CLIMATE CHANGE AND AGRICULTURE SECTOR IN EGYPT: EFFECTS AND ADAPTATION

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Abstract

The review aims to present an overview of the effects of climate change and the adaptation strategies to mitigate its impacts on the agriculture sector in Egypt. The main changes in the Egyptian climate would be an increase in temperature, evapotranspiration and sea level. Simulation studies show that reduce production, increase water demands of crops and lose agricultural lands are likely to be the main impacts of climate change on the Egyptian agriculture sector. The effects of climate change on aquaculture can be on natural resources that are necessary for aquaculture productions such as water availability, land, feed, seed, and energy inputs. However, different adaptation options involve that improving the technical water application efficiency and water conservation, as well as selection and breeding tolerant crops to heat, salinity and water use efficiency. Changing the time of sowing and management practices, encouraging farmers to adopt crops that high return with less water use and developing new crop models can consider other agricultural options for adapting climate change. The government should take extreme efforts to enhance the productivity of the agriculture sector and mitigate the risks of climate change impacts.

Keywords: climate change, Egyptian agriculture, Nile delta, vulnerability

Introduction

Egypt occupies the northeastern corner of Africa from 24° to 36° East Longitude and 22° to 31° North latitude. It is bordered in the east by the Red Sea and in the north by the Mediterranean Sea (Figure 1). The total land area of Egypt is 997,688 km^2, which can divide to three major geographical regions: the Nile Valley (Upper Egypt, Lower Egypt and the Nile Delta), the Eastern Desert, and the Western Desert (El-Ramady et al., 2013). Egypt has an arid climate with hot dry summers (May to October) and moderate winters (November to April). The average annual temperature is 14°C in winter and around 30°C in summer (El-Ramady et al., 2013). Rainfall in Egypt is minimal except in a narrow band along the northern coastal areas with 100–200 mm. The precipitation in the Delta is 40–60 mm, and in Middle Egypt less than 20 mm, while, in the south and the desert area there is no rain at all (Elmenoufy et al., 2017).

Most agricultural activities are located in Nile Valley (from the High Aswan Dam in the South to the Nile Delta in the North). The Nile Delta region is regarded as an important region because it contains over 60 % of the population and 63 % of the agricultural lands (Hereher, 2009). Agriculture is an essential sector in Egypt because it accounted for about 12 % of the gross domestic product and employed 29 % of the labour force (Tellioglu and Konandreas, 2017). Egypt has a unique agricultural system and all agricultural lands are irrigated with Nile River water which is stored in Lake Nasser behind the High Aswan Dam (Attia, 2009). Agriculture lands that used are around three million hectares (Table 1) (Kniivilä et al., 2013).

Table 1. Agricultural land in Egypt

Agro-climatic zone	Area (10^3 feddans)*	Percentage (%)
Western Desert	74.626	0.91
Along Suez Canal	157.819	1.92
Nile Valley	2795.001	33.97
Nile Delta	5200.330	63.20
Total	8227.776	100.00

**A feddan is the Egyptian unit. It is equal to (1.1 acres or 0.48 hectares), (Hereher, 2009)*

Agricultural year in Egypt has three seasons to grow plants. The first season is winter, which starts from October to December and plants will be harvested from April to June. Usually, this season includes the main crops such as wheat, barley, berseem (an Egyptian clover used for fodder), lentils, winter onions and winter vegetables. The second season is summer, which starts from March to June and plants will be harvested from August to November. This season includes crops cotton, rice, maize, sorghum, sesame, groundnuts, summer onions and summer vegetables. The third growing season is called 'Nili' and it is a delayed summer season. This season includes crops rice, sorghum, berseem and some vegetables (Kniivilä et al., 2013). Besides, there are perennial crops such as sugarcane in Upper and Middle Egypt and grapes, citrus, bananas, mangoes, olives and dates (Kniivilä et al., 2013).

Figure 1. Map of Egypt

Despite all controversies and debates, climate change is a reality with a broad range of adverse and dire implications on the earth. These implications will have direct or indirect effects on food production systems and global biodiversity. Egypt is regarded as one of the expected countries to be vulnerable to climate change impacts, and any attempt to assess the future of Egyptian agriculture must consider the complex interactions of climate change impacts and the growth of population (Figure 2). The task is made all the more difficult by the possibility of a significant changing trend expected to result from the climate change effects. The purpose of this review is to provide general information about the impacts of predicted climate change on the agriculture sector in Egypt. Also, a brief discussion about agricultural adaptation options may contribute to significant mitigation to the impacts of climate change.

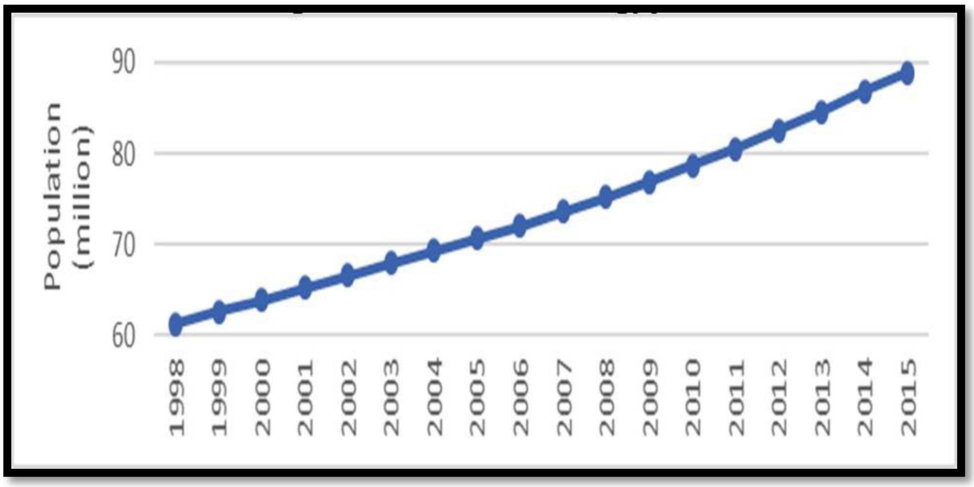

Figure 2. Total population in Egypt, (CAPMAS, 2016)

Historical and Predicted Changes in Egyptian Climate

Historical Changes in Egyptian Climate

Data collected by Cairo stations indicated that there is a general trend towards warming of the air temperature (Figure 3). These trends are in agreement with trends in the global mean surface temperature since the late 20th century. The most probable cause of the recent observed warming is a combination of internally and externally forced natural variability and sources (Hussein and Mohamed, 2016).

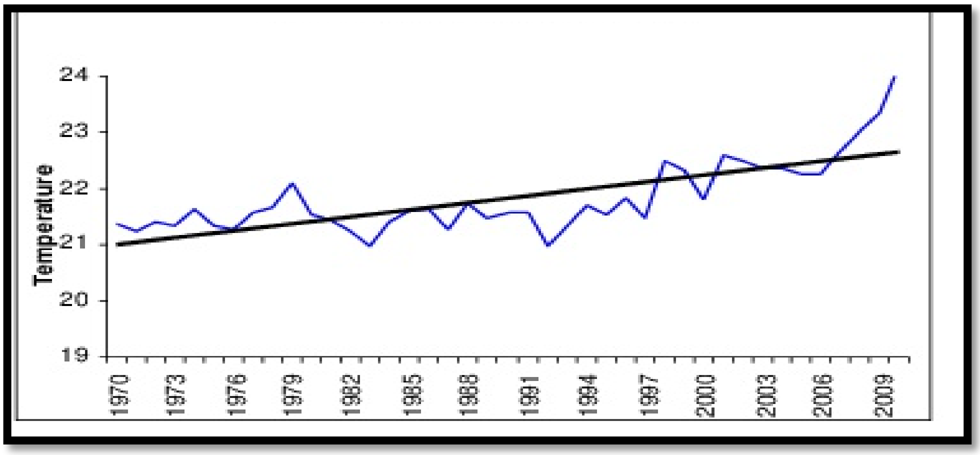

Figure 3. Mean annual temperature trends for Cairo/Egypt, (Hussein and Mohamed, 2016)

The historical rainfall data also showed an increase in the rainfall amount over whole Egypt during the period of 1980 – 2015, with the intensity of about 70mm (Figure 4). However, the rainfall is not considered a valuable water resource in Egypt because Egypt receives more than 95% of its various freshwater resources from outside its international borders. According to the historical and observed data, there is a decrease in the availability of total renewable freshwater per capita in Egypt (Figure 5). An ever-increasing population, climate change and upstream Nile projects are expected to intensify water scarcity in Egypt (Tellioglu and Konandreas, 2017).

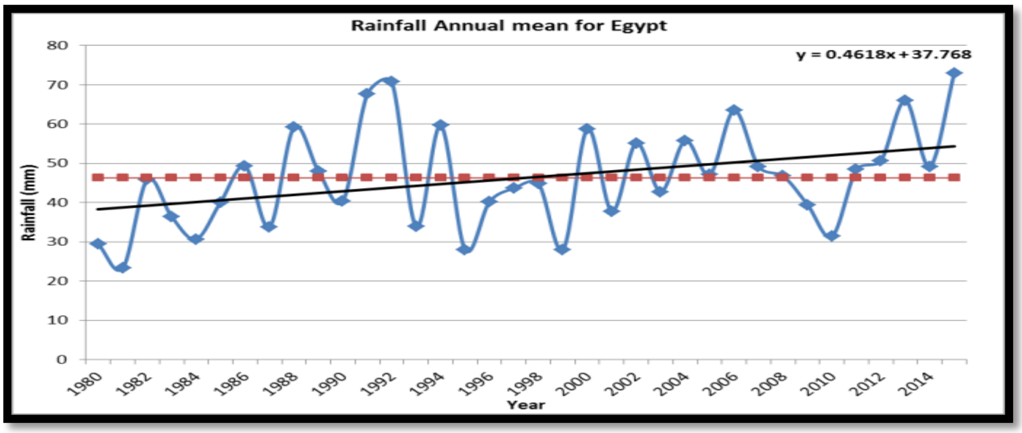

Figure 4: Rainfall trend analysis for whole Egypt, (Elmenoufy et al., 2017)

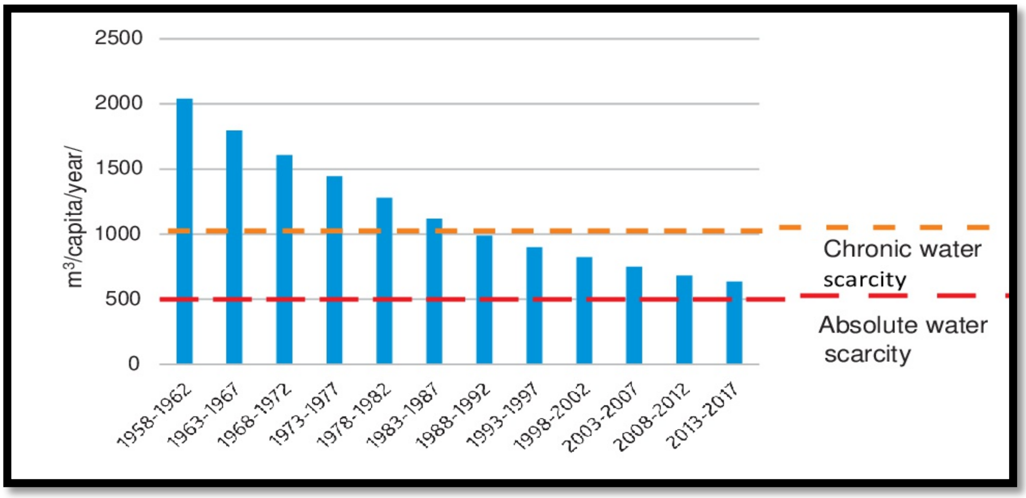

Figure 5. The availability of total renewable freshwater per capita, (Tellioglu and Konandreas, 2017)

The yearly variations of sea level showed there is an increasing trend in the sea level (Figure 6). This increase during the eight years is strongly affected by meteorology such as wind force and atmospheric pressure system (Hussein et al., 2010).

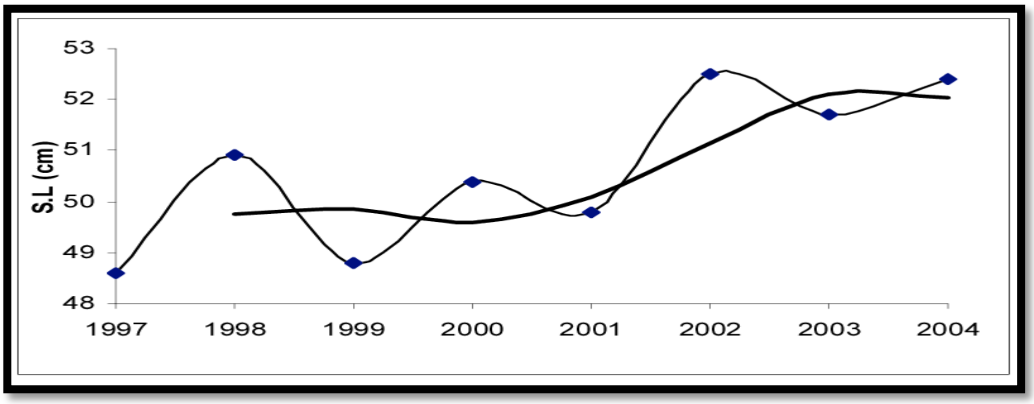

Figure 6. The mean annual sea-levels measured at Alexandria, (Hussein et al., 2010)

Predicted Changes in Egyptian Climate

In the African continent, the warming will be more massive in all seasons than the global annual mean warming. The annual rainfall will also decrease in Mediterranean Africa and the northern Sahara (IPCC, 2007). Most of the existing studies about climate change used GCM models such as (CGCM2, ECHAM4 and HadCM3) to predict climate change scenarios for Egypt (Attia, 2009). In these models, mean annual temperature, precipitation, and potential evapotranspiration presented for two of the SRES emission scenarios (A2 and B2) and three future periods to get a better understanding to the future changes of Egyptian climate (Attia, 2009).

Temperature

CGCM2, ECHAM4 and HadCM3 models indicated that temperature would continue to increase with the times especially in the southern and western regions of Egypt. The CGCM2 model predicts that some areas in southern regions will be warmer due to the increase in temperature by 5.85°C. However, by 2050s the three models predict less warming will be in the northern regions and more in the southern regions. The average increase in temperature will be about 2.5°C. By 2080s, the average increase in temperature will range between (2.3

and 4.2°C) across Egypt. Generally, these models predict less warming in the northern parts and more warming to the southern parts of Egypt (Table 2) (Attia, 2009).

Table 2. Spatially Averaged Temperature Anomalies (°C) over Egypt for three future periods

Model	A2			B2		
	2020s	2050s	2080s	2020s	2050s	2080s
CGCM2	1.38	2.70	4.19	1.32	2.14	2.91
ECHAM4	1.04	2.13	3.81	0.78	1.78	2.70
HadCM3	1.34	2.54	4.26	1.48	2.27	3.19

Source: (Attia, 2009)

Potential evapotranspiration

The three models showed there is a gradual increase in evapotranspiration with the time and this increase ranges between 5 % and 14 % by the 2080s depending on the model and scenario. It should note that evapotranspiration also depends on temperature; so, daily evapotranspiration will increase in the warmer climate especially in southern parts of Egypt, towards Aswan and western desert (Table 3).

Table 3. Spatially Averaged evapotranspiration Anomalies (%) over Egypt for three future periods

Model	A2			B2		
	2020s	2050s	2080s	2020s	2050s	2080s
CGCM2	6%	9%	14%	7%	8%	10%
ECHAM4	1%	4%	9%	1%	4%	5%
HadCM3	4%	7%	12%	4%	6%	8%

Source: (Attia, 2009)

Precipitation

In Egypt, the rainfall is low, irregular and unpredictable. The northern coast is the only region with considerable rainfall. These models also showed the northern coast is the only area with measurable precipitation in Egypt. In general, the three models showed similar precipitation patterns for all periods. The models predict that reductions in rainfall over the northern coast. The predicted reductions in coastal precipitation range between 10 % and 30

% depending on the model and scenario used (Attia, 2009). However, the rainfall is not a valuable water resource in Egypt because it is account 3.5% of its freshwater resources (El-Ramady et al., 2013).

Sea level rise

Many factors can cause sea level rise in the Mediterranean region, and these can be: climate change, local tectonics for subsidence and seasonal oceanographic process (Frihy, 2003). These three causes of sea level rise are applicable to northern areas of Egypt. Frihy (2003) reported that the global sea level rise by 2100 would be between 23 and 96 cm, with a mid-estimate of 55 cm. It is also predicted that global average sea levels may rise between 7 and 36 cm by the 2050s, between 9 and 69 cm by the 2080s and 30–80 cm by 2100. The majority of this change will occur due to the expansion of the warmer ocean water (Roaf et al., 2005). Nicholls and Leatherman (1995) estimated that one meter global sea level rise by 2100 would give rise about 0.37 meter sea level rise at the Nile delta. It is reported that the average sea level rise by 2100 at the Nile delta margin and Alexandria in Egypt would be 26 cm and 10 cm respectively (Milliman et al., 1989). El-Shaer (1997) also estimated that sea level rise in the northern Delta would be ranged between 20 to 40 cm by the next 50 years. El-Raey (2010) estimated that even with a sea level rise of only 50 cm, approximately 30% of the cities of Alexandria and Port Said would be damaged.

Effects of Climate Change

Effects of Climate Change on Agriculture

The Egyptian agriculture sector is more likely to be vulnerable to climate change. Changes in the Egyptian climate such as increasing temperatures can directly affect plant production through heat stress or indirectly through higher plant water demand and increasing transpiration (Eid et al., 2007). High temperatures can also cause a decrease in crops yield due to a shortening of the grain-filling period; and affecting other physiological processes (Attia, 2009). According to Eid et al. (2007), climate change could reduce national production of all crops in Egypt, and this reduction ranges from 11 % for rice, 28 % for soybeans, 15 % for wheat and 19 % for maize by 2050. Also, climate change could increase crops demand water by 6 to 16 % by 2100. At the Upper Egypt site, the yield of all crops can be reduced by about 20 % with the warmer scenario (Eid et al., 2007).

Egyptian agriculture sector depends on the Nile River as the primary water source. Thus, sensitive crops are likely to suffer from drought stress and salt stress because of the limitation in water. High temperatures are likely to increase evaporation rates and crop water requirements; so, this can directly decrease crop water use efficiency and increase irrigation demands of crops (Ludwig, 2006). Irrigation efficiency for Egypt is low due to inefficient flood irrigation practices which are used by Egyptian farmers (Attaher et al., 2010). Increase irrigation will lead to elevate water-table and soil salinization, as well as decrease crop yields because it impedes aeration and leaches nutrients (El-Shaer, 1997).

High evaporation rates may also accelerate soil salinization by accelerating the transport of harmful salts to the soil surface, and as a result of that significant area under poor drainage systems will become unsuitable for agriculture (El-Shaer, 1997). Degradation of water resources, inefficient flood irrigation practices and poor water management are already ill-drained lands at the lower Nile Delta which are already subjected by the water-table rise, and saline-water intrusion (El Raey, 2010). Thus, under these conditions more agricultural lands will indeed become unsuitable for agriculture in the future.

Egypt is one of the most countries that may face risks from the effects of rising sea level in the future (El Raey, 2010). Thus, rising sea level is another change in the Egyptian climate which may affect agriculture sector by losing agricultural lands (Mervat and Yasser, 2016).

The low-lying lands along the northern Delta are the most areas that may be affected by sea level rise and approximately 12.5 % of the existing agricultural land in the Delta may be lost by rising sea level one meter (Elsharkawy et al., 2009). Rising sea level will accelerate the intrusion of saline water into surface bodies of water, and this may increase the tendency toward water logging and salinization of low-lying lands; results in significant areas will become unusable for agriculture (Elsharkawy et al., 2009).

Changing the climate in the future may also affect livestock production in Egypt through harmful heat stress, the availability of fodder and new animal diseases (Sadek et al., 2015). The availability of fodder will decrease due to climate change impacts on crops production, reducing agricultural lands and higher competition for water resources between fodder and cereal crops (Elsharkawy et al., 2009).

Effects of Climate Change on Aquaculture

The effects of climate change on aquaculture are more complicated than those on terrestrial agriculture owing to the much wider variety of species produced (Brander, 2007). Aquaculture in Egypt is currently regarded as the primary source of fish supply accounting for almost 78.8% (1.56 million tons) of the total fish production of the country (Soliman, 2017) (Figure 7).

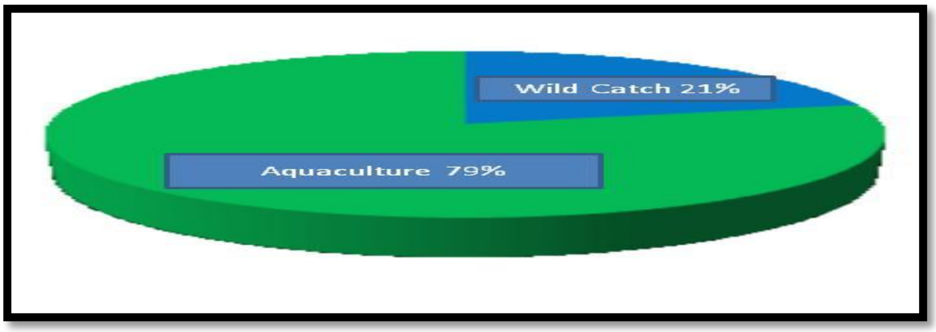

Figure 7. Total annual fisheries and aquaculture production in Egypt, (Soliman, 2017)

Effects of climatic change on aquaculture can be either direct or indirect impacts. It can affect natural resources such as water, land, feed, seed, and energy inputs (Soliman, 2017). Climate change can decrease the water availability in the major rivers and streams; changing in precipitation can also cause a spectrum of changes in water availability ranging from droughts to floods, and this can reduce water quality (IPCC, 2007), leading to significant effects in fish spawning, migration and seed availability. It can also lead to an increase in drought periods, which results in less water retention time in water bodies (Goswani et al., 2006).

Rising sea level will destroy weak parts of the sand belt, which is necessary to protect lakes and the low-lying reclaimed lands and this will have severe effects on fish population and species in these lakes because one-third of Egypt's fish catches are made in these lakes (Elsharkawy et al., 2009). Sea level rise is also expected to change the water quality which caused the fish distribution to move northwards and go into deeper waters (Elsharkawy et al., 2009). Inland freshwater aquaculture practices will threaten by rising sea levels through the movement of saline water further upstream in rivers and salinization of groundwater supplies (IPCC, 2007).

The increase in global warming and temperature will affect on pond aquaculture through solar radiation, air temperature, wind velocity, and water turbidity results to increase in vaporization, cloud cover and subsequent reduction in solar radiation reaching the ponds. As a result, the rate of algal blooms and red tides on the surfaces of water will increase; and can affect on water quality and survival of fish in the ponds (Soliman, 2017). Increasing temperatures can reduce the level of dissolved oxygen and increase metabolic rates of fish, which leads to the decline in production and increase in feed requirements while also increasing the risk of spread of disease and fish deaths (FAO, 2008).

One of the biggest challenges facing the future aquaculture industry is access to proteins, minerals and fatty acids. More than 85% of the world fish stocks are already fully exploited, thus increasing the use of wild-caught fish as ingredients in the aquaculture fish feed is no longer possible (Pile and Barlow, 2002). Loss of productivity from the capture fisheries oils can cause fewer raw materials availability for fish meal and fish oil industry. The changes in the sea circulation patterns can influence fish meal and fish oil supplies (Pile and Barlow, 2002). The ingredients in the feed that fed to fish have already replaced by plant sources. Climate changes could also reduce the agricultural production of soybean, corn and other ingredients that today's fish feeds rely on them. The use of soybean meals and corn meal for the production of biofuel instead of the usual feed formulation poses both economic and social challenges, especially in the aquaculture sub-sector. Therefore, the industry has to search for new and sustainable resources to produce cultured fish, such as algae. The industry is in need of innovative solutions to solve this urgent challenge.

Adaptation to Climate Change

Agriculture Adaptation Options to Climate Change

The future strategies to adapt the impacts of climate change can involve water and land management. First agricultural adaptation can be the improvement of water use efficiency and technical application efficiency (Tellioglu and Konandreas, 2017). This includes maintaining the whole system of supplying water. So, water should be available on demand and be delivered in proper quantities in exact time. The government should provide farmers by guidance about optimal crop selection, irrigation and fertilization to enhance the adoption of water preservation; as well as training programs to farmers who need to modernize their irrigation systems (El-Shaer, 1997). The government should also establish strong rules to avoid excessive water such as establishing water meters to measure the amount of water that used, and water pricing especially when using water more than which is supposed to use

(Attia, 2009). Moreover, modern methods of irrigation should be adopted, and these methods should be based on the high frequency and low volume application of water (Tellioglu and Konandreas, 2017).

On the other hand, adaptations of land should include the management of low-lying lands on the northern border of the Delta. It is clear that when sea level rise will affect agricultural lands in this area (submergence and salinization), and produce the highest damage. One of the adaptation options for these lands is that some lands need to be retired from agricultural practice. As a result, the amount of water which is used to irrigate these lands will be available and can be used to irrigate new lands outside the Nile Valley and the Delta (Eid et al., 2007).

Breeding and selection crops can be another adaptation option; which can help to find crops that tolerant to heat and salinity, efficient in using water, and suitable for different production methods (Attia, 2009). Thus, these crops can minimize water use and maximize the yield. Moreover, extensive efforts should be made by the government to encourage farmers for adopting crops that high return and water conserving instead of growing crops that characterized by water consuming such as rice and sugarcane (Attia, 2009).

The government should put the policy of crops which can give farmers the possibility of adapting the suitable crops in each area (Eid et al., 2007). Changing time of sowing and management practices can also be another option to adapt the impacts of climate change and reduce yield losses in the warmer climate (Eid et al., 2007). Alternative cultivation methods such as hydroponics and the vertical farm systems should be considered to mitigate the damaging effects of climate change on Egyptian agriculture (Kalantari et al., 2017).

It will be essential for Egypt to develop and test new crop models which can help to adapt the impact of climate change. These models can be used to know appropriate crops, varieties, and management strategies for maximizing production and minimizing risks of changing the climate. Furthermore, the adaptation for livestock should be by improving the low productivity, and this can be achieved by developing new breeding and feeding programs (Sadek et al., 2015).

Aquaculture Adaptation Options to Climate Change

The first adaptation step is that developing new strains of aquaculture species that are tolerant to lower water quality and higher levels of salinity to survive with changes driven by climate change. This is a relevant issue for many countries; where freshwater will be a limiting factor by climate change, as seems to be the case for Egypt (FAO, 2008). The development of strains of farmed aquatic organisms with improved salinity tolerance has already been practised (Abu Hena et al., 2005); while, the development of strains tolerant of higher or lower temperatures, and other environmental variables impacted by climate change, need to be studied as solutions for adaptation to climate change**.** Using non-native aquatic species such as euryhaline and estuarine species as well as species tolerant to warmer water also need to be proposed as a means of adaptation to climate change (Harvey et al., 2017).

Recirculation aquaculture systems can be a promising aquaculture method of fish farming that can be used in Egypt aquaculture farming. In recirculation aquaculture systems, fish is cultured under entirely controlled environmental conditions independent of their natural environment. Recirculation aquaculture systems are land-based fish production systems in which water from the rearing tanks is reused after mechanical and biological purification to reduce water and energy consumption as well as reduce discharged water to the environment (Schneider et al., 2010). Moving water-based aquaculture especially cages and pens for finfish onto land and employing recirculating aquaculture system technologies are being proposed like means of reducing exposure to climatic changes. In such systems, water quality, temperature, dissolved oxygen, salinity and pH, can be controlled to meet the biological and environmental requirements of cultured species. Recirculation aquaculture systems, however, remain relatively expensive regarding both capital and operational costs and require high levels of technical expertise (Murray et al., 2014).

Aquaponic systems which refer to the production of fish and plants in an integrated system can be another application to produce food in areas where freshwater is limited (Somerville et al., 2014). Aquaponic systems can be regarded as a particular type of recirculation aquaculture systems, and thus shares many of the same attributes. It is also worth pointing out that neither system is likely to be immune from extreme climate events in small areas developing states or coastal areas vulnerable to such events without further development (Somerville et al., 2014). The integrated aquaculture with agriculture through the use of groundwater and effluent discharge should be developed to mitigate the limitations of freshwater and brackish water (Soliman, 2017).

On the farm level, well-designed and well-built ponds can also help to mitigate some of the effects of climate change. For example, deeper ponds provide a thermal refuge and higher dissolved oxygen reserves for fish, while raised pond embankments can help prevent fish escapes and serve as water storage during droughts (Harvey et al., 2017). Converting flow-through ponds and raceways into more water-efficient techniques is also desirable, as is reducing seepage through the use of pond liners (Harvey et al., 2017).

Recent advances in remote sensing platforms (e.g., drones and satellite constellations) are now being integrated with information and communication technologies; examples include early warning information systems (e.g., weather forecasts and early detection) and communication of risks using mobile communication devices (e.g., smartphones and tablets), cloud-based data systems and useful simulations. Stronger materials and better system designs coupled with the development and implementation of proper technical guidelines can play a role in reducing vulnerability to climate change in the marine aquaculture subsector of the country (Soliman, 2017).

Reducing the amount of imported fishmeal and feed ingredients through the usage of local ones is another important thrust area to be taken care. Research on the utilization of agricultural meals and oils to replace the use of fish meals and fish oil is a significant subject of aquaculture research and development. Furthermore, the focus should be addressed toward reducing the impact of aquaculture industry on climate change and fossil fuels depletion by investigating how to reduce energy utilization through energy conservation, proper energy management in feed manufacturing, and introduce possible renewable energy approaches in aquaculture industry (Soliman, 2017).

Conclusion

The Egyptian agriculture sector is more likely to be vulnerable to climate change because it depended on the Nile River as the primary water source and based on traditional irrigation methods. The main changes in the Egyptian climate are increase temperature, decrease precipitation, increase evapotranspiration and rising sea level. Nile Valley and the Delta regions will be more likely to have potential impacts of these changes.

For the agriculture sector, climate change studies predict a reduction in the productivity of major crops in Egypt because of heat stress, water stress, and increase salinity. In addition, most productive arable land in the Nile Delta will be lost because of sea level rise and saltwater intrusion. Increase temperatures and evapotranspiration are likely to increase crop water requirements and increase irrigation demands of the agriculture sector. The effects of climatic change on aquaculture could be either direct or indirect impacts. It can affect natural resources that are necessary for aquaculture production. These resources include water, land, feed, seed, and energy inputs.

Several adaptation options can help the Egyptian agriculture sector to adapt climate change impacts such as improving the technical water application efficiency and saving water by establishing water metering, water pricing and using modern methods of irrigation. Another adaptation option involves that some lands in Nile Valley and the Delta need to be retired from agricultural practice. The selection and breeding tolerant crops to heat and salinity and water use efficiency can be considered another adaptation option. Furthermore, developing and testing new crop models, changing the time of sowing, encouraging farmers to adopt crops that high return and less water use can consider other agricultural options to adapt to climate change impacts. On the other hand, aquaculture adaptation involves the development of new strains which are tolerant to salinity, temperature and other environmental conditions. Increase the efficient use of land, water, food, seed and energy through intensification systems which use less land and freshwater. The utilization of alternative renewable energy systems and feed sources can be one of the choices for adaption to climate change in the aquaculture sector. Thus, it recommended that enormously efforts should be taken by the Egyptian government to enhance the productivity of the agriculture sector and minimize the risks which associated with climate change.

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