Impact of Climate Change on Water Quality (Case Study of Lake Qarun in Fayoum Governorate, Egypt)

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Abstract: Lake Qarun is classified as an endorheic body of water, signifying that it lacks a direct hydrological connection to the ocean. Its surface area encompasses approximately 55,000 feddan. The governmental authority is actively engaged in initiatives aimed at augmenting and enhancing its operational productivity. The ichthyic production sector is not insulated from the adverse effects of climate change, as evidenced by the detrimental influence of escalating carbon dioxide concentrations on the natural growth and reproductive cycles of fish, the repercussions of elevated temperatures on aquatic food webs and the periodicity of biological phenomena, as well as the consequences of water contamination in northern lakes, which is attributable to effluent from sewage, agricultural practices, and industrial discharge, ultimately leading to a decline in fish populations due to the migration of certain species. Furthermore, there is an increased susceptibility of fish to disease as a consequence of pollution, fluctuating temperatures, and reduced oxygen availability, alongside alterations in spawning periods due to rising temperatures, escalating organic waste, and thermal stress, which collectively impact the production of fish feed and contribute to a rise in associated costs. Consequently, the surveillance and assessment of water quality in freshwater lakes, such as Lake Qarun in Egypt, is imperative, given that it serves as a vital resource for human consumption, wildlife, and aquatic organisms. This research primarily sought to investigate the economic and social ramifications of climate change, to elucidate the challenges encountered by fishermen from their perspective, and to quantify the standard effect of these challenges on overall revenue, ultimately aiming to formulate a proactive strategy to adapt to prospective climate change. The findings of the investigation revealed that the water quality index scores exhibited fluctuations throughout the period from 2012 to 2021; however, all scores remained within the second category of the water quality index classification, thereby categorizing the waters of Lake Qarun as conducive to supporting aquatic life. Regarding the mineral index, it was determined that the lake is experiencing mineral pollution, as the index value surpassed one. The investigation put forth several recommendations aimed at enhancing the fishing sector in Lake Qarun, while simultaneously prioritizing environmental preservation, advancing sustainable development, alleviating the repercussions of climate change, and adapting to its effects, thereby ensuring ongoing productivity and achieving food security, in alignment with various objectives outlined in both the United Nations Sustainable Development Strategy and Egypt's Vision 2030.

Key Words: Climate change, Lake Qarun, water quality.

1. I. INTRODUCTION

Throughout history, fishing has constituted a significant source of sustenance, employment opportunities, and economic advantages for individuals engaged in this vital sector globally. As knowledge has advanced, the previously held notion that water resources are boundless has been swiftly dispelled, acknowledging that while these resources are renewable, they possess inherent limitations (UNESCO, 2020). The fisheries sector holds considerable importance within the agricultural domain for a multitude of reasons, notably its role in supplying essential animal protein (Inayathulla, 2013). Current data suggests that the approximate volume of fish production in Egypt for the year 2020 is around 2.01 million tons, with natural fisheries contributing merely 20.8%, equating to an estimated 418.7 thousand tons. The per capita fish consumption from the total available for consumption is approximately 22.68 kg annually in 2020 (Afify, 2019). In 2021, the overall fish production in Egypt accounted for approximately 67.5 billion pounds of the total agricultural production value, representing a

contribution rate of about 9.12%. The monetary value of the requirements for fish production in the same year is estimated at 30.01 billion pounds of the total production requirements, amounting to a rate of approximately 10.08%. The fish production originating from Fayoum Governorate in the year 2021 contributed roughly 816 million pounds, which constitutes a mere 1.2% of the total value of fish production. The monetary requirements for fish production in Fayoum Governorate for the same year are approximately valued at 358 million pounds, accounting for only about 1.19% of the total value of the production requirements for fish (Environmental Affairs Agency). Lake Qarun is categorized as an inland, closed lake that is not interconnected with the sea, covering an area of 55 thousand feddan. Acknowledging the significance of Lake Qarun, and in alignment with the state's policy to bolster fishery resources in Egypt as a principal source of protein, efforts are being made to enhance and optimize its production efficiency. Climate change exerts influence on ecosystems, societal structures, and economies in a myriad of ways, with water serving as the primary conduit through which these effects manifest. In certain instances, these repercussions are markedly apparent—exemplified by the heightened frequency and intensity of storms, floods, and droughts. The water-related ramifications of climate change encompass adverse effects on food security, public health, energy generation, and biodiversity, as well as on the daily subsistence of the most vulnerable populations, including women, men, and children. Such impacts have the potential to (and have indeed) precipitate increased social disparities, widespread migration, and conflict (UNESCO, 2020).

The fish production industry is subject to the adverse effects of climate change, as evidenced by the detrimental influence of elevated carbon dioxide concentrations on the natural growth and reproductive processes of fish, the repercussions of increasing temperatures on aquatic food webs and the seasonal variations of biological phenomena, the consequences of water contamination in northern lakes attributable to sewage discharge, agricultural runoff, and industrial effluents, which adversely affect fish populations due to the migration patterns of certain fish species, the heightened risk of disease afflictions in fish resulting from pollution, temperature fluctuations, and diminished oxygen availability, the alteration of fish spawning periods due to rising temperatures, the accumulation of organic waste, and thermal stress, as well as the repercussions of these transformations on fish feed production leading to escalated costs (Khalifa. 2017). The World Bank's report on development and climate change published in 2010 elucidates that the global mean temperature has risen by approximately one degree Celsius since the commencement of the industrial era, primarily as a consequence of anthropogenic activities and the imperatives of environmentally detrimental development, which have resulted in elevated global concentrations of carbon dioxide and other greenhouse gases, thereby instigating the greenhouse effect. The principal ramifications of global warming induced by increased carbon dioxide levels include the rise in sea and ocean levels, which poses a threat to extensive regions of river deltas, coastal areas, and low-lying terrains, alongside other consequences that significantly impact ecosystems and biodiversity, including natural fisheries and aquaculture (Svobodova. 1993). Consequently, it is imperative to address these alterations through various adaptive strategies aimed at alleviating their impacts on the fishing sector. The quality and availability of surface water bodies, such as lakes, are contingent upon climatic conditions, watershed characteristics, regional geography, as well as natural and anthropogenic inputs and outputs. The integrity of lake water can be compromised by microbiological and chemical contaminants. The monitoring and evaluation of water quality in freshwater lakes, such as Lake Qarun in Egypt, is of paramount importance due to its significance for human consumption, wildlife sustenance, and aquatic ecosystems. The aquatic environment is subject to an array of pollutants emanating from the leakage of industrial, agricultural, and domestic wastewater (UNESCO. 2020).

Research problem: The research problem pertains to Lake Qarun located within the Fayoum Governorate, which is recognized as a significant natural fishery for fish production in Egypt, distinguished by its diversity and extensive fish production capabilities. However, its relative contribution to overall fish production in Egypt remains limited and falls short of the anticipated level, accounting for approximately 1.03%, 0.72%, and 0.33% of the total lakes, natural fisheries, and overall fish production in Egypt, respectively, in the year 2021, during which a decline in fish production quantities from Lake Qarun was recorded. This observed reduction in output can be attributed to a myriad of factors, encompassing alterations in natural conditions, notably climate change, alongside anthropogenic influences and resultant water pollution, among others. These detrimental impacts adversely influence the economic circumstances of fishermen operating in

the lake, thereby affecting their income levels and quality of life. Projections suggest that Egypt is among the nations facing significant challenges in addressing the consequences of the climate change crisis across numerous vital sectors, including the fisheries sector. Consequently, it is imperative to investigate the ramifications of climate change as one of the contemporary variables contributing to the decline in fish production within the lake, with the objective of formulating strategies for the enhancement and advancement of production therein.

Research objective: The primary objective of this research is to conduct a thorough analysis of the effects of climate change on Lake Qarun and its associated fish production, by examining both the quantitative and qualitative evolution of fish populations within the lake, assessing the influence of climate change on the physicochemical properties of the water and its overall quality and suitability for ichthyological growth, investigating the economic and social ramifications that climate change imposes on the fishing community, identifying the challenges that fishermen encounter from their perspective, and estimating the impact of these challenges on total revenue. Subsequently, a forward-looking strategy will be developed in an effort to adapt to anticipated climate changes.

II. Methodology

This study employed both descriptive and inferential analytical methodologies to evaluate data procured from two principal sources: secondary data, comprising both published and unpublished materials sourced from various organizations such as the General Authority for Fish Resources Development, the Central Agency for Public Mobilization and Statistics, and the Environmental Affairs Agency, in addition to relevant websites, literature, research studies, and reports pertinent to the field of inquiry. Primary data were acquired through direct personal interviews conducted with the sample population, complemented by a specifically designed questionnaire aimed at facilitating the collection of data from the research participants.

The study utilized primary (field) data to fulfill its objectives, employing the exhaustive census methodology for fishermen, whose population approximated 23 individuals, as documented in the records maintained by the Lake Qarun Administration. The selection of this methodology (exhaustive census) is attributable to the limited number of individuals engaged in this occupation, a phenomenon that may be associated with the migration of fishermen to alternative lakes as a consequence of the production challenges encountered by Lake Qarun.

III. Results and Discussion

First: The annual evolution of Egyptian fish production from its diverse sources and the production and qualitative distribution of fish in Lake Qarun during the period (2010-2021).

1- The annual evolution of Egyptian fish production from its diverse sources:

Table No. (1) Illustrates the annual evolution of the aggregate Egyptian fish production during the period (2010-2021), revealing that the average production approximated 1.66 million tons, characterized by a progressive annual growth rate of 4.6%. The production peaked in 2019, achieving approximately 2.04 million tons, with an increase rate constituting about 22.9% of the overall average, while the lowest production was recorded in 2010 at around 1.30 million tons, reflecting a decrease rate of approximately 21.7% of the overall average.

Regarding the sources of Egyptian production, it was determined that the average yield from natural fisheries amounted to approximately 373.49 thousand tons, which signifies approximately 22.3% of the total fish production during the aforementioned period, with a declining annual growth rate of 1.2%. The output reached its zenith in 2021, recording a production of approximately 425.76 thousand tons, an increase rate representing about 14% of the overall average, while the lowest production was observed in 2016 at about 335.61 thousand tons, corresponding to a decrease rate of roughly 10.15% of the overall average. Additionally, it was identified that the average production from aquaculture reached approximately 1.29 million tons, which accounts for about 77.7% of the total fish production during the specified period, exhibiting an increasing annual growth rate of 5.7%. The production peaked in 2019 at around 1.64 million tons, with an increase rate of approximately 27.13% of the overall average, whereas the lowest production was noted in 2010 at approximately 0.919 million tons, marking a decrease rate of about 28.76% of the overall average.

Table No. (1) Annual development of Egyptian fish production from its various sources and production in Lake Qarun during the period (2010-2021)

Years	Total Fish Production	Total natural fisheries	%of total production	Aquaculture	%of total production	Qarun Lake	% of total natural fisheries	%of total production
2010	1304794	385209	29.52	919585	70.48	3903	1.01	0.30
2011	1362174	375354	27.56	986820	72.44	4364	1.16	0.32
2012	1371975	354237	25.82	1017738	74.18	4410	1.24	0.32
2013	1454401	356857	24.54	1097544	75.46	4420	1.24	0.30
2014	1481882	344791	23.27	1137091	76.73	4518	1.31	0.30
2015	1518943	344112	22.65	1174831	77.35	1124	0.33	0.07
2016	1706273	335613	19.67	1370660	80.33	878	0.26	0.05
2017	1822800	370959	20.35	1451841	79.65	1061	0.29	0.06
2018	1934742	373285	19.29	1561457	80.71	832	0.22	0.04
2019	2038991	397042	19.47	1641949	80.53	-	-	-
2020	2010579	418683	20.82	1591896	79.18	-	-	-
2021	2001958	425769	21.27	1576189	78.73	71	0.02	0.004
Average	1667459	373493	22.40	1293967	77.60	2558	0.68	0.15
Growth Rate %	4.6 (196.014)**	1.2 (4.215) -	-	5.7 (176.448) **	-	-25 (20.313) **	-	-

* The growth rate of Egyptian fish production from its various sources and Qarun Lake production was calculated for the average period (2010-2021).
** Significant at the 0.01 level. * Significant at the 0.05 level. - Not significant
Source: Collected and calculated from data: General Authority for Fish Resources Development, Annual Fish Statistics Book, various publications.

2- Annual evolution of ichthyic production and the qualitative distribution of fish within Lake Qarun:

Table No. (1) Illustrates the annual evolution of fish production in Lake Qarun throughout the temporal span of (2010-2021). It is evident that the mean production from Lake Qarun was approximately 2.55 thousand tons, constituting about 0.68% and 0.15% of natural fisheries and total fish production, respectively, for the duration specified. This figure signifies a minimal percentage that fails to adequately reflect the economic significance of the lake, accompanied by a declining annual growth rate of 25%. The pinnacle of production was attained in 2014, reaching approximately 4.52 thousand tons, which corresponds to an increase of about 77.25% relative to the overall mean. Conversely, production plummeted to its nadir in 2021, recording merely about 71 tons, which indicates a decrease of approximately 2683.2% of the overall mean. It is noteworthy that fish production within the lake ceased due to the Safe Belt Project, aimed at enhancing the lake's condition and eliminating pollutants during the years 2019 and 2020. Table No. (2) further delineates the qualitative distribution of fish in Lake Qarun within the timeframe of (2010 - 2021), whereby the principal fish species sourced from the lake's fisheries were identified based on the quantities harvested from the various species. The relative significance of these fish indicates that the production of Nile tilapia - Oreochromis niloticus (Linnaeus, 1758) [Cichlidae], Shrimp - Indian white prawn - Penaeus indicus (H. Milne Edwards, 1837) [Penaeidae], Mullet - Flathead grey mullet - Mugil cephalus (Linnaeus, 1758) [Mugilidae], and Common sole - Solea solea (Quensel, 1806) collectively accounts for approximately 94.08% of the lake's total production for the average period (2010 - 2021). In accordance with the

relative significance, tilapia fish emerged as the foremost species, comprising about 27.81% of the lake's fish production. This was followed closely by mullet fish, which occupied the second position with approximately 27.66%, followed by Common solefish in third place, accounting for around 21.17%, and finally, shrimp in fourth place, representing approximately 17.44%. Furthermore, a statistically significant annual decrement was observed, with decreases of approximately 26.8%, 36.4%, 39.8%, and 33.7% in the production of the aforementioned species, respectively, whereas other fish constituted about 5.92% of the lake's total production.

Table No. (2) Qualitative distribution of fish in Qarun Lake during the period (2010-2021) in tons.

Years	Tilapia	Shrimp	Mullet	Common sole	Others#	Total
2010	996	684	1379	783	38	3880
2011	1173	699	1424	1018	42	4356
2012	1226	912	1283	946	43	4410
2013	1265	902	1207	1002	44	4420
2014	1312	862	1198	1111	35	4518
2015	426	102	191	176	229	1124
2016	327	147	151	139	114	878
2017	225	91	142	137	466	1061
2018	156	58	92	90	436	832
2019	0	0	0	0	0	0
2020	0	0	0	0	0	0
2021	0	0	0	6	65	71
Average	592.17	371.42	588.92	450.67	126	2129.17
% relative Importance	27.81	17.44	27.66	21.17	5.92	100
Growth Rate %	-26.8 (22.827)**	-36.4 (19.762)**	-39.8 (35.854)**	-33.7 (20.929)**	-	-

Other species are (anchovy, hanshan, dennis, sejan, grouper, and catfish).
* The growth rate of fish production from Qarun Lake was calculated for the average period (2010-2021).
** Significance at 0.01 level. * Significance at 0.05 level. - Not significant
Source: Collected and calculated from data, General Authority for Fish Resources Development, Annual Fish Statistics Book, various editions.

- The development of relative humidity: The same table also shows the annual development of relative humidity during the mentioned period, which showed that the average relative humidity reached about 53%, with a decreasing annual growth rate that is not statistically significant, and the relative humidity reached its maximum in 2013 at about 56%, with an increase rate representing about 5.66% of the general average, and the relative humidity reached its lowest in 2011 at about 51%, with a decrease rate representative.

- Rainfall rate: The same table also shows the annual development of rainfall rate throughout the specified period, which revealed that the average rainfall was around 8.99 mm/year, with a declining annual growth rate that was not statistically significant. Rainfall peaked in 2015 at 11.3 mm/year, indicating a 25.7% rise over the general average, and peaked in 2014 at 7.1 mm/year, representing a 21.02% reduction over the general average.

Table No. (3) Development of Egypt's carbon dioxide emissions and climate variables in Fayoum Governorate during the period (2010-2022).

Years	Egypt's carbon emissions (in million tons equivalent)	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall rate (mm/year)
2010	174.60	34.34	15.60	55	7.8
2011	181.95	31.55	16.66	51	9.5
2012	187.73	31.87	17.80	53	10.7
2013	196.9	33.96	16.55	56	8.8
2014	197.14	31.57	15.90	53	7.1
2015	201.34	34.89	17.47	52	11.3
2016	206.2	33.71	16.63	54	8.4
2017	209.96	33.18	15.87	53	7.3

2018	206.75	31.15	15.36	55	7.6
2019	199.9	33.13	17.33	53	8.4
2020	201.97	31.36	17.27	53	10.1
2021	204.74	31.83	16.94	52	9.8
2022	208.01	32.52	17.56	53	9.4
Average	201.88	32.65	16.79	53	8.99
Growth Rate	0.7 (8.111)*	-0.3 (0.853)-	0.2 (0.113)-	-0.2 (1.053)-	0.1 (0.007)-

** Significant at 0.01 level. * Significant at 0.05 level. - Not significant

Source: Compiled and calculated from data: Central Agency for Public Mobilization and Statistics, Annual Bulletin of Environmental Statistics - Part Two: Environmental Quality and Energy, various issues.

Third: The development of chemical and physical variables of Lake Qarun water during the period (2012-2022):

Physical and chemical changes in water are among the reasons that also cause harm to fish and affect production, because they affect the properties of water (Svobodova. 1993), and thus affect the quality and quality of water.

As temperature affects both the metabolism of fish and thus their growth and weight gain, and the speed of the spread of diseases. It also affects all physiological functions of fish. The degree of transparency of water expresses the extent of the ability of light to penetrate through the water, and the degree of transparency is affected by the amount of suspended materials present in the water, as there is always an inverse relationship between the degree of transparency of water and the amount of suspended materials in it resulting from drain water and pollutants thrown into the lake (Khalifa. 2017).

As for salinity, it affects the types of living organisms that can live in the water. The pH affects the availability of nutrients and the toxicity of other pollutants (such as ammonia, hydrogen sulfide, cyanide, and heavy metals) to fish.

Lack of oxygen leads to suffocation and death of fish, as fish exposed to oxygen-deficient water do not eat, gather near the water surface, and gasp for air. The factor responsible for the significant decrease in oxygen concentration in water is most often pollution from degradable organic matter (including wastewater from agriculture, food industry, and public sewage). Table (4) shows the values of these variables, which are within the internationally acceptable range.

Table No. (4) Annual development of the values of some hydrochemical variables of Lake Qarun during the period (2012 - 2021).

Years	Tempretu re	Transpare ncy level	Salini ty	Hydrogen ion concentrat ion PH	Dissolv ed oxygen DO	Bio-Oxygen Depleti on BOD	Chemical Oxygen Consumpti on COD
Unit	Celsius	centimeter	g/l	-	mg/L	mg/L	mg/L
Accepta ble range*	8-28	-	-	6-9	4.2-12.6	3-6	-
2012	21.12	86	32.22	8.3	9.11	5.26	55.13
2013	21.71	85.25	21.84	8.43	8.45	4.61	39.4
2014	21.31	103.28	16.82	8.12	8.28	4.36	31.85
2015	20.9	121.3	11.8	7.8	8.1	4.1	24.3
2016	24.595	51.75	35.12 5	8.485	7.19	6.415	26.25
2017	14.43	46.5	33.23	8.44	11.82	8.5	26.4
2018	17.94	50.20	35.82	8.45	10.00	8.46	27.16
2019	21.45	53.89	38.4	8.45	8.18	8.42	27.91
2020	22.64	43.88	36.32	8.44	5.92	8.5	30.26
2021	22.64	43.88	36.32	8.52	5.83	7.98	30.26
Averag e	20.87	68.59	29.79	8.34	8.29	6.66	31.89
Growth rate %	0.0005 (1.756)-	-10.1 (14.054)**	7.3 (3.430	0.4 (2.092)-	-3.3 (2.145)-	8.4 (16.485	-4.6 (3.871)-

			)-			)**	

*Globally permissible limit.
Source: Collected and calculated from data:
- Central Agency for Public Mobilization and Statistics, Annual Bulletin of Environmental Statistics - Part Two: Environmental Quality and Energy, various issues.

Ammonia pollution of lakes occurs from organic origin (sewage, agricultural wastes, or the reduction of nitrates and nitrites by bacteria in anoxic waters) or from inorganic origin (industrial effluents). Nitrate is generally present with nitrate and ammonia nitrogen in surface waters but its concentrations are usually low because of its stability. The toxic effect of nitrite on fish is not fully known; it depends on a number of internal and external factors (such as fish species, age, and general water quality). The toxicity of nitrate to fish is very low, and it is not necessary to monitor nitrate concentrations. However, water quality standards for both ammonia and nitrate should be established to prevent excessive growth of algae and plants, which can have a secondary effect on fish. Phosphorus is an essential element for aquatic organisms and their growth, and the concentration of phosphorus in water bodies increases as a result of sewage, industrial or agricultural drainage, which leads to many environmental problems (Environmental Affairs Agency. 2020). Table (5) shows the development of these variables in Lake Qarun during the period (2010-2021), which is within the internationally acceptable range. Phosphorus exceeded the internationally acceptable maximum during the period (2010-2021) except for the year 2019, when its value reached 98.740 micrograms/liter.

Table No. (5) Annual development of the values of some hydrographic variables (mineral salts) of Lake Qarun during the period (2010 - 2021)

Years	Ammonia	Nitrites	Nitrates	Total phosphorus
Unit	mg/L	micrograms/liter	micrograms/liter	micrograms/liter
Acceptable range*	0.5-2.2	5-60	10-14.7	25-100
2012	0.205	23.790	0.238	256.730
2013	0.309	16.410	0.113	132.080
2014	0.300	16.335	0.122	210.040
2015	0.290	16.260	0.126	288.000
2016	0.375	38.005	0.130	286.500
2017	1.400	40.710	0.130	285.000
2018	1.035	45.525	0.160	191.870
2019	0.670	50.340	0.190	98.740
2020	0.558	53.879	0.159	186.586
2021	0.680	58.954	0.160	179.638
Average	0.582	36.021	0.153	211.518
Growth rate %	14.6 (8.341)*	15.3 (27.147)**	1.1 (0.159)-	-3.5 (0.783)-

*Globally permissible limit.
Source: Collected and calculated from data:
- Central Agency for Public Mobilization and Statistics, Annual Bulletin of Environmental Statistics - Part Two: Environmental Quality and Energy, various issues.

The toxic effect of metals is particularly evident in the early stages of fish development. Another potentially harmful property of many metals is their ability to accumulate in sediments and in aquatic plants and animals (bioaccumulation). The physical and chemical properties of water strongly influence the toxicity of these metals to fish. Table (6) shows the annual development of the content of Lake Qarun of various metals during the period (2010 - 2021), which shows that it is within the internationally acceptable range.

Table No. (6): Annual development of the content of Lake Qarun of various minerals during the period (2010 - 2021)

micrograms/liter

Years	Iron Fe	Manganese Mn	Copper Cu	Zinc Zn	Chrome Cr	Nickel Ni	Cadmium Cd	Lead Pb	Mercury Hg
Acceptable range*	<300	<300	1-112	10-2000	2-20	10-150	<5	1-100	<1
2012	286.39	17.29	6.22	18.98	33.44	8.37	2.18	55.84	0.2
2013	149.23	19.56	4.35	8.24	14.01	28.94	2.1	83.27	0.223
2014	179.96	22.87	6.75	13.50	15.33	18.19	1.77	59.85	0.13
2015	210.68	26.17	9.15	18.75	16.64	7.44	1.43	36.43	0.03
2016	226.34	17.02	3.91	13.93	6.31	5.49	0.4	19.96	0
2017	196.4	19.93	6.26	20.02	7.83	5.33	1.11	22.79	0
2018	220.09	22.04	5.53	27.09	9.08	5.04	0.84	21.18	0
2019	243.77	24.15	4.79	34.16	10.32	4.75	0.56	19.57	0
2020	282.95	34.81	8.38	39.59	16.58	7.13	0.776	19.57	0
2021	282.95	34.81	8.38	39.59	16.58	7.13	0.776	20.63	0
Average	227.88	23.87	6.37	23.39	14.61	9.78	1.19	35.91	0.06
Growth rate %	3.6 (2.733)$^{-}$	6.2 (9.623)*	2.7 (0.711)$^{-}$	14.4 (20.471)**	- 5.3 (1.003)$^{-}$	-11.6 (4.362)$^{-}$	-13.7 (8.864)*	-15.9 (22.874)**	-

Globally permissible limit.

** Significant at 0.01 level. * Significant at 0.05 level. - Not significant

Source: Collected and calculated from data:

- Environmental Affairs Agency, Annual Report of the Environmental Monitoring Program for Egyptian Lakes "Lake Qarun", various publications.
- Central Agency for Public Mobilization and Statistics, Annual Bulletin of Environmental Statistics - Part Two: Environmental Quality and Energy, various issues.

Fourth: The impact of climate change on Lake Qarun:

Tables (7), (8), and (9) show the correlations between the different climate variables and each of the water properties, water quality indicators, and minerals.

Table (7) indicates a strong correlation between the climate indicators represented by carbon emissions, maximum and minimum temperatures, relative humidity, and rainfall rate, and the lake water properties represented by the degree of transparency, biological oxygen uptake, chemical oxygen consumption, ammonia, and some minerals such as manganese, copper, chromium, nickel, and mercury.

Table No. (7): Significant correlations between different climate variables and lake water properties during the period (2012-2021)

	carbon emissions	Maximum temperature	Minimum temperature	Relative humidity	Rainfall rate
Minimum temperature					0.827** (0.003)
Rainfall rate			0.827** (0.003)		
Transparency level	-0.657* (0.039)				
BOD	0.638* (0.047)				
chemical oxygen consumption COD	-0.717* (0.020)				
Ammonia	0.806** (0.005)				
Manganese Mn				-0.660* (0.038)	
Copper Cu				-0.823** (0.003)	
chrome Cr			0.705* (0.023)		0.750* (0.012)
Nickel Ni	-0.693* (0.026)				
Mercury Hg	-0.826** (0.003)				

** Significant at 0.01 level. * Significant at 0.05 level. - Not significant

Source: Collected and calculated from data:
- Egyptian Environmental Affairs Agency, Annual Report of the Environmental Monitoring Program for Egyptian Lakes "Lake Qarun", various publications.
- Central Agency for Public Mobilization and Statistics, Annual Bulletin of Environmental Statistics - Part Two: Environmental Quality and Energy, various publications.

Tables (8) and (9) indicate a strong correlation between water properties represented by water temperature, transparency, salinity, ammonia and nitrite content of the lake, water acidity, dissolved oxygen, bio-oxygen uptake, nitrates, and the lake's mineral content represented by iron, zinc, nickel, cadmium, lead, and mercury.

Table No. (8): Significant correlations between the properties of lake water and each other during the period (2012-2021)

	temperature	Transparency level	Salinity	Ammonia	Nitrites
Hydrogen ion concentration PH		-0.768** (0.010)	0.823** (0.003)	0.701* (0.024)	0.811** (0.004)
Dissolved oxygen DO	-0.802** (0.005)				
BOD		-0.863** (0.001)	0.765** (0.010)	0.821** (0.004)	0.815** (0.004)
Ammonia		-0.796** (0.006)	0.650* (0.042)		
Nitrites		-0.900** (0.000)	0.948** (0.000)	0.721* (0.019)	
Nitrates			0.664* (0.036)		

** Significant at 0.01 level. * Significant at 0.05 level. - Not significant

Source: Collected and calculated from data:
- Egyptian Environmental Affairs Agency, Annual Report of the Environmental Monitoring Program for Egyptian Lakes "Lake Qarun", various publications.
- Central Agency for Public Mobilization and Statistics, Annual Bulletin of Environmental Statistics - Part Two: Environmental Quality and Energy, various publications.

Table No. (9): Significant correlations between the properties of lake water and its content of various minerals during the period (2012-2021)

	Transparency level	Salinity	Hydrogen ion concentration PH	BOD	Ammonia	Nitrites	Nitrates
Fe							0.859** (0.001)
Zn	-0.732* (0.016)	0.817** (0.004)		0.729* (0.017)		0.888** (0.001)	0.706* (0.022)
Ni		-0.720* (0.019)	-0.651* (0.041)	-0.716* (0.020)	-0.748* (0.013)		
Cd		-0.756* (0.011)	-0.792** (0.006)			-0.657* (0.039)	
Pb	0.643* (0.045)	-0.863** (0.001)	-0.691* (0.027)	-0.668* (0.035)		-0.778** (0.008)	
Hg	0.753* (0.012)	-0.767** (0.010)	-0.756* (0.011)	-0.767** (0.010)	-0.792** (0.006)	-0.765** (0.010)	

** Significance at 0.01 level. * Significance at 0.05 level.
Source: Compiled and calculated from data:
- Egyptian Environmental Affairs Agency, Annual Report of the Environmental Monitoring Program for Egyptian Lakes "Lake Qarun", various publications.
- Central Agency for Public Mobilization and Statistics, Annual Bulletin of Environmental Statistics - Part Two: Environmental Quality and Energy, various publications.

Fifth: Water Quality:

1- Water Quality Index (WQI):

The Water Quality Index is a numerical measure that expresses water quality by combining a number of variables, with the aim of providing a simple and concise way to express water quality, quality and suitability for different uses (Inayathulla and Paul. 2013). The Water Quality Index is used to evaluate water quality for different purposes such as drinking, irrigation and aquatic life. The sub-quality index is calculated for a number of parameters according to the following equation (Afify et al. 2019):

$$Qi = \frac{(Vi - Vo)}{(Si - Vo)}$$

Where: Qi = sub-quality index of parameter i.
Vi = observed value of parameter i.
Si = standard permissible value of parameter i.
Vio = optimum value of parameter i in pure water.

All ideal values (Vio) are taken as zero for drinking water except pH = 7.0, DO = 14.6 mg/L and fluoride = 1 mg/L. For pH, the ideal value is 7.0 (for natural water) and the permissible value is 8.5 (for contaminated water). Therefore, the pH sub-quality index is calculated from the following relationship:

$$QpH = \frac{(Vph - 7)}{(8.5 - 7)}$$

Where: VpH = Observed pH value. For dissolved oxygen DO, the ideal value (Vio) is 14.6 mg/L and the standard value allowed for drinking water is 5 mg/L. Therefore, the sub-quality index is calculated from the following relationship:

$$QDO = \frac{(VDO - 14.6)}{(5 - 14.6)}$$

Where: VDO = observed value of dissolved oxygen. Then the unit weight (Wn) is calculated, and the unit weight (Wi) calculation for various water quality parameters is inversely proportional to the recommended standards.

$$Wi = \frac{k}{Si}$$

Where: Wi = relative weight of parameter i.
Si = standard value of parameter i.
K = constant of proportionality and is given as follows:

$$k = \frac{1}{\sum_i^n \frac{1}{Si}}$$

Finally, WQI is calculated from the following equation:

$$WQI = \frac{\sum_i^n = QiWi}{\sum_i^n = Wi}$$

The following table No. (10) shows the classification of water quality status based on the water quality index.

Table No. (10): Classification of water quality based on the WQI value

Classification	WQI	Water quality status
A	0-25	Excellent
B	26-50	Good
C	51-75	Poor
D	76-100	Very Poor
E	Above 100	Inadequate

Source: Collected and calculated from data:
- Central Agency for Public Mobilization and Statistics, Annual Bulletin of Environmental Statistics - Part Two: Environmental Quality and Energy, various issues.

A number of physical, chemical and biological factors that have a direct effect on fish life were selected, namely: pH, ammonia, DO, BOD, nitrate, total phosphorus, Fe, Mn, Cu, Zn, Cr, Ni, Cd, Pb and Hg. The optimum and global standard limits were used for each variable.

2- Metal quality indices: There are a number of indices to determine the metal pollution of lake water, and the Metal index (MI) was used, and it is calculated as follows:

$$MI = \sum_{i=1}^{n} \frac{Ci}{MACi}$$

Where: Ci = concentration of element i.
MACi = maximum permissible concentration.

The index value is due to comparing the element concentration value with the maximum permissible value of the element in the water, and an increase in the index value above one is considered a warning of water pollution with metals.

The results shown in Table No. (11) indicate the variation in the degrees of the water quality index during the period (2012 - 2021), but they all fall into the second category of the water quality index classification, which classifies the waters of Lake Qarun as good for aquatic life.

The results shown in the same table indicate the variation in the degrees of water pollution with metals during the period (2012 - 2021), but they all suffer from the presence of metal pollution as the index value exceeded one.

Table No. (11): Annual development of the values of both water quality and metal indices during the period (2012 - 2021)

years	WQI	MI
2012	41	4.00
2013	41	2.97
2014	35	2.71
2015	30	2.44
2016	32	1.48
2017	38	1.66
2018	37	1.74
2019	36	1.81
2020	40	2.38
2021	41	2.39

Average	37	2.36
Growth Rate %	0.5 (0.136)-	-5.5 (3.427)-

** Significant at 0.01 level. * Significant at 0.05 level. - Not significant

Source: Collected and calculated from data:

- Egyptian Environmental Affairs Agency, Annual Report of the Environmental Monitoring Program for Egyptian Lakes "Lake Qarun", various publications.
- Central Agency for Public Mobilization and Statistics, Annual Bulletin of Environmental Statistics - Part Two: Environmental Quality and Energy, various publications.

Sixth: Fishermen's perspectives on climate change and its impact on fish output, as well as their recommendations for dealing with it, in the Qarun Lake research sample.

Climate change has a severe impact on fish output in Qarun Lake, limiting the lake's development and advancement. The study relied on original data collected through personal interviews with Lake Fisherman. As a result, this section focuses on identifying fishermen's perspectives on climate change and its impact on fish production, as well as their proposals for dealing with it in the study sample at Qarun Lake in Fayoum Governorate, in order to make appropriate recommendations to limit or mitigate the negative effects on fish production.

This is done along four axes: the first is the respondents' level of awareness about the problem of climate change; the second is the most significant climate changes observed from the respondents' perspective; the third is the impact of climate change on fish production and fishing practices used to adapt to those changes; and the fourth is the fishermen's proposals in the study sample to confront and confront the problem of climate change. 1- The respondents' level of awareness of the issue of climate change and its potential effects on fish farming. Table No. (12) shows the opinions of the fishermen in Lake Qarun about their level of awareness of the problem of climate change and its potential impacts on fish farming, through two parts, the first of which deals with (awareness of the problem of climate change), where about 65.22% of the total size of the study sample confirmed their awareness and understanding of the problem of climate change, while about 34.78% did not confirm their awareness of the problem. Whereas over 69.57% of the sample denied knowing about the possible effects of climate change on fish farming, while roughly 30.43% of the sample acknowledged knowledge of and comprehension of these effects.

There is an imbalance in the ecological and biological systems of Lake Qarun, some of which may be caused by climate change due to rising temperatures and increasing alkalinity in the lake water as a result of fishermen's lack of understanding of the extent of the impact of climate change. The above illustrates the low level of awareness and understanding of fishermen regarding the potential impacts of climate change on fish farming. They believe that climate change only refers to an increase or decrease in temperature, which caused variations in the quantity of fish produced in the lake, so impacting their means of subsistence. As a result, fisherman must become more knowledgeable about the effects of climate change on fish production in lakes.

Table No. (12) The relative frequency of the respondents' knowledge of the study sample about the problem of climate change and its potential effects on fish farming.

No	Statement	Yes	%	No	%	Total
1	Awareness of the problem of climate change	15	65.22	8	34.78	23
2	Awareness of the potential impacts of climate change on fish farming	7	30.43	16	69.57	23

Source: Collected and calculated from questionnaire data.

2- The most important climate changes observed from the point of view of the study sample.

Data in Table No. (13) show the most important climate changes observed from the point of view of the study sample, which are the rise in temperature, the relative frequency of which represents about 93.30% of the total frequency of the study sample, and in second place came the change in the dates of the seasons and their overlap, and its relative frequency represents about 69.56%, while in third place came the presence of unusual winds, storms and nuclei and changing their dates, and its relative frequency represents about 52.17%, and in

fourth place came the increase in the humidity rate, which reduces the percentage of oxygen and increases ammonia, and its relative frequency represents about 43.47%, while in fifth and last place came the short winter period and the long hot weather period, and its relative frequency represents about 39.13%.

Table No. (13) Relative frequency of the most important climate-related changes observed by fishermen in the study sample

No	Problem	Frequency	٪
1	High temperature	19	82.61
2	Change in the dates of the seasons and their overlap	16	69.56
3	The presence of unusual winds, storms and nuclei and their changing dates	12	52.17
4	High humidity, which reduces the percentage of oxygen and increases ammonia	10	43.47
5	Short winter and long hot weather	9	39.13

Source: Collected and calculated from questionnaire data.

3- The ramifications of climate change on aquatic production from the standpoint of the study cohort and the fishing methodologies they have employed to adjust to and mitigate these alterations:

It is unequivocal that there exists a substantial reduction in fish production, attributable to various factors in addition to climate change, including the contamination of lake water due to sewage discharge and the proliferation of the isopod insect. Nevertheless, the participating fishermen concurred that one of the most significant consequences of climate change, manifested in the form of elevated temperatures, is the accelerated deterioration of fish aboard vessels prior to their transit to the shore. This contraction in production precipitates a decline in financial returns, thereby exacerbating the economic and living circumstances of fishermen, which has consequently prompted the relocation of fishermen to alternative aquatic bodies such as Lake Nasser and the Red Sea.

The data presented in Table (14) elucidate the principal methodologies adopted by the study's fishermen to acclimatize to climate change, most notably the alteration of fishing expedition times to commence from 5 pm until 7 am, as opposed to the previous initiation at 1 pm, with its relative frequency accounting for approximately 73.91% of the total frequency within the study sample. In the subsequent position, the acquisition of motors for vessels to facilitate a more rapid exit from the lake rather than relying on oars was noted, with a relative frequency of about 56.52%, while the third rank was occupied by the construction of tents to shield the deck of the boat, thereby diminishing the intensity of solar radiation on both the fishermen and the fish, with a relative frequency of approximately 43.47%. Lastly, the procurement of larger quantities of ice to preserve the fish aboard the vessel was recorded in the fourth position, with a relative frequency of around 34.78%.

Table No. (14) Relative frequency of the most important practices undertaken by fishermen to adapt to climate change

No	Statement	Frequency	٪
1	Changing fishing times	17	73.91
2	Purchasing a motor for the boat to speed up the exit from the lake	13	56.52
3	Making tents to cover the deck of the boat	10	43.47
4	Purchasing more ice	8	34.78

Source: Collected and calculated from questionnaire data.

4- Recommendations proposed by the sampled fishermen to address and mitigate the challenges posed by climate change.

The sampled fishermen collectively recognized the deficiency of supportive agencies that offer assistance to fishermen, and they concurred that they are devoid of governmental or non-governmental support to aid them in navigating the ramifications of climate change. Furthermore, they highlighted the inadequacy of financial allocations within the Lakes Support Fund aimed at addressing the repercussions of climate change. Additionally, they noted the absence of organized guidance seminars and workshops conducted by specialists in fish production to elucidate the detrimental effects of climate change on the variability and reduction of fish production in Lake Qarun.

The data presented in Table No. (15) delineate the paramount recommendations offered by the fishermen of the study sample to confront and tackle the issue of climate change. The foremost suggestion pertained to the provision of information, whether regarding meteorological conditions prior to fishing expeditions or general insights on climate change and strategies for coping with it, with a relative frequency of approximately 86.96% of the total frequency of the study sample. The second suggestion involved the necessity of receiving training pertinent to climate change and methodologies for addressing it, alongside educational programs focusing on sustainable fishing practices to enhance fishing efficiency, which garnered a relative frequency of about 69.56%. The third recommendation emphasized the need for financial assistance to upgrade fishing apparatus to combat the effects of climate change, such as modernizing boats by acquiring refrigeration systems for storing fish prior to venturing into the lake, with a relative frequency of around 60.87%.

Table No. (15): The relative frequency of the most important suggestions of the fishermen of the study sample to address and confront the problem of climate change

No	Statement	Frequency	٪
1	Providing information	20	86.96
2	Training on good fishing practices	16	69.56
3	Financial support	14	60.87

Source: Collected and calculated from questionnaire data.

Seventh: Systematic evaluation of the repercussions of the challenges encountered by the fishermen of the study sample on overall revenue:

The respondents from the fishing community within the study sample reached a consensus that the predominant issues afflicting Lake Qarun include water pollution and the proliferation of diseases impacting fish, both of which can adversely influence fish production. They also concurred on the issue of insufficient information in general, exemplified by a lack of awareness regarding optimal fishing times, which have shifted from commencing at one in the afternoon to now starting between five in the afternoon and seven in the morning. Moreover, they indicated a deficiency in marketing information, encompassing aspects such as pricing and the most favorable sales outlets.

These challenges have been categorized into financial issues and production and marketing dilemmas, with Tables No. (16) and (17) illustrating the relative frequency of the most salient problems encountered by the respondents from the fishermen of Lake Qarun in Fayoum Governorate.

As for the financing problems, it was found that the problem of the lack of sufficient self-financing ranked first with a relative importance of about 20% of the total opinions of the respondents, followed by the high interest rate on loans, and the high burdens of financing through the bank with a relative importance of about 17% for each, then the difficulty of dealing and the many procedures to obtain bank loans, and the short grace periods and bank repayment with a relative importance of about 15% for each, followed by the lack of the necessary guarantees to borrow from the bank, and the insufficiency of the value of the loans provided with a relative importance of about 8% for each.

Table No. (16): The relative frequency of the most important financial problems facing fishermen in the study sample

No	Statement	Frequency	٪
1	Lack of sufficient self-financing	18	20

2	High interest rates on loans	15	17
3	Lack of necessary guarantees to borrow from the bank	7	8
4	Difficulty of dealing and many procedures to obtain bank loans	13	15
5	Inadequate value of loans provided	7	8
6	Short grace and repayment periods	13	15
7	High financing burdens through the bank	15	17
	Total	88	100

Source: Collected and calculated from questionnaire data.

Regarding the challenges associated with production and marketing, it has been determined that the issue of insufficient nearby sales outlets, as well as the concern regarding the failure to release fry into the lake, occupies the primary position among the challenges, each carrying a relative significance of approximately 16%. Following this, the elevated expenses related to packaging and preservation rank next, with a relative importance of around 15%. Subsequently, the diminished productive efficiency of the labor force is noted with a relative importance of approximately 14%, followed by the considerable costs associated with fuel, which hold a relative importance of about 12%. Additionally, the issues surrounding the lack of nearby sales outlets and the failure to release fry into the lake are again highlighted, each possessing a relative importance of roughly 10%. This is succeeded by the inadequacy of appropriately equipped transportation vehicles and the considerable distance of markets from the farm, each contributing a relative importance of approximately 7% and 1%, respectively.

Table No. (17) Relative frequency of the most important problems facing fishermen in the study sample

No	Problem	Frequency	٪
1	Lack of transportation to transport workers	9	10
2	Low productivity of workers	13	14
3	Distance of markets from the farm	1	1
4	High transportation costs	9	10
5	High packaging and storage costs	14	15
6	Lack of nearby outlets for sale	15	16
7	Lack of equipped vehicles for transportation	7	7
8	Lack of seed dumping in the lake	15	16
9	High fuel costs	11	12
	Total	94	100

Source: Collected and calculated from questionnaire data.

By evaluating the repercussions of the challenges encountered by the fishermen within the studied sample, which significantly affect the overall revenue, and after excluding the issues that the sample participants reached consensus on, a dummy variable model was employed. This model elucidates the impact of the decline in total revenue attributable to the problem under investigation, with the intercept of the equation (the constant) representing the mean total revenue in the absence of the specified problem. The influence of the problem is manifested through the X coefficient, which quantifies the reduction in total revenue. The estimation results are presented in Tables Nos. (18) and (19). It is evident that a statistically significant correlation

exists between the average total revenue and the lack of adequately equipped transportation vehicles, with the average total revenue of the farm in the absence of this problem estimated at around 63 thousand pounds. The decrease in the total revenue of the farm attributable to this challenge is approximately 16 thousand pounds, and the statistical significance of this decline has been established, resulting in total revenue of the farm in the presence of the issue amounting to about 47 thousand pounds. Table No. (19) indicates that while the problem of exorbitant packaging and storage costs exerts a significant impact, it does not culminate in a decrease in total revenue. This phenomenon may be attributable to the proactive measures undertaken by fishermen to mitigate such issues; for instance, consumers may absorb the increased costs associated with packaging, thereby leading to a rise in consumer prices.

Table No. (18): Estimating the impact of financial problems facing fishermen on the average total revenue in the study sample

No	Average (μ)	Impact	Rate of Change (α)	Significance of Impact	Model Significance	Revenue in the Presence of the Issue	Issue
1	Inadequate self-financing	58793	- 857	(-0.109)-	0.001	(0.012)-	-
2	High interest rates on loans	62110	- 6114	(-0.917)-	0.039	(0.841)-	-
3	Lack of necessary guarantees for bank borrowing	57902	722	(0.103)-	0.001	(0.011)-	-
4	Difficulty and complexity of procedures for obtaining bank loans	57183	1663	(0.255)-	0.003	(0.065)-	-
5	Insufficient loan amounts offered	58006	382	(0.054)-	0.000	(0.003)-	-
6	Short grace and repayment periods	55968	3813	(0.589)-	0.016	(0.346)-	-
7	High financing burdens through banks	60767	-4055	(-0.602)-	0.017	(0.362)-	-

Whereas:
(1) Revenue is not estimated in the presence of the problem unless the impact of the problem is statistically significant.
(**) indicates significance at the (0.01) level, (*) indicates significance at the (0.05) level, (-) is not significant.
Source: Collected and calculated from the questionnaire data.

Table No. (19) Estimating the impact of production and marketing problems facing fishermen on the average total revenue in the study sample.

No	Problem Description	Average (μ)	Impact	Rate of Change (α)	Significance of Impact	Model Significance	Revenue in the Presence of the Issue
1	Lack of transportation for labor	56541	4043	(0.615)-	0.018	(0.378)-	-
2	Decreased worker productivity	60595	-4374	(-0.677)-	0.021	(0.458)-	-
3	Distance of markets from the farm	57219	20781	(1.366)-	0.082	(1.866)-	-
4	High transportation costs	60483	-6031	(-0.928)-	0.039	(0.860)-	-
5	High packaging and preservation costs	49749	13756	(2.325)*	0.205	(5.407)*	-

6	Lack of nearby sales outlets	56131	3053	(0.451)$^{-}$	0.010	(0.204)$^{-}$	-
7	Absence of equipped transport vehicles	63006	-16044	(-2.629)*	0.284	(6.911)*	46962
8	Non-seeding in the lake	52552	8542	(1.307)$^{-}$	0.075	(1.707)$^{-}$	-
9	High fuel costs	60418	-4799	(-0.750)$^{-}$	0.026	(0.563)$^{-}$	-

Whereas:
(1) Revenue is not estimated in the presence of the problem unless the impact of the problem is statistically significant.
(**) indicates significance at the (0.01) level, (*) indicates significance at the (0.05) level, (-) is not significant.
Source: Collected and calculated from the questionnaire data.

Eighth: A prospective framework for the enhancement and expansion of the ichthyological resources of Lake Qarun:

The advancement of fish production avenues within Fayoum Governorate constitutes a critical component of the overarching development of Egyptian fisheries, as the augmentation of fish yield from these aquatic environments will unequivocally contribute to an increase in the overall fish production within Egypt. Furthermore, this improvement is anticipated to elevate the economic conditions of fishermen in Fayoum Governorate, thereby enhancing their quality of life. Nevertheless, this sector is confronted with numerous adversities, including environmental pollution, unsustainable fishing practices, and the ramifications of climate change. Consequently, this strategic framework is designed to establish a comprehensive approach to the sustainable development of the ichthyological resources in Lake Qarun, mindful of these prevailing challenges. The principal components for formulating a strategy aimed at enhancing the ichthyological sector in Lake Qarun are delineated as follows:

• Environmental conservation and enhancement of water quality: This objective is pursued through:

- The establishment of wastewater treatment facilities to avert the discharge of pollutants into the lake.
- The treatment of agricultural runoff prior to its release into the lake.
- The promotion of organic fertilizers and pesticides as preferable alternatives to their chemical counterparts, alongside educational initiatives for farmers regarding the environmental hazards posed by chemical agrochemicals.

• Augmentation of productivity: This objective is pursued through:

- Provision of fish fry:
- The establishment and enhancement of fish hatcheries for the propagation of both indigenous and exotic fish species.
- The periodic release of fry into the lake to ensure the sustainability of fish populations.
- Advancement of fishing methodologies to promote sustainability: This objective is pursued through:
- The utilization of contemporary fishing apparatus and techniques that mitigate ecological impacts.
- The regulation of fishing efforts within the lake to avert overexploitation of fish stocks.
- Administrative enhancement and capacity building: This objective is pursued through:
- The conduct of regular fish stock assessments to evaluate ichthyological populations.
- The provision of training and advisory services to fishermen regarding optimal aquaculture practices.

• Support for the fishery sector: This objective is pursued through:

- The provision of low-interest loans to fishermen for the modernization of their fishing gear and equipment.
- The improvement of infrastructure surrounding the lake to facilitate the mobility of fishermen and transport vehicles.
- The provision of health and social insurance for fishermen and their dependents.
- The provision of contemporary fishing equipment at subsidized rates for fishermen.

• Marketing of fish products: This objective is pursued through:

- Enhancement of marketing infrastructure:
- The establishment of state-of-the-art fish markets for the sale of both fresh and frozen fish, equipped with refrigeration and freezing capabilities.

- Promotion of fish products: This is achieved through:
- Domestic and international promotion of fish products sourced from Lake Qarun.
- Participation in global fish product expos.
- The initiation of marketing campaigns to bolster the visibility of fish products within Egypt.

• Fortification of partnerships among relevant stakeholders: including the Ministry of Agriculture and Fisheries, the Ministry of Environment, various governmental bodies, non-governmental organizations, and the private sector.

• Enhancement of legislative frameworks and regulations: This is achieved through:

The enactment of laws aimed at safeguarding the environment from contamination.

- The implementation of stringent regulations to combat over fishing.

• Scientific inquiry: This is accomplished through:

o Financing research initiatives aimed at the advancement of sustainable aquaculture methodologies.

o Facilitating investigations into the repercussions of climate change on aquatic biodiversity, as well as orchestrating conferences and workshops to disseminate the findings of scientific studies.

o Publishing awareness materials and bulletins that emphasize the significance of conserving fish populations.

• Sustainability: This is achieved through:

o Implementing fishing techniques that are sustainable and do not deplete fish populations.

o Minimizing the consumption of energy and water resources in aquaculture.

o Engaging in the recycling and repurposing of waste materials.

• Climate change: This is addressed through:

o Cultivating fish species that exhibit enhanced resilience to climate change.

o Safeguarding aquatic ecosystems from climate change impacts such as elevated sea levels and severe weather events.

o Establishing early warning systems to predict storms and flooding.

• Furthermore, it is crucial to fortify international collaboration:

o Exchange knowledge and experiences regarding optimal practices for mitigation and adaptation within the fisheries domain.

o Engage in global initiatives aimed at confronting the challenges posed by climate change.

• Integrating adaptation into development strategies:

o Embedding climate change adaptation strategies within national and regional developmental frameworks.

o Allocating requisite resources for the execution of adaptation strategies.

o Ensuring the involvement of all relevant stakeholders in the planning and execution processes.

By employing a comprehensive strategy that encompasses these pivotal axes, the fisheries sector can effectively address and adjust to the ramifications of climate change, thereby ensuring sustained productivity and achieving food security. It is important to acknowledge that the implementation of this strategy aligns with several objectives articulated in both the United Nations Sustainable Development Strategy and Egypt Vision 2030, as delineated below:

- UN **Goal 14:** Marine Life Underwater: The strategy plays a crucial role in the preservation, protection, and sustainable utilization of marine ecosystems, thus fostering sustainable development. It advocates for the sustainable management of fisheries, effectively curtailing overfishing, illegal and unreported fishing practices, and the degradation of fisheries resources.

- UN Goal 2: End hunger, achieve food security, improve nutrition and eliminate all forms of malnutrition; Goal 3 in Egypt's Vision: Strong Economy: Competitive and Diversified Economy; and Goal 7 in Egypt's Vision: Egyptian Peace and Security: The strategy is instrumental in augmenting fish production from Lake Qarun, which serves as a vital food source for the populace and is rich in protein, minerals, and vitamins.

- UN Goal 8: Promote sustainable and inclusive economic growth, full productivity, full employment and decent work for all; and Goal 1 in Egypt's vision: Quality of life: Improving the quality of life of the Egyptian citizen and improving his standard of living: The strategy facilitates the creation of new employment opportunities within the fisheries sector. Furthermore, it

enhances productivity and elevates the value of fish products, thereby contributing to poverty alleviation by generating job opportunities and income for local communities.

- UN Goal 13: Take urgent action to combat climate change and its effects: The strategy fortifies adaptation measures to climate change and safeguards marine ecosystems from its adverse impacts.

- UN Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development; and Goal 8 in Egypt's vision: Leadership: Strengthen Egyptian leadership: The strategy fosters enhanced collaboration among diverse stakeholders to advance fisheries development in Lake Qarun. It promotes the exchange of experiences and information among nations regarding sustainable fisheries development practices, as well as the acquisition of financial and technical support from developed nations to facilitate the implementation of sustainable development initiatives.

- Goal 5 of Egypt's vision: Environmental sustainability: An integrated and sustainable ecosystem: The strategy endorses the judicious utilization of resources in a manner that safeguards the rights of future generations by addressing the impacts of climate change and bolstering the capacity for sustainable production and adaptation.

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