

Sustainable Development of Ecotourism in the Lake Qarun Area, Fayoum

Hossam Ashraf Mostafa¹, Prof. Dr. Mona Hassan Soliman², Prof. Abdullah Badawy Mohammed³

¹Department of Architecture, Faculty of Engineering, Fayoum University, Fayoum, Egypt. Email: ha3546@fayoum.edu.eg

²Professor, Architectural Design and Theories of Architecture Department of Architecture -Dean, Faculty of Engineering, Fayoum University Email: mhs00@fayoum.edu.eg, Orcid : <https://orcid.org/0000-0002-8462-2194>

³Professor, Architectural Engineering Department, Faculty of Engineering, Fayoum University, Egypt
Email: Abg00@fayoum.edu.eg , Orcid : <https://orcid.org/0000-0002-5145-5756>

Corresponding Author: Hossam Ashraf Mostafa Abdelraheem (Email: ha3546@fayoum.edu.eg)

Abstract: Fayoum Governorate possesses unique natural, environmental, and cultural resources that make it one of Egypt's most promising ecotourism destinations. Among these resources, Lake Qarun stands out due to its rich biodiversity and significant environmental, tourism, and economic value. However, the region is currently facing several environmental and urban challenges that have negatively affected the sustainability of its natural resources and tourism potential.

This paper aims to develop an integrated vision for the sustainable development of the Lake Qarun area by achieving a balance between economic growth and environmental conservation. The proposed approach is based on analyzing the area's natural, cultural, and tourism assets, identifying the major environmental challenges, and applying principles of urban planning and ecotourism to formulate practical and sustainable development proposals.

The findings indicate that deteriorating water quality, increasing salinity levels, pollution caused by agricultural and industrial wastewater, and sand encroachment represent the major constraints hindering the sustainable development of the region. Accordingly, the study proposes a set of sustainable solutions, including upgrading wastewater treatment systems, establishing a salt extraction plant, reclaiming desert lands, expanding aquaculture projects and environmentally friendly industries, and improving tourism infrastructure through the development of a cable car system, a sustainable tourist resort, daily-use chalets, a public park, an open-air theater, a medicinal plants garden, and the Fayoum Astronomical Center. These initiatives are expected to enhance the region's tourism attractiveness while promoting economic development and conserving its natural resources.

The paper is organized into nine main sections: Introduction, Literature Review, Research Problem and Objectives, Methodology, Results and Discussion, Conclusion, Recommendations, Limitations and Future Research, and Declarations.

Keywords: Ecotourism; Sustainable Development; Lake Qarun; Environmental Pollution; Urban Planning; Protected Areas

1. Introduction

Ecotourism has emerged as one of the most sustainable forms of tourism, offering an effective approach to balancing economic development with the conservation of natural resources. By promoting the sustainable utilization of environmental and cultural assets while minimizing the adverse impacts of human activities, ecotourism plays a significant role in achieving sustainable development. In this context, Fayoum Governorate, particularly the Lake Qarun area, represents a unique destination owing to its remarkable natural, biological, geological, and cultural diversity, making it one of Egypt's most promising ecotourism destinations. Nevertheless, despite these valuable resources, the region continues to face several environmental and urban challenges that hinder the achievement of sustainable development.

The most significant challenges include the deterioration of lake water quality caused by the discharge of agricultural, domestic, and industrial wastewater, increasing salinity levels, the accumulation of heavy metals, declining biodiversity, and reduced fish production. Furthermore, the inadequate utilization of the area's natural and



tourism resources within an integrated planning framework has created a noticeable gap between the region's substantial development potential and its current level of development. These challenges highlight the urgent need for a comprehensive sustainable development strategy.

The significance of this study lies in establishing an integrated planning framework that combines environmental conservation with tourism and economic development in the Lake Qarun area, in line with the Sustainable Development Goals (SDGs) and Egypt's regional development strategy. The study also seeks to maximize the utilization of the area's natural and environmental resources by proposing practical development projects that contribute to environmental improvement, tourism promotion, and employment generation for local communities.

Accordingly, this paper aims to propose an integrated sustainable development framework for the Lake Qarun area by analyzing its natural, environmental, and tourism characteristics, assessing the major challenges affecting the region, and developing practical planning and development proposals that achieve a balance between economic growth and environmental conservation.

Research Question

How can sustainable tourism development be achieved in the Lake Qarun area through the effective utilization of its natural, environmental, and cultural resources while mitigating the environmental challenges that threaten the sustainability of its ecosystem?

The remainder of the paper is organized as follows. Section 1 (this section) introduces the research problem and its significance. Section 2 reviews the theoretical background and previous studies. Section 3 defines the research problem and objectives. Section 4 presents the research methodology and study area. Section 5 presents the analysis and evaluation results together with the discussion. Section 6 concludes the paper and outlines the proposed sustainable development framework and projects. Section 7 presents the study's recommendations. Section 8 notes the study's limitations and directions for future research, and Section 9 presents the declarations.

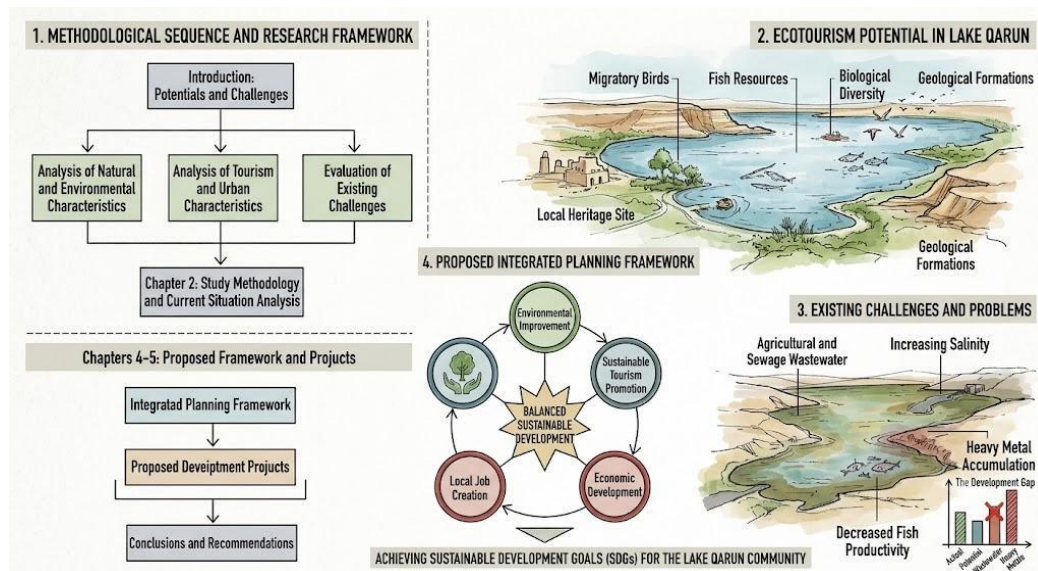


Figure (1) An Integrated Methodological and Planning Framework for Ecotourism Development in the Lake Qarun Area

2. Literature Review

The Lake Qarun area and the Fayoum Depression have received considerable attention in the scientific literature due to their unique geological, environmental, and tourism characteristics. Previous studies have investigated the

region from various perspectives, providing a comprehensive understanding of its natural resources, environmental challenges, and development opportunities.

Early research primarily focused on the geomorphological and geological evolution of the Fayoum Depression. Abu Al-Hajjaj (1967) and Abdel Latif (1977) examined the geological formations, landforms, and natural processes that shaped the region, while Azab (2001) investigated the geological structure surrounding Lake Qarun, highlighting the influence of tectonic features on the area's environmental characteristics and development potential.

Subsequent studies shifted their attention toward environmental assessment and water resource management. Nazeer (1993), Abdel Tawab (1995), and Mustafa (2003) investigated environmental degradation, water resources, and the geomorphological changes affecting Lake Qarun. Their findings emphasized the increasing impacts of pollution, rising salinity levels, and the continued deterioration of the lake ecosystem. In addition, Al-Ebrahim (2003) demonstrated the effectiveness of remote sensing and Geographic Information Systems (GIS) in monitoring environmental changes and identifying suitable areas for sustainable development.

From a tourism and planning perspective, several studies explored the region's development potential. Rabie (2010) highlighted the significance of ecotourism as a key driver of sustainable economic development, while the General Organization for Physical Planning (2011) identified Lake Qarun as one of the strategic development hubs in Northern Upper Egypt. Furthermore, studies conducted by the Egyptian Environmental Affairs Agency (EEAA) emphasized the importance of conserving biodiversity within the Lake Qarun Protected Area. Likewise, UNESCO recognized nearby heritage sites, particularly Wadi El-Hitan, as internationally significant natural assets that strengthen the region's tourism appeal and support sustainable development.

Despite the valuable contributions of these studies, most have addressed the geological, environmental, and tourism dimensions independently, without proposing an integrated framework that combines environmental conservation, sustainable tourism, urban planning, and economic development. Therefore, the present study seeks to bridge this research gap by proposing a comprehensive sustainable development framework for the Lake Qarun area that balances ecosystem conservation with the sustainable utilization of the region's tourism and natural resources, thereby supporting long-term regional sustainable development.

2.1 Novelty of the Study

Unlike previous studies that mainly focused on individual environmental, geological, or tourism aspects of the Lake Qarun region, the present study proposes an integrated sequential development framework. The framework begins with environmental rehabilitation through wastewater treatment, salinity reduction, and remediation of heavy-metal contamination (particularly cadmium and nickel), followed by the implementation of sustainable regional development projects. These projects include improving cross-lake connectivity between the northern and southern shores, promoting scientific and ecotourism, and maximizing the environmental and economic value of the protected areas. This sequential planning methodology integrates ecosystem restoration with sustainable tourism and regional development into a unified planning strategy.

Building upon these previous studies, the present research synthesizes the existing knowledge into a unified conceptual framework that integrates environmental, tourism, urban, and socio-economic dimensions. Rather than addressing these aspects separately, the study adopts a multidisciplinary approach that combines Geographic Information Systems (GIS), environmental assessment, sustainable tourism principles, and spatial planning strategies to formulate a comprehensive development framework. This integrated perspective not only supports evidence-based decision-making but also enhances the resilience and long-term sustainability of the Lake Qarun area by aligning environmental conservation with economic growth and community development.

2.2 Recent Studies (2022–2025)

More recent research has continued to refine the understanding of Lake Qarun's environmental and developmental trajectory. Abdelbaki et al. (2022) reviewed the lake's entangled ecological history and proposed an

integrated management plan aimed at rehabilitating its fisheries and overall ecosystem. Building on multi-temporal satellite imagery spanning 1985–2023, Khalifa et al. (2025) modeled a Water Quality Index (WQI) for the lake using GIS interpolation and found values ranging from 84.33 to 305.53, indicating that large parts of the lake are currently unsuitable for aquatic life, with the sharpest degradation occurring near intensively farmed and urbanized shorelines. At the sediment level, Aljahdali et al. (2025) analyzed 38 bottom-sediment samples and confirmed elevated concentrations of iron, copper, zinc, chromium, nickel, cobalt, lead, and cadmium, concentrated mainly in the eastern sector of the lake near the Al-Wadi and El-Bats drains — a spatial pattern consistent with, and more granular than, the contamination levels reported in the present study. Complementing this, Goher and Khedr (2024) applied a set of novel combined toxicity indices to Lake Qarun sediment and confirmed varying degrees of metal pollution across twenty-one measured elements.

On the tourism and planning side, ALBaz (2025) evaluated an eco-lodge project near the Wadi El-Rayan lakes using SWOT analysis and LEED green-building criteria, offering a recent architectural precedent for low-carbon, sustainability-certified tourism infrastructure directly relevant to the resort and chalet proposals discussed later in this paper. At the institutional level, a GEF-funded ecosystem restoration plan prepared jointly by the Egyptian Ministry of Environment, EEAA, UNEP, and IUCN (2022) set out a management strategy for the Wadi El-Rayan and Lake Qarun protected areas, emphasizing biodiversity protection, community involvement, and capacity building — confirming that the integrated, multi-stakeholder direction proposed in the current study is consistent with ongoing national and international restoration efforts.

Taken together, these recent contributions confirm that the core environmental problems identified in earlier literature — salinity increase, heavy-metal accumulation, and wastewater-driven degradation — persist and, in several respects, have intensified through 2025. At the same time, they show a growing shift toward higher-resolution spatial monitoring (GIS/remote sensing), sediment-level risk assessment, and green-building practice in tourism development, all of which the present study incorporates into its integrated framework.

No.	Author(s)	Year	Field	Methodology	Key Findings	Research Gap
1	Yusuf Abu Al-Hajjaj	1967	Geomorphology	Geomorphological analysis	Studied the origin and evolution of the Fayoum Depression and its natural characteristics.	Provides the natural basis and geological background for sustainable development planning in the area.
2	Abdel Aziz Abdel Latif	1977	Physical Geography	Geographical analysis	Analyzed the natural factors affecting the Fayoum Depression, including climate, soil, and water resources.	Supports understanding of the environmental characteristics and natural resources of the study area.
3	Azab	2001	Geology	Geological analysis	Examined the geological structure surrounding Lake Qarun and its impact on the area's properties.	Helps assess the suitability of the area for developmental projects.
4	Al-Ebrahim	2003	Remote Sensing & GIS	Satellite imagery and GIS	Identified development potentials using remote sensing techniques and spatial analysis.	Supports the use of spatial tools in sustainable planning and monitoring.

No.	Author(s)	Year	Field	Methodology	Key Findings	Research Gap
5	Hanaa Nazeer	1993	Environment	Environmental analysis	Discussed environmental changes, pollution, and desertification impacts in Fayoum Governorate.	Highlights the main environmental challenges addressed in the current study.
6	Noura Abdel Tawab	1995	Water Resources	Hydrological analysis	Studied water sources and their relationship with the ecological system in the Fayoum Depression.	Supports evaluation of water resources and their role in sustainability.
7	Jehan Mustafa	2003	Lake Geomorphology	Geomorphological analysis	Investigated the changes that occurred in Lake Qarun and the factors influencing it.	Explains the natural evolution of the lake environment.
8	Hani Rabie	2010	Ecotourism	Descriptive and analytical study	Highlighted the ecotourism potential of Lake Qarun and opportunities for its development.	Supports the ecotourism development axis in line with sustainability principles.
9	General Organization for Physical Planning	2011	Regional Planning	Strategic planning	Identified Lake Qarun as a key development axis in the Northern Upper Egypt region.	Strengthens the strategic planning vision for the study area.
10	Egyptian Environmental Affairs Agency (EEAA)	2007 / 2015	Environmental Management	Environmental monitoring	Emphasized the importance of biodiversity protection and monitored pollution, including heavy metals in the lake.	Confirms the need for environmental protection and pollution control measures.
11	UNESCO	2005	Natural Heritage	Environmental assessment	Confirmed the global significance of Wadi El-Hitan and the areas surrounding Lake Qarun.	Enhances the environmental and tourism value of the study area.
12	Abdelbaki et al.	2022	Fisheries / Lake History	Historical review and integrated management analysis	Reviewed the entangled history of Lake Qarun and proposed an integrated management plan for ecosystem rehabilitation and sustainable fisheries.	Provides an up-to-date rehabilitation framework that supports the present study's integrated approach.
13	Khalifa et al.	2025	Water Quality / GIS	Multi-temporal remote sensing (1985–2023), GIS-based Water Quality Index modeling	Found WQI values of 84.33–305.53, indicating the lake is unsuitable for aquatic life, with degradation concentrated near agricultural and urbanized zones.	Confirms and updates the water-quality deterioration trends addressed in the current study using recent satellite data.

No.	Author(s)	Year	Field	Methodology	Key Findings	Research Gap
14	Aljahdali et al.	2025	Sediment Geochemistry	Analysis of 38 bottom-sediment samples; geochemical and human-health risk indices	Identified elevated Fe, Cu, Zn, Cr, Ni, Co, Pb, and Cd concentrations, highest in the eastern lake sector near the drains.	Reinforces the heavy-metal contamination findings and refines their spatial pattern for targeted remediation.
15	Goher & Khedr	2024	Sediment Toxicology	Novel Combined Toxicity Indices (CTI); 21-metal fractionation analysis	All applied indices confirmed varying degrees of metal pollution in Lake Qarun sediment.	Supports the case for the proposed heavy-metal extraction and remediation project.
16	ALBaz	2025	Ecotourism / Green Architecture	SWOT analysis; LEED BD+C evaluation of an eco-lodge case study	Evaluated an eco-lodge project near Wadi El-Rayan lakes as a model for sustainable, low-carbon ecotourism architecture.	Provides a recent architectural precedent relevant to the tourism-infrastructure proposals in the current study.
17	EEAA / UNEP / IUCN / CEDARE	2022	Protected-Area Management	GEF-funded ecosystem restoration planning (EMPA Project)	Proposed a restoration plan for Wadi El-Rayan and Lake Qarun protected areas addressing biodiversity threats and community involvement.	Confirms institutional momentum toward integrated restoration, aligning with the current study's recommendations.

Table (1) Summary of Previous Studies

3. Research Problem and Objectives

3.1 Research Problem

The Lake Qarun area and the Fayoum Depression are facing a range of interconnected environmental and developmental challenges. These include the deterioration of water quality due to the discharge of agricultural and domestic wastewater, increasing salinity levels, and contamination by heavy metals, all of which have contributed to the decline of biodiversity and fish production. Moreover, the unsustainable use of natural resources, coupled with inadequate environmental and development planning, has intensified the pressures on the region's ecosystem. Despite the area's exceptional natural, cultural, and tourism assets, these resources have not been effectively utilized within an integrated development framework that balances environmental conservation with economic and social development. Consequently, there is an urgent need to establish a sustainable development framework capable of addressing these challenges while ensuring the efficient and sustainable use of the region's natural resources.

3.2 Research Objectives

3.2.1 Main Objective

The primary objective of this study is to propose an integrated framework for the sustainable development of the Lake Qarun area by achieving a balance between ecosystem conservation and tourism and economic development, thereby enhancing the efficient utilization of natural resources and improving environmental quality.

3.2.2 Specific Objectives

- To evaluate the major environmental challenges facing Lake Qarun, particularly water pollution, increasing salinity, and ecosystem degradation.
- To analyze the natural, tourism, and economic potential of the study area and assess their contribution to sustainable development.
- To propose a set of sustainable planning solutions and development projects that improve environmental conditions, enhance tourism attractiveness, and promote regional economic development.

4. Research Methodology

4.1 Research Design

This study adopts an integrated mixed-method research design combining qualitative and quantitative approaches to evaluate the environmental and tourism conditions of the Lake Qarun area and to develop a sustainable development framework that balances environmental conservation with tourism and regional economic development. The research methodology follows three complementary scientific approaches: the inductive approach to investigate the current environmental and tourism conditions, the analytical approach to evaluate spatial, environmental, and socio-economic characteristics, and the deductive approach to formulate practical planning recommendations and sustainable development strategies. This integrated methodological framework ensures a comprehensive understanding of the interactions between environmental resources, tourism potential, and sustainable regional development.

4.2 Study Area

The study focuses on the Lake Qarun region in Fayoum Governorate, Egypt, one of the country's most valuable ecological and tourism destinations. The area contains diverse natural resources, protected areas, archaeological sites, and unique landscapes that support ecotourism activities. However, the region is currently facing several environmental challenges, including increasing salinity, water pollution, biodiversity degradation, urban expansion, and pressures associated with tourism development. These characteristics make Lake Qarun an appropriate case study for investigating sustainable ecotourism development.

4.3 Data Collection

The research relied on both primary and secondary data sources.

- Primary data were collected through field visits, direct observations, structured questionnaires, and interviews with specialists, local stakeholders, and officials involved in environmental management and tourism planning. These data were used to evaluate environmental conditions, identify development constraints, and assess local perceptions regarding sustainable tourism development.
- Secondary data were obtained from scientific publications, governmental reports, planning documents, environmental statistics, topographic and thematic maps, satellite imagery, and official databases provided by relevant governmental authorities. These datasets provided the environmental, spatial, and socio-economic information required for comprehensive analysis.

4.4 Spatial and Environmental Analysis

- Geographic Information Systems (GIS) were employed to organize, integrate, and analyze spatial datasets. GIS techniques were used to prepare thematic maps, analyze land-use patterns, identify environmentally sensitive areas, evaluate tourism resources, and support spatial decision-making for sustainable development.

- Remote sensing techniques were utilized to investigate environmental characteristics and monitor spatial changes within the study area through the interpretation of satellite imagery. The integration of GIS and remote sensing provided an effective framework for identifying environmental degradation, evaluating natural resources, and locating potential development zones.

4.5 Statistical and Strategic Analysis

- Questionnaire responses were statistically analyzed to identify the major environmental and tourism issues affecting the study area and to support the interpretation of field observations. Descriptive statistical techniques were employed to summarize and evaluate respondents' opinions and to generate indicators supporting the proposed development framework.
- A SWOT analysis was conducted to assess the strengths, weaknesses, opportunities, and threats associated with the Lake Qarun area. The results were integrated with the spatial and environmental analyses to identify development priorities and formulate practical planning strategies that enhance tourism competitiveness while preserving environmental resources.

4.6 Research Framework

The research was implemented through four sequential stages.

- Data Collection: Compilation of primary and secondary environmental, tourism, and spatial datasets through field investigations and documentary sources.
- Current Situation Assessment: Evaluation of the existing environmental, tourism, and land-use conditions using GIS, remote sensing, and statistical analysis.
- Development Potential Analysis: Identification of environmentally suitable areas and assessment of development opportunities based on environmental, social, economic, and tourism sustainability considerations.
- Framework Development: Formulation of an integrated sustainable development framework supported by planning strategies and practical development projects that promote ecotourism while conserving the ecological integrity of the Lake Qarun region.

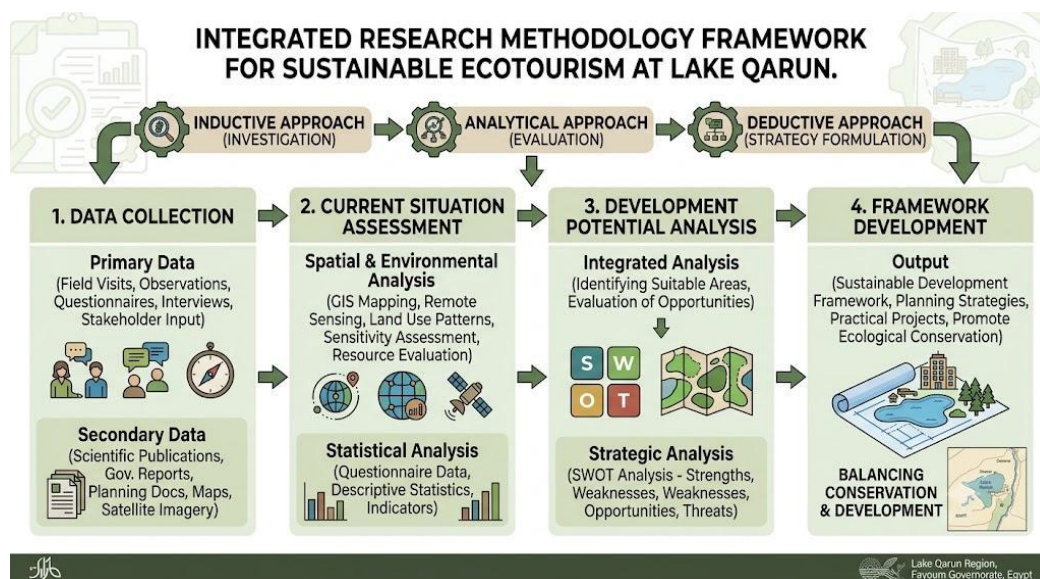


Figure (2) Four Sequential Stages for the Research



Figure (3) Research Methodology

5. Results and Discussion

5.1 Results

- The analysis revealed that Lake Qarun possesses exceptional natural and ecological characteristics, making it one of Egypt's most important ecotourism destinations. Nevertheless, the study identified several environmental challenges that significantly threaten the sustainability of the lake ecosystem and limit its development potential.
- The lake depends primarily on agricultural drainage water, in addition to domestic and industrial wastewater, while groundwater represents only a minor source of recharge. This hydrological system has resulted in the continuous accumulation of pollutants, increased salinity, elevated ammonia concentrations, deterioration of water quality, and degradation of the lake's visual landscape.
- Environmental analysis indicated that heavy metal contamination, particularly cadmium and nickel, exceeds internationally accepted limits in most parts of the study area. Approximately 92.5% of the area is affected by cadmium contamination, posing serious environmental and ecological risks.

- The study also demonstrated a continuous increase in water salinity, ranging from approximately 13 g/L near the southern shoreline to 39.8 g/L in the northern sector, exceeding the salinity of the Mediterranean Sea. Elevated salinity has contributed to biodiversity loss, fish mortality and declining fish production, degradation of aquatic vegetation and wetland habitats, and reduced tourism attractiveness.
- Furthermore, fluctuations in the lake water level have generated several environmental impacts, including shoreline inundation, soil waterlogging, expansion of salt flats, deterioration of agricultural land, and damage to tourism facilities. The environmentally balanced water level was estimated at approximately -43.8 m below sea level.
- Finally, historical analysis revealed noticeable fluctuations in the lake surface area during the last century as a result of changes in water inflow, evaporation rates, and human interventions. These variations reflect the sensitivity of the lake ecosystem to both natural and anthropogenic factors and emphasize the need for integrated environmental management.
- Overall, the findings indicate that the environmental degradation of Lake Qarun is primarily driven by the continuous discharge of untreated agricultural, domestic, and industrial wastewater. Therefore, improving wastewater treatment and reducing pollutant and salt loads before discharge into the lake represent the most effective approach to restoring water quality, protecting biodiversity, improving the visual landscape, and supporting sustainable tourism and long-term regional development.

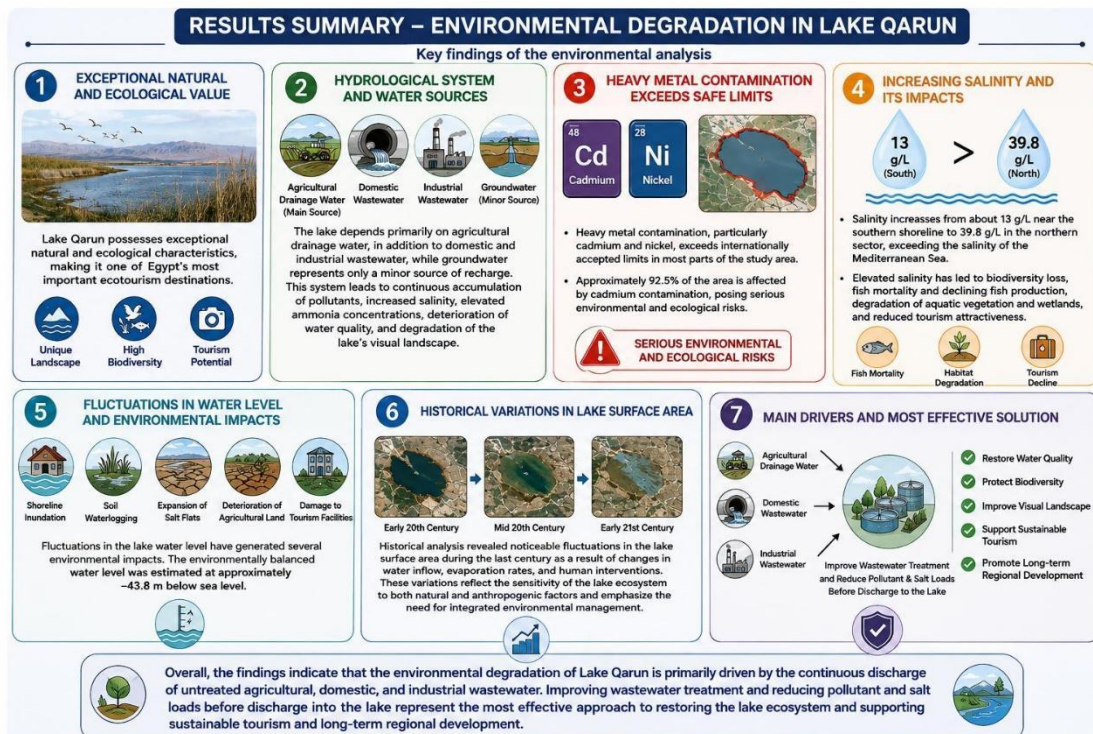


Figure (4) Results Summary

5.2 Discussion

- The findings indicate that the environmental degradation of Lake Qarun is primarily the result of cumulative anthropogenic pressures rather than natural environmental changes alone. Although the lake possesses exceptional ecological, geological, and cultural resources that qualify it as one of Egypt's most valuable

ecotourism destinations, its closed hydrological system has made it highly vulnerable to the continuous accumulation of pollutants and dissolved salts. Consequently, the environmental carrying capacity of the lake has gradually declined, threatening both ecosystem stability and sustainable regional development.

- The principal contribution of this research is not limited to identifying environmental problems; rather, it introduces a sequential planning methodology in which ecological restoration constitutes the prerequisite for sustainable regional development. This approach demonstrates that environmental rehabilitation should precede tourism and infrastructure investments to ensure long-term environmental, economic, and social sustainability.
- The dominance of agricultural drainage as the principal water source explains the progressive increase in salinity and nutrient enrichment observed throughout the lake. Additional inputs from domestic and industrial wastewater further accelerate environmental deterioration by introducing organic pollutants, ammonia, pathogenic microorganisms, and heavy metals. These combined pressures have significantly reduced water quality and altered the ecological balance of the lake, which is consistent with previous studies identifying wastewater discharge as the primary driver of environmental degradation in Lake Qarun.
- Heavy metal contamination represents another critical environmental concern. The widespread distribution of cadmium and nickel above internationally accepted limits indicates long-term accumulation within the lake ecosystem. Such contamination poses considerable ecological risks through bioaccumulation and food-chain transfer, affecting aquatic organisms and potentially threatening human health. Similarly, the observed increase in salinity, which in some locations exceeds that of the Mediterranean Sea, has contributed to biodiversity loss, fish mortality, degradation of aquatic vegetation, and declining tourism attractiveness. These findings emphasize that water quality deterioration extends beyond ecological impacts to include significant economic and social consequences.
- Furthermore, fluctuations in lake water level and historical changes in lake surface area demonstrate the sensitivity of the Lake Qarun ecosystem to both climatic variability and human interventions. Shoreline inundation, expansion of salt flats, deterioration of agricultural lands, and damage to tourism facilities illustrate the interconnected nature of environmental and socio-economic systems within the study area. Therefore, environmental management should not focus solely on pollution control but should adopt an integrated landscape-scale approach that considers hydrology, biodiversity conservation, land use planning, and tourism development simultaneously.
- From a sustainable development perspective, the results suggest that environmental restoration should be integrated with economic development rather than treated as separate objectives. Improving wastewater treatment before discharge, reducing pollutant and salt loads, restoring wetland habitats, and protecting biodiversity would create the environmental conditions necessary for ecotourism development. At the same time, carefully planned green industries, environmentally compatible tourism infrastructure, and community-based development projects could diversify the local economy while minimizing environmental impacts.
- Overall, the study demonstrates that the sustainable future of Lake Qarun depends on adopting an integrated environmental planning strategy that balances ecosystem conservation with socio-economic development. Such an approach would contribute not only to improving environmental quality but also to enhancing tourism competitiveness, creating employment opportunities, and achieving long-term regional sustainability.

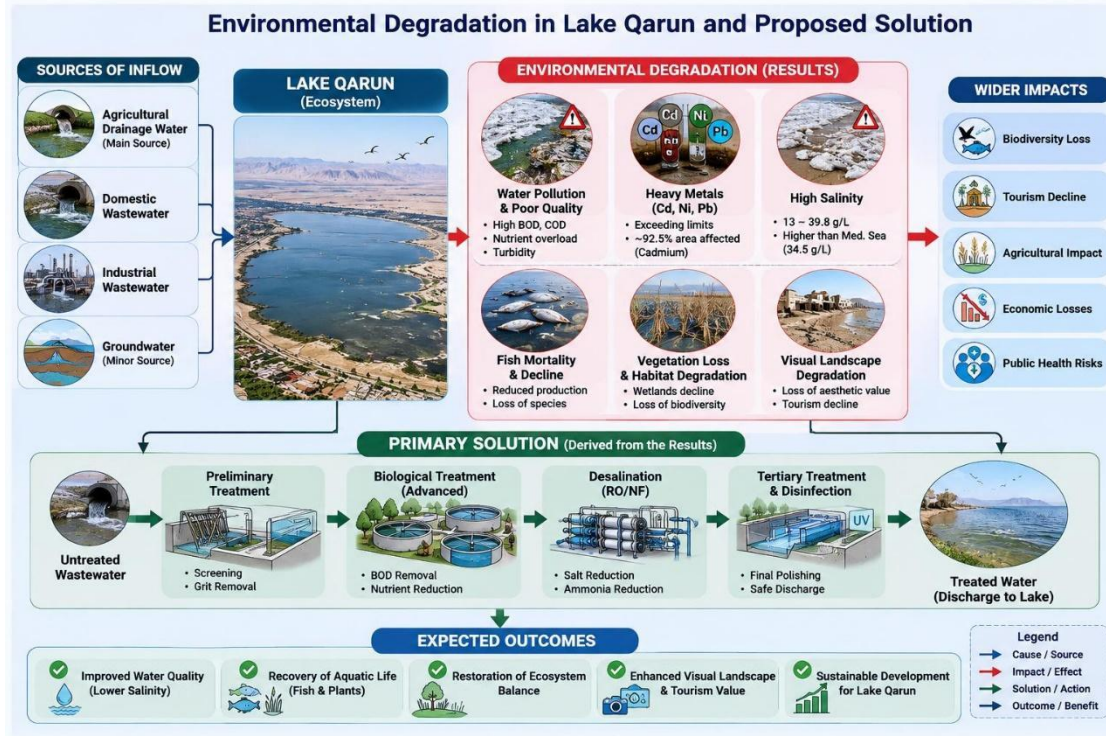


Figure (5) Discussion and Proposed Solutions

6. Conclusion

The findings of this study revealed that the environmental challenges facing Lake Qarun, including water quality deterioration, increasing salinity, heavy metal accumulation, and biodiversity decline, require an integrated sustainable development approach rather than isolated solutions. The proposed framework aims to achieve a balance between environmental protection, economic development, and improving the quality of life for local communities through sustainable management of the lake's natural resources.

The study presents an integrated vision for the sustainable development of the Lake Qarun region based on environmental rehabilitation, green industries, sustainable agriculture, and eco-tourism development. This approach can contribute to restoring the ecological balance of the lake, enhancing local economic activities, creating employment opportunities, and transforming Lake Qarun into a national model for sustainable development and environmental resilience.

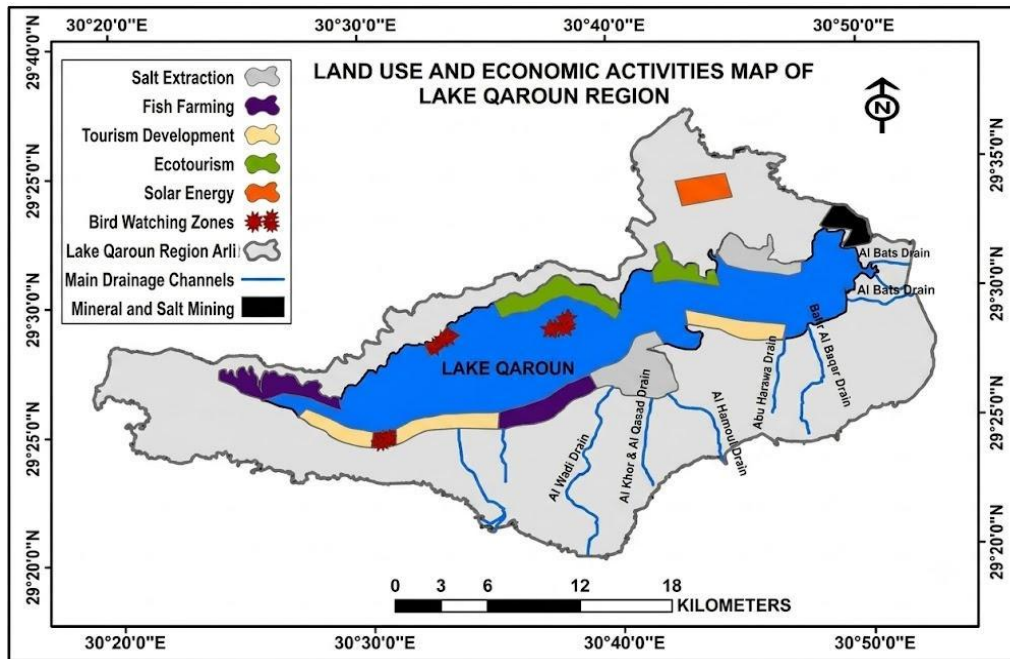


Figure (6) Proposed Sustainable Development Map for the Lake Qarun Area, Fayoum

6.1 The Proposed Sustainable Development Projects Include:

- Establishing a heavy metal extraction project from lake sediments, particularly cadmium recovery using distillation furnaces, with an attached zinc refining plant to utilize extracted resources after conducting the required technical and environmental assessments.
- Developing date-processing industries to utilize palm residues, such as seeds and leaves, as renewable energy sources for extraction processes, supporting the circular economy concept.
- Improving, expanding, and upgrading wastewater treatment systems in Fayoum Governorate, with the implementation of integrated treatment solutions to prevent untreated domestic and agricultural wastewater discharge into the lake.
- Treating agricultural and domestic wastewater before entering Lake Qarun to reduce pollution levels and heavy metal concentrations.
- Expanding the reclamation of desert lands north and east of the lake using treated water from Al-Bats and Al-Wadi drains, supported by modern irrigation techniques.
- Establishing a salt extraction plant to support salinity management and maximize the economic utilization of extracted salts.
- Developing sustainable employment opportunities for local communities through salt and mineral industries, fish farming activities, and eco-tourism projects.
- Designing a cable car system connecting the northern and southern shores of Lake Qarun to enhance accessibility and tourism connectivity.
- Establishing the Fayoum Astronomical Center as a scientific, cultural, and eco-tourism destination specialized in astronomy and observation of celestial bodies.

- Developing a sustainable tourist resort on the northeastern shore of the lake inspired by the desert environment and local heritage.
- Establishing daily-use tourist chalets along the southern shore of the lake to support local tourism activities.
- Creating a public park and an open-air theater for international festivals and cultural events.
- Establishing a botanical garden showcasing rare medicinal and aromatic plants and supporting environmental awareness.
- Regulating fishing activities and protecting wetlands, salt marshes, and natural habitats to maintain ecological balance and conserve migratory bird ecosystems.



Figure (7) Composite Strategy for Lake Qarun, Fayoum

6.2 6.2 Examples of National Projects to Achieve Sustainable Development in the Lake Qarun Area

6.2.1 Lake Qarun Cable Car Project

- Seamless Coast-to-Coast Connection: Efficiently linking the northern and southern shores of Lake Qarun to enhance accessibility and cut down travel time between key destinations.
- Panoramic Aerial Experience: Offering visitors breathtaking 360° views of the lake, surrounding desert plains, and unique historical and natural landmarks from above.
- Eco-Friendly Infrastructure: Providing a low-emission, sustainable transport solution that minimizes environmental impact on sensitive ecosystems.
- Boosting Local Tourism & Economy: Creating an iconic landmark that attracts domestic and international tourists, driving sustainable economic growth across the region.

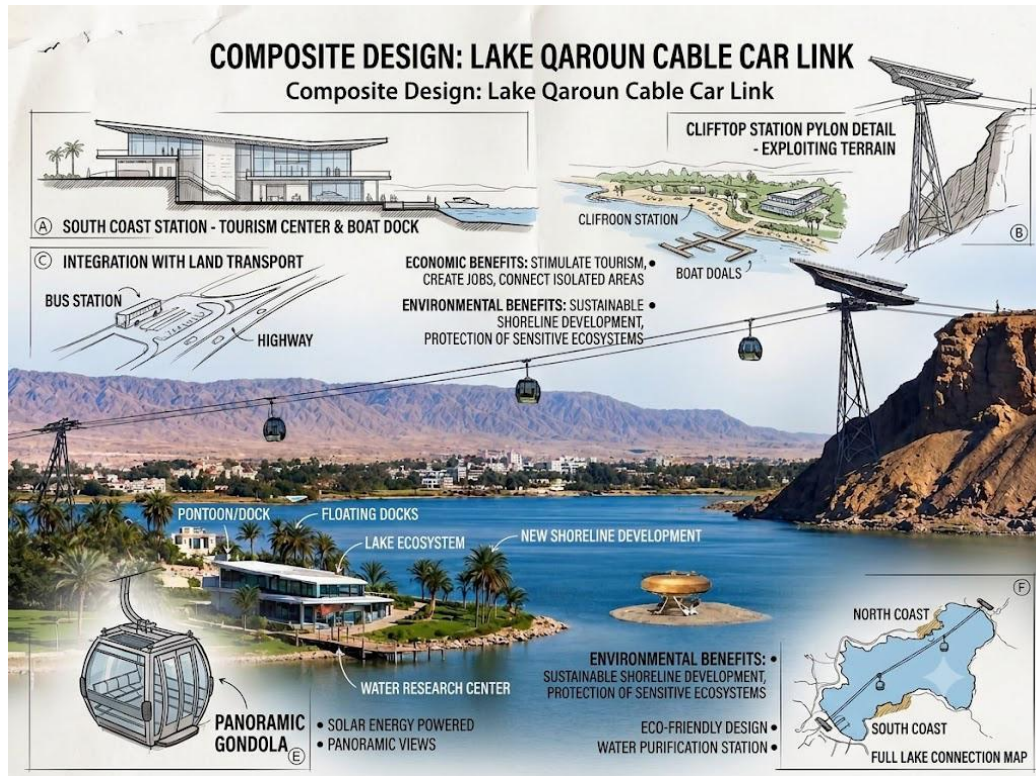


Figure (8) Composite Design for the Lake Qaroun Cable Car

- **Integration with Tourist Attractions:** Connecting major ecotourism destinations, including Wadi El-Hitan, Wadi El-Rayan, Tunis Village, and archaeological sites, through an integrated transportation network that enhances the overall visitor experience.
- **Employment and Community Development:** Creating new job opportunities for local communities in transportation, tourism services, hospitality, and maintenance, while supporting small and medium-sized enterprises (SMEs) and promoting community participation in sustainable tourism.
- **Smart and Sustainable Tourism Management:** Incorporating smart technologies such as digital ticketing, real-time visitor information systems, and environmental monitoring to improve operational efficiency, enhance visitor satisfaction, and ensure the long-term sustainability of the project.

VISUAL ATTRACTION ELEMENTS FOR FAIYUM CABLE CAR TRIPS

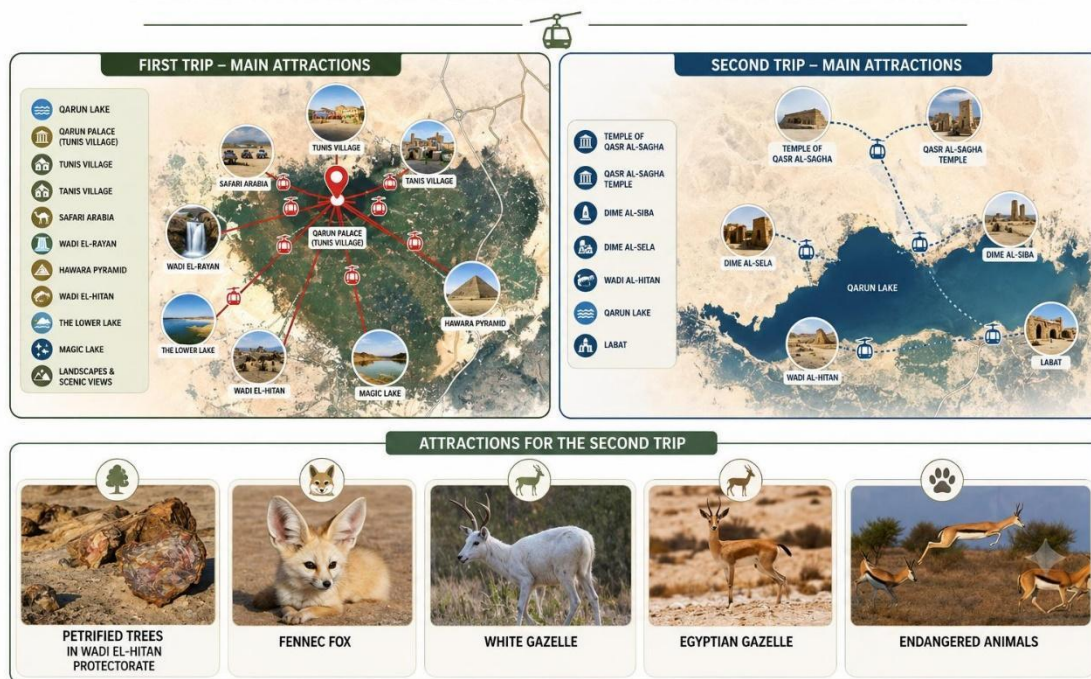


Figure (9) Visual Attraction Elements for Fayoum Cable Car Trips



Figure (10) Connecting the Southern and Northern Coasts of the Lake

6.2.2 Fayoum Astronomical & Marine Observatory Project

- A Global Destination for Scientists: Leveraging Fayoum's exceptionally clear skies to establish a premier astronomical research center, attracting scientists and stargazers from around the world.
- Astrotourism & Cultural Experience: Offering a unique stargazing experience free from light pollution, alongside interactive workshops and scientific lectures.
- Aquatic Shows & Documentaries (Wadi El-Hitan): Utilizing the submerged water structure for interactive shows and documentaries that bring to life the prehistoric marine ecosystem and the history of whales in the region.
- An Integrated Vision: Blending astronomy with natural heritage to create a world-class, sustainable scientific and eco-tourism hub.

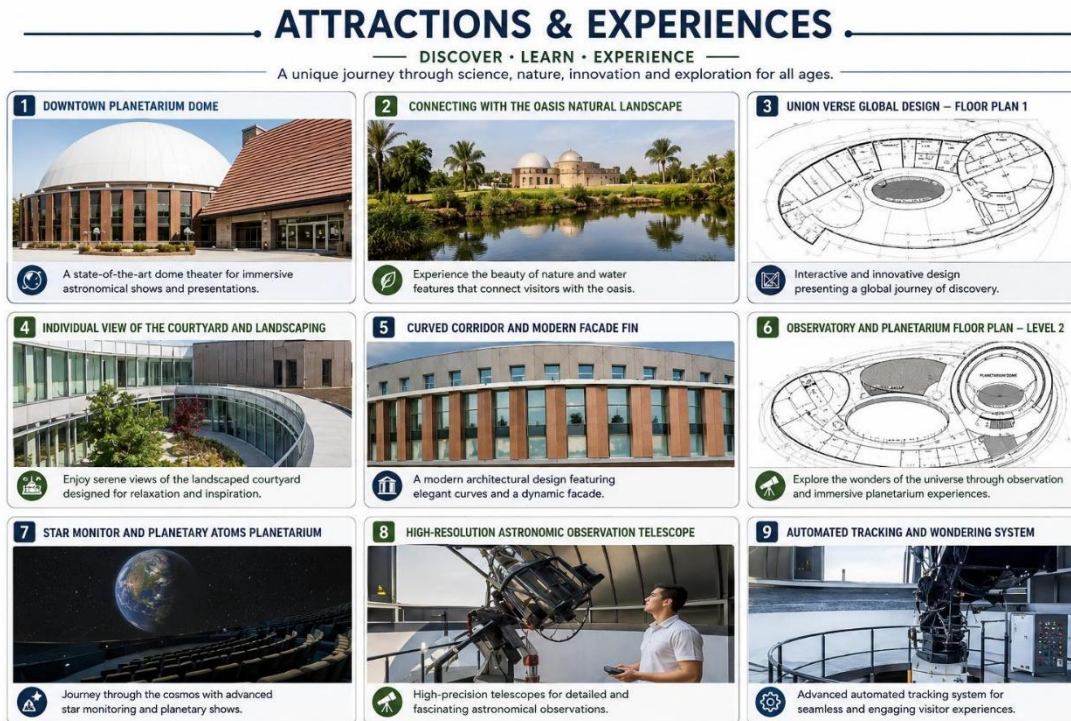


Figure (11) Proposed Fayoum Astronomical & Marine Observatory Project

- Climate and Environmental Monitoring Center: Establishing advanced monitoring facilities to study climate change, air quality, biodiversity, and lake ecosystems, providing valuable scientific data to support environmental management and sustainable development.
- Educational and Innovation Hub: Creating partnerships with universities, research institutions, and international organizations to host scientific conferences, training programs, student field schools, and innovation initiatives in astronomy, marine sciences, and environmental sustainability.



Figure (12) Composite Design: Fayoum Astronomical & Marine Observatory

7. Recommendations

Based on the findings of this study, the following recommendations are proposed to support the environmental restoration and sustainable management of Lake Qarun:

7.1 Wastewater Management and Pollution Control

- Establish and upgrade wastewater treatment facilities for agricultural drainage, domestic sewage, and industrial effluents before their discharge into the lake.
- Enforce stricter regulations on industrial discharge, particularly regarding heavy metals such as cadmium and nickel, in line with national and international environmental standards.
- Promote the adoption of best agricultural practices, including controlled use of fertilizers and pesticides, to reduce nutrient and chemical loading into agricultural drains.
- Encourage the use of constructed wetlands or bio-remediation systems as a cost-effective pre-treatment option before drainage water reaches the lake.

7.2 Salinity and Water Level Management

- Develop an integrated water balance management plan to regulate inflows and reduce excessive salinity accumulation.
- Investigate the feasibility of controlled freshwater inputs or water exchange mechanisms to mitigate the closed-basin salinization effect.
- Monitor water level fluctuations regularly to minimize shoreline erosion, salt flat expansion, and waterlogging of adjacent agricultural lands.

7.3 Environmental Monitoring and Research

- Implement a continuous, long-term water quality monitoring program covering salinity, nutrients, heavy metals, and microbiological indicators across representative sampling stations.
- Utilize remote sensing and GIS-based tools to track temporal changes in lake surface area, water level, and land use in the surrounding region.
- Conduct further research on the bioaccumulation of heavy metals, particularly cadmium, in fish and other aquatic organisms to assess risks to public health.

7.4 Ecosystem and Biodiversity Protection

- Designate and protect critical habitats, including wetland areas and aquatic vegetation zones, that support biodiversity and fish populations.
- Support fish stock rehabilitation programs and evaluate the introduction of salinity-tolerant species where appropriate.
- Establish buffer zones around the lake to reduce direct pollutant runoff and protect sensitive ecological areas.

7.5 Sustainable Tourism Development

- Integrate environmental quality improvement measures into ecotourism development plans to enhance the lake's aesthetic and recreational value.
- Develop tourism infrastructure with environmental safeguards that minimize additional pressure on the lake ecosystem.
- Raise public and stakeholder awareness on the ecological and economic importance of Lake Qarun through educational and community engagement programs.

7.6 Institutional and Policy Framework

- Strengthen coordination among relevant governmental authorities, research institutions, and local communities to implement an integrated management strategy.
- Develop a comprehensive Lake Qarun management plan that combines pollution control, water resource management, biodiversity conservation, and sustainable tourism objectives.
- Allocate sufficient funding and technical support for the implementation and enforcement of environmental regulations specific to the Lake Qarun basin.

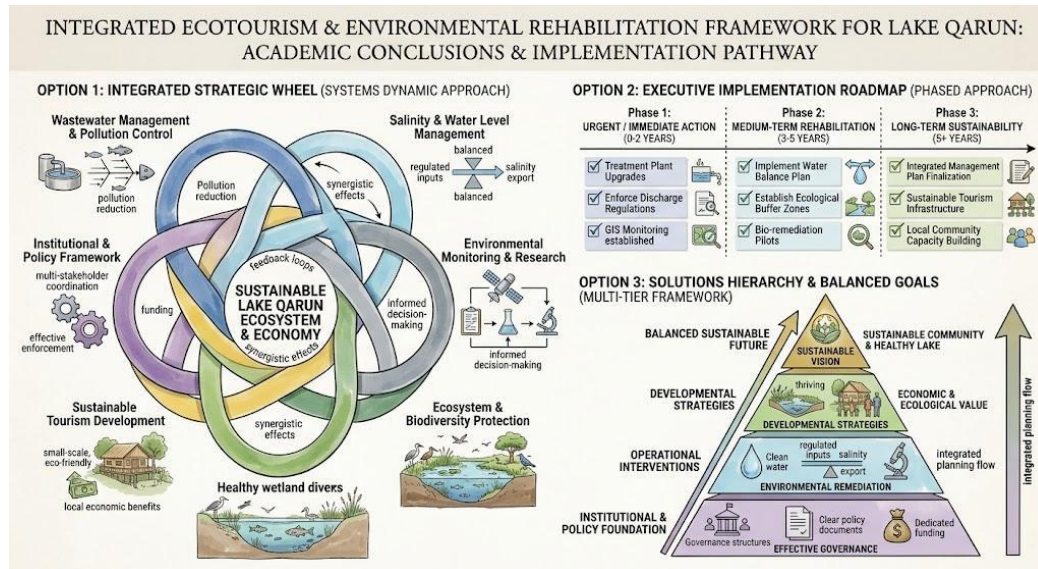


Figure (13) Conceptual Models and Academic Pathways for the Integrated Sustainable Management of Lake Qarun

8. Limitations and Future Research

This study is subject to several limitations that should be acknowledged. First, the analysis relies in part on secondary environmental data and previously published measurements, which may not fully capture current, real-time lake conditions; continuous, long-term field monitoring would strengthen future findings. Second, the proposed development projects (such as the cable car system, the astronomical and marine observatory, and the heavy metal extraction facility) are presented as conceptual planning proposals; each would require detailed feasibility, environmental impact, and cost-benefit studies before implementation. Third, the questionnaire-based assessment of stakeholder perceptions reflects the views of the specific sample consulted and may not be fully generalizable to all stakeholder groups in the region.

Future research is recommended to: (1) conduct continuous, multi-seasonal water quality and heavy-metal monitoring to validate and update the environmental findings presented here; (2) undertake detailed engineering and financial feasibility studies for each proposed project; (3) assess the carrying capacity of the lake ecosystem under the proposed tourism development scenarios; and (4) evaluate the socio-economic impacts of the proposed projects on local communities through longitudinal studies.

9. Declarations

9.1 Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

9.2 Conflicts of Interest

The authors declare no conflict of interest.

9.3 Data Availability Statement

The environmental and hydrological datasets analyzed in this study were derived from previously published sources and official reports cited throughout the manuscript (Egyptian Environmental Affairs Agency, published

journal articles, and governmental statistical yearbooks). Additional data supporting the findings of this study are available from the corresponding author upon reasonable request.

9.4 Author Contributions

Hossam Ashraf Mostafa Abdelraheem: Conceptualization, Methodology, Investigation, Formal Analysis, Writing – Original Draft, Visualization. Mona Hassan Soliman: Supervision, Validation, Writing – Review & Editing. Abdallah Badawy Mohamed: Supervision, Validation, Writing – Review & Editing. All authors have read and agreed to the published version of the manuscript.

9.5 Ethical Approval

This study did not involve experiments on humans or animals requiring formal ethical approval. Stakeholder consultations were conducted anonymously and voluntarily, with informed verbal consent obtained from all participants.

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