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Using Geoinformatics for Evaluating Lake Nasser's Land Use Indicators for Fish Production Sustainability

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Abstract:

Lake Nasser is situated in an important dynamic zone, acting as an interface between major natural earth surface systems. Shoreline change, a common challenge in coastal environments, is predominantly driven by natural processes leading to dynamic alterations in coastal areas. Such changes have implications for the vulnerability of coastal environments and associated features, including shoreline stabilization. This study employs Landsat satellite data spanning from 1975 to 2022 to analyze urban expansion, shoreline dynamics, and alterations in Lake Nasser's cover over time. A comprehensive time series, incorporating Landsat MSS, TM, ETM, and OLI, was compiled, covering the years 1975, 1985, 1990, 2000, 2010, 2000, and 2022. Rigorous corrections, encompassing geometric, radiometric, and atmospheric aspects, were applied to the images. The findings revealed a notable increase of 58.66 km² in Lake Nasser's cover over the past 47 years, comprising various elements such as buildings, natural features, and specific points. Notably, the built coastal area expanded by 259.068 km² during this period. These observations contribute to the assessment of the total economic value (TEV) associated with Lake Nasser.

Keywords: Lake Nasser, Remote Sensing, Geoinformatics, Change Detection, Fish Production, Land use/Land cover, Egypt.

1. Introduction

Lakes play a vital role not only as significant components of the Earth's hydrosphere but also as reliable recorders of regional climate changes across various time scales and human activities surrounding them. Consequently, lakes are frequently recognized as crucial information carriers that unveil both global climate change and the corresponding regional responses, as highlighted in studies by Cenderelli and Wohl (2001), Ding et al. (2006), Yao et al. (2014), and Liu et al. (2014). Aswan Governorate, situated in Egypt's southern region near the Sudanese border, centers around its capital, Aswan, and is divided into five administrative districts: Aswan, Daraw, Kom Ombo, Nasr El Nuba, and Edfu, according to the Central Agency for Public Mobilization and Statistics (CAPMAS). With a population of around 1.4 million, the majority relies on tourism, drawn by its historical significance, pleasant climate, and strategic position as Egypt's southern entrance. Notable attractions include the temples of Abu Simbel, Kalabsha, Philae, Kom Ombo, and Edfu, alongside the Nubia Museum and modern sites like the High Dam and Aswan Botanical Garden. However, since the 2011 revolution, the decline in tourism has adversely affected the economy, prompting a shift towards agriculture and fisheries as alternative income sources, as noted by Halls et al. (2015).

Aswan High Dam stands as a monumental engineering feat, which constructed in the 1960s and creating the second-largest artificial lake in Africa. Positioned roughly 9 km upstream from its predecessor, the new dam is a formidable rock-fill structure, fortified with impermeable clay.

It stretches an impressive 3600 m in length, 980 m in base width, and towers to a height of 111 m. Capable of accommodating a maximum water flow of 11,000 cubic meters per second, it comprises a staggering 43 million m³ of material. The reservoir it forms extends up to 35 km in width at its broadest and spans approximately 480 km from the High Dam to the Dal Cataract in Sudan when at its maximum storage level of 183 m above sea level. (Bishai et al., 2000; van Zwieten et al., 2011). The dam was constructed to regulate Nile River flooding and store surplus water for release during the dry season, leading to the creation of Lake Nasser, named after President Nasser. This reservoir has become a vital fish source for Aswan and Egypt at large (Habib et al., 2014). The region experiences extreme dryness and near-cloudless skies, relying solely on the Nile River as its water source. Despite its vastness, Lake Nasser is more accurately described as a slow-moving river than a typical lake (Entz, 1976). Studies have shown variations in morphometric characteristics across different areas, with some regions featuring narrow and steep sections while others have wider, gently sloping areas (Crul, 1992; Habib et al., 2015).

The shoreline of Lake Nasser displays varying slopes, with the eastern shore, marked by rocky terrain, being steeper compared to the flatter, sandy western shore. This contrast is accentuated by the presence of khors, contributing to the eastern shoreline being almost twice as long as the western one (Ahmed et al., 1993). These khors, some stretching up to 55 km at a lake water level of 180 m, are vital spawning and feeding grounds for fish, essential for fishing activities. Characterized by their shallowness and rich phytoplankton abundance, the khors experience minimal water currents, mainly influenced by fluctuations in lake water levels. Notably, there are discernible annual fluctuations in water levels, typically reaching their lowest points in mid-July or August (van Zwieten et al., 2011; Habib et al., 2015).

Satellite remote sensing techniques are widely used for detecting and monitoring changes in land cover across various scales. Time series analysis of remote sensing data is particularly useful for observing and assessing urban development and associated land use changes (Khaled et al., 2019). Integrating geographical information systems (GIS) and global positioning systems (GPS) enhances the effectiveness of remote sensing in evaluating changes in land, coastal areas, fish productivity, climate change, and thermal stress events (Khaled et al., 2019; Khaled et al., 2020; Mahdy et al., 2022; Khaled et al., 2023a; Khaled et al., 2023b; Said et al., 2024). Change detection algorithms are crucial for identifying disturbed areas and understanding the extent and spatial patterns of change. A common quantitative approach involves analyzing sequences of classified images over time (Khaled et al., 2019; Khaled et al., 2020). This paper aims to employ remote sensing techniques to achieve several objectives: (1) evaluate the changes in shoreline and urban land use/cover over the past four decades in lake Nasser, (2) assess the fisheries along the lake coast, and recognizing their pivotal role in influencing sustainable development in Aswan.

2. Materials and Methods

2.1. Study Area

Lake Nasser, a reservoir situated along the course of the Nile River, originated from the construction of the Aswan High Dam (Ghobrial. 2008; Hala. 2011). Positioned on the border between Egypt and Sudan, it lies between latitudes 21° 00’ 00’’, 23° 46’ 44’’ N, and longitudes 30° 34’ 10’’, 33° 28’ 18’’ E. With a surface area of approximately 5248 km², a maximum capacity of 165 km³, and an average depth of 130 m, the lake maintains a surface elevation of 175 m. The delineation of fishing zones, assigned to specific fishing organizations and companies, is governed by a series of decrees (Figure 1).

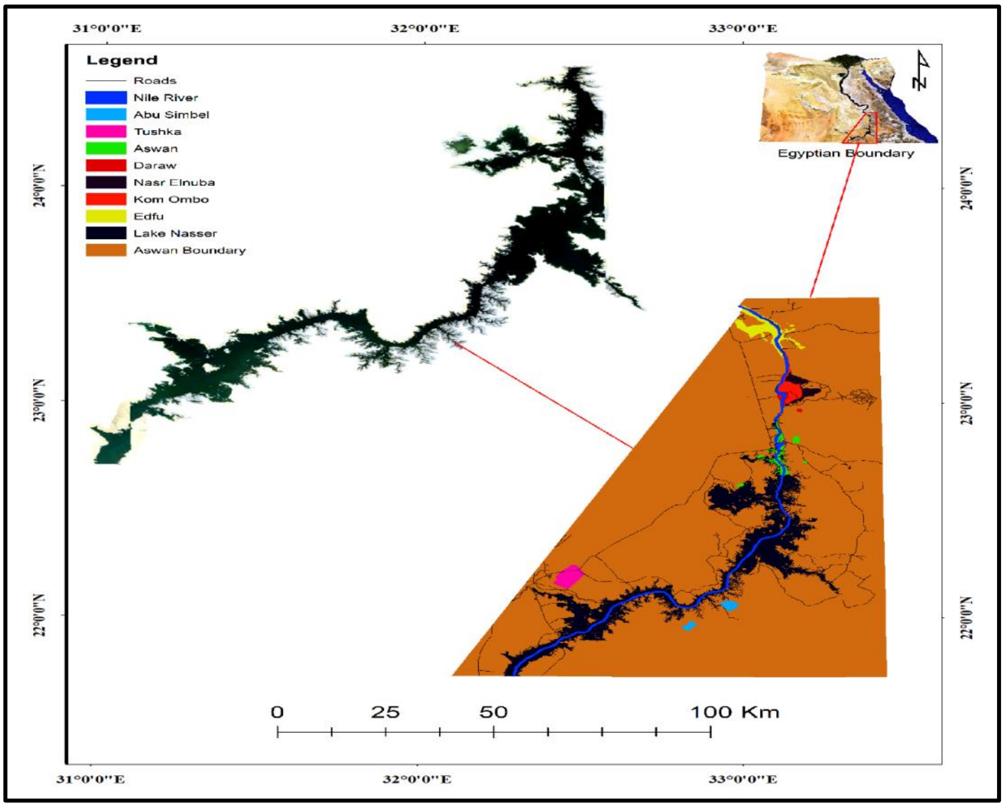

Figure (1): Map of Aswan Governorate and Lake Nasser.

2.2 Remote Sensing Data

Eighteen satellite images acquired through the Landsat series of sensors were utilized to assess changes. These images encompassed data from the Landsat 4-MSS, 5-TM, 7-ETM, and 8-OLI sensors, spanning the years 1975, 1985, 1990, 2000, 2010, and 2022 (Table 1). The imagery was sourced from the United States Geological Survey (USGS) (http://earthexplorer.usgs.gov/). Notably, each Landsat sensor featured slightly different spectral band combinations. Additionally, fish abundance data collected by the General Authority for Fish Resources Development (GAFRD), spanning the period from 1970 to 2022, was incorporated into the study.

Table (1): Images from the Landsat sensors used in the present study.

Sensor	Landsat 4MSS	Landsat 5TM	Landsat 7ETM	Landsat 8OLI
Path/Row	174/44 175/44 175/45	174/44 175/44 175/45	174/44 175/44 175/45	174/44 175/44 175/45
Acquisition Date	30/03/1975 24/03/1985	19/06/1990 25/02/2010	01/09/2000	09/05/2022
Resolution/meters	60	30	30	30

2.3. Methods

2.3.1. Preprocessing

All satellite images underwent georeferencing and geometric correction to align with the WGS 84 datum (World Geographic System) and UTM (Universal Transverse Mercator) projection with Zone 36 North. The images underwent radiometric and atmospheric corrections; Conversion from digital number (DN) values to physical units ($W\ m^{-2}\ sr^{-1}\ \mu m^{-1}$) was achieved using the calibration data provided in the image header file. Processing of all images was conducted using ENVI 4.7 software.

2.3.2. Image Processing

ISODATA unsupervised classification was implemented on all images, resulting in 5 classes for water and 30 for land. Class validation involved selecting random points for each class in the study area around Lake Nasser. Approximately 100 references. The generation of a classification has two distinct steps: training and classification. Training is the process of setting a spectral envelope for a class and, for supervised classification, requires a priori information about the image data to be mapped (Green et al., 2000; Khaled et al., 2020), which was selected as a reference for each habitat class at different locations, including all areas (land and water bodies) of this study. GPS points above water measurements were also taken for the validation of the image data. Selected per class were chosen collectively in different regions of the study area and were the same for both images, Landsat. These points were randomly selected at the same latitude and longitude in both images. The algorithm then compares the pixel data in the image to the user-defined parameters and produces a classification output. The supervised classification was performed by the maximum like hood algorithm using ENVI 4.7 software.

2.3.3. Change Detection Analysis

The change detection analysis utilized the results of the supervised classification across all satellite images from 1975 to 2022. The outcomes of the supervised classification were transformed into vector layers using ENVI 5.0 software, and ArcGIS version 10.7 facilitated contextual editing for each class to finalize the calculation of class areas. The variation in each class in sequential satellite images was then computed in ArcGIS. Fish production data analysis, descriptive analysis was conducted using the IBM SPSS software package (Version 22), while Microsoft Excel was employed for generating graphs.

3. Results

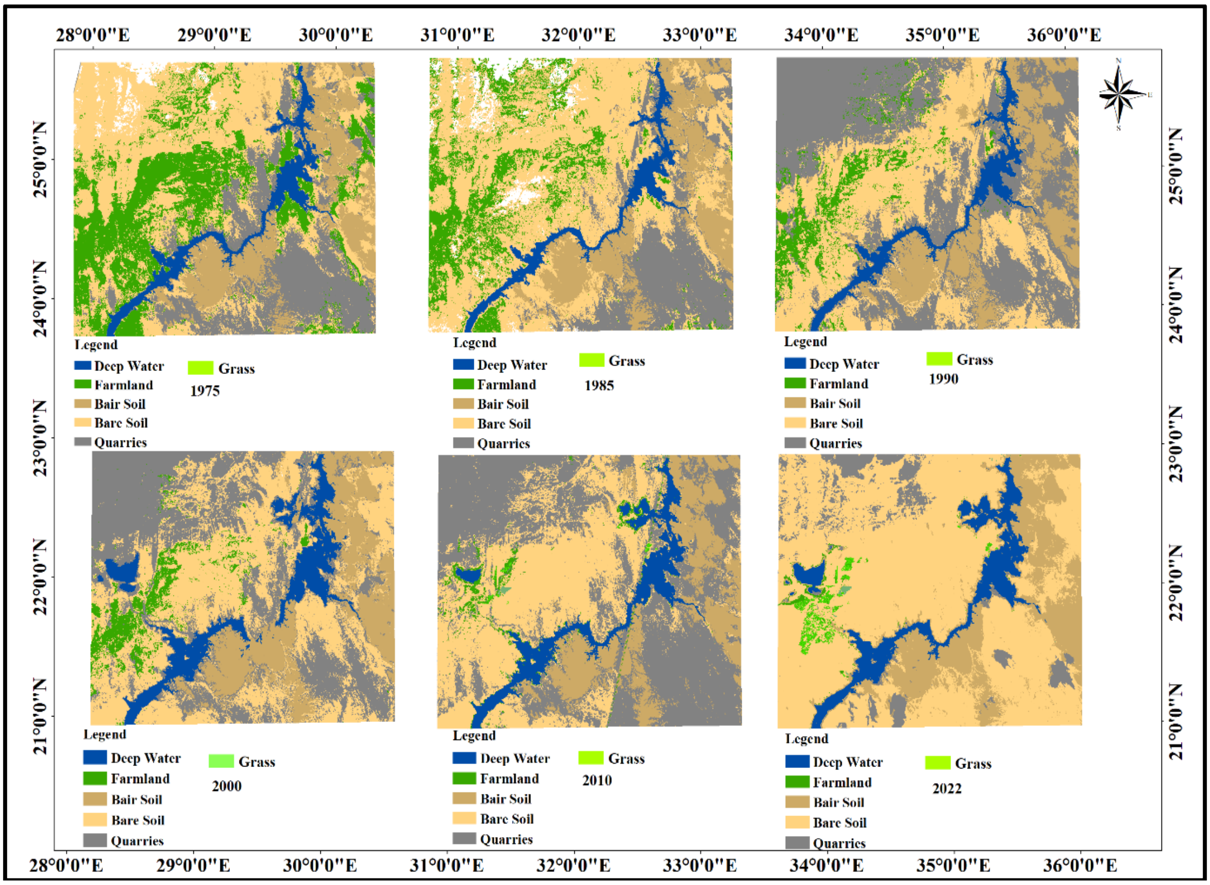

Figure (2): Supervised classification of Lake Nasser land use/land cover for 1975 and 2022.

3.1. Land Use Land Cover Changes

Land use/land cover change and assessment through the maximum likelihood algorithm and change detection analyses show the spatial representation of LULC types of major classes of land cover and use through the last five decades (1975 - 2022), as shown in (Table 2, Figure 4). The maximum likelihood algorithm, depending on the ground control points and the LULC class verification for accuracy assessment, resulted in nine major identified classes being merged into the following lake areas; urban, shoreline, and roads.

3.1.1. Urban

The result shows that the urbanized area increased during the 47-year time series of image analyses. Changes in urban area in the 47 years studied are tabulated in Table 2 and shown in Figures (2 and 3). The urban area in 1975, which includes buildings, natural, places, and points was about 76 km^2, but it reached 496 km^2 in 2022. The overall conclusion was that the urban area increased by about 870 km^2 during the time spam of analyses.

3.1.2. Shoreline

Lake Nasser's shoreline is notably irregular, featuring numerous side channels known as khors. Stretching over 300 km within Egypt's borders, the lake encompasses a shoreline area of approximately 5,22 km^2. Over the past 47 years, changes in the Lake Nasser shoreline have been influenced by coastal development, urbanization, and road construction, as documented in Table 2. Notably, during a phase of significant development efforts, including the Toshka and Abu Simbel projects aimed at desert reclamation and tourism industry expansion between 1985 and 1990, land erosion averaged about 2,98 km (refer to Figures 3 and 4). Specifically, shoreline erosion averaged approximately 3.92 km^2 per year from 1975 to 1985.

3.1.3. Lake Area

The lake has become a crucial fish source for Aswan residents and neighboring areas in Upper Egypt. Its coastline spans approximately 5,22 km^2, while the lake itself covered 59 km^2 from 1975 to 2022. In 1985, the coastline decreased notably to 2,98 km^2, coinciding with the lake shrinking to 33 km^2 due to reduced water levels and insufficient rainfall. Despite this, the lake remained a vital fish source for the region, as shown in Table 2 and Figures 3 and 4. The western sector experienced an average annual expansion of 33 km^2. The shoreline length stayed constant at 5,22 km, while the total change rate of the shoreline area was 59 km^2. This trend can be represented by the linear equation $y = 0.6156x - 1182.4$, with 'x' representing the year.

3.1.4. Road and Waterway Changes

Table 2 and Figure 2 display the changes in waterway area and road length over the 47-year study period. In 1975, the ratio of waterway area to road length was approximately 31 km. Initially, the road network spanned about 137 km, while the waterway was extended to 51 km by 2022.

3.2. Fish Production Changes

From 1975 to 2022, changes in land use and cover have led to an expansion of the lake area, fostering the emergence and growth of creeks and increasing fish stocks and production over 47 years. Both fresh and salted fish production totaled 15 tons in 1975. Initially managed by The General Authority for Fisheries Development until 2000, the oversight of Lake High Dam of Lake Nasser was then transferred to the Ministry of Agriculture before gaining independence and affiliation with the Ministry of Fisheries in 2010. This transition coincided with a decline in production, dropping to 83 tons. Presently, under the supervision of the Ministry of Interior to combat smuggling and theft, production has surged to 35 tons in 2022 (Table 2 and Figures 5).

Table (2): the time series changes in land use/land cover, Lake Nasser body size, and fish production from 1975 to 2022.

Class Year	Land cover /Km^2		Urban /Km^2	Rail Ways Length/ Km	Roads Length/ Km	Water Ways Length/ Km	Shoreline /km^2	Lake Area/Km^2	Production /tons
	Farmland	Grass							
1975-1985	20	07	76	03.3	31	31	3.92	34	15
1985-1990	23	13	216	16.8	10	13	2.98	33	26
1990-2000	39	42	200	19.5	79	23	3.45	45	22
2000-2010	46	62	310	20.1	98	49	5.31	56	83
2010-2022	06	81	344	21.8	110	51	4.27	56	16
1975-2022	394	156	496	22.8	137	51	5.22	59	35

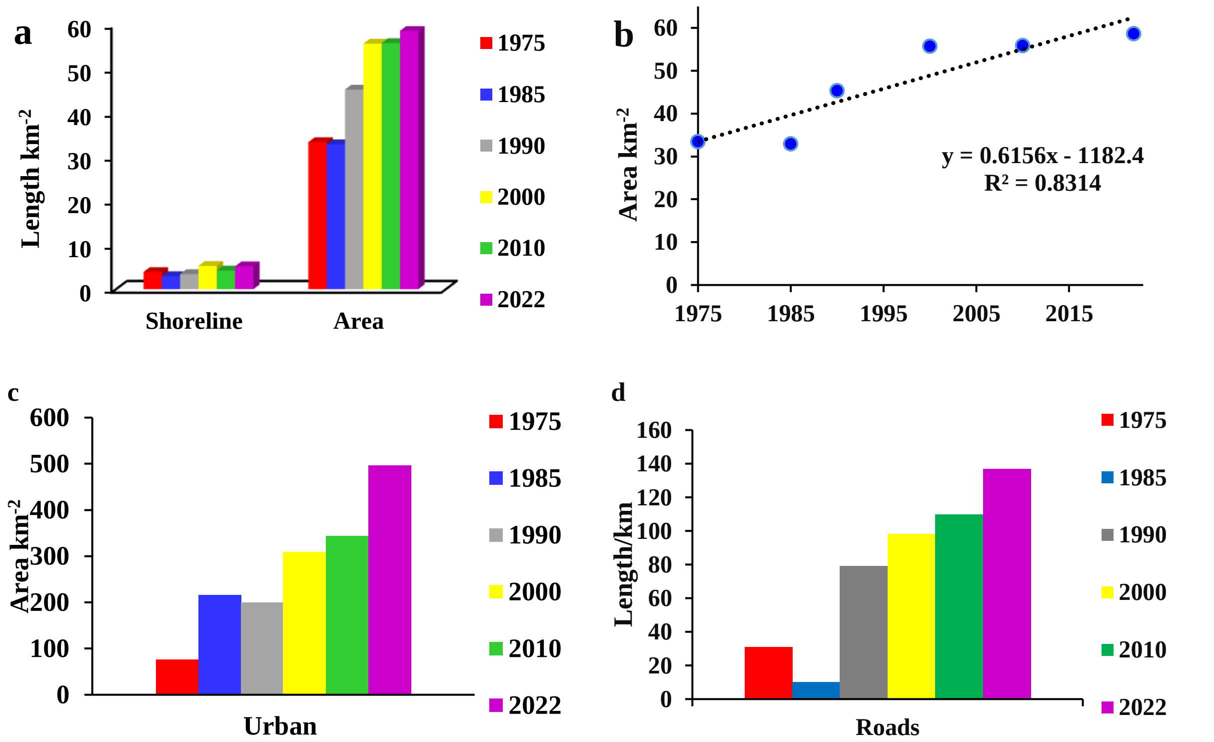

Figure (3): Shows the change rate for shore line (a), trend of urban (b), urban area (c), and roads (d).

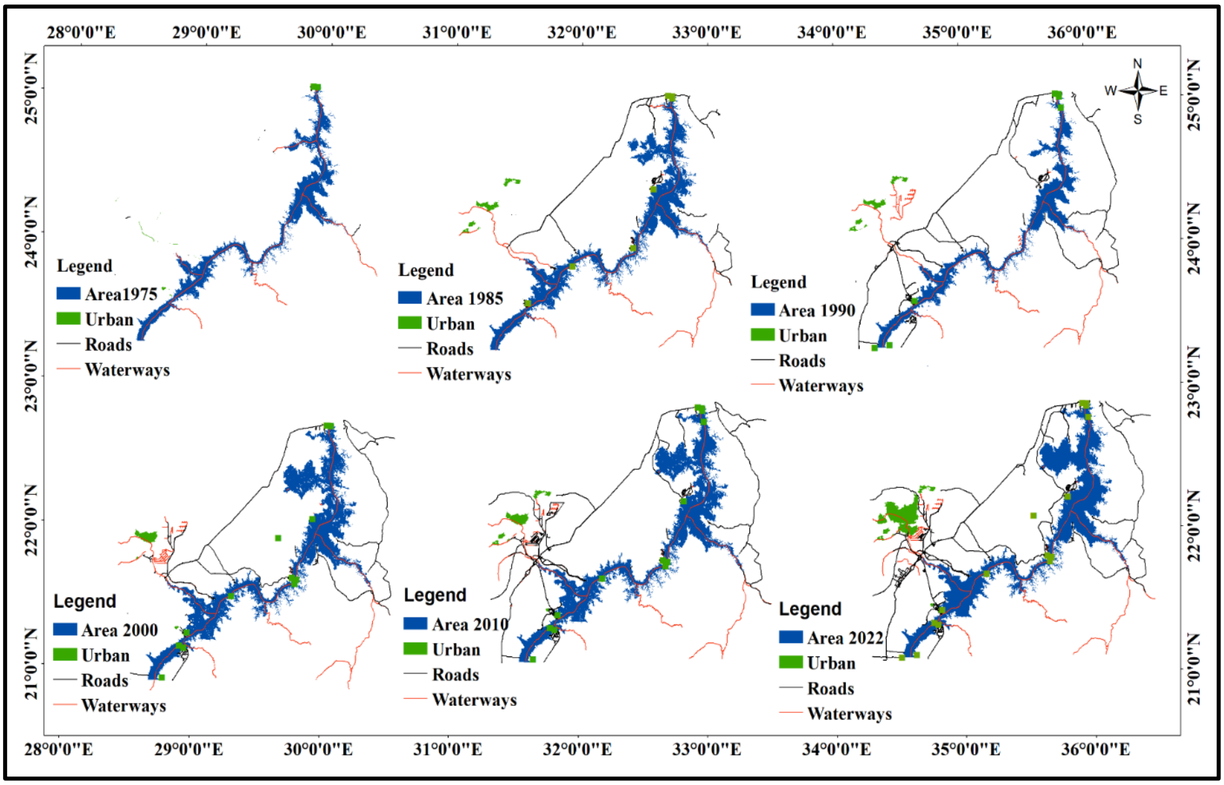

Figure (4): Changes in urban area and in the road network around Lake Nasser between 1975 and 2022.

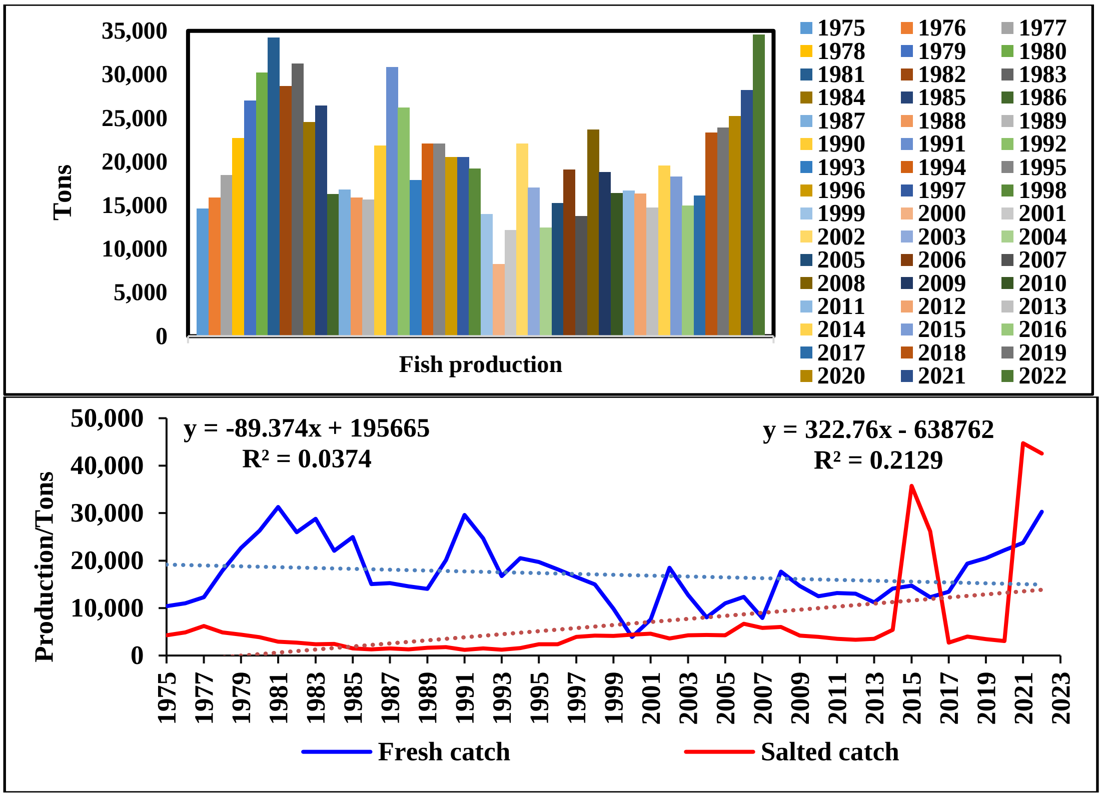

Figure (5) illustrates the total catch of fish production from Lake Nasser over the past five decades, based on statistics provided by GAFRD. The upper graph displays the overall production trend, while the lower graph depicts the trend of total catch for both fresh and salted fish.

4. Discussion

Satellite images revealed an expansion in Lake Nasser's coverage by 59 km^2, while its coastal line was estimated at 5.22 km^2. Urban development, including buildings, farmland, and grass, increased by approximately 259 km^2. Additionally, the length of roads experienced an estimated increase of 137 km over the past 47 years (from 1975 to 2022). Changes in Lake Nasser were detected using satellite imagery and Geographic Information Systems (GIS). Eighteen Landsat images were utilized to examine land cover changes in the lake and its surroundings. The findings indicated a decrease in Lake Nasser's total area from 588 km^2 in 2000 to about 5364.4 km^2 in 2019. Post-classification change detection revealed that the water body decreased from 548 km^2 in 2000 to 449 km^2 in 2019, while shallow water increased from 402 km^2 to 573 km^2 during the same period. The classification accuracy for Landsat-7 ETM+ 2000 and Landsat-8 OLI/TIRS 2019 images was found to be 83.95% and 85.71%, respectively. Notably, significant changes in land cover occurred from 2000 to 2019 (Mohamed et al., 2018).

In line with the current study, Soha and Ismail (2020) monitored and detected changes in Lake Nasser using integrated techniques of satellite images and GIS. They utilized two Landsat images acquired in 2000 and 2019 to investigate land cover changes in the lake and its surroundings. The findings revealed that Lake Nasser's total area decreased from 588 km2 in 2000 to about 536 km^2 in 2019. Furthermore, Elsayed et al. (2010) analyzed reservoir volume fluctuations between 1984 and 2015 using data from the JRC Global Surface Water (GSW) dataset and the satellite altimetry database DAHITI. The GSW dataset, with its high accuracy and 30 m resolution, enabled detailed calculations of lake area globally over an extended period. This approach is expected to improve estimates of water volume fluctuations compared to current techniques, as it is not constrained by complex and computationally intensive classification procedures.

Lake areas and water levels were combined in a regression analysis to establish the hypsometry relationship (dh = dA) (Busker et al., 2019). Additionally, there is a high potential for measuring lake volume dynamics using a pre-classified Global Surface Water (GSW) dataset, which facilitates scalability to a comprehensive global volumetric dataset. Consequently, volume variations can now be calculated using GSW lake areas as input, independent of altimetry data, enabling volume calculations dating back to 1975. The rise in water level leads to the inundation of new lands on both sides of Lake Nasser, with the extent depending on the slope. Consequently, areas with gentle slopes, such as the extensive khors, experience increased water coverage and storage (Salem, 2010). Lake Nasser is primarily influenced by climate change in East Africa (El Gammal, 2010). The construction of the Renaissance Dam in Ethiopia poses a significant security challenge to Egypt's water security. Despite the growing population and development rates, Egypt's share of water from the Nile has remained unchanged since the 1950s. Hence, the Ethiopian Dam could be considered a disruptive disaster for Egypt's development trajectory (El Bedawy, 2014).

5. Conclusion and Recommendations

This study employed two software programms, ArcGIS 10.8 and ENVI 4.7, to analyze the coastal environment of Lake Nasser, focusing on the interface between land and water. These tools were utilized to interpret location measurements, acquisition times of satellite images, and changes in the lake's size across different years, with one image per decade. The evaluation also considered fish production levels and the number of boats in Lake Nasser, highlighting economic losses in the Aswan region over the past 47 years (1975-2022).

The estimated reduction in fish production over the period from 1975 to 2022 amounts to 19.942 tons. Continued trends indicate a persistent expansion of Lake Nasser's coverage in the years to come. To tackle concerns regarding overfishing, especially in Khor areas affected by trawling and poisons, it is recommended to implement a comprehensive monitoring program utilizing remotely sensed data. Despite these challenges, there is optimism stemming from the agricultural, construction, and investment projects led by Aswan, particularly in the vicinity of Lake Nasser.

References

Bishai HM, Adel-Malek SA and Khalil MT. (2000). Lake Nasser. Publication of National Biodiversity Unit No.11-2000.

Cenderelli and Wohl. (2001). Flow hydraulics and geomorphic effects of glacial-lake outburst floods in the Mount Everest region, Nepal. 28(4):385 – 407.

Crul RCM. (1992). Models for estimating potential fish yield of African inland waters. CIFA Occasional Paper No. 16.

Ding et al. (2006). Biochar to improve soil fertility. (2):60- 2016.

El Bedawy, R. (2014). Water Resources Management: Alarming Crisis for Egypt. J. Manag. and Sustain. 4(3): 108- 124.

El Gammal, E.A. (2010). Assessment Lake Nasser within the Climatic Change. J. Amer. Sci. 6(7): 305- 312.

Elsayed A. El Gammal, Salem M. Salem, Alaa Eldin A. El Gammal. (2010). Change detection studies on the world's biggest artificial lake (Lake Nasser, Egypt). (13) 89–99.

Entz BGA. (1976). Lake Nasser and Lake Nubia. In Rzoska J, ed. The Nile, Biology of an Ancient River, The Hague: Dr. W. Junk B.V. Publishers. 271–88.

Ghobrial, M., (2008): "River Nile, History, Present and Future Prosperity". National Institute of Oceanography and Fisheries, Alexandria, Egypt.

Habib OA, Nasr Allah A and Dickson M. (2014). Fisheries situation analysis in Aswan. Youth Employment in Aswan Governorate Project.

Habib OA. (2015). Literature review of fisheries stock assessments in Lake Nasser. Youth Employment in Aswan Governorate Project.

Hala M. E. (2011). "Estimation of Evaporation Losses from Lake Nasser using Remote Sensing and GIS RASTER Calculator model". Survey Research Institute, National Water Research Center, pp 1-8.

Halls AS, Habib OA, Nasr-Allah A and Dickson M. (2015). Lake Nasser fisheries: Literature review and situation analysis. Penang, Malaysia: WorldFish. Program Report: 2015-42

Hamed, M., A. (2017). "Estimation of Water Quality Parameters in Lake Nasser using Remote Sensing techniques". Twentieth International Water Technology Conference, IWTC20, Hurghada, 18-20 May 2017, pp 630-644.

Khaled, M. A., Al-Jamali, F. H., Said, R. E. M., Mohammad, A. S., Ahmed, M. H., & Ahmed, H. O. (2023b). Analysis of SST and Chl-a data from MODIS-Aqua in the Major Egyptian Fishing Zones of the Red Sea. The Egyptian Journal of Aquatic Research. https://doi.org/https://doi.org/10.1016/j.ejar.2023.08.006

Khaled, M., Muller-Karger, F., Obuid-Allah, A., Ahmed, M. & Kafrawy, S. (2019). Using Landsat Data to Assess the Status of Coral Reefs Cover along the Red Sea Coast, Egypt. International Journal of Ecotoxicology and Ecobiology, 4, 17-31. https://doi.org/10.11648/j.ijee.20190401.13.

Khaled, M., Muller-Karger, F., Obuid-Allah, A., Ahmed, M., El-Kafrawy, S. (2023a): Long-Term Detection of Coral Reef Thermal Stress Events Using Daily Satellite Data in the Red Sea. In: Gad, A.A., Elfiky, D., Negm, A., Elbeih, S. (eds) Applications of Remote Sensing and GIS Based on an Innovative Vision. ICRSSSA 2022. Springer Proceedings in Earth and Environmental Sciences. Springer, Cham. https://doi.org/10.1007/978-3-031-40447-4_41.

Khaled, M., Obuid-Allah, A., Muller-Karger, F., Ahmed, M., Kafrawy, S. and Thabet, A. A. (2020). Benthic Habitat Mapping Using Remote Sensing Data at Hurghada Region, Red Sea Coast, Egypt. Assiut Univ. J. of Zoology., 49(2), 20-34. 10.21608/AUNJ.2020.221184.

Lillesand, T. M., Kiefer, R. W. and Chipman, J. W. (2004). Remote Sensing and Image Interpretation. New York: John Wiley and Sons, Inc.

Liu et al. (2014). Effects of temperature on life history traits of Eodiaptomusjaponicus (Copepoda: Calanoida) from Lake Biwa (Japan). Limnology. 15:85–97.

Mahdy, A., Said, R. E., Khaled, M. A., & Abdelsalam, A. A. (2022). First record of red tide in Elba protectorate coast using Sentinel-3 and its impacts on ecosystem. The Egyptian Journal of Remote Sensing and Space Science, 25(3): 803-813.

McFeeters, S.K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing 17:1425–1432.

Mohamed I. EL-Mekawy, Zeinab Salah and M. M. Abdel Wahab. (2018). Climatology of Lake Nasser in Egypt. 8(3): 719-726. ISSN 2077-4613.

Said R. E.M., Hasieb H. E., Khaled M. A., Mohammed-AbdAllah E., Osman A. G.M. (2024) . Regional variability in remotely sensed data with respect to the distribution of some snapper fishes (Family: Lutjanidae) between the Red Sea and the Arabian Gulf, Scientific African. https://doi.org/10.1016/j.sciaf.2024.e02104.

Salem, A.H. (2010). General description of lake Nasser. Conservation Ecology of the Nile crocodile" and Community Environmental Education to resolve the conflicts between the Nile Crocodiles and Man, in Lake Nasser –Egypt. 22p.

Soha A, Mohamed and Ismail Yousse. (2022). Sustainable Development in Nasser Lake using the Integration of Multi-Temporal Remote Sensing Imagery and GIS. 6-2020.

Tim Busker, Ad de Roo1, Emiliano Gelati, Christian Schwatke, Marko Adamovic1, Berny Bisselink, Jean-Francois Pekel, and Andrew Cottam. (2019). A global lake and reservoir volume analysis using a surface water dataset and satellite altimetry. Hydrol. Earth Syst. Sci., 23, 669–690, 2019. https://doi.org/10.5194/hess-23-669-2019.

van Zwieten PAM, Bene C, Kolding J, Brummett R and Valbo-Jorgensen J. (2011). Review of tropical reservoirs and their fisheries – The cases of Lake Nasser, Lake Volta and Indo-Gangetic Basin reservoirs. FAO Fisheries and Aquaculture Technical Paper No. 557. Rome: Food and Agriculture Organization of the United Nations.

Yao, L. and Schaich, K.M. (2014). Accelerated solvent extraction improves efficiency of lipid removal from dry pet food while limiting lipid oxidation. J. Amer. Oil Chemists' Soc. 92(1):141–151.