Challenges and Issues in Water, Climate Change, and Food Security in Egypt

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Abstract Climate change is a real and growing problem and a complex phenomenon that alters the whole environment in which humans live. The impacts of climate change on freshwater systems and their management are mainly due to the observed and projected increases in temperature and precipitation variability. Developing countries, such as Egypt, are the most threatened by drastic impact of climatic changes on agriculture and food security. Several studies reported that Egypt is one of the most vulnerable countries to the potential impacts and risks of climate change, even though it produces less than 1% of the world total emissions of GHG, with a vulnerability of all sectors of development and a low resilience of the majority of stakeholders. One of the main challenges facing water management in Egypt is the expected impacts of climate change on the Nile flows and the different demands of the water sector. This in turn will directly affect the agricultural sector which is a key sector for the socio-economic development in Egypt, and plays a significant role in the Egyptian national economy. Climate change, population growth, and economic development will likely affect the future availability of water resources for agriculture in Egypt. The demand and supply of water for irrigation is expected to be influenced not only by changing hydrological regimes (through changes in precipitation, potential and actual evaporation, and runoff at the watershed and river basin scales), but also by concomitant increases in future competition for water due to population and economic growth. Egypt is therefore in a situation where it must plan for several different future scenarios, mostly negative, if climate change results in increased temperatures and decreased precipitation levels. Egypt's negative environmental consequences of climate warming represent rise of sea level, water scarcity, agriculture and food insufficiency, and pressures on human health and national economy. Even in the absence of any negative effects of

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climate change, Egypt is dealing with a steady growth in population, increased urbanization, and riparian neighbors with their own plans for securing future water needs. All of these will require Egypt to put water resource planning as a top national security priority. The future impact of the above negative environmental consequences of climate change scenarios, the adaptation measures, and mitigation polices are the main points of concern in this chapter.

Keywords Climate change, Food security, Freshwater in Egypt, Population increase, Sustainable planning

Contents

1 Introduction

Climate change is a real and growing problem for the world [1]. It is a complex phenomenon that alters the whole environment in which humans live. A change in climate state can be identified by detecting changes in the mean and/or the variability of its properties, and that continues for an extended period of time, typically decades or longer [2]. Changes in the atmospheric profusion of greenhouse gases and aerosols, in both solar radiation and in land surface properties alter the energy balance of the climate system. These progressions are communicated regarding radiative forcing, which is utilized to think about how a scope of human and natural factors drives cooling or warming influences on global climate. Since the IPCC third assessment report, new records and related modelling of greenhouse gases, solar activity, land surface characteristics, and some aspects of aerosols have increased the performance of the quantitative estimation of radiative forcing [3]. Global climate change will have profound implications for the quality of life of hundreds of millions of people [4]. In the last few years, climate change has become one of the most heavily researched subjects in science. There is no doubt about the increase in mean global surface temperature by $0.6 \pm 0.2°C$ over the twentieth century [5, 6] is a consequence of climate variability as well as of enhanced emission of greenhouse gases due to human activities [7]. From the recent Intergovernmental Panel on Climate Change fourth assessment report [8], little doubt remains that the climate system has warmed in recent decade [9].

Developing countries – such as Egypt – are the most threatened by drastic impact of climatic changes on agriculture and food security, as their economic base is linked to agriculture and a large proportion of their populations depends directly on agriculture and agriculture related business. The first and second Egyptian communications reports [10, 11], which were prepared by the Egyptian Environmental Affairs Agency (EEAA), reported that Egypt is one of the most vulnerable countries to the potential impacts and risks of climate change, with a vulnerability of all sectors of development and a low resilience of the majority of stakeholders.

Climate change is likely to increase the stress on currently stressed resources, especially in the developing world [12]. Studies have shown that most systems are sensitive to both the magnitude and the rate of climate change [13]. However, the vulnerability of a system to the expected change depends on economic strength and existing infrastructure as well as overall country resilience to cope with different risks. Most developing countries, such as Egypt, are generally more vulnerable and less able to adapt [14, 15]. In order to reduce the expected impacts of climate change, it is necessary to both reduce (mitigate) emissions of heat-trapping pollution and build resilience (adapt) to the impacts of climate change. However, even with strong programs to reduce greenhouse gas emissions (which proved to be a very difficult process), the effects of climate change will persist due to the longevity of certain greenhouse gases in the atmosphere and the absorption of heat by the oceans. Therefore, adaptation has a major role to play in reducing the impacts of climate change on people, businesses, and society.

Several sectors such as water resources, agricultural and food security, coastal, tourism, and health are highly vulnerable sectors with serious socioeconomic implications. Egypt is considered as limited water resources country and the available water for irrigation varies due to changes in freshwater availability and to competition among various water users [16, 17]. Main challenges facing water managers regarding water issues in Egypt, are climate change impacts on the Nile flow and the increasing demands of the water sector. This in turn will directly affect the agricultural sector, which is a key sector for the socio-economic development in Egypt, and plays a significant role in the Egyptian national economy [18]. In Egypt, agriculture consumes the biggest amount of the available water with a sharing exceeds 85% of the total demand for water. In the Egyptian economy, the agricultural sector contributes about 20% to Gross Domestic Product (GDP) and provides about 40% of total employment [16]. In view of the expected increase in demand from other sectors, such as municipal and industrial water supply, the development of Egypt's economy strongly depends on its ability to conserve and manage its water resources. Climate change, furthermore, may cause salinity challenges, where high extraction levels and declining inflows provide less dilution. Saline environments tend to hinder agricultural production by lowering crop yields, often quite substantially.

Climate change, population growth, and economic development will likely affect the future availability of water resources for agriculture in Egypt. The demand and supply of water for irrigation is expected to be influenced not only by changing hydrological regimes (through changes in precipitation, potential and actual evaporation, and runoff at the watershed and river basin scales), but also by concomitant increases in future competition for water due to population and economic growth [19]. So, an integrated study is essential to examine cropping systems, crop water demand, and water availability for irrigation under changing climate, population growth, and economic development conditions. This study should include an assessment of adaptation strategies for the water resources and agriculture sectors to achieve resilient agricultural production, which is a necessary element to achieve food security.

2 Country Background

Egypt is located on the northeastern side of Africa with an area of 1,001,449 km^2, has coastlines on the Mediterranean Sea and the Red Sea (Fig. 1). Geological history of Egypt has produced four major physical regions, as follows: Nile valley and Nile delta about 4% of the total; Eastern desert (from the Nile Valley all the way to the Red Sea coast) about 22%; Western desert (from the Nile west to the Libyan border) about 68%, and the Sinai Peninsula with about 6%. Egypt is located

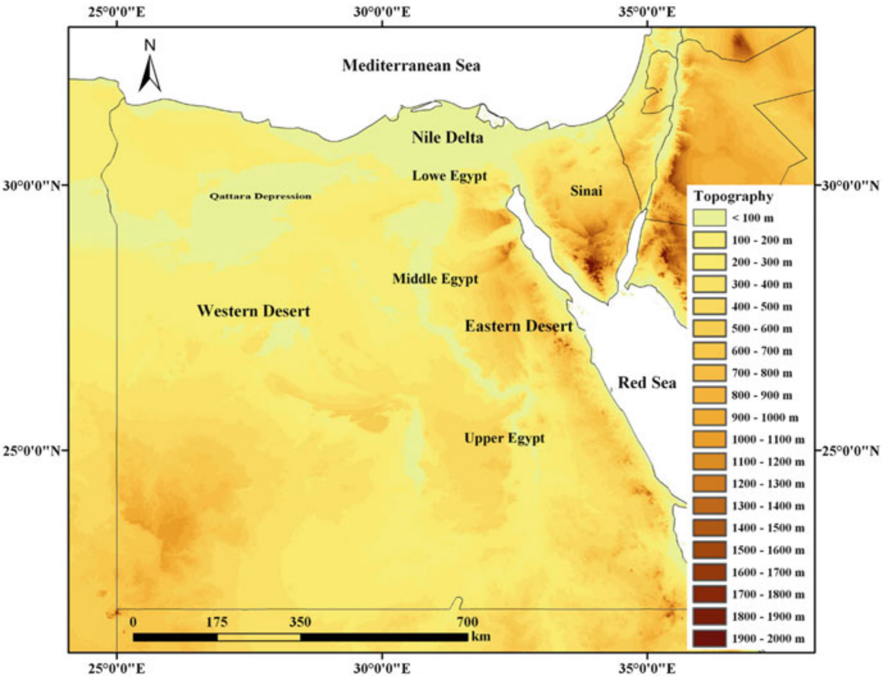

Fig. 1 Egypt's topography [20]

in a semi-arid zone and its climate is characterized by hot dry summers, moderate winters with very little rainfall. Egypt relies on the Nile River as its main resource of freshwater to meet the requirements of increasing demands in agricultural, industrial, and domestic sectors. With about 95% of the population (84 million in 2012) living along the Nile Delta, any changes in water supply due to climate change, with the certainty of increased demographic pressure, would pose a serious risk to the whole country. In addition, sea level rise (SLR) threatens settlements and agriculture in the Nile Delta as well as in the Red Sea. Besides, higher temperatures alone would evaporate more water, increase the need for water supplies, create more heat stress, exacerbate already high levels of air pollution, and may drive away tourists. The delta has been formed through annual supply of nutrients and sediment deposits for thousands of years by the Nile, forming a topsoil of about 20 m in depth over the original shallow sea bed. Intensive farming has been going on in the delta for 5,000–6,000 years.

With the construction of the High Aswan Dam, the delta no longer receives nutrients and sediments, and heavy fertilization is used instead. In addition to that, the outer edges of the delta are eroding in some places as much as 90–100 m a year. Besides, some coastal lagoons have seen increasing salinity levels. Most of the Nile delta is used for agriculture, where perennial irrigation allows two or three crops a year. Industry is another important activity distributed over the whole area. Water is provided to the intensive agriculture in the Delta across a complicated system of irrigation canals. The irrigation and drainage system in Egypt is complicated, moreover a large portion of the agricultural drainage water is reused to supplement shortage of the freshwater requirements especially in the low reaches of the canals. Water quality in the irrigation and drainage canals is getting worse as we move downstream due to the intensive pollution load from the heavy agricultural activities and high population density.

3 Present Status of Water Resources

Egypt, like any other country lies in arid region, faces the serious challenge of minimizing the gap between its limited water resources and the increasing water demand. Egypt considers the River Nile its “main artery of life,” being the exclusive source that covers nearly about 95% of the requirements [21, 22]. The other riparian countries depend on the Nile water in various ways according to each country’s precipitation and water use patterns. These riparian countries, compared with Egypt, are less vulnerable to fluctuations of the Nile flows and being mostly humid and/or less populated than Egypt [23, 24]. The main water management issues in Egypt arise mainly from quality of supply and demand management responses to water shortage. Although the fact that decreasing Nile water availability with respect to increasing in both populations and requirements for development is an alarming issue, Egypt has not yet reached the situation of a crisis. In Egypt, water resources are limited to the Nile River, rainfall and flash floods, deep groundwater, and potential desalination of sea and brackish water. Each of these resources has its limitation of usage, whether these limitations are related to quantity, quality, space, time, or exploitation cost. Table 1 and Fig. 2 present the

Table 1 Egypt water balance in 2015 – supply versus demand [27]

Water balance for the current situation			
Uses (km^3/year)	Sector	Quantity (km^3/year)	Water resources
9.50	Municipal	Traditional water resources	
4.00	Industry	55.50	Nile River
64.00	Agriculture	2.00	Deep ground water
3.20	Evaporation losses, Navigation and environment needs	1.30	Rains and torrents
		0.20	Desalination
80.70	Total	59.00	Sub-total
Industry water uses don't include electrical station cooling		Untraditional water resources (reuse)	
		6.20	Shallow ground water
Industry uses 2.0 km^3 directly from the Nile and canals network and groundwater		15.50	Drainage water reuse
		21.70	Sub-total
80.70	Total uses	80.70	Total water available

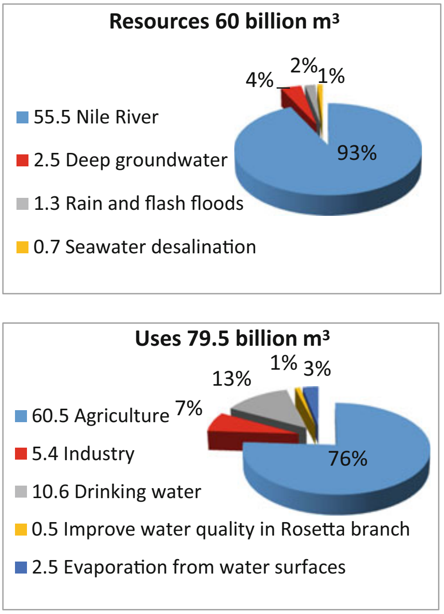

Fig. 2 Water resources of Egypt

water demand in Egypt in 2015, illustrating how these water requirements were satisfied through process of non-conventional water resources, including water savings and possibilities of reuse. The share of Nile water in Egypt is 55.5 billion m^3 per year, representing 93% of the country's available traditional water resources; desalinated seawater comprises only 0.70%. Egypt is a very arid country and the rainfall declines very rapidly from coastal to inland areas and occurs only in winter in the form of scattered showers, therefore deep groundwater plus rain and flash floods is 3.3 billion m^3 per year (6% of available water resources). Non-conventional water resources have been considered for a long time in Egypt, and the drainage water reuse in 2015 was 21.7 billion m^3 per year. It can be clearly seen in Table 1 that the Nile basin inside Egypt is a closed system and inputs (resources) and outputs (demands) are balanced. Managing water resources becomes a more complex issue because it is influenced by the potential impacts of climate change. Several studies predict that climate change will intensify and accelerate the hydrological cycle, which will result in more water and wetter weather being available in some parts of the world and less water and dry weather being available in other parts of the world. Weather patterns are predicted to be more extreme. Those regions adversely affected are expected to receive drought and/or possible flood events. Egypt is vulnerable since the Nile waters are highly sensitive to impacts of climate change on trends of both rainfall and temperature. Some studies showed that temperature changes affect rainfall, therefore it could be expected that climate change will take the form of changes in levels of rainfall and that the resulting effect on the Nile river flow will be from moderate to extreme.

4 Population

Only small communities are spreading throughout the desert areas of Egypt and these communities are clustered around oases and historic trade and transportation routes. The Egyptian government has attempted to urge migration to newly irrigated land reclaimed from the desert [25]. However, as people are moving to the cities in search of employment and a higher standard of living the proportion of the population living in rural areas has continued to decrease. Egypt is considered as the most populous country in the Arab world and the third most populous country within Africa. Most of the country is desert, therefore nearly 97% of the country's people is concentrated in a narrow strip of fertile land along the Nile River, which represents only about 5% of Egypt's land area [26]. These densely populated areas in Egypt, which occupy about 4% of the country's area, are among the world's most densely populated regions where the population density is about 1,600 inhabitants per km^2 [27]. As shown in Fig. 3, Egypt's population was about 24 million in 1955, swelling to 35 million in 1970 and reaching 93 million in 2015. Egypt's rapid population growth, 49% between 1995 and 2016 from 62 million to 93 million (Fig. 3), puts pressure on the country's natural resources, economy, and environment and is threatening the health care and well-being of its Egyptian people. The

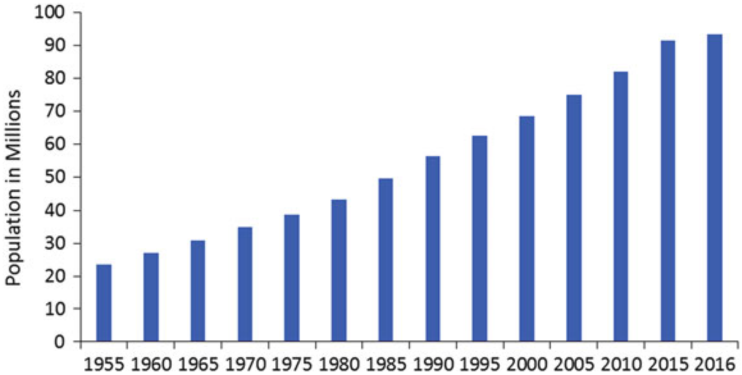

Fig. 3 Egypt's population grew by 49% between 1955 and 2016

Central Agency for Public Mobilization and Statistics (CAPMAS) indicated, in its report titled "Water Resources and Means to Rationalize their Use," that the per capita annual share of water decreased from a water excess of about 2,500 m^3 in 1947 to a sufficient level of 1,900 m^3 in 1970 then water scarcity with 660 m^3 in 2013. By 2025, an Egyptian's share in annual water will drop to 582 m^3 as forecasted by CAPMAS. The United Nations declared that a population where per capita annual water resources are below 1,000 m^3 faces water scarcity and at a level of 500 m^3 the country approaches the absolute water scarcity. With the current population growth of about 2.6% a year, the Egyptian government faces several challenges in providing for the basic requirements of its citizens, including jobs, suitable housing, sanitation, health care, and education. Moreover, Egypt is faced with shortages of freshwater resources and energy, which are necessary for sustaining health care, food production, food security, and economic development.

5 Climate and Climate Changes

The word climate refers to the representative conditions of the lower surface atmosphere of the earth at a specific location. The variables, which are mainly used by meteorologists to measure daily weather phenomena are air temperature, precipitation, atmospheric pressure and humidity, wind, and sunshine and cloud cover. Climate changes can refer to long-term changes in average weather conditions, or all changes in the climate system, including the drivers of change, or the changes themselves and their effects, or only human-induced changes in the climate system. Various evidence from records of the climate system and global climate model results have led to the conclusion that human activities are contributing to a warming of the earth's atmosphere [1].

5.1 Climate Changes and Its Impact on Water Resources of Egypt

The hydrologic system, as an integrated part of the earth's geophysical system, both affects and is affected by the climatic condition [28]. Changes in temperature affect the rates of evapotranspiration, characteristics of cloud, soil moisture, storm intensity, and both snowfall and snowmelt regimes. At the same time, changes in precipitation have an effect on the timing and magnitude of floods and droughts, shift runoff regimes, and alter groundwater recharge rates [29]. Exact information about precipitation amounts reaching the land surface is of special importance for freshwater assessment and management related to agriculture land use, hydrology and risk reduction of flood and drought [30]. There are likely more regions in the world where the frequency of heavy precipitation events has increased than where it has decreased (Fig. 4).

The Nile River basin has a drainage area more than 3 million km^2 and about 73% of the drainage basin located in Sudan and Egypt with net consumption of water (Fig. 5). The Nile River basin crosses six hydroclimatic zones, namely: (1) lake plateau territory (Burundi, Rwanda, Tanzania, Kenya, and Uganda); (2) Sudd freshwater swamp (southern Sudan); (3) Ethiopian highlands; (4) Sudan plains (central Sudan); (5) northern Sudan and Egypt (from the Atbara and Nile Rivers confluence to Cairo), and (6) Mediterranean zone (coastal region with no measurable rainfall) [33]. In the Nile River basin, the ratio of the producing watershed to consuming watershed is low. Ethiopia, with about 12% of the drainage basin, generates about 86% of the river annual-round flow, while the remaining 14%

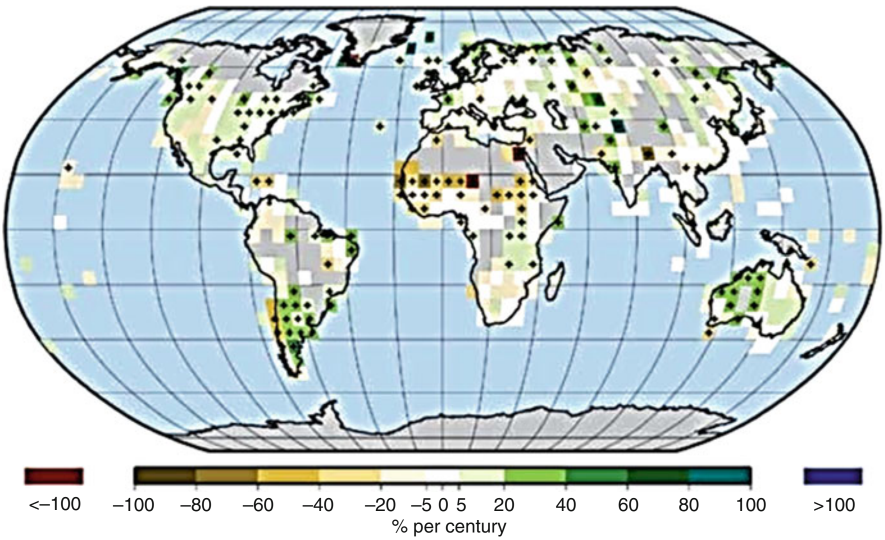

Fig. 4 Observed change in annual precipitation over land, 1901–2005 [31]

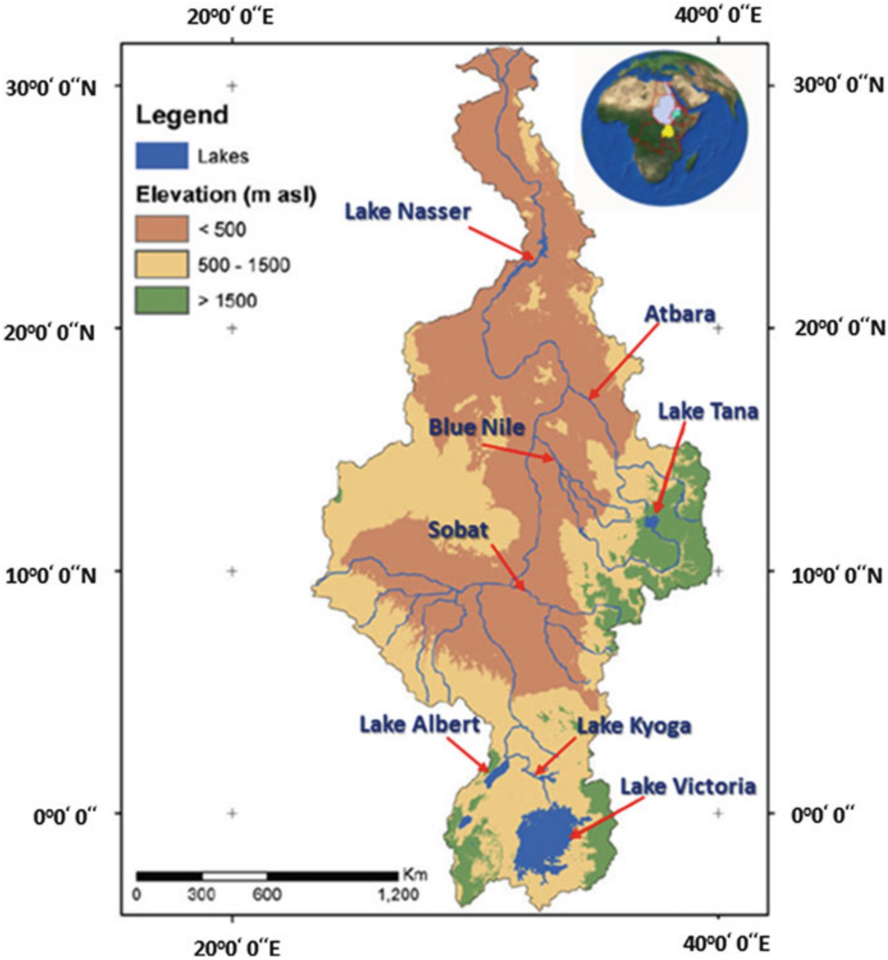

Fig. 5 Nile River basin. After [32]

comes from the White Nile, which has a larger drainage basin. The Ethiopian highlands generate a discharge of 87% of the total Nile flow at the Aswan dam in Egypt. The Blue Nile River basin, which has drainage area of 324,530 km^2, is the main source of the Nile River and contributes about 60–69% of the main Nile discharge.

A large number of studies have been carried out in the Nile River basin to investigate historical trends in rainfall. Several studies have also been conducted, using climatic model output as the input of hydrological models, in order to project future hydrological regimes [34]. Studies over the Nile basin provide conflicting evidence regarding the existence of any long-term trend in the historical rainfall. While there is generally insignificant change in the annual rainfall series in most of the Nile sub-basins, the trend appears to be decreasing seasonality in some key watersheds of the upper Nile in Ethiopia such as the southern Blue Nile and Baro-Akobo. The magnitudes (and sometimes the signs) of the trends in rainfall varied from season to season, and also from one station (or subregion) to another. Some studies also supported the idea that, except for Lake Victoria, all sub-basins of Nile experienced slightly-to-strongly decreasing trends in precipitation. The three catchments of Bahr el Ghazal, Sobat, and Central Sudan recorded significant drops in annual precipitation, whereas the observed changes in many other catchments were not significant. Regarding the future projections of rainfall in the Nile river basin, a large number of studies have been carried out to project future regimes of rainfall. Results of several studies showed that, in contrast, the rainfall changes did not suggest that there was any consensus among general circulation models (GCMs) regarding rainfall trends for the region. Most of ensembles examined in the literature did not show any statistically significant changes in median. Several studies indicated that there was no consensus among the GCMs about the sign of the rainfall change in the Nile River basin [35]. Thus, there are large uncertainties in predicting climatic change impact on rainfall trends over the Nile basin and their impacts on its flows. By nature, the future is uncertain and this is partly handled via emissions' scenarios that capture different visions of how the world will develop in the future in terms of population, technology, and energy use.

Several studies showed that projected changes in rainfall trends in different sources of the Nile as well as their impact on the Nile flow into Egypt remain considerably uncertain [36]. However, more certain is that temperatures will continue to increase because of climate change. This will likely lead to significant increase in the evaporative losses from the Nile River over Egypt and Sudan where the Nile flows with very slight flow-gradient over a semi-arid region. Moreover, higher temperatures will also increase demands for water for agriculture, domestic, and industrial uses [37]. A number of studies investigated the implications of fluctuations in Nile flows for water resources in Egypt, mainly since a prolonged period of drought during the 1970s and 1980s [38]. Table 2 shows the results of three Global Circulation Models (GCMs) used in 1996 to estimate projected Nile flows [39]. Results indicated that even with increases in the amount of rainfall, Nile flows would decrease in two of the three scenarios as a result of increase in temperature.

Table 2 Nile flows under GCM scenarios

	Base	UKMO	GISS	GFDL
Precipitation	100	122	131	105
Temperature	0	4.7	3.5	3.2
Flow (billion m^3)	84	76	112	20
% of base	100	91	113	24

6 Food Security

Food security is a concept that envelops more than just crop production, but is a complicated interaction between food accessibility and socio-economic, policy and health issues that impact access to food, utilization, and stability of food supplies. In 1996 the World Food Summit characterized food security as existing "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs, and their food preferences are met for an active and healthy life" [40]. The food production is not the only largest consumer of water, it is also the biggest unknown with respect to future global water demand [41, 42]. In Egypt, most croplands depend basically on irrigation water from the Nile rather than on local climatic conditions.

Recent years various simulation studies report that Egypt may go through increasing pressures on food security as a result of climate change. However, socio-economic aspects may play an important role in mitigating this situation somewhat. A study by Falkenmark et al. [43] investigated the projections of available water for crops and suggested that Egypt would be a food importing country in 2050. This result was obtained based on a global analysis of food security under some scenarios of climate change, and this analysis considers the importance of water availability for ensuring global food security. Crop suitability was projected under the pattern of climate change from 21 GCMs with two emissions scenarios.

Simulation was performed for the years 2030, 2050, 2080, and 2100. Under the climate projections, only one GCM projects an increase in suitability for cultivation in current Egyptian croplands. Regarding the mitigation scenario, this single model projects about 2% of current Egyptian croplands to be more suitable by 2100. All other investigated models project no increases in suitability. By 2030, under both emissions scenarios, between 40 and 67% of current Egyptian croplands are projected to become less suitable for cultivation as defined by local climatic conditions. Therefore, for Egypt, projected changes in local climate lead to conditions, which are less suitable for cultivation over most of current cropland areas. It is worth mentioning that changes in the availability of Nile river water for irrigation have not been considered in this analysis.

7 Towards Mainstreaming Adaptation Responses

Climate change adaptation is a concept of adjusting to a changing climate in order to reduce the negative impacts already occurring and taking advantage of new opportunities. Climate change adaptation plans and strategies are essential tools to avoid disruptions to governmental operations and allow to design and implement programs that are capable of achieving their goals across the various projected future climate scenarios. Climate change adaptation plans are vital for Egypt, especially in the water sector, which affects all other sectors. Agriculture also needs to adapt to climate changes including more expected extreme weather events. There are three main pathways for agricultural development, namely: conventional agriculture, organic agriculture, and conservation agriculture. These three pathways have different approaches for addressing the above issues [26]. Agriculture production must increase to satisfy the requirements of the growing population; however, this production will have to be achieved in an environmentally friendly way. As a result of the rapid population growth, Egypt's per capita share of water is expected to be reduced by half by 2050 even in the absence of climate change. Therefore, some measures are needed to be considered such as: improvement of the irrigation system, more efficient water delivery, better control on water usage, augmented farm productivity, redesign of canal cross sections to reduce evaporation losses, change of cropping patterns, enact programs for upgrading water quality to minimize pollution, with a high priority to recycling of both industrial and sewage waste, and launch public awareness campaigns on water shortage.

8 Conclusion

Egypt faces the urgent challenge of closing the growing gap between its limited water resources and the increasing water demand. The Nile River, the sole source that covers nearly 95% of the Egyptian population requirements, is highly sensitive to climate change, both in amount of rainfall and variations in temperature. There are large uncertainties in predicting climatic change impact on rainfall trends over the Nile basin and their impacts on its flows. Climate change, furthermore, may cause salinity challenges, where high extraction levels and declining inflows provide less dilution. Saline environments tend to hinder agricultural production by lowering crop yields, often quite substantially. Continued high rate of natural population increase will result in a population of 140 million inhabitants by 2050, and Egypt's per capita share of water is expected to be reduced by half even in the absence of climate change. Agriculture production has to increase by 70% within 2050 in order to keep pace with this rapid population growth, in a way that preserves the environment, to reduce the vulnerability of agriculture to climate change. A number of climate change adaptation options are vital for Egypt, especially in the water and in agriculture sectors. Increasing water availability and increasing the reliability of water in agriculture is one of the preferred options to increase crops productivity and contribute to poverty reduction in Egypt. Developing sustainable water policies and related strategies is a must, taking into account country-specific legal, institutional, economic, social, physical, and environmental conditions. These policies and strategies must integrate the different sectors depending on water.

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