P < 0.05$) without any temporal differences, while chlorophyll-a did not reveal any spatial or temporal variations. The average values for nitrites, ammonia, nitrates, phosphates, total phosphorus, silicates, and chlorophyll-a respectively, were fluctuated between 61.80 and 270.02 µg/l, 1222.72–1593.5 µg/l, 115.27–2095.73 μg/l, 25.17– 94.03 μg/l, 213.20–872.90 μg/l, 289.79–3829.83 μg/l, and 115.86–133.19 mg/l. The immediate consequences of domestic sewage inflow into this area from the Bahr El-Baqar drain caused an abrupt increase in ammonia concentrations in Lake Manzala at site 1. As a result, especially at high temperatures, the rate of ammonification increases, turning organic matter into ammonia; thus, the highest ammonia value was recorded during the summer (Xie et al. 2022). Despite the construction of large treatment ponds for organic sewage from Bahr El-Baqar and the development processes, the effect of this treatment is not yet clear totally. The south and southeast regions are still severely polluted due to high nutrient loading from various effluent inflows into the lake. With the exception of this region, the lake's nutrient distribution displayed irregular narrow variations (Abd Ellah 2021). These values were lower than those recorded before the development of the lake (Deyab et al. 2019; Elmorsi et al. 2017; Khatita et al. 2017; Serag et al. 2022). However, the relatively high nutrient concentrations at the station close to the drains' point of discharge showed that the drains had a significant impact on the level of nutrients that were discharged into the lake. In general, the nutrients in the water of Manzala Lake are in the following order: $SiO_4 > NH_4 > NO_3 > NO_2 > PO_4$. These nutrients appeared in high concentrations in different lakes around the world with different values, such as Oubeira Lake in the extreme northeast of Algeria (Messerer et al. 2019); Lake Tonga in northeastern Algeria (Loucif et al. 2020) and Poyang Lake in China (Xu et al. 2022).

Table 5 shows a Pearson correlation matrix of the relationship within and between the physiochemical characteristics of Manzala Lake water. Strong correlations were found between several parameters including organic compounds, nutrients, and other parameters. Temperature was positively correlated with EC (r = 0.60), Salinity (r = 0.62) and TDS (r = 0.62), respectively. While it was negatively correlated with PO4 (r=-0.62). EC has a strong negative correlation with PO_4 (r=-0.85), TP (r=-0.86), and NH_4 (r=-0.76), a moderate negative correlation with NO2 (r=-0.58), and Chl (r=-0.57) and a strong positive correlation with Salinity (r = 0.99) and TDS (r = 0.99). While TDS showed a strong negative correlation with PO4 (r=-0.84) and NH_4 (r=-0.76). Values of pH also demonstrated strong negative correlation with NH_4 (r=-0.94) and PO_4 (r=-0.86) and strong positive correlation with TP (r = 0.71). In contrast, COD has a moderate positive correlation with NO2 (r = 0.54) and BOD with NH_4 and PO_4 (r = 0.58, and r = 0.56), respectively.

According to Kebede and Kebedee (2012), Principle component analysis (PCA) was used in combination between bio-indicators and environmental parameters. In this study, it was used to link the water variables and their sources. PCA explained the extracted data, as PC1, PC2 and PC3 explain 54.44, 16.4 and 15.56% of the correlation matrix, respectively. It was observed that NH_4_W, NH_4_S, SiO_4_W, TP_W, Chl_W and NO_3_W positively correlated with PC1 and related mostly to the sites of 1 (Bahr El-Baqar drain which is the source of various types of pollutants) and site 5 may be attributed to agricultural and sewage wastes from Hadous drain. Silicates' concentrations in summer season negatively correlated to PC1 and mostly attributed to site 7. The concentrations of NO_2_W, Chl_S, NO_2_S, PO_4_S, TP_S and NO_3_S were correlated more with sites of 2, 3, and 4 (Fig. 6).

In a similar case study, Kilen, a brackish lake in Jutland, Denmark, has been monitored for salinity, temperature, and temperature change since 1972. Palaeo-limnological data show the lake has been nutrient-rich for 100 years, with eutrophication peaking from the mid-1980s to the late 1990s. Lake recovery over the last 20 years has been driven by reducing TN and TP loading and improving water clarity, and macrophytes cover. The low N: P ratio suggests that summer is predominately N-limited, suggesting that previous management focused on TP reduction had minimal effect on water quality. It was recommended that future management continue to reduce nutrient loads in both TN and TP to ensure sustained recovery (Lewis et al. 2023).

Land use/cover change along the studied area within different periods

Change detection in the LULC of an area is one of the most significant indicators of regional and global ecological and environmental sustainability (Hossen and Negm 2016). The areas of LULC in Manzala Lake with a coastal area opposite to it in Km^2 ranged between 761.61, 241.66, 568.88, 97.67, 320.95, and 22.17 in the year 1998; 725.75, 757, 351.33, 121.97, 48.25, and 8.64 in the year of 2010; and 1019.34, 607.76, 172.65, 157.25, 54.11, and 1.84 in the year of 2022 (Table 6). These areas ranged between 1042, 498, 201, 188, 83, and 0.00 for the projected classes of 2034 for water, crops (agricultural areas), flooded vegetation, urban areas, bare lands and sabkha. The values of accuracy assessment of the images were illustrated in Tables 6, 7 and 8.

The order of different classes in the studied areas take the following orders; 2010 < 1998 < 2022 for water; 1998 < 2022 < 2010 for crops; 2022 < 2010 < 1998 for flooded vegetation and sabkha; 1998 < 2010 < 2022 for urban areas and 2010 < 2022 < 1998 for bare lands (Fig. 7) (Table 9). It is clear that the expansion in urban areas in the recent decade at the year of 2022. Other studies supported this, for example, in Pakistan's Southern Punjab Province; the lands that were formerly used for vegetation have been changed into urban areas. This was attributed to the increase in the sectors of commercial activities and infrastructure (Hu et al. 2023). The predicted simulated map showed also an increase in the built-up areas in Lake Manzala area. In

Table 5 Pearson's correlation between physiochemical parameters at Manzala Lake

Parameter	NH_4	NO_2	NO_3	SiO_4	PO_4	TP	Chl-a	DO	BOD	COD	pH	TDS	Salinity	EC	Trans.	Depth	T°C
NH_4	1																
NO_2	0.308	1															
NO_3	0.139	0.633*	1														
SiO_4	0.297	0.002	0.216	1													
PO_4	0.892*	0.479	0.173	0.209	1												
TP	0.928*	0.363	0.127	0.236	0.966*	1											
Chl-a	0.214	0.556	0.482	0.502	0.476	-0.045	1										
DO	-0.659	0.311	0.368	-0.103	-0.552	-0.194	0.158	1									
BOD	0.587	-0.373	-0.122	0.332	0.561	-0.238	0.081*	-0.809	1								
COD	-0.001	0.547	0.268	0.112	0.051	-0.442	0.365	0.362	-0.489	1							
pH	-0.943	-0.381	-0.264	-0.266	-0.864	0.709	-0.213	0.534	-0.554	0.046	1						
TDS	-0.763	-0.589	-0.346	-0.117	-0.850	-0.855	-0.587	0.315	-0.276	-0.370	0.679*	1					
Salinity	-0.770	-0.589	-0.344	-0.117	-0.854	-0.861	-0.580	0.323	-0.281	-0.367	0.685*	0.9999*	1				
EC	-0.769	-0.586	-0.334	-0.113	-0.853	-0.862	-0.570	0.318	-0.279	-0.361	0.680*	0.996**	0.997*	1			
Trans.	-0.252	0.246	0.036	-0.460	-0.121	-0.089	-0.045	0.266	-0.389	0.169	0.374	-0.016	-0.021	-0.065	1		
Depth	-0.465	-0.180	-0.031	0.335	-0.475	-0.487	0.023	0.257	-0.180	-0.129	0.471	0.591	0.588	0.558	0.305	1	
T°C	-0.562	-0.435	-0.491	-0.290	-0.621	-0.579	-0.583	0.432	-0.426	-0.127	0.581	0.626*	0.624*	0.604	0.211	0.126	1

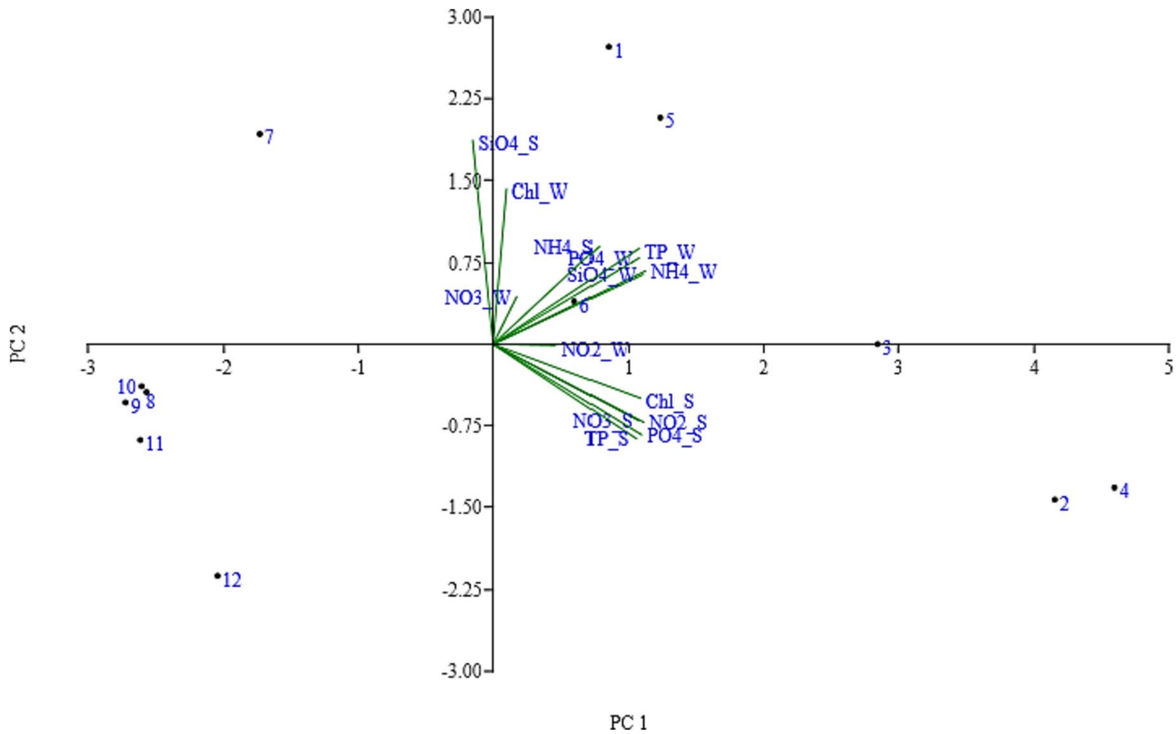

Fig. 6 PCA for water parameters within different locations in Manzala Lake, *w: winter and s: summer*

Table 6 The accuracy assessment and kappa values for LULC image of 1998

OID	Class	Water	Crops	Flooded veg.	Urban	Bare	Sabkha	Total	U_Accuracy	Kappa
1	Water	31	0	1	0	0	0	32	0.97	0
2	Crops	0	9	0	0	1	0	10	0.90	0
3	Flooded veg.	1	0	33	0	0	0	34	0.97	0
4	Urban	0	0	1	2	3	0	6	0.33	0
5	Bare	0	0	2	0	14	0	16	0.88	0
6	Sabkha	0	0	1	0	0	1	2	0.50	0
7	Total	32	9	38	2	18	1	100	0	0
8	P_ Accuracy	0.97	1	0.87	1	0.78	1	0	0.90	0
9	Kappa	0	0	0	0	0	0	0	0	0.86

OID object identifier, *veg* vegetation

Table 7 The accuracy assessment and kappa values for LULC image of 2010

OID	Class	Water	Crops	Flooded veg.	Urban	Bare	Sabkha	Total	U_Accuracy	Kappa
1	Water	40	2	0	0	0	0	42	0.95	0
2	Crops	0	34	5	0	0	0	39	0.87	0
3	Flooded veg.	0	1	8	0	0	0	9	0.89	0
4	Urban	0	0	0	2	3	0	5	0.40	0
5	Bare	3	0	0	0	1	0	4	0.25	0
6	Sabkha	0	0	0	0	1	0	1	0	0
7	Total	43	37	13	2	5	0	100	0	0
8	P_ Accuracy	0.93	0.92	0.62	1	0.2	0	0	0.85	0
9	Kappa	0	0	0	0	0	0	0	0	0.77

Table 8 The accuracy assessment and kappa values for LULC image of 2022

OID	Class	Water	Crops	Flooded veg.	Urban	Bare	Sabkha	Total	U_Accuracy	Kappa
1	Water	48	0	0	0	0	0	48	1	0
2	Crops	7	23	1	0	0	0	31	0.74	0
3	Flooded veg.	0	0	10	0	0	0	10	1	0
4	Urban	2	0	0	5	1	0	8	0.63	0
5	Bare	0	0	0	0	2	0	2	1	0
6	Sabkha	0	0	0	0	0	1	1	1	0
7	Total	57	23	11	5	3	1	100	0	0
8	P_ Accuracy	0.84	1	0.91	1	0.67	1	0	0.89	0
9	Kappa	0	0	0	0	0	0	0	0	0.83

Bhutan's high altitude city of Thimphu, the prediction analysis for the year 2050 expected a huge increase in built-up areas with a reduction of forest cover.

(Wang et al. 2021). It was obvious that during the period close to 2010, the cultivated lands were expanded not only in the area around the coastal lagoons of Egypt but also in other African countries like Northern Ethiopia, whereas the extension of cultivated areas increased by 11.14% in the period between 2005 and 2014 may be due to the population increase (Ayele et al. 2018).

Transition and prediction of LULC along the studied area within different periods

The ecosystems of wetlands are one of the most diverse and productive systems that make suitable habitats for wildlife. Urbanization and industrialization may cause the degradation of these habitats. The Markov model was known as a stochastic model to create quantifiable comparisons of lake changes during different periods. For achieving the aims and objectives of sustainable development, the CA-Markov model is significant to LULC planning and design. CA-Markov model is an important technique in simulation process of different environmental factors (Ma et al. 2012; Hua 2017). The CA-Markov was used to simulate the long-term changes in landscape over a period of time (Tariq and Shu 2020). The period here was for 12 years; whereas this difference in period was selected randomly to represent the past state of the lake. The probability of change from 1998 to 2010 is illustrated in Table 10.

During the period from 1998 to 2010, the constant areas of different classes in the studied area were 607.288, 230.091, 271.038, 43.945, 33.895, and 3.938 km^2 for water, crops, flooded vegetation, urban, bare lands and sabkha, respectively, (Table 11). The area of surface water lost nearly 35.866 km^2 = 4.7% from its area in 1998. The crops or agricultural areas were increased by 68.07% = 515.263km^2 in the year 2010. The flooded vegetation areas were decreased by 38.24% from its total area. The urban areas were increased in 2010. And barren areas were decreased by 84.96% (272.643 km^2). The sabkha area was converted to other classes by 61.03% with 13.527km^2. The increased land use/cover areas were for crops and urban lands, whereas, other classes were decreased.

In the Keta Lagoon, the speed up in land uses dynamics (1991–2007) and transformation was related to the population growth and increase in socio-economic activity. More areas classified into marshes, vegetation and croplands were converted into built-up areas. The cultivated areas recorded a net gain of 125.51 km^2, dense vegetation and marshes losses 151.37 km^2 and 2.44 km^2. It was also estimated that, the building of saltpans aids in a small increase in water extent (Duku et al. 2021).

The constant areas of different land covers were 661.355, 512.172, 66.186, 75.474, 11.756 and 1.761 km^2 for water, crops, flooded vegetation, urban, bare lands and sabkha, respectively in the period between 2010 and 2022. The class of water increased by 293.567 km^2 (28.8%). The agricultural areas were lost 149.22 km^2 (19.715%). About 178.687 km^2 (50.86%) form the flooded vegetation cover was disappeared may due to enhancement in the lake. The crowding of urban areas increased from 2010 to 2022 by 35.278 km^2 (22.44%). Also, the barren areas increased in 2022 than those of 2010 by 5.857 km^2 (10.82%). The decrease in sabkha area has occurred with 6.797 km2 (78.68%). The loss and gain for each class are illustrated in Table 12.

In the period from (1998 to 2022); the constant areas of the classes were 655.286, 214.469, 114.782, 47.485, 19.352, and 1.698 for water, crops, flooded vegetation, urban, bare lands and sabkha. The area of surface water in the studied area was increased by 25.28% with 257.707 km^2. The agricultural activities were increased by 366.058 km^2 (60.24%). Huge areas of flooded vegetation disappeared from 1998 to 2022 to other classes by 69.65% (nearly 396.225 km^2). The crowding of urban areas was increased by 59.577 km2 (37.89%). Whereas, the dynamics of land use, particularly the urban/built-up development in this area, are what caused urban sprawl (Mathanraj et al. 2015). The barren areas were decreased in this period by 83.14% (loss of 266.791 km^2).

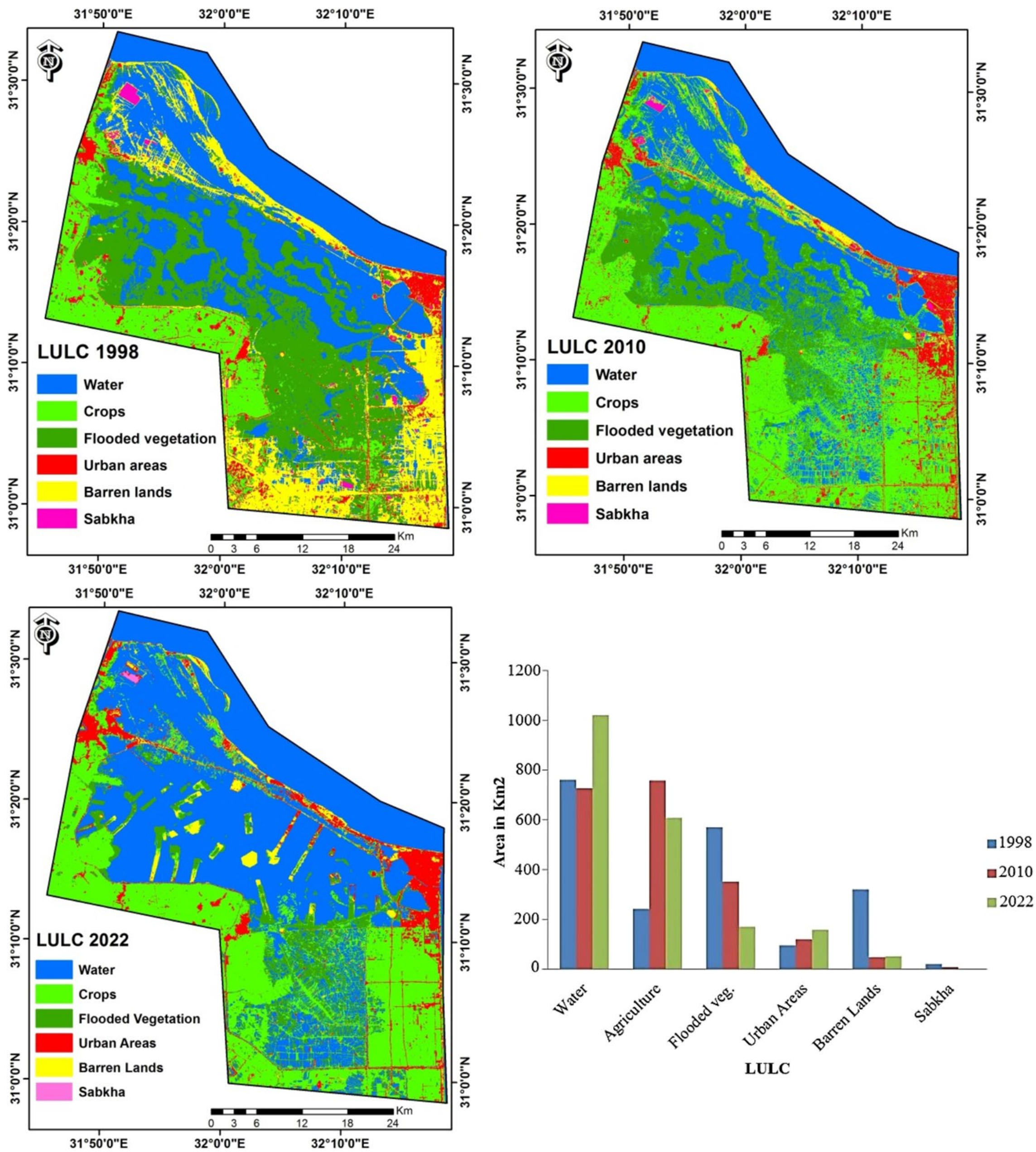

Fig. 7 Land use/cover LULC of Manzala Lake during three different periods (1998, 2010 and 2022) and distribution of areas in km^2

Table 9 The areas of LULC activity within the studied area during different periods and the projected image

Activity	Area in Km^2/Year			
	1998	2010	2022	Predicted 2034
Water	761.61	725.75	1019.34	1042
Crops	241.66	757	607.76	498
Flooded vegetation	568.88	351.33	172.65	201
Urban areas	97.67	121.97	157.25	188
Bare lands	320.95	48.25	54.11	83
Sabkha	22.17	8.64	1.84	00

The sabkha area was decreased also by 20.325 km^2 from its area (nearly 91.69%), (Table 13).

The area of Manzala Lake decreased by 0.2% from the total area in 1972 compared with its area in 2017, this may be attributed to the effect of the Mediterranean Sea that makes Lake's soils to be eroded and lost (Mohamed 2019). Hafiz et al. (2019) assessed the change in Manzala Lake areas also during the period (1992–2019) and discovered a 6.95% and an 8.87% decrease in surface water and bare lands, respectively. The class of flooded vegetation was increased by 15.82%. The increase in surface water in this

Table 10 Probability of change from 1998 to 2010 in Markov model

Class	Water	Crops	Flooded veg.	Urban	Bare	Sabkha
Water	0.6782	0.1479	0.1366	0.0186	0.0167	0.0021
Crops	0.0133	0.8082	0.1108	0.0662	0.0004	0.0012
Flooded veg.	0.1689	0.4044	0.4047	0.0146	0.0069	0.0005
Urban	0.0163	0.5611	0.0125	0.3815	0.0185	0.0102
Bare	0.0885	0.6155	0.0224	0.1747	0.0907	0.0082
Sabkha	0.1998	0.4299	0.0102	0.1463	0.0644	0.1494

Table 11 Conversion in the Manzala Lake's area in km^2 from 1998 to 2010

Class	Water	Crops	Flooded veg.	Urban	Bare	Sabkha	1998
Water	*607.288*	70.997	65.478	8.809	8.038	0.972	761.581
Crops	0.787	*230.091*	6.618	4.013	0.020	0.068	241.596
Flooded veg.	83.805	203.250	*271.038*	7.191	3.348	0.224	568.856
Urban	1.375	48.758	1.112	*43.945*	1.572	0.864	97.626
Bare	28.143	194.582	6.867	54.837	*33.895*	2.572	320.896
Sabkha	4.317	9.182	0.204	3.143	1.380	*3.938*	22.165
2010	725.715	756.859	351.318	121.938	48.253	8.638	2012.721

Table 12 Conversion in the Manzala Lake's area in km^2 from 2010 to 2022

Class	Water	Crops	Flooded veg.	Urban	Bare	Sabkha	2010
Water	*661.355*	20.810	23.172	8.830	11.506	0.005	725.677
Crops	107.886	*512.172*	80.708	49.320	6.762	0.022	756.870
Flooded veg.	229.079	35.399	*66.186*	6.412	14.243	0.000	351.319
Urban	5.537	30.043	1.981	*75.474*	8.888	0.017	121.940
Bare	14.160	8.777	0.493	13.029	*11.756*	0.036	48.250
Sabkha	1.228	0.450	0.092	4.154	0.953	*1.761*	8.638
2022	1019.244	607.650	172.632	157.218	54.107	1.841	2012.694

Table 13 Conversion in the Manzala Lake's area in km^2 from 1998 to 2022

Class	Water	Crops	Flooded Veg.	Urban	Bare	Sabkha	1998
Water	*655.286*	52.875	25.740	14.648	13.008	0.001	761.558
Crops	3.381	*214.469*	10.712	12.773	0.264	0.000	241.599
Flooded veg.	285.814	135.285	*114.782*	16.850	16.127	0.000	568.857
Urban	3.173	40.288	2.881	*47.485*	3.813	0.000	97.641
Bare Lands	66.537	156.703	17.546	60.618	*19.352*	0.142	320.898
Sabkha	5.073	8.037	0.972	4.842	1.544	*1.698*	22.166
2022	1019.265	607.657	172.632	157.216	54.107	1.841	2012.719

study may be attributed to the enhancement of the lake after 2019, which no longer occurs. There is a possibility that the sea water has no or low changes during different periods. There were various factors that control the change in the components of Manzala Lake as; the surface water area was increased, may attributed to the drilling activities especially in the last ten years and parallel to this huge amounts of flooded vegetation and islets were removed completely from the lake. These finds were agreed with previous study on a similar lake of Burullus (Abd El-Hamid et al. 2023).

These conclusions were agreed with Hossen and Negm (2016). Also, they found that the agricultural areas increased by 28.57%, urban and barren lands decreased by 28.57% also during the period of 1984 to 2015. They also expected that the surface water area would be reduced by 84.67% if the present activities were continued and posed a threat to the environment and fisheries. Using a linear regression model, another study has predicted that the lake's surface water area will shrink by 25.24% from 2015 to 2030 as an interpretation of the negative impact of anthropogenic activities. The validation of the CA-Markov process for projecting land use and covering changes in the future computes numerous Kappa Indices of Agreement ($K_{standard}$) that observe to what extent the comparison map will agree or disagree with the referenced map (Mondal et al. 2019). The values of validation of these indices for kappa for no ability (K_{no}), kappa for location ($K_{location}$), kappa for strata (K_{strata}) and kappa for standard ($K_{standard}$) were 0.7316, 0.8603, 0.8603 and 0.6821. So the values of kappa here ranged between substantial to almost perfect agreement.

Mondal et al. (2019) found a $K_{standard}$ value of 0.79 in the CA-Markov validation process of LULC prediction in their study on a part of the Brahmaputra River Basin of India. Also, validation results in the Dedza district of Malawi were 0.97, 0.95 and 0.97 for K_{no}, $K_{standard}$ and $K_{location}$, respectively (Munthali et al. 2020). Mishra et al. (2014) found that the accuracy in their study was 72%. Abd El-Hamid et al. (2021) obtained Kappa values of $K_{standard}$, $K_{location}$ and K_{no} of 0.7993, 0.8614 and 0.8235. The projected map of the area with recent development showed other results that the surface water will increase by 2034 if the recent development continues as the surface water area may increase. The benefit of projected LULC images in future planning was that they could be used as early warnings for development and to protect the protected areas and biodiversity from anthropogenic activities. So this projected map may aid in management and planning either in reducing the contamination sources or exploitation of protected areas without disturbing the environmental perspective (Hua 2017). Lazri et al. (2014) advised to make the most dependable analysis by using a large database. So the transition matrix would be more representative of changes in studied phenomenon trends that further make more accurate application. In addition, the validation in the case of more data could be beneficial to understand the behavior of studied case. The transition areas between different periods along the studied area are illustrated in Fig. 8. Whereas, Fig. 9 indicated the produced projected image of 2034.

While this study successfully investigated the status of pollution and anthropogenic-induced environmental changes after recent developments by evaluating and predicting changes using Markov chain models in Manzala Lake and evaluating its water quality parameters, there were some limitations. The first limitation was that this study was conducted after the compliance of more than 95% of ELDP works, and it wasn't totally finished. However, we thought this wouldn't affect the results significantly. Another limitation was that no study has been performed to determine how this project will affect the environment of the lake, which leaves a gap in the literature in this area. Also the availability of high quality images may have high cost. Finally, it is important to follow up and monitor changes in a long-term study for managing the lakes' land resources, determine how

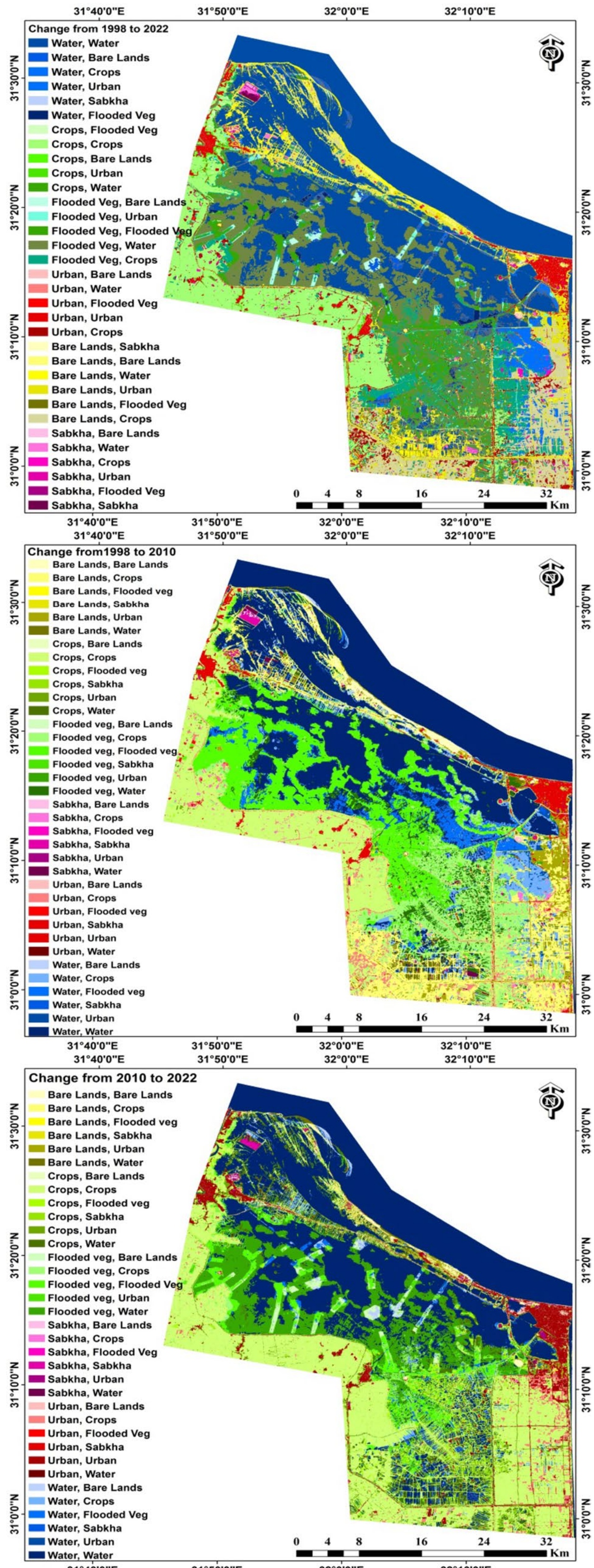

Fig. 8 Transition areas between different periods along the studied areas

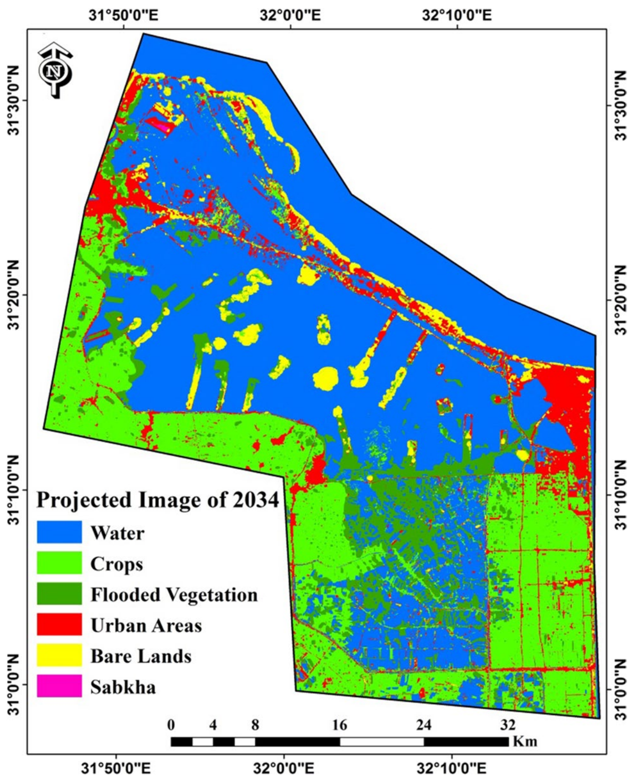

Fig. 9 The projected image of study area at 2034

these projects will affect the environment, and combat the literature gap.

Conclusion and recommendations

Manzala Lake is a part of the Egyptian Lakes Development Project (ELDP), which was applied to improve the properties and productivity of the Egyptian lakes. This project affects cover, the levels of contaminants, and the physiochemical properties of the lake's water. The south and southeast parts were still severely polluted due to high nutrient loading from various drains inflows into the lake causing extreme environmental stress. Dredging and Deeping the Boughaz area aid in enhancing the water quality. Large important areas as islets were lost that may affect to some extent on the biodiversity especially bird habitats. Huge vegetative areas were fully removed. Vegetation may also grow again in the southern parts.

Projection of maps in Manzala Lake could be suitable for early warnings for development and to protect the protected areas and biodiversity from anthropogenic activities. Additional new searches could be conducted to examine the enduring changes occurred within the Egyptian Lakes Development Project (ELDP) on the ecological conditions of Manzala Lake. It is highly recommended to use new remediation techniques especially at the outlets of drains to sustain the resources of the Lake for future purposes (sustainability). Keeping the habitats of different organisms in the lake within the new development is also important and substantial. Monitoring water quality and remediation processes to drains water would aid in sustainability and works of development.

Acknowledgements The authors would like to thank the National Institute of Oceanography and Fisheries and Environmental Sciences Department, Faculty of Science, Damietta University in conduct of the research. The comments of the editors and reviewers are also gratefully acknowledged.

Author contributions MAE contributed to the investigation, data collection and analysis, writing original draft, review, editing, and supervision; BAE contributed to material preparation, sample collection and analysis and writing; MAZ contributed to supervision, visualization, review and editing and DAE contributed to the investigation, data collection and analysis, writing original draft, review, editing, and supervision.

Funding Open access funding provided by The Science, Technology & Innovation Funding Authority (STDF) in cooperation with The Egyptian Knowledge Bank (EKB). No funding received.

Data availability All data are available in this manuscript.

Declarations

Ethical approval This paper does not contain any studies with human participants or animals performed by any of the authors.

Competing interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Note: This study was conducted after the compliance of nearly more than 95% of ELDP works.