Mediterranean Aquaculture Journal 2023 10 (1):40-53

Original Article

Risk assessment and vulnerability of aquaculture activities in the Nile Delta to climate change impacts and its implications on food security

Naglaa F. Soliman*

Department of Marine Environment, Faculty of Aquaculture and Marine Fisheries, Arish University, Arish, Egypt

ABSTRACT: Despite all debates and controversies, a global consensus has reached that climate change is a reality. It is predicted to lead adverse and irreversible implications on the earth. These implications may include increased global temperature, sea level rise, and extreme weather events, which will have direct or indirect impacts on food production systems and global biodiversity. In this context, aquaculture is no exception. This paper discusses potential impacts of climate change on aquaculture and food security in the Nile Delta of Egypt. The assessment considered mainly inundation by sea level rise, heat stress and increasing water salinity due to Sea level rise. Results showed that, the total areas of fish farms that would be vulnerable to inundation, according to the RCP2.6 and RCP8.5 scenarios were found to be about 57176.64 feddan and 63025.95 feddan, respectively. These areas represent 54.35 and 59.92% of the total area of the present fish farms of Kafr El Sheikh Governorate. The combined effects of rising temperatures, sea level and salinities in the study area may result in a number of positive impacts on aquaculture activities such as increased growth rates and food conversion efficiencies of target species, longer growing seasons, reduced cold water mortality and expansion of areas suitable for aquaculture.

Key word: Aquaculture, Sea Level Rise, GIS, Food Security

Received: May, 13, 2023

Accepted: June, 7, 2023

1. INTRODUCTION

Fish plays an important role in food security by providing an inexpensive source of nutrients, including high quality protein, omega-3 polyunsaturated fatty acids, and micronutrients (Li and Hu, 2009). The stagnation on wild fish catch has created a gap between the supply and the increased demand for fish. This difference has been filled by aquaculture, which has been responsible for most of the net growth in fish production during the last decade (Delgado et al., 2003). Accordingly, aquaculture is being recognized as an important way of increasing fish production.

Correspondence :

Naglaa F. Soliman

Department of Marine Environment, Faculty of Aquaculture and Marine Fisheries, Arish University, Egypt

Mail: Naglaa_farag2007@yahoo.com

Beyond ensuring food security, aquaculture is becoming increasingly significant in supporting many communities' lives, employment opportunities, and economic growth, particularly in developing nations; in 2018, over 20 million people worldwide were employed in the industry (FAO, 2020). Aquaculture is vulnerable to climate change, despite its increasing relevance for global food security and economic growth (Pernet and Browman, 2021).

With a total output volume of over 1.8 million tons, Egypt has the biggest aquaculture sector in Africa and is now regarded as the primary source of fish supply (Kaleem and Sabi, 2021). Due to the quick adoption of new technologies like the use of extruded feed, water circulation systems, and improved farm management techniques, the production of fish has increased significantly from 0.54 million tons in 2005 to 1.59 million tons in 2020 (GAFRD, 2020). This tremendous development in aquaculture has created a large number of jobs for farm technicians and skilled labor. Furthermore, new industries and financial services associated with aquaculture provide additional jobs. In this respect, it was estimated that the aquaculture value chain employs at least 100,000 full time equivalents, 50 percent of whom are youth (Macfayden *et al.,* 2011). In such a case sustainability of aquaculture activities can contribute largely to poverty alleviation improves poor people's food and nutrition security through increased supply of protein and essential micronutrients (Kantor and Kruijssen, 2014). In Egypt, most of the fish farms are located through the Nile Delta region and concentrated mainly in the Northern lakes (Maruit, Edko, Burullus and Manzala) (FAO, 2010). A considerable proportion of fish farms total area is located in Kafr El Sheikh Governorate, which produces more than a half of the total aquaculture fish production.

Climate is an environmental factor that has considerable direct and indirect effects on aquaculture productivity (Hamdan *et al.* 2011). Directly increase of a few degrees in water temperature can set off ecological changes that will affect most forms of aquatic life. For instance, rising temperatures similarly reduce levels of dissolved oxygen and increase metabolic rates of fish, leading to increases in fish deaths, declines in production or increases in feed requirements while also increasing the risk and spread of disease (FAO, 2008) (Pandit and Nakamura, 2010). Indirectly, changes in rain fall will cause a spectrum of changes in water availability ranging from droughts and shortages to floods and will reduce water quality, while salinization of groundwater supplies and the movement of saline water further upstream in rivers caused by rising sea levels will threaten inland freshwater aquaculture (IPCC, 2007). Increased run-off bringing in nutrients from sewage or agricultural fertilizers may cause algal blooms which in turn lead to reduced levels of dissolved oxygen and ‘fish kills’ (Diersing, 2009). Moreover, risks associated with climate change may significantly affect aquaculture activities. For example, wide areas of aquaculture ponds existing in the low laying land may be highly vulnerable to be inundated by sea level rise.

Egypt is considered as one of the top five countries expected to be vulnerable to sea level rise impacts (Dasgupta, *et al.,* 2007). As a result of global sea level rise, wide areas of the Nile delta coastal zone will be susceptible to salt water intrusion and inundation with a wide range of implications. Climate change and associated risks may affect fisheries and aquaculture directly by influencing fish stocks and hence production quantities and efficiency, or indirectly by influencing fish prices or the cost of goods and services required by fishers and fish farmers (Muir and Allison, 2006).This consequently, will have significant impacts on aquaculture productivity and thus may threaten food security in Egypt. In spite of the escalating importance of aquaculture industry in the recent years and the increasing share of Egypt in the industry; few studies were conducted addressing the sustainable development of aquaculture systems in Egypt (El Gayar, 2003, El Sayed, 2007, Golding and Kamel, 2013, Kaleem and Sabi, 2021) disregarding the consequences of climate changes on aquaculture.

Therefore, it is crucial to evaluate the threats and difficulties that climate change presents to aquaculture in order to put specific adaptation and resilience-building measures into place that will protect future output.

This study aims mainly to assess the vulnerability of aquaculture activities in the Nile Delta to climate change, focusing on the impacts of sea level rise, increasing temperature and higher levels of salinity.

It is believed that such an assessment may assist in supporting decision and policy-making process in terms of sustainability of aquaculture activities and, in turn, attaining food security.

2. MATERIALS AND METHODS

2.1. Study area

Kafr El-Sheikh Governorate is located on the Mediterranean Sea coast to the east of Damietta branch of the River Nile, extends from 30° 59′ 38″ to 31 36 00 Latitude, and from 30° 21′ 40″ to 31° 18′ 40″ Longitude (Hassan et al., 2013). In addition to its strategic position, Lake El Burullus, the largest of Nile Delta lakes is located in the governorate. It is the thirteenth largest governorate in Egypt with a population of about 3,620,887 (CAPMAS, 2021). The governorate is administratively subdivided into ten districts, where fish-farming sector is considered one of the main sectors that dominates the economic activity (Fig. 1) (El Kholei, 2014).

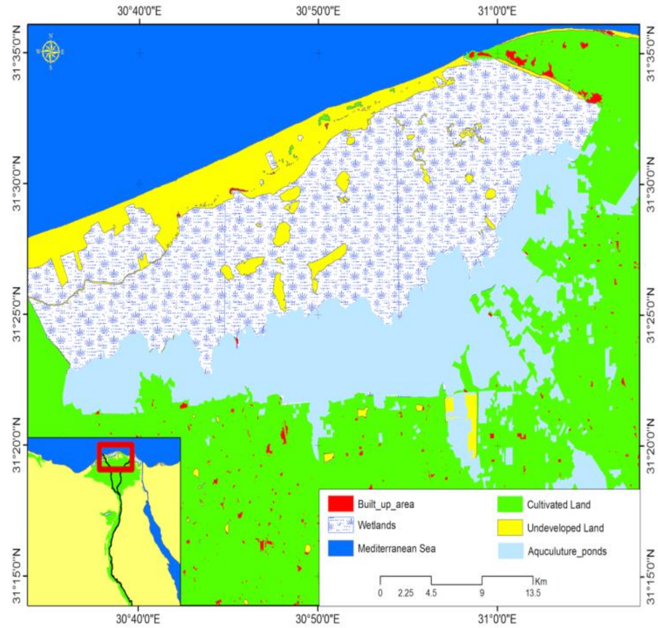


Fig. 1: Study area

Kafr El Sheikh Governorate, as a part of the Nile Delta, is highly vulnerable to SLR impacts, which may lead to increased flooding, damage to urban centers and infrastructure, retreat of barrier dunes, increases soil and lagoon water salinity, and decreased fisheries production (MSEA, 2001, Hassan and Abdrabo, 2013).

In this respect, it was argued that among the coastal governorate of the Nile delta, Kafr El Sheikh was found to be highly vulnerable to sea level rise impacts under different hypothetical scenarios; namely 0,25, 0.5, 1.0, and 1.5 m (Dawod *et al.*, 2008).

Also, it was estimated that more than 22% of the total governorate area would be vulnerable to inundation under B1 and A1F1 Scenarios (Hassan, 2013). Similarly, it was estimated that northeastern parts of Kafr El Sheikh governorate which represent about 10-15% of its total area are vulnerable to inundation by sea level by the year 2100 (Zaid *et al.*, 2014). It was estimated that considerable proportions of farmed fish accounting for 55% of the total production in Egypt, are produced in Kafr El Sheikh, such a considerable share produced from small and medium-scale privately owned farms. Pond culture farms occupied 105183 feddan in 2020 and generated roughly 599043 tons of fish (231893, 327750, and 39900, tons) from privately owned, temporary, and leased fish farms, respectively), but only 11574 tons of fish from government fish farms. While 5942 tons were generated from rice fields and 82068 tons were produced in cage cultures (GAFRD, 2020).

According to recent estimates, tilapia accounted for 71.95% by volume of aquaculture production in Kafr El Sheikh Governorate in 2020, followed by carp (15.15%) and mullets (12.26%) (GAFRD, 2020). Kafr El Sheikh has a major fish market El Borsa, which is responsible for setting the daily price of fish in Kafr El Sheikh Villages and neighborhoods, as well as in surrounding governorates (Kantor and kruijssen, 2014).

2.2. Methodology

For the purpose of this study, three main risks associated climate change and may affect aquaculture activities in Kafr El Sheikh Governorate are considered including inundation by sea level rise, increasing temperature and higher levels of water salinity. To assess vulnerability of aquaculture activities to these risks, a methodology of three main steps was developed including:

2.2.1. Assessing vulnerability to inundation by sea level rise

Such an assessment requires integrating a wide range of spatial variables that determine vulnerability level. For this purpose, GIS have been employed in the assessment due to their great capabilities to deal with spatial data. In this respect a geodatabase for the study area was generated. The developed geodatabase involved primarily layer representing the spatial extent of aquaculture ponds in the study area. This layer was created from a Landsat-8 (OLI_TIRS) image.

Also, the developed geodatabase included various variables determining vulnerability to inundation by sea level rise such as topography, subsidence kevel of the Nile Delta and elevation. Each of these variables was represented in a raster surface depicting the subtle variations in each variable over space. Using GIS Spatial Analyst Tools, the relative sea level rise up to the year 2100 was calculated according to the following formula (Hassan, 2013):

$$R_{SLR} = (G_{SLR}) + (V*T)$$

Where:

R_{SLR}; Relative sea level rise
G_{SLR}; Global sea level rise
V; Annual rate of land subsidence
T ; Number of years between present and future year of concern

As for global sea level rise RCP2.6 and RCP5.8 scenarios; the most optimistic and pessimistic case scenarios, were applied, according to these two scenarios the expected average global SLR was estimated to be 40 and 65 cm up to 2100, respectively (IPCC, 2013).

According to Stanley and Warn (1993) and Stanly (1997) the rates of subsidence of the northern sections of the Nile delta during Holocene varied widely in different parts between 0.5 and 4.5 mm/year (Stanley and Warne, 1993; Stanley, 1997).

Thereafter, the calculated relative SLR was used in relation to land elevation to delineate those low laying land that would be threatened by inundation due to SLR.

Furthermore, for each species and per scenario, a measure of exposure to coastal flooding was calculated, associated with sea level rise. This took account of both inherent differences between culture types in exposure to flooding, and of expected average global SLR at different scenarios (Stanley, 1997; Engelhard *et al.,* 2022). Firstly, for each species a sensitivity score to flooding was defined as 1 (low), 2 (medium) or 3 (high), based on culture type and biological characteristics. Species typically reared in floating sea cages were scored as having ‘low’ sensitivity as these facilities are not directly impacted by flooding or coastal inundation (although extreme weather could lead to losses particularly if cages are inadequately engineered). Species cultured in ponds or raceways, often located in low-lying terrain close to the sea and prone to inundation, were scored as having 'high' sensitivity. Species reared in Recirculation Aquaculture System (RAS) were scored as having 'medium' sensitivity as these are typically connected with coastal areas. Secondly, for each scenario a flooding hazard score was calculated, using the area predicted to be flooded if mean sea level rises by 40 and 65 cm. For each species and per scenario, exposure to flooding was then calculated as cultured species' sensitivity to flooding × scenario' flood hazard.

2.2.2. Assessing impacts of increasing temperature

Increasing temperature is expected to have significant impacts on growth rate of fish and consequently may affect aquaculture productivity in the study area. To assess the vulnerability of aquaculture to increasing temperature data on the expected temperature in the study area by 2100 according to RCP 8.5 scenario was acquired (Earth System Grid Federation).

The data that downloaded in Net CDF format were further manipulated through Multidimensional Data Tools in ArcGIS and masked to obtain the expected temperature within the study area. Thereafter, for each species, the sensitivity to thermal stress from climate change was assessed. In this analysis, thermal sensitivity takes account of species' upper temperature tolerance ranges, in relation to lake temperatures at current situation and as projected by SLR scenarios. To describe the species' upper temperature tolerance, data on their 'maximum preferred temperature' (TP90) were determined. TP90 is defined as the 90th percentile temperature, based on sea surface temperatures in the observed distribution range of the species in the wild. Thus, for a given species' wild population, it may be assumed that 90% of individuals occur in areas with annual mean sea temperatures below TP90. We then combined each species' TP90 with current lake temperature and as projected by SRL scenarios, to calculate the 'thermal safety margin; TSM', as the difference between TP 90 and surface water temperature. If TSM is positive, the species' maximum preferred temperature is higher than the mean annual surface water temperature, indicating the species is unlikely to suffer substantially from thermal stress if held under ambient conditions. If TSM is negative, mean ambient temperatures are beyond the species' optimal thermal tolerance ranges; if held under ambient conditions these species are likely to be at risk of thermal stress particularly during the warmer season(s).

2.2.3. Assessing impacts of higher levels of water salinity

As a result of higher sea level rise in the future and associated inundation as well as salt-water intrusion, the salinity in aquaculture ponds will increase considerably. To acquire data on current levels of water salinity in the study area and estimated levels in the future, due to sea level rise, a literature review was conducted. The acquired data was employed to assess the impacts of increased salinity in aquaculture productivity.

The **r**elative hazard from salinity increase in lake water, assessed for aquaculture species by different locations. For each species, sensitivity to salinity increase risk is scored (1 low, 3 high) based on culture type and biological characteristics. For each location, salinity increase hazard is scored (1 low, 4 high), based on geographical patterns and projected seawater inundation intensity and direction. Relative hazard per species and location is then calculated as sensitivity × hazard.

3. Results and Discussion

While the environmental conditions in Egypt are generally favorable for fish production, the colder winter months from January through April place constraints on the fish farming sub-sector, due to the lack of cold tolerance of fish and a growth period that is limited to around 8 months. Stocking typically (though not always) takes place in April, and harvesting in November and December. Some farmers try to avoid overwintering of fish due to the associated risks of both mortalities and also losses from theft. This 8 month growing period has obvious implications for the size of fish at harvest, and therefore the market price achieved (Macfadyen et al., 2011).

Adopting the methodology discussed in section (2), the vulnerability of aquaculture activities in Kafr El Sheikh Governorate was assessed assuming business as usual scenario, which implies no adaptation undertaken. The assessment cover three main potential risks associated with climate change that may affect the productivity of aquaculture activities. These risks include inundation, heat stress and increasing salinity.

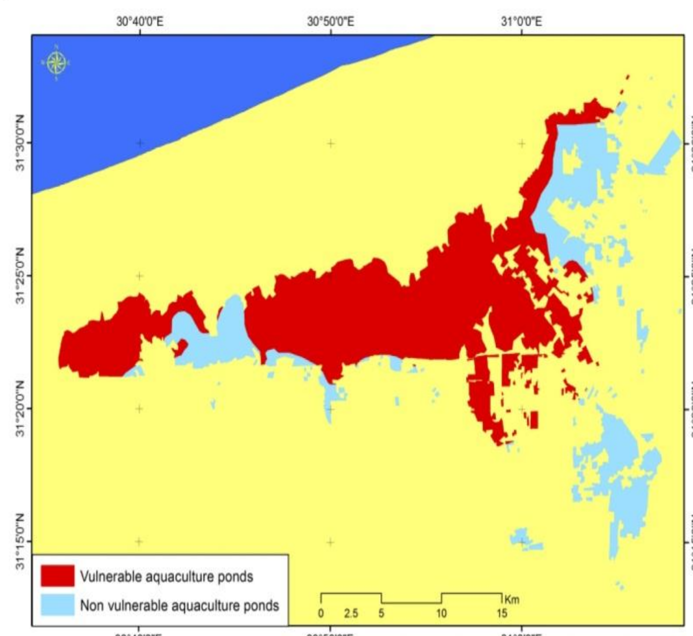
The potential impacts of the considered risks associated with climate changes on aquaculture productivity will be discussed in the following sub-sections.

3.1. Vulnerability to inundation

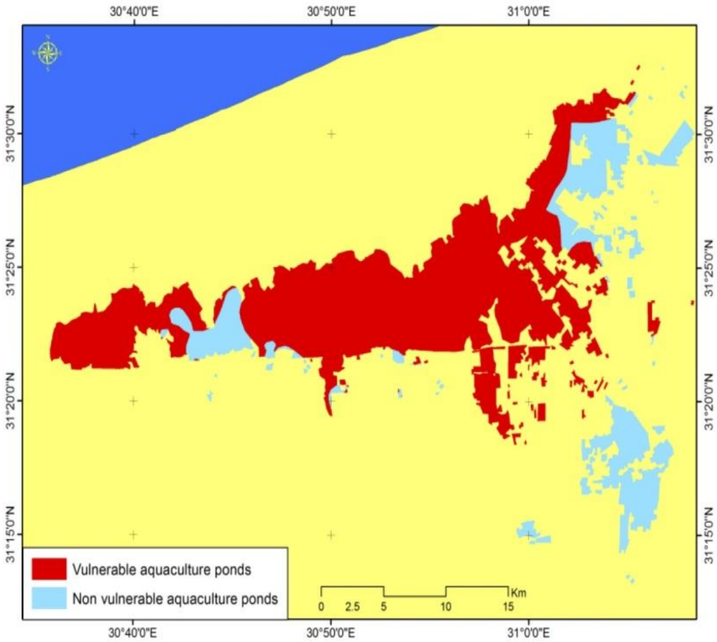
Results in Fig. 2 showed that fish farming was predominantly applied along the southern shores of El Burullus lagoon. Fish farming is a new activity introduced to the study area during the nineteenth of the last Century as an alternative to a relatively high outcome/acre of aquaculture compared to agriculture. Another important factor is that the rural people forced to shift to fish farm activities due to the problem of water logging southern of the Burullus borders (El-Asmar and Al-Olayan, 2013). On the other hand, these areas are below the present sea level and will be the highly vulnerable to the risk of inundation in case of sea level rise (El-Asmar and Al-Olayan, 2013).

Currently, the total areas that are used for aquaculture activities are estimated as much as 86693.365 feddan. It was found that the total areas of fish farms that would be vulnerable to inundation under RCP2.6 and RCP8.5 scenarios were estimated to be about 57176.64 and 63025.95 feddan, respectively. These areas represented 54.35 and 59.92% of the total area of the present fish farms of Kafr El Sheikh Governorate; 105183 feddan estimated by GAFRD, 2020 (Fig. 2 a & b).

It can be noted that there was a slight difference exist between the two scenarios in terms of spatial extent of SLR impacts. (Fig. 2a &b).



(a) RCP 2.6 Scenario



(b) RCP 8.5 Scenario

Fig. 2 a & b: Fish farms vulnerable to inundation due to SLR by the year 2100 according to RCP 2 .6 and RCP 8.5 scenarios.

This could be attributed to slight difference between averages global SLR under the two considered scenarios, which is associated with low varied land topography, prevailed in the study area. Due to slight difference between the two scenarios, it was decided to focus the analysis, in the following subsections, on the potential impacts of climate change on aquaculture activities in the study area under RCP 8.5 scenario.

It was found that most of the area vulnerable to inundation was El Burullus wetland, which hosts mostly fish farms in the study area. It is worth mentioning that inundation of wetlands and fish farms, in the case of the Nile Delta, may have a number of adverse impacts on biodiversity and fish production due to increasing salinity of water, which ultimately, may threat its biodiversity. This consequently, means that inundation of fish farms can adversely influence food production and employment opportunities in the area.

Yet, it was argued that inundation of wetlands cannot be seen as a net economic loss. Rather, if proper adaptation options are carried out, it could turn into a good opportunity for increasing fisheries productivity (Hassan and Abdrabo, 2013). This in turn entails an integrated analysis for the impacts of different risks associated with climate changes.

As sea levels rise, flooding of low lying areas and salinization of groundwater and soil will create ideal conditions for aquaculture in many areas (MAB, 2009), while simultaneously rendering them unsuitable for regular agriculture. There has been a suggestion that Bangladesh could turn from a “rice-bowl into a fish-pond” due to this and increases in other flooding (WorldFish Center, 2007a).

Table 1 shown that flooding exposure is assessed as intermediate for culture in ponds and raceways. While it was relatively low for culture in RAS which have controlled environmental conditions but typically are located in coastal zones. This risk factor is low for species farmed in floating sea cages, appear to render cages least susceptible to losses from this hazard.

Table 1: Relative exposure to flooding assessed for Kafr El Shaikh Governorate aquaculture.

Cultured method	Sensitivity to flooding	Relative exposure (RCP 2.6 Scenario)	Relative exposure (RCP 8.5 Scenario)
Ponds	3	1.95	2.19
Raceways	3	1.95	2.19
RAS	2	1.3	1.46
Cages	1	0.65	0.73
Inundated area with sea level rise		57176.64	63025.95
Total area		86693.365	86693.365
Flooding hazard		0.65	0.73

3.2. Impacts of increasing temperature

Growth of fish is a complex process affected by many behavioral, physiological, nutritional, and environmental factors; however, temperature is recognized as one of the most important single abiotic factor affecting growth, food intake, and food conversion of fish (Martinez et al., 1996). *O. niloticus* is known to tolerate high temperatures. It cannot tolerate for a long period water temperature between 10 and 15 °C (Ballarin and Hatton, 1979), and does not survive below 10 °C (Chervinski and Lahav, 1976). The optimum temperature for feeding, growth and reproduction is between 22 and 30 °C (Caulton, 1982), while good growth was recorded in the upper portion of this range (Hauser, 1977). Thus, at higher or lower temperatures, feeding and growth rates are reduced, and at 20 °C or less, feeding and growth are stopped (Caulton, 1982).

However, most tilapias do not eat or grow at temperatures below 15 °C (Dendy *et al.*, 1979).

The climate of Burullus protected area is arid Mediterranean. The mean annual rainfall is less than 200mm. The summer months (June – September) are almost entirely rainless, while the winter months (November-February) are the wettest (Kassas *et al.*, 2002). The temperature typically varies from 9°C to 30°C and is rarely below 6°C or above 32°C. The warm season lasts from June 6 to October 10 with an average daily high temperature above 28°C. The hottest day of the year is August 5th with an average of 30°C and low of 24°C. The cold season lasts from December 10 to March 21 with an average daily high temperature below 20°C. The coldest day of the year is February 2nd with an average below of 9°C and high of 18°C (El Adawy *et al.,* 2013). Field observations by Noor El Deen and Zaki (2012) showed that in Kafr El Sheikh fish farm, water temperature was 18 - 28°C that is suitable to fish growth. While during January, February, and March temperature dropped to 10 °C and lower, which is not only unsuitable to tilapia growth but also threatening tilapia survival. So, fish mortality started to be observed.

The average temperature for the period 2001-2005 in the study area ranged between 11.5 °C in January and 25.2 °C in August (Fig. 3). Currently the aquaculture season extend usually between April to November with average temperature not less than 15 °C. Under RCP 8.5 scenario, the average temperature in the study area is expected to range between 15.9 °C in January and 28.8 °C in August for the period 2091-2100.

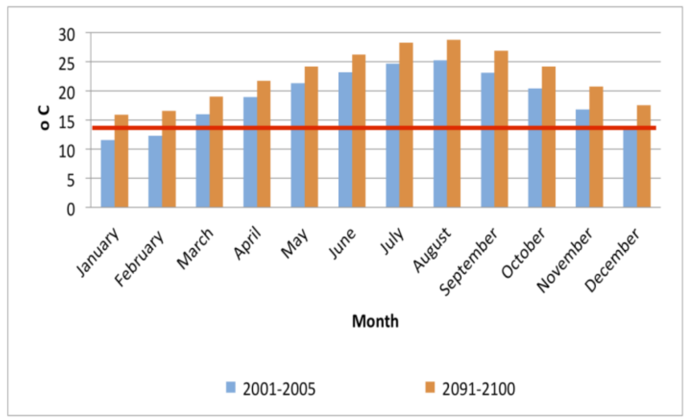


Fig 3: The simulated results of temperature for the period 2001-2005 in the study area under RCP 8.5

This will lead to prolonged aquaculture season extending all over the year (12 months) instead of only 8 months in the warm season from April to December. Such a prolonged aquaculture season may have positive implications on increase fish productivity about 25% compared to current productivity in a relatively short aquaculture season extending for about 8 months. World fish Center 2007 stated that not all the climate changes are negative. One of the benefits of rising water temperatures and sea levels include reduced cold water mortality of valuable fish and expansion of areas suitable for brackish or saltwater aquaculture such as shrimp and mud crab (World Fish Center, 2007b). Also these results are in agreement with Brander (2007) and IPCC (2007) they stated that rising temperatures may result in increased growth rates and food conversion efficiencies, longer growing seasons, reduced cold water mortality and expansion of areas suitable for aquaculture (Brander, 2007; IPCC, 2007).

On the other hand, Table 2 shows that mullet and carb have negative thermal safety margins at SLR scenario, indicating thermally stressful conditions for this species. While, thermal risk is assessed as low for tilapia at both current situation and after conducting SLR scenario.

Table 2: Risk from thermal sensitivity, assessed for Kafr El Shaikh Governorate aquaculture.

Species	Maximum preferred temperature (TP 90 °C)	Species sensitivity margin (current situation)	Species sensitivity margin RCP 8.5 Scenario
Tilapia	30.0 °C	4.8	1.2
Mullet	27.9 °C	2.7	-0.9
Carb	28.5 °C	3.3	-0.3
Maximum surface temperature		25.2 °C	28.8 °C

3.3. Vulnerability to increasing salinity

Tilapia fish, despite being freshwater fishes, are believed to have been from marine ancestors (Kirk, 1972). It is no surprise therefore that most of these fishes are able to tolerate a wide range of water salinity. They can grow and reproduce normally in brackish water. Some species can even grow and reproduce at very high water salinity (El-Sayed, 2006). Baroiller *et al.*, (2000) stated that *Oreochromis niloticus* does not tolerate salinities above 20 ppt and might not be suitable for culture in full-strength seawater (37 to 40 ppt). The Blue and Nile tilapias can reproduce in salinities up to 10 ppt to 15 ppt, but perform better at salinities below 5ppt.

Previous studies have reported no differences in growth between salinities of 0 and 11ppt (Payne and Collinson 1983) and Suresh and Lin (1992) documented optimal Nile tilapia growth in salinities ranging from 5 to 10 ppt.

After the building of the Aswan dam and the construction of a dense irrigation network which discharges into El Burullus Lake, the Lake slowly changed from a salt water lake into a fresh water lake. The distribution of salinity levels in the Lake depends on the amount of water discharged from the drains, the amount of seawater coming in through al Boughaz and the degree of mixing (Kholief, 2013).

Field observations by Younis and Nafea. 2012 (Table 3) showed that the lowest levels of salinity are detected in summer, when it ranges between (2.00 to 11.1 ppt; 0.80 to 2.92 ppt, and 0.80 to 1.66 ppt) at the Easter, Middle and western part of the lake, respectively.

Table 3: The simulated results of Salinity of El Burullus lake; Kafr El Shaikh Governorate due to SLR and the increase rate of evaporation.

Cold season			Warm season		
Location	Observed	Estimated according to SLR	Location	Observed	Estimated according to SLR
East			East		
Min	4.10	4.80	Min	2.00	2.34
Max	16.20	18.95	Max	11.1	12.99
Average	8.67	10.14	Average	5.61	6.56
Middle			Middle		
Min	1.22	1.27	Min	0.80	0.84
Max	2.40	2.51	Max	2.92	3.05
Average	1.874	1.96	Average	1.88	1.96
West			West		
Min	1.50	1.57	Min	0.80	0.84
Max	2.22	2.32	Max	1.66	1.73
Average	1.89	1.98	Average	1.12	1.17

The salinity decreased during summer and increased during winter due to the sea water inflows to the lake during this period (El El-Shinnawy, 2002). Generally, the salinity decreases further away from Al Boughaz (Kholief, 2013). The western section receives fresh Nile water from Brimbal Canal, while the eastern side of the lake receives water directly from the sea and therefore, water in this side is much salty (Younis and Nafea. 2012).

On the other hand, due to sea level rise, the lake might be subjected to an increase of sea water intrusion into the lake through a single northern inlet connecting the lake with the Mediterranean Sea (Eladawy *et al.,* 2013). According to Elsadawy *et al.* (2013) the highest increase of salinity was found around the area near Boughaz (inlet). It reached 17% of the recent value while the mid part is affected by an increase of salinity around

4.5%. The estimated increase in salinity due to SLR along the Eastern, middle and western part of the lake are presented in Table 3.

The average salinity in the study area is expected to be (10.14, 1, 96, 1.98 ppt) in the eastern, middle and western part of the lake during the cold season. While during the warm season, the predicted salinities expected to reach values of (6.56, 1.96, and1.17) for the eastern, middle and western part, respectively. It is worth mentioning that tilapia can tolerate this range of salinities during the cold and warm season, as they can grow and reproduce normally. These ranges of salinities might be suitable for culture in full-strength.

Table 4: Risk from increase of salinity due to inundation, assessed for Kafr El Shaikh Governorate aquaculture.

Species	Sensitivity to salinity increase	Species relative hazard by location		
		Western side	Middle side	Eastern side
Tilapia	1	1	2	4
Mullet	1	1	2	4
Carb	2	2	4	8
Increase in salinity hazard		1	2	4

Table 4 shows the relative hazard from salinity increase in lake water, assessed for aquaculture species by different locations. The hazard from increase in salinity levels in lake water was assessed as greatest for fish species cultured in cages and raceways. Increase in salinity hazard is assessed as high (score 8) for carb in the eastern side of the lake and would potentially have relatively low risk value (score 2 and 4) at the western and middle side of the lake. This hazard is assessed as relatively minor for tilapia and mullet as these species can tolerate higher level of salinity. For carb, tilapia, and mullet reared in RAS and ponds increase in salinity hazard is assessed as low owing to the controlled conditions.

3.4. Adaptation and mitigation measures

The study at hand examined probable effects of climate change on aquaculture and suggested several viable options for adaptations, which may be summed up as follows:

- Raising the walls and floor of fish ponds so that they drain adequately as sea level rises.
- Select sites for freshwater ponds carefully: Locating ponds where they will not be affected by sea level rise or saltwater intrusion will help safeguard investments.

4. CONCLUSION

Aquaculture is considered as one of the most important sources of animal protein production. It is the hope for solving protein shortage problem in Egypt. On the other hand, Egypt is considered as one of the top five countries expected to be mostly vulnerable to climate change impacts, in particular sea level rise. Climate change is no longer simply a potential threat that can be avoided. This paper reviewed the importance of aquaculture, with particular reference to fish production and job opportunities in one of the top farmed fish producers in Egypt; Kafr El Skeikh Governorate. It focused on the likely impacts of climate change on these activities and on food security expressed as inundation by sea level rise, heat stress and increasing water salinity. The assessment conducted in this study, which focused on the risks of inundation due to SLR, increasing temperature and higher levels of salinity showed that more than 54.35 and 59.92% of the total area of the present fish farms of Kafr El Sheikh Governorate would be vulnerable to inundation according to RCP2.6 and RCP8.5 scenarios. No significant difference was noticed between the two scenarios in terms of spatial extent of SLR impacts. On the other hand, flooding exposure is assessed as intermediate for culture in ponds and raceways, relatively low for culture in RAS and low for species farmed in floating sea cages. Mullet and carb have negative thermal safety margins, while tilapia have low risks at both current situation and after conducting RCP8.5 scenario. Increase in salinity hazard is assessed as high for carb and relatively minor for tilapia and mullet reared in cages and raceways. On the contrary, tilapia, and mullet reared in RAS and ponds increase in salinity hazard is assessed as low owing to the controlled conditions. The integrated assessment considering the impacts of rising temperatures and salinities in the study area reveled that expected climate change may result in some positive impacts such as increased growth rates and food conversion efficiencies of *tilapia niloticus*, longer growing seasons, reduced cold water mortality and expansion of areas suitable for aquaculture**.** This in turn may ensure higher productivity of aquaculture activities and support food security in Egypt.

REFERENCES

Ballarin, J.D. & Hatton, J.D. 1979. Tilapia: A guide to their biology and culture in Africa. Stirling Uni., 174pp.

Baroiller, J.F., Clota, F., Cotta, H.D., Derivaz, M., Lazard, J. & Vergent, A. 2000. Seawater adaptability of two tilapia species (*S. melanotheron* and *O. niloticus*) and their reciprocal F1 hybrids. Page 303 in K. Fitzsimmons and J.C. Filho, editors. Proceedings of the 5th Int. Sym. Tilapia in Aquacult. Rio de Janeiro, Brazil, 3-7 September 2000.

Brander, K.M. 2007. Global fish production and climate change. Proc. the National Acad. Sci. 104 (50), 19704–19714.

CAPMAS. 2021. Central Agency for Public Mobilization and Statistics.

Caulton, M.S. 1982. Feeding, metabolism and growth of tilapias: some quantitative considerations. In: Pullin, R.S.V., Lowe-McConnell, R.H. (Eds.), The Biology and Culture of tilapias. ICLARM, Manila, Philippines, pp. 157–180.

Chervinski, J. & Lahav, M. 1976. The effects of exposure to lowtemperature on fingerlings of local tilapia (*Tilapia aurea*) (Steindachner) and imported tilapia (*Tilapia vulcani*) (Trewavas) and *Tilapia nilotica* (Linne) in Israel. Bamidgeh 28, 25–29.

Dasgupta, S., Laplante, B., Murray, S. & Wheeler, D. 2009. Sea-Level Rise and Storm Surges. Policy Research Working Paper 4901, Washington: The World Bank- Development Research Group- Environment and Energy Team.

Dawod, G.M. 2008. Estimation of sea level rise hazardous impacts in Egypt within a GIS environment. The third national GIS symposium in Saudi Arabia, Al-Khobar, April 17-9

Delgado, C.L., Wada, N., Rosegrant, M.W., Meijer, S. & Ahmed, M. 2003. Fish to 2020. Supply and demand in changing global markets. IFPRI/World Fish center, Washington, DC.

Dendy, J. S., Varikul,V., Sumawidjaja, K. & Potaros, M. 1979. Production of tilapia mossambica, plankton and benthos as parameters for evaluatingnitrogen in pond fertilizers. FAO Fish. Rep, 44:226-240.

Diesering, N. 2009. Phytoplankton blooms: The basics. Florida keys National marine sanctuary, key West, Florida, USA, 2pp.

El-Adawy, A., Negm, A.M., Elzeir, M.A., Saavedra, O. C., El-Shinnawy, I.A. & Nadaoka, K. 2013. Modeling the hydrodynamics of salinity of El Burullus Lake (Nile Delta, Northern Egypt).

El-Asmar, H.M. & Al-Olayan, H.A., 2013. Environmental impact assessment and change detection of the coastal desert along the central Nile Delta coast, Egypt. International journal of remote sensing applications, 2 (2), pp.24-29.

El-Gayar, O. 2003. Aquaculture in Egypt and issue for sustainable development. Aquacult. Econ. & Manag. 7(12): 137-154.

El Hasanen, K. S. 2013. Lake Burullus; Internal Document Provided to CDI.

El-Kholei, A. 2014. What are the Economic Characteristics of Fish Farming Ponds in Southern Sidi-Salem District (Kafr El-Sheik Governorate)? J. Amer. Sci., 10(4), 43-54.

El-Sayed, A.F.M. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Egypt. In Hasan M.R., Hecht T, De Silva S S, and Tacon A G J (eds), Study and analysis of feeds and fertilizers for sustainable aquaculture development. FAO fishing technical paper. No. 497. Rome FAO.

El-Shinnawy, I. 2002. Al-Burullus Wetland's hydrological study. Med. Wet. Coast, Global Environmental Facility (GEF) and Egyptian Environmental Affairs Agency (EEAA), Cairo, Egypt.

Engelhard, G.H., Howes, E.L., Pinnegar, J.K. & Le Quesne, W.J.F. 2022. Assessing the risk of climate change to aquaculture: a national-scale case study for the Sultanate of Oman. Climate Risk Management 35: 100416

FAO. 2008. Climate change implications for fisheries and aquaculture. In: The state of fisheries and aquaculture. FAO, Rome, Italy, pp.87-91.

FAO.2010. "The State of World Fisheries and Aquaculture (2010)" FAO Fisheries and Aquaculture Department, Food and Agriculture Organisation, Rome.

FAO.2020. Fishery and aquaculture statistics. Global production by production source 1950-2018 (FishstatJ). Retrieved from FAO Fisheries and Aquaculture Dept.

GAFRD. 2013. The General Authority for Fishery Resources Development: Summary Production Statistics

GAFRD. 2020. The General Authority for Fishery Resources Development: Summary Production Statistics

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. & Toulmin, C. 2010. Food security: the challenges of feeding 9 billion people. Science 327 (812): 812-818.

Goulding, I., Kamel, M. 2013. Institutional, policy and regulatory framework for sustainable development of the Egyptian aquaculture sector. World Fish, Penang, Malaysia. Project Report: 2013-39.

Hassan, M.A. 2013. GIS-based risk assessment for the Nile Delta coastal zone under different sea level rise scenarios case study: Kafr El Sheikh Governorate, Egpt. J Coastal Conserv, 17:743-754.

Hassaan, M. A. & Abdrabo, M. A. 2013. Vulnerability of the Nile Delta coastal areas to inundationby sea level rise. Environ Monit Assess. 185:6607–6616

Hamdan, R., Kari, F. & Othman, A. 2011. Climate variability and socioeconomic vulnerability of aquaculture farmers in Malaysia, Proceeding of the 2011 International Conference on Business and Economics Research, Singapore, 2011, pp. 47-52.

Hauser, W.J. 1977. Temperature requirement of tilapia. Calif. Fish Game. 63 (4), 228–233.

IPCC. 2007. Climate Change 2007: Synthesis Report – Contribution of Working Groups I, II, and III to the Fourth Intergovernmental Panel on Climate Change. Core Writing Team: R.K. Pauchauri and A. Reisinger, eds. IPCC, Geneva, Switzerland, 8 pp.

Kaleem, O. & Sabi, A. B. 2021. Overview of aquaculture systems in Egypt and Nigeria, prospects, potentials, and constraints. Aquacult. & Fish. 6: 535-547.

Kantor, P. & Kruijssen, F. 2014. Informal fish retailing in rural Egypt: Opportunities to enhance income and work conditions for women and men. Worldfish, Penang, Malaysia. Project Report: 2014-51.

Kassas, M. 2002. Management plan for burullus protectorate area. Med Wet Coast, Global Environmental Facility (GEF) and

Egyptian Environmental Affairs Agency (EEAA), Cairo.

Li, D. & Hu, X. 2009. Fish and its multiple human health effects in times of threats to sustainability and affordability are there alternatives? Asia Pacific journal of clinical nutrition, 18.4: 553-563

Likongwe, J.S., Stecko,T.D., Stauffer, J.R. & Carline, R. F. 1996. Combined effects of water temperature and salinity on growth andfeed utilization of juvenile Nile tilapia *Oreochromis niloticus* (Linnaeus). Aquaculture, 146:37–46.

MAB (Multi-Agency Brief) .2009. Fisheries and aquaculture in a changing climate. FAO, Rome, Italy, 6 pp.

Macfadyen, G., Nasr Allah, A., Kenaway, D., Ahmed, M.F.M., Hebicha, H., Diab, A., Hussein, S.M., Abouzied, R.M. & Naggar, G.El. 2011. Value-chain analysis of Egyptian aquaculture Project report 2011–54. The World Fish Center, Penang, Malaysia (84 pp)

Martinez, C.A.P., Cristina, C.S. & Ross, L.G. 1996. The effects of water temperature on food intake, growth and body composition of *Cichlasoma urophthalmus* (Guter) juveniles. Aquacult. Res. 27,455–461.

McElwee, K., Lewis, K., Nidiffer, M.& Buitrago, P. 2002. Studies on potential use of salinity to increase growth of Tilapia in Aquaculture in Malawi. 9th Ann. Tech. Rep. Pond Dynamics/Aquaculture CRSP, Oregon State Uni., Corvallis, Oregon.

Muir, J. and Allison, E., 2006. The threat to fisheries and aquaculture from climate change—World Fish Centre Policy Brief. Word Fish Centre, Penang, 8.

Noor, E. L., Deen, A.I.E. & Mona, S.Z., 2010. Impact of climatic changes (oxygen and temperature) on growth and survival rate of Nile tilapia (*Oreochromis niloticus*). Report and Opinion, 2, pp.192-195.

Palter, J. B., Marinov, I., Sarmiento, J. L., & Gruber, N. 2006. Large-scale, persistent nutrient fronts of the world. Handbook of Environmental Chemistry, 5, 1–12.

Pandit, N.P. & Nakamura, M. 2010. Effect of high temperature on survival, growth and feed conversion ratio of Nile tilapia, *oreochromis niloticus*. Our Nature, 8:219-224.

Paulty, D., Moreau, J. & Prein, M. 1988. A comparison of overall growth performance of tilapia in open waters and aquaculture. In the 2th Int. per. Of tilapia in open waters and aquaculture. Sym. On Tilapia in Aquacult. (Eds R. S. V.Pullin, T. Bhukaswan, K. Tanguthai, J.L. Maclean). PP 469-479.

Payne, A. I. & Collinson, R. I. 1983. A comparison of the biologicalcharacteristics of *Sarotherodon niloticus* (L) with those of *S. aureus* (Steindachner) and other tilapia of the delta and lower Nile. Aquacult. 30, 335–351.

Pullin, R. S. V. & McConnell, R. H. L. 1982. The biology and culture of tilapia. ICLARM, Philippines: 432 p.

Stanley, D. J. & Warne, A.G. 1993. Nile Delta: Recent geological evolutionand human impact. Sci, 260:628–634.

Soliman, N. F. 2017. Aquaculture in Egypt under changing climate. Alexandria Research Center for Adaptation to Climate Change (ARCA).

Suresh, A.V. & Lin, K. 1992. Tilapia culture in saline waters: a review. Aquacult., 106, 201-226.

Stanley, D.J., 1997. Mediterranean deltas: subsidence as a major control of relative sea-level rise. Bulletin de l'Institut océanographique. Monaco, n special 18, ClESM Science Series. 3, pp. 35–62

Yazdi, S.K. & Shakouri, B. 2010. The effects of climate change on aquaculture. Int. J. of environ. sci. & dev., 1(5)

Younis, A. M. & Nafea, E. M. 2012. Impact of Environmental Conditions on the Biodiversity of Mediterranean Sea Lagoon, Burullus Protected Area, Egypt. World Appl. Sci. J. 19 (10): 1423-1430.

World Fish Center. 2007a. Fisheries and aquaculture can provide solutions to cope with climate change. Issues Brief No.1701. World Fish Center, Penang, Malaysia, 4 pp.

World Fish Center .2007b. The threat to fisheries and aquaculture from climate change. Policy Brief. World Fish Center, Penang, Malaysia, 8 pp.

Zaid,S.M., Mamoun, M.M. & Mobark, N.M. .2014. Vulnerability assessment of the impact of sea level rise and land subsidence on north Nile Delta region. World Appl. Sci. J., 32 (3): 325-342.