water

MDPI

Article

Potential Climate Change Impacts on Water Resources in Egypt

Soha M. Mostafa [1], Osama Wahed [2], Walaa Y. El-Nashar [2], Samia M. El-Marsafawy [3], Martina Zeleňáková [4,*] and Hany F. Abd-Elhamid [2,5]

1 Technical Office of General Administration of WR&I for El-Sharkia Governorate, Ministry of Water Resources and Irrigation, Zagazig 44519, Egypt; ahmed_marim@yahoo.com
2 Department of Water and Water Structures Engineering, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt; ssalem070@gmail.com (O.W.); walaanashar@yahoo.com (W.Y.E.-N.); hany_farhat2003@yahoo.com (H.F.A.-E.)
3 Soils, Water & Environment Research Institute (SWERI), Agricultural Research Center (ARC), Giza 12112, Egypt; samiaelmarsafawy797@hotmail.com
4 Institute of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, 04200 Košice, Slovakia
5 Center for Research and Innovation in Construction, Faculty of Civil Engineering, Technical University of Košice, 04200 Košice, Slovakia
* Correspondence: martina.zelenakova@tuke.sk; Tel.: +421-55-602-4270

Abstract: This paper presents a comprehensive study to assess the impact of climate change on Egypt's water resources, focusing on irrigation water for agricultural crops, considering that the agriculture sector is the largest consumer of water in Egypt. The study aims to estimate future climate conditions using general circulation models (GCMs), to assess the impact of climate change and temperature increase on water demands for irrigation using the CROPWAT 8 model, and to determine the suitable irrigation type to adapt with future climate change. A case study was selected in the Middle part of Egypt. The study area includes Giza, Bani-Sweif, Al-Fayoum, and Minya governorates. The irrigation water requirements for major crops under current weather conditions and future climatic changes were estimated. Under the conditions of the four selected models CCSM-30, GFDLCM20, GFDLCM21, and GISS-EH, as well as the chosen scenario of A1BAIM, climate model (MAGICC/ScenGen) was applied in 2050 and 2100 to estimate the potential rise in the annual mean temperature in Middle Egypt. The results of the MAGICC/SceGen model indicated that the potential rise in temperature in the study area will be 2.12 °C in 2050, and 3.96 °C in 2100. The percentage of increase in irrigation water demands for winter crops under study ranged from 6.1 to 7.3% in 2050, and from 11.7 to 13.2% in 2100. At the same time, the increase in irrigation water demands for summer crops ranged from 4.9 to 5.8% in 2050, and from 9.3 to 10.9% in 2100. For Nili crops, the increase ranged from 5.0 to 5.1% in 2050, and from 9.6 to 9.9% in 2100. The increase in water demands due to climate change will affect the water security in Egypt, as the available water resources are limited, and population growth is another challenge which requires a proper management of water resources.

Keywords: climate change; water resources; agricultural crops; Middle Egypt; climate and irrigation models

check for updates

Citation: Mostafa, S.M.; Wahed, O.; El-Nashar, W.Y.; El-Marsafawy, S.M.; Zeleňáková, M.; Abd-Elhamid, H.F. Potential Climate Change Impacts on Water Resources in Egypt. *Water* **2021**, *13*, 1715. https://doi.org/10.3390/w13121715

Academic Editor: Maria Mimikou

Received: 6 May 2021
Accepted: 17 June 2021
Published: 21 June 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The climate change impact on Egypt's water resources can be considered a significant challenge due to the dependence of its large and growing population on the Nile River. Egypt has already reached the water poverty limit. Changes in the flow of the Nile will surely affect the country's economy, as it supplies irrigation water for agriculture. The flow of the Nile may be decreased due to climate change and regional change, such as constructing new dams on the river. Therefore, research has focused on irrigation water for agricultural crops, considering that the water consumption in the agriculture sector is the largest consumption of Egypt's water resources. Many international studies have been carried out in this regard, including Hammond [1], who stated that, due to climate and socioeconomic changes, management of water resource in the Nile Basin will become increasingly complex. Cunha et al. [2] studied irrigation adoption in Brazil under the effects of climate change. A number of different climate scenarios were employed under temperature and precipitation projections for the 2010–2099 periods. The results show that climate change will affect irrigation adoption. Fader et al. [3] assessed how irrigation requirements in the Mediterranean region may be affected due to climate change and increases in atmospheric CO_2 concentrations in the context of demographic and technological change. The Mediterranean region, when applying some climate models at 3 °C global warming and above, showed a signal of increasing the net irrigation requirements, without the positive effects of higher CO_2 concentrations in the atmosphere. Rolim et al. [4] anticipated that, to maintain current crop yield levels, water demand for irrigation will be increased. Kakumanu et al. [5] stated that in recent years, water resources, agriculture, ecology, and other disciplines have become hotspots for research under the conditions of climate change characterized by global warming. In India, water resource availability and the agricultural food production system is affected by climate change. Studies suggested decreasing trends in rainfall and increasing trends in surface temperature. Various adaptation strategies were developed and implemented to mitigate climate change effects through the Climate Adapt program. Bocci and Smanis [6] indicated that for all southern Mediterranean countries, general atmospheric circulation model predicted changes in temperature and precipitation patterns are already affecting the sector through greater exposure to risks of floods and extreme droughts.

Ritchie and Roser [7] indicated that one of the world's most pressing challenges is climate change. Global temperatures have increased by around 1 °C since pre-industrial times due to greenhouse gas emissions caused by human activities. These gases include carbon dioxide (CO_2), methane, and others. Globally, the emissions of CO_2 are over 36 billion tons per year, and present a continuous increase over 400 ppm concentrations in the atmosphere. These are the highest levels in about 800,000 years. Today, China is the largest CO_2 emitter worldwide (about 25% of emissions). This is followed by the USA (15%); EU-28 (10%); India (7%); and Russia (5%). Although less than 1% of emissions are contributed by the world's poor countries, they will be the most vulnerable to the impact of climate change. The predicted warming will be about 3.1 to 3.7 °C under current policies.

Schilling et al. [8] studied and compared the climate change vulnerability of Algeria, Egypt, Libya, Morocco, and Tunisia, and linked it to its social implications. The results suggested that all countries are exposed to have strong temperature increases and a high drought risk under climate change. Across North Africa, the combination of climate change and strong population growth is very likely to further aggravate the already scarce water situation. In the same trend, Driouech et al. [9] studied future changes in temperature, precipitation, and related extreme events in the Middle East and North Africa (MENA) region using Regional Climate Model ALADIN-Climate over the CORDEX-MENA domain. They found that projected changes in the temperature rate amounted to 0.2 °C/decade to 0.5 °C/decade, depending on the scenario. Drought is projected to increase in the northern half of the region independently from the index used. ALADIN-Climate results corroborate previous studies, projecting the MENA region to host global hot spots for drought in the late twenty first century. Zittis et al. [10] added that global climate predictions suggest a significant strengthening of summer heat extremes in the MENA region. They added that, on a business-as-usual pathway, unprecedented super- and ultra-extreme heatwave conditions will appear in the second half of this century. These events comprise extremely high temperatures (up to 56 °C and higher) and will be of prolonged duration (several weeks), being possibly life threatening for humans. By the end of the century, about half of the MENA population (approximately 600 million) could be exposed to annually frequent super- and ultra-extreme heatwaves.

Driouech et al. [9] used Regional Climate Model ALADIN-Climate to study future changes of temperature, precipitation, and associated extreme events in the MENA region. The study concluded that 0.2 °C/decade to 0.5 °C/decade over land are the warming rate ranges, depending on the scenario. Duration and magnitude of projected heat waves are expected to be increased. The northern half of the region is expected to have an increase in drought.

Mohammad et al. [11] investigated the changes in a 20-year (2000–2019) mean surface temperature (ST), wind speed (WS), and albedo (AL) data from the Global Land Data Assimilation System (GLDAS) over the globe with respect to those in 1961–1990. The results showed that the mean of monthly global mean surface temperature (GMST) anomalies in 2000–2019 is 0.54 °C higher than that in 1961–1990. Increasing greenhouse gas (GHG) emissions and variations of the North Atlantic Oscillation (NAO) are the main causes of increasing ST across the globe, particularly in the northern hemisphere (NH). Regarding these topics, there are many studies carried out in Egypt and the Arab region, for example El-Ramady et al. [12] concluded that, due to the hot climate, agriculture in Egypt is expected to be especially vulnerable. Crop productivity is expected to reduce due to further warming. Nour El-Din [13] in "Proposed Climate Change Adaptation Strategy for the Ministry of Water Resources & Irrigation in Egypt" stated that, due to science progress, knowledge, and acquired capacity in dealing with climate change impacts, the water strategy should be continuously revised and updated. In the Annual Report of the Arab Forum for Environment & Development, Sadik et al. [14] stated that in the next few decades, one of the main drivers reducing levels of food security in the Arab world will be climate change.

Water availability is reduced by climate change and therefore will significantly limit crop productivity in affected areas due to the increase in demand of water needed for irrigation. El Agroudy et al. [15] indicated that water storage in front of the Renaissance Dam will cause a lack of incoming water to Nasser Lake up to approximately 25–33 billion m^3 per year, and if there will be no pulling of shortage from Dam Lake, this will result in wasting about 3–5 million acres of Egypt's cultivated area. Mahmoud and El-Bably [16] revealed that evapotranspiration may increase as the warmer temperatures expected with climate change will increase evaporation. Increasing crop water requirements due to climate change will affect crops production indirectly.

Most of the research conducted in Egypt was aimed at studying the impact of climate change on the productivity or water consumption of a particular crop, however studies on the impact of climate change on the total water needs required for major crops under climate change conditions have not been considered to date.

This study focuses on providing decision makers with data on the amount of irrigation water needed for major crops under climate change conditions, in an effort to manage saving methods for these quantities from now on, or to determine the appropriate area that can be grown under future conditions and to develop plans and strategies to utilize the lost area in the event of an inability to provide quantities under climate change conditions.

Accordingly, the current study aims to investigate the impact of climate change on Egypt's water resources focusing on the agriculture sector. The study also aims to determine solutions to reduce the pressure on the water budget of agricultural crops through adaptation measures.

2. Study Area

Egypt lies in the north eastern north of the African continent; the Mediterranean Sea lies on its northern coasts and the Red Sea lies on its eastern coasts. Egypt's location is between longitude 22° to longitude 32°, and between latitude 24° to latitude 37°. Egypt's land frontiers border Palestine to the northeast, Sudan to the south, and Libya to the west. Its total area is about one million km^2. The total population of Egyptians hit 104.2 million citizens (both living in Egypt and abroad). In Egypt, there are three types of climate. On the northern coast, there is a Mediterranean climate, while there is a desert climate in inland areas, and on the Red Sea coast there is a milder desert climate. Agriculture area in year 2017, according to the Central Agency for Public Mobilization and Statistics (CAPMS), was approximately 3.8 million hectares (1 hectare (ha) = 10,000 m^2).

More than 95% of Egypt's freshwater resources come from Nile River. Egypt is considered as a downstream country and the Nile water comes from outside its international borders. Egypt's annual share of the river′s water is 55.5 BCM.

In the western desert region and Sinai, groundwater exists in the nonrenewable deep aquifers, with a yearly extraction of about 0.9 BCM. Reuse of drainage is another important source of water that Egypt adopted, which produces about 4.5 BCM in the Nile Delta.

The current study is focused on the Middle Egypt region. It includes four governorates: Elgiza, Bani-Sweif, Al-Fayoum, and Elmenia, as shown in Figure 1. As a result of the lack of weather data for a long period, Giza governorate has been relied upon to represent Middle Egypt region, due to the existence of sufficient data for it. Its irrigated area is approximately 1.1 million feddan (1 fed. = 0.42 ha). In the summer season, cotton and maize are the main crops. In the winter season, wheat and berseem are the main crops.

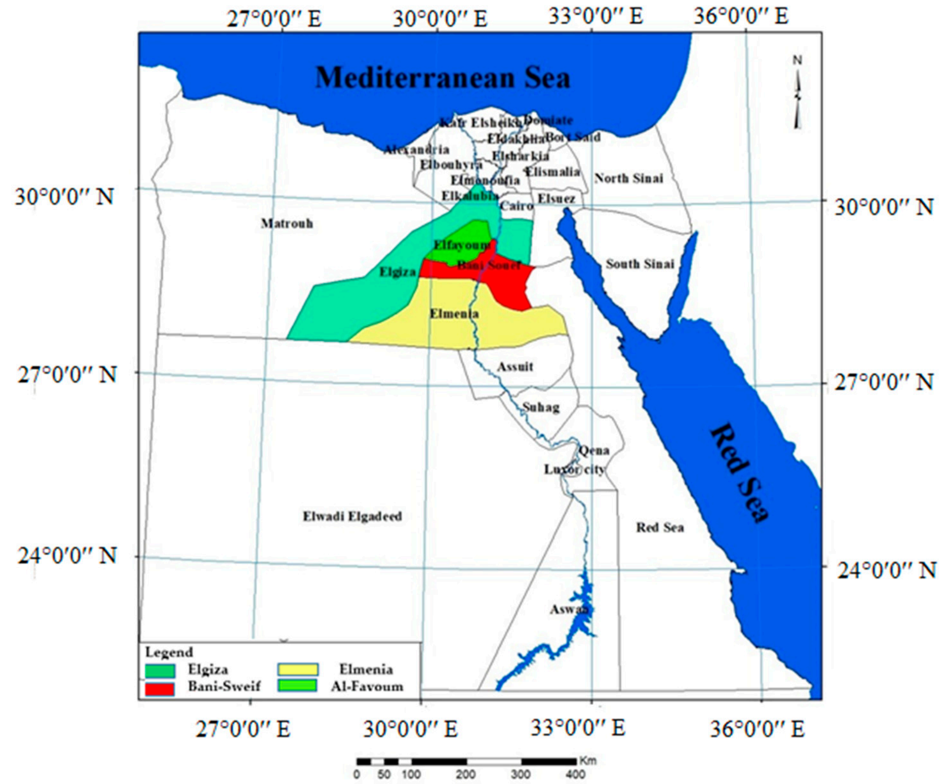

Figure 1. Location map of the study area.

3. Methodology

The Methodology of this study includes the following steps:

1. Define the Characteristics of the study area;
2. Collect climatic data, water resources data and crop data;
3. Use MAGICC/SCENGEN model version 5.3 [17] to assess the impact of climate change by focusing on greenhouse gas emissions and their impact on the rise of temperature at the regional level in Egypt (more details in Figure 2);
4. Use CropWat8.0 model to calculate irrigation water requirements (IWR) under current and future climate conditions.

CROPWAT is developed by the Land and Water Development Division of FAO. It is used as a support decision tool (www.fao.org/land-water/databases-and-software, accessed on 25 January 2019).

CROPWAT8.0 calculation procedures are based on two FAO publications. These publications of the Irrigation and Drainage Series are named No. 56 "Crop Evapotranspiration—Guidelines for computing crop water requirements" and No. 33 is titled "Yield response to water" [18].

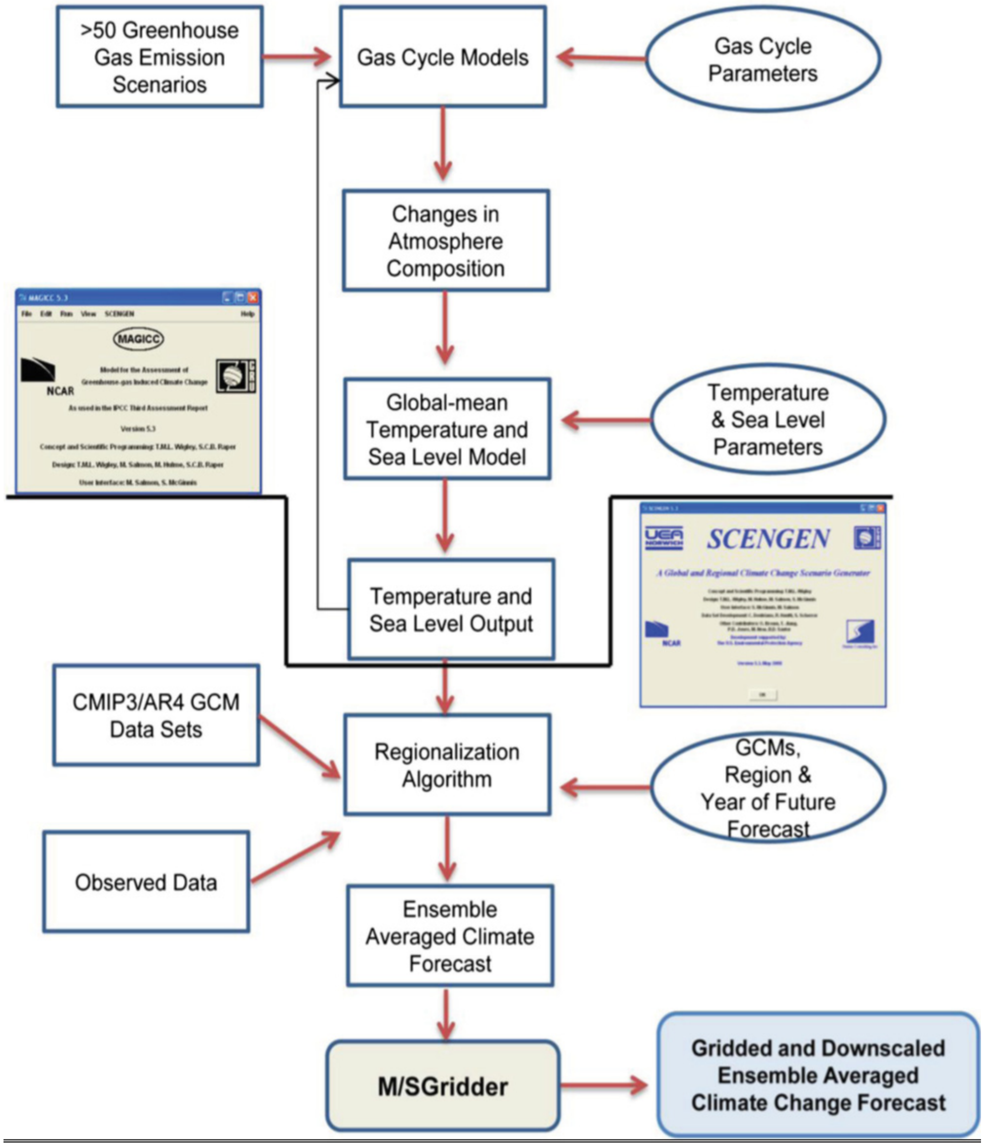

Figure 2. Structure and flow of the MAGICC/SCENGEN software. Elliptical shapes are used to highlight user defined model parameters, Fordham et al. doi:10.1111/j.1600-0587.2011.07398.x. [19].

3.1. Calculation of Irrigation Water Requirements

To calculate irrigation water requirements, three steps have been done as follows:

3.1.1. Calculation of the Reference Crop Evapotranspiration (*ETo*)

The *ETo* was calculated by FAO Penman–Monteith method, using the decision support software CROPWAT8.0 developed by FAO, based on Allen et al. [20]. The equation used for calculating *ETo* is described as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where *ETo* is the reference crop evapotranspiration (mm day^{-1}), *Rn* is the net radiation at the crop surface (MJ m^{-2} day^{-1}), *G* is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2 m height (°C), U_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), $(e_s - e_a)$ is the vapor pressure deficit (kPa), Δ is the slope of the pressure-temperature curve (kPa °C^{-1}), and γ is the psychrometric constant (kPa °C^{-1}).

3.1.2. Calculation of the Crop Water Use (Crop Evapotranspiration, ETc)

The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement (crop evapotranspiration). According to Allen et al. [20], crop evapotranspiration (ETc) is calculated by multiplying the reference crop evapotranspiration (*ETo*), by crop coefficient (Kc):

$$\mathrm{ETc} = \mathrm{Kc}\ ETo \tag{2}$$

where: ETc is the crop evapotranspiration (mm day^{-1}), Kc is the crop coefficient (dimensionless), and *ETo* is the reference crop evapotranspiration (mm day^{-1}).

3.1.3. Calculation of the Irrigation Water Requirements (IWR)

$$\mathrm{IWR} = \mathrm{ETc}/\mathrm{IE} \tag{3}$$

where: IE is the irrigation efficiency.

The irrigation efficiency values used in this study were:

- 60% for surface irrigation system [21];
- 75% and 80% for the sprinkler and drip irrigation systems, respectively.

The study of the climate change impact on the irrigation water requirements was achieved through the results of the MAGICC/SCENGEN model predictions. Current weather data has been converted to what is expected in 2050 and 2100 using the results of the model, and irrigation water requirements were calculated

Calculations of IWR under current and future climatic changes conditions have been implemented on the following crops:

- Winter crops: barley, faba bean (dry), wheat, potato, and tomato;
- Summer crops: cotton, maize, sunflower, potato, and tomato;
- Nili crops: potato and tomato.

In addition, total irrigation water requirements according to the cropped area in 2013/2014 were calculated on the old and new lands.

4. Results

4.1. Climate Change Impacts

GCMs are used to simulate climate change. The atmospheric concentrations of greenhouse gases were gradually increased, and the impacts on the climate model were monitored. Decisions regarding how concentrations of greenhouse gases will alter in the future have been made. Scenarios using these decisions are applied into the GCM. SRES (Special Report on Emissions Scenarios) may be the best-known emissions scenarios [22]. For impact and adaptation studies, these scenarios and model output are still in use. (https://coastadapt.com.au, accessed on 21 May 2021).

MAGICC/SCENGEN is a coupled gas-cycle/climate model (MAGICC; Model for the Assessment of Greenhouse-gas Induced Climate Change) that drives a spatial climate-change SCENario GENerator (SCENGEN). Since 1990, IPCC [23] has used MAGICC to produce projections of future global-mean temperature and sea level rise.

SCENGEN was derived using global-mean temperatures from MAGICC. A scaling method described in Santer et al. [24] was applied to SCENGEN to produce spatial patterns of change from a database of atmosphere/ocean GCM (AOGCM) data from the CMIP3/AR4 archive [17].

4.2. Impact of Climate Change at the National Level of the Study Area

Change in annual mean temperature has been predicted in 2050 and 2100 using MAGICC/SCENGEN model under the conditions of the four selected models CCSM-30, GFDLCM20, GFDLCM21, and GISS-EH, as well as the scenario of A1BAIM (from SRES families). The A1B marker scenario (A1B-AIM) emissions increase through 2030, and subsequently decline to levels similar to those in 1990. After 2030, declining population levels, the introduction of modern management techniques, and the increased recycling result in a reduction in the waste which is sent to landfills, thus in a reduction in waste emissions. Emissions from biomass burning in A1B-AIM are assumed to decline steadily through the adoption of bio-recycling and other "no-waste" agricultural practices. Similarly, CH4 emissions from fossil fuel production and use grow through 2030 and subsequently decline as fossil fuel production falls (www.grida.no/climate/ipcc, accessed on 21 May 2021).

The forecasts were made to cover the entire study area (Middle Egypt region). The prediction was implemented at the coordinates of latitude 27.5° to 30.0° N, and longitude 30.0° to 32.5° E. The results of the MAGICC/ SENGEN model showed that climate changes resulting from increased global greenhouse gas emissions would cause an increase in the average global surface temperature, at different degrees depending on the latitudes of each country. According to the study area's latitude, results showed that the possible rise in the average temperature in 2050 would reach 2.12 °C, while the possible increase in 2100 would reach 3.96 °C (Figures 3 and 4).

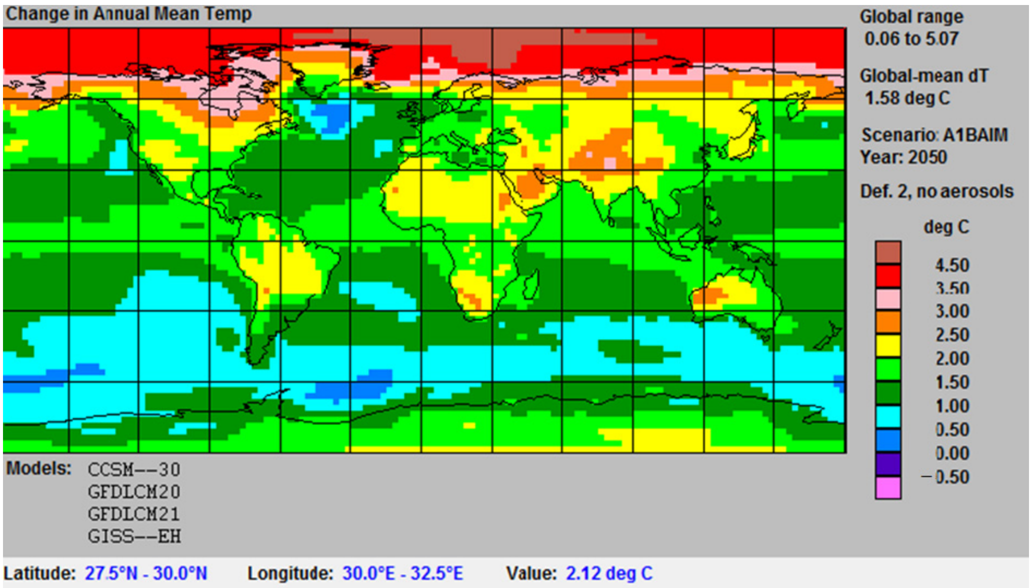

Figure 3. Change in annual mean temperature in 2050 at the regional level at latitude 27.5° N–30.0° N and longitude 30.0° E–32.5° E.

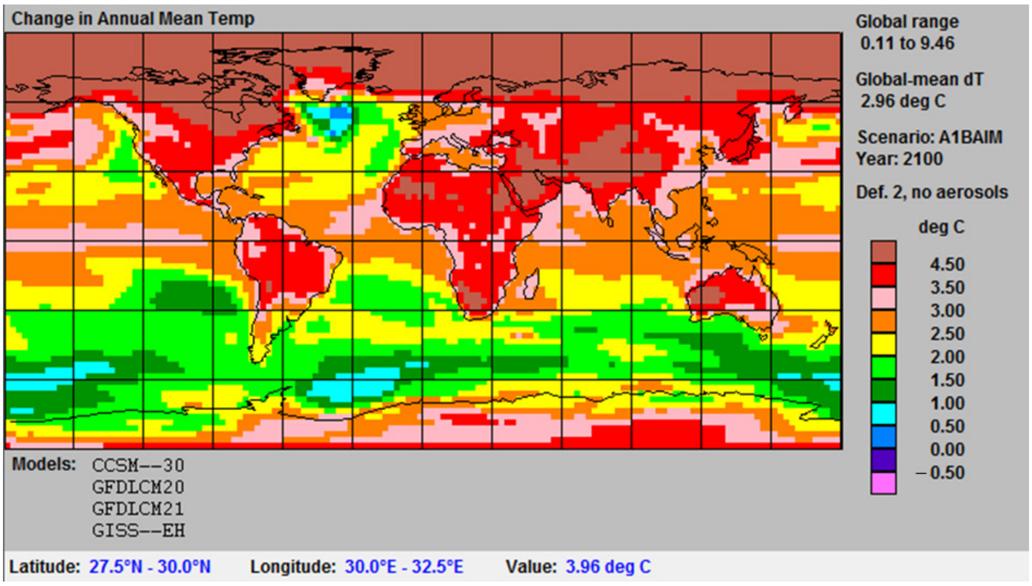

Figure 4. Change in annual mean temperature in 2100 at the regional level at latitude 27.5° N–30.0° N and longitude 30.0° E–32.5° E.

4.3. Impact of Climate Change on Irrigation Water Requirements (IWR) in Egypt

4.3.1. Winter Crops

Results as presented in Figure 5 indicate average IWR over 30 years for some of the main winter crops in Middle Egypt under current and climate change conditions. Values of IWR under current conditions varied from 3792 to 5693 m^3/ha for barley; 4060 to 5782 m^3/ha for faba bean; 5462 to 8177 m^3/ha for wheat; 4862 to 6650 m^3/ha for potato; and 5107 to 6972 m^3/ha for tomato. Increasing IWR is always due to high temperature, increased wind speed, or low relative humidity.

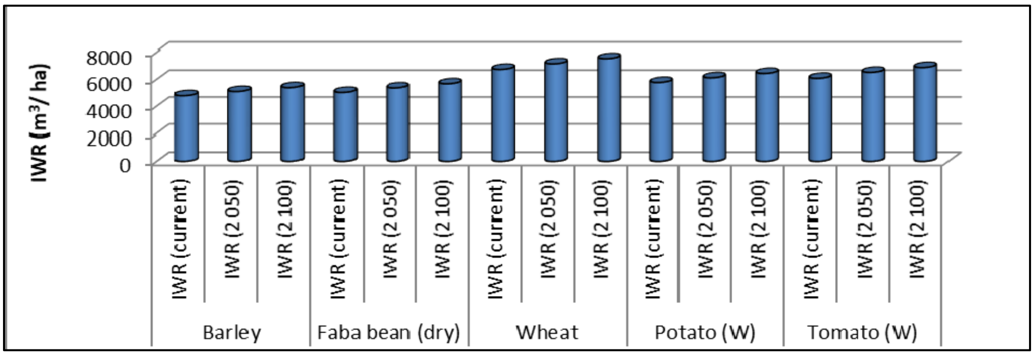

Figure 5. Average irrigation water requirements (IWR) for some main winter crops in Middle Egypt under current and climate change conditions over 30 years.

In regards to future climate changes and their effects on the water needs of winter crops, the results indicated that values of IWR in 2050 varied from 4023 to 6090 m^3/ha; 4317 to 6205 m^3/ha; 5773 to 8712 m^3/ha; 5148 to 7048 m^3/ha; and 5457 to 7253 m^3/ha for the respective winter crops. However, in 2100, the values ranged between 4240 and 6477 m^3/ha; 4558 and 6590 m^3/ha; 6063 and 9240 m^3/ha; 5423 and 7420 m^3/ha; 5755 and 7653 m^3/ha, respectively. The change in percentage of IWR under climate change conditions, compared to current conditions (Figure 6), ranged from +6.1 up to +7.3% in 2050 and from +11.7 up to +13.2% in 2100.

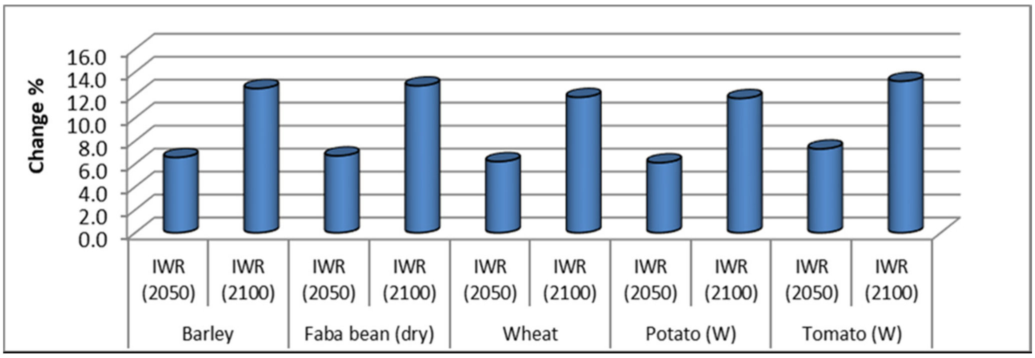

Figure 6. Change percentage in irrigation water requirements (IWR) for some main winter crops in Middle Egypt under climate change conditions compared to current conditions.

4.3.2. Summer Crops

Average values of IWR for summer crops over 30 years are listed in Figure 7. Results under current conditions showed the seasonal IWR ranged between 11,372 and 15,745 m^3/ha for cotton; 9362 and 12,517 m^3/ha for maize; 6308 and 8790 m^3/ha for sunflower; 7002 and 10,400 m^3/ha for potato; and 11,180 and 15,535 m^3/ha for tomato. However, in 2050, the values varied from 11,888 to 16,538 m^3/ha for cotton; 9782 to 13,107 m^3/ha for maize; 6585 to 9218 m^3/ha for sunflower; 7360 to 10,962 m^3/ha for potato; and 11,700 to 16,330 m^3/ha for tomato.

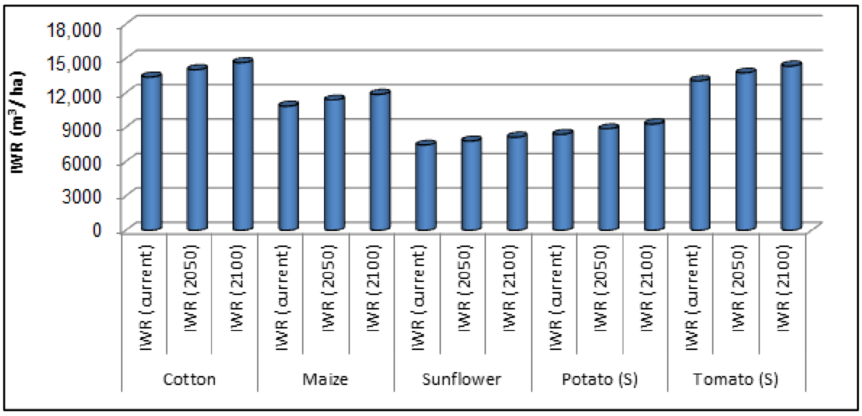

Figure 7. Average irrigation water requirements (IWR) for some main summer crops in Middle Egypt under current and climate change conditions over 30 years.

In 2100, they ranged from 12,367 to 17,273 m^3/ha for cotton; 10,178 to 13,665 m^3/ha for maize; 6842 to 9610 m^3/ha for sunflower; 7690 to 11,513 m^3/ha for potato; and 12,182 to 17,073 m^3/ha for tomato. The change in percentage of IWR increased up to 5.8% in 2050 and 10.9% in 2100 (Figure 8).

4.3.3. Nili Crops

Values of IWR for Nili crops are presented in Figure 9. Results under current conditions revealed that seasonal IWR over three decades ranged from 9520 to 12,602 m^3/ha for potato and 10,567 to 14,142 m^3/ha for tomato. Concerning the values in 2050, the amounts varied from 9963 to 13,222 m^3/ha for potato and 11,077 to 14,858 m^3/ha for tomato. In 2100, the values ranged from 10,382 to 13,797 m^3/ha for potato and 11,560 to 15,525 m^3/ha for tomato. The change in percentage of IWR under climate change compared to current conditions (Figure 10) reached approximately +5% in 2050 and +10% in 2100.

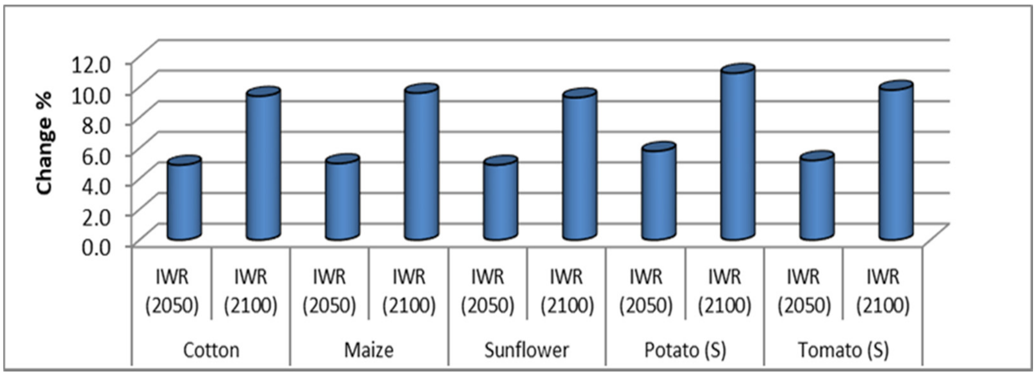

Figure 8. Change percentage in irrigation water requirements (IWR) for some main summer crops in Middle Egypt under climate change conditions compared to current conditions.

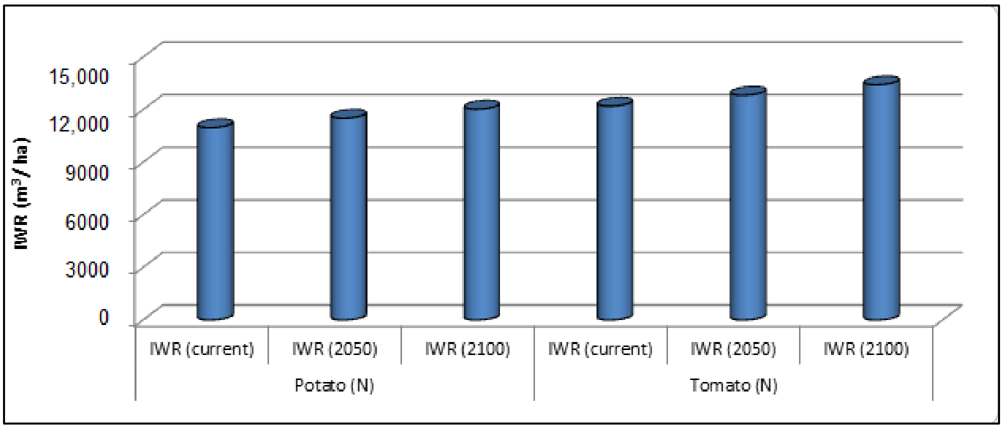

Figure 9. Average irrigation water requirements (IWR) for some Nili crops in Middle Egypt under current and climate change conditions over 30 years.

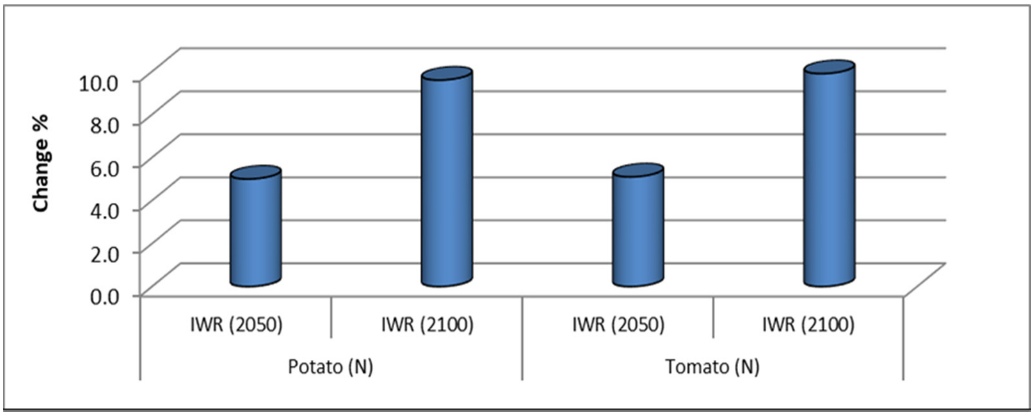

Figure 10. Change percentage in irrigation water requirements (IWR) for some Nili crops in Middle Egypt under climate change conditions compared to current conditions.

4.4. Total Irrigation Water Requirements (IWR) According to Cropped Area

Results as tabulated in Tables 1 and 2 indicate total IWR for the crops in the study in the old and new lands under current and climate change conditions according to the total cropped area in 2013/2014 winter season and 2014 summer and Nili seasons.

Table 1. Total irrigation water requirements (IWR, m^3) for some main crops in the old lands of Middle Egypt under current and climate change conditions.

	Crop	Area (ha) *	IWR (Current)	Total IWR (Current)	IWR (2050)	Total IWR (2050)	IWR (2100)	Total IWR (2100)
Winter crops	Barley	2488	4777	11,885,176	5090	12,664,611	5377	13,378,252
	Faba bean (dry)	654	5023	3,284,969	5358	3,503,950	5667	3,706,327
	Wheat	251,939	6738	1,697,467,006	7155	1,802,567,559	7535	1,898,444,345
	Potato	11,393	5764	65,672,417	6113	69,650,473	6439	73,355,096
	Tomato	11,767	6076	71,494,331	6520	76,723,455	6881	80,964,151
Summer crops	Cotton	10,538	13,373	140,919,405	14,034	147,887,950	14,631	154,185,576
	Maize	266,390	10,837	2,886,957,227	11,384	3,032,554,161	11,877	3,163,958,428
	Sunflower	1320	7445	9,827,400	7810	10,308,613	8138	10,742,453
	Potato	5540	8379	46,419,352	8865	49,114,562	9288	51,456,136
	Tomato	9387	13,062	122,611,951	13,740	128,977,902	14,344	134,643,999
Nili crops	Potato	16,839	10,970	184,720,088	11,514	193,875,827	12,025	202,497,020
	Tomato	9435	12,199	115,098,613	12,822	120,972,425	13,411	126,531,213

* Source of data: Economic Affairs sector (EAS)—Bulletin of Important indicators of the Agricultural Statistics, Volumes No. 2013–2014. Ministry of Agriculture and Land Reclamation.

Table 2. Total irrigation water requirements (IWR, m^3) for some main crops in the new lands of Middle Egypt under current and climate change conditions.

	Crop	Area (ha) *	IWR (Current)	Total IWR (Current)	IWR (2050)	Total IWR (2050)	IWR (2100)	Total IWR (2100)
Winter crops	Barley	834	3821	3,186,992	4072	3,396,233	4302	3,587,609
	Faba bean (dry)	112	3768	421,960	4018	450,049	4250	476,042
	Wheat	14,983	5391	80,768,359	5724	85,760,028	6028	90,321,519
	Potato	676	4324	2,922,855	4585	3,099,516	4829	3,264,376
	Tomato	7187	4558	32,754,753	4890	35,145,628	5160	37,088,214
Summer crops	Cotton	0	10,030	0	10,525	0	10,974	0
	Maize	9608	8128	78,089,020	8538	82,032,303	8908	85,586,863
	Sunflower	202	5584	1,127,918	5857	1,183,148	6104	1,232,941
	Potato	294	6284	1,847,423	6649	1,954,831	6966	2,048,029
	Tomato	4569	9796	44,759,066	10,305	47,083,735	10,758	49,152,160
Nili crops	Potato	500	8228	4,113,750	8635	4,317,563	9019	4,509,554
	Tomato	37	9149	338,504	9616	355,801	10,058	372,151

* Source of data: Economic Affairs sector (EAS)—Bulletin of Important indicators of the Agricultural Statistics, Volumes No. 2013–2014. Ministry of Agriculture and Land Reclamation.

4.4.1. Old Lands

Results as listed in Table 1 indicated that current total IWR in the old lands registered 11.9, 3.3, 1697.5, 65.7, and 71.5 million m^3 for winter crops of barley, faba bean (dry), wheat, potato, and tomato, respectively. However, the total values for the respective crops under climate change recorded 12.7, 3.5, 1802.6, 69.7, and 76.7 million m^3 in 2050, and 13.4, 3.7, 1898.4, 73.4, and 81.0 million m^3 in 2100. Regarding the summer crops in the old lands, current values for respective crops of cotton, maize, sunflower, potato, and tomato were 140.9, 2887.0, 9.8, 46.4, and 122.6 million m^3; 147.9, 3032.6, 10.3, 49.1, and 129.0 million m^3 in 2050; and 154.2, 3164.0, 10.7, 51.5, and 134.6 million m^3 in 2100. Regarding Nili crops of potato and tomato, total IWR for the two crops were 184.7 and 115.1 million m^3 under current conditions; 193.9 and 121.0 million m^3 in 2050; and 202.5 and 126.5 million m^3 in 2100, respectively.

4.4.2. New Lands

Results shown in Table 2 indicate that the values of total IWR for winter crops of barley, faba bean (dry), wheat, potato, and tomato, respectively, were 3.2, 0.42, 80.8, 2.9, and 32.8 million m^3 under current conditions; 3.4, 0.45, 85.8, 3.1, and 35.1 million m^3 in 2050; and 3.6, 0.48, 90.3, 3.3, and 37.1 million m^3 in 2100. As for summer crops of maize, sunflower, potato, and tomato, respectively, the total amounts listed 78.1, 1.13, 1.85, and 44.8 million m^3 for current conditions; 82.0, 1.18, 1.95, and 47.1 million m^3 in 2050; and 85.6, 1.23, 2.05, and 49.2 million m^3 in 2100. It is worth mentioning that the cotton crop was not sown in the new lands in Middle Egypt, according to the Economic Affairs sector (EAS)

Ministry of Agriculture in 2014. Regarding Nili crops, values of total IWR for potato and tomato, respectively, reached 4.1 and 0.34 million m^3 under the current conditions; 4.3 and 0.36 million m^3 in 2050; and 4.5 and 0.37 million m^3 in 2100.

4.4.3. The total Increase in IWR due to Climate Change

Data as tabulated in Table 3 indicate the total IWR under current and climate change conditions. The results represent the total IWR for the studied crops in the old and new lands, according to the total cropped area in 2013/2014.

Table 3. Increase required in irrigation water under the conditions of future climatic changes compared to current irrigation water amounts according to the total cropped area in 2013/2014.

	Crop	Total IWR (Current)	Total IWR (2050)	Amount of Excess of IW	Total IWR (2100)	Amount of Excess of IW
Winter crops	Barley	15,072,168	16,060,844	988,676	16,965,861	1,893,693
	Faba bean	3,706,929	3,953,999	247,070	4,182,369	475,440
	Wheat	1,778,235,364	1,888,327,587	110,092,223	1,988,765,864	210,530,500
	Potato	68,595,272	72,749,989	4,154,717	76,619,472	8,024,200
	Tomato	104,249,083	111,869,083	7,619,999	118,052,365	13,803,282
Summer crops	Cotton	140,919,405	147,887,950	6,968,545	154,185,576	13,266,171
	Maize	2,965,046,247	3,114,586,464	149,540,218	3,249,545,291	284,499,045
	Sunflower	10,955,318	11,491,761	536,444	11,975,394	1,020,077
	Potato	48,266,775	51,069,393	2,802,618	53,504,164	5,237,389
	Tomato	167,371,017	176,061,637	8,690,620	183,796,159	16,425,142
Nili crops	Potato	188,833,838	198,193,389	9,359,551	207,006,574	18,172,736
	Tomato	115,437,117	121,328,226	5,891,109	126,903,363	11,466,246

The results showed that the increase in IWR under future climatic changes compared to current conditions will range from 0.25 million m^3 to 150 million m^3 in 2050, while the increase will range from 0.48 million m^3 to 285 million m^3 in 2100.

Increasing temperature results in increased evapotranspiration to lower the temperature of the atmosphere surrounding the plant, so that the plant can perform its vital functions to the fullest; however, if the plant is exposed to water deficit during the high temperature, this will affect its activity and vitality, as it affects the process of photosynthesis, and thus decrease its production. Chowdhury et al. [25] indicated that, on an average, 1 °C increase in temperature may increase the overall crop water requirements (CWR) by 2.9% in Al-Jouf, Saudi Arabia.

In the same way, Radwan [26] showed that Egypt is one of the countries affected by climate change effects, within its borders and outside its borders, within the whole Nile Basin. The River Nile is expected to be severely reduced.

Khordagui [27] expected that the Nile water would be reduced by 20% over the next 50 years. Meanwhile, the increasing temperatures will cause a rise in the evaporation process in natural ecosystems, which will lead to an increased water demand (IPCC [28]).

5. Conclusions

Although Egypt has limited water resources, climate change will put greater pressure on this important resource. Therefore, all efforts must be made to preserve every water droplet. As the agriculture sector consumes the largest amount of water resources, this sector must apply all agricultural practices that will rationalize water and raise the efficiency of irrigation at the field level; this will maximize the utilization, maintenance, and sustainability of every drop of water. The objectives of this study are to assess the climate change impact on water resources and the necessities of the agriculture sector from water resources under future conditions. The current study was carried out in the Middle Egypt region. Two models were used in the present study: the first is a climate model called MAGICC/SCENGEN model, and the second is an irrigation model named CROPWAT. The results of the climate model showed that increasing the concentration of the emission of global greenhouse gas would affect the average temperature of the earth's surface, and it would increase at different degrees. The rate of rise in temperature at the regional level (study area) will reach about 2.12 °C by 2050, and 3.96 °C by 2100. Future climatic changes will require more irrigation water to cover the actual demands of crops. The percentage of increase in irrigation water demands for winter crops under study ranged from 6.1 to 7.3% in 2050 and from 11.7 to 13.2% in 2100. At the same time, the increase in irrigation water needs for summer crops ranged from 4.9 to 5.8% in 2050 and from 9.3 to 10.9% in 2100. For Nili crops, the increase ranged from 5.0 to 5.1% in 2050 and from 9.6 to 9.9% in 2100. The increase in IWR under future climatic changes compared to current conditions (according to the total cropped area in the old and new lands in 2013/14) will range from 0.25 to 150 million m^3 in 2050, and from 0.48 to 285 million m^3 in 2100.

Author Contributions: Conceptualization, S.M.M., M.Z., and O.W.; methodology, W.Y.E.-N., S.M.E.-M., and H.F.A.-E.; validation, S.M.M. and S.M.E.-M.; formal analysis, M.Z. and H.F.A.-E.; investigation, S.M.M.; data curation H.F.A.-E. and W.Y.E.-N.; writing—original draft preparation, S.M.M. and H.F.A.-E.; writing—review and editing H.F.A.-E. and M.Z.; supervision, M.Z.; project administration, O.W.; funding acquisition, M.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by project of the Ministry of Education of the Slovak Republic VEGA 1/0308/20 Mitigation of hydrological hazards, floods and droughts by exploring extreme hydroclimatic phenomena in river basins and project HUSKROUA/1702/6.1/0072 Environmental Assessment for Natural Resources Revitalization in Solotvyno to prevent the further pollution of the Upper-Tisza Basin through the preparation of a complex monitoring system.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hammond, M. *The Grand Ethiopian Renaissance Dam and the Blue Nile: Implications for Transboundary Water Governance*; Discussion Paper 1307; Global Water Forum: Canberra, Australia, 2013.
2. Cunha, A.D.; Coelho, A.B.; Féres, J.G.; Braga, M.J. *Effects of Climate Change on Irrigation Adoption in Brazil*; Acta Scientiarum: Rio de Janeiro, Brazil, 2014.
3. Fader, S.; Bloh, W.; Bondeau, A.; Cramer, W. Mediterranean irrigation under climate change: More efficient irrigation needed to compensate for increases in irrigation water requirements. *Hydrol. Earth Syst. Sci.* **2016**, *20*, 953–973. [CrossRef]
4. Rolim, J.; Teixeira, J.; Catalão, J.; Shahidian, S. The Impacts of Climate Change on Irrigated Agriculture in Southern Portugal. *Irrig. Drain.* **2017**. [CrossRef]
5. Kakumanu, K.R.; Kaluvai, Y.R.; Nagothu, U.S.; Lati, N.R.; Kotapati, G.R.; Karanam, S. Building Farm-Level Capacities In Irrigation Water Management To Adapt To Climate Change. *Irrig. Drain.* **2018**. [CrossRef]
6. Bocci, M.; Smanis, T. Assessment of the impacts of Climate Change on the Agriculture Sector in the Southern Mediterranean. Union-For-The-Mediterranean, A DGNEAR Project Led by Atkins Together with Pescares Italia Srl, GIZ and SML. 2019. Available online: https://ufmsecretariat.org/wp-content/uploads/2019/04/Climate-Change-impact-on-Agriculture.pdf (accessed on 22 December 2020).
7. Ritchie, H.; Roser, M. CO_2 and Greenhouse Gas Emissions. OurWorldInData.org. August 2020. Available online: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions (accessed on 15 January 2021).
8. Schilling, J.; Hertig, E.; Tramblay, Y.; Scheffran, J. *Climate Change Vulnerability, Water Resources and Social Implications in North Africa. Regional Environmental Change*; Springer: Berlin/Heidelberg, Germany, 2020; Volume 20. [CrossRef]
9. Driouech, F.; ElRhaz, K.; Moufouma-Okia, W.; Arjdal, K.; Balhane, S. Assessing Future Changes of Climate Extreme Events in the CORDEX-MENA Region Using Regional Climate Model ALADIN-Climate. *Earth Syst. Environ.* **2020**, *4*, 477–492. [CrossRef]

10. Zittis, G.; Hadjinicolaou, P.; Almazroui, M.; Bucchignani, E.; Driouech, F.; El Rhaz, K.; Kurnaz, L.; Nikulin, G.; Ntoumos, A.; Ozturk, T.; et al. Business-as-usual will lead to super and ultra-extreme heatwaves in the Middle East and North Africa. *NPJ Clim. Atmos. Sci.* **2021**, *4*, 20. [CrossRef]
11. Valipour, M.; Bateni, S.; Jun, C. Global Surface Temperature: A New Insight. *Climate* **2021**, *9*, 81. [CrossRef]
12. El-Ramady, H.R.; El-Marsafawy, S.M.; Lewis, L.N. *Sustainable Agriculture and Climate Changes in Egypt*; INRA-CMSE-PME, UMR1347; Springer: Berlin/Heidelberg, Germany, 2013.
13. El-Din, M.M.N. *Climate Change Risk Management in Egypt*; UNESCO-Cairo Office: Cairo, Egypt, 2013.
14. Sadik, A.; El-Solh, M.; Saab, N. *Arab Environment 7, FOOD Security, Challenges and Prospects. Annual Report of the Arab Forum for Environment & Development*; AFED: Beirut, Lebanon, 2014.
15. El Agroudy, N.; Shafiq, F.; Mokhtar, S. The Impact of Establishing the Ethiopian Dam Renaissance on Egypt. *J. Basic Appl.* **2014**, *4*, 1–5.
16. Mahmoud, M.A.; El-Bably, A.Z. *Crop Water Requirements and Irrigation Efficiencies in Egypt. Conventional Water Resources and Agriculture in Egypt*; Springer: Berlin/Heidelberg, Germany, 2019.
17. Wigley, T. MAGICC/SCENGEN 5.3: USER MANUAL (Version 2). National Center for Atmospheric Research, Boulder, CO 80307. Version 1, June 2008 Version 2, September 2008. 2008. Available online: http://www.cgd.ucar.edu/cas/wigley/magicc/UserMan5.3.v2.pdf (accessed on 12 January 2021).
18. Robinson, S.; d'Croz, D.M.; Islam, S.; Sulser, T.B.; Robertson, R.D.; Zhu, T.; Gueneau, A.; Pitois, G.; Rosegrant, M.W. The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description for Version 3. Available online: https://www.ifpri.org/publication/international-model-policy-analysis-agricultural-commodities-and-trade-impact-0 (accessed on 12 June 2020).
19. Fordham, D.A.; Wigley, T.M.L.; Watts, M.J.; Brook, B.W. Strengthening forecasts of climate change impacts with multi-model ensemble averaged projections using MAGICC/SCENGEN 5.3. *Ecography* **2012**, *35*, 4–8. [CrossRef]
20. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. Crop evapotranspiration: Guide-lines for computing crop water requirements. In *FAO Irrigation and Drainage Paper No. 56*; FAO: Rome, Italy, 1998; 300p.
21. Jensen, M.E. *Design and Operation of Farm Irrigation System*; (ASAE Monograph, No. 3); American Society of Agricultural Engineers: St. Joseph, MI, USA, 1980.
22. Nakicenovic, N.; Swart, R. Special Report of Working Group III of the Intergovernmental Panel on Climate Change. In *Published for the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2000.
23. IPCC Report. Chapter 5: Food Security—IPCC SRCCL. In *Final Government Distribution*; 2019. Available online: https://www.ipcc.ch/site/assets/uploads/2019/08/2f.-Chapter-5_FINAL.pdf (accessed on 10 August 2020).
24. Santer, B.D.; Wigley, T.M.L.; Schlesinger, M.E.; Mitchell, J.F.B. Developing climate scenarios from equilibrium GCM results. *Max Planck Inst. Meteorol. Tech. Rep.* **1990**, *47*, 29.
25. Chowdhury, S.; Al-Zahrani, M.; Abbas, A. Implications of climate change on crop water requirements in arid region: An example of Al-Jouf, Saudi Arabia. *J. King Saud Univ. Eng. Sci.* **2016**, *28*, 21–31. [CrossRef]
26. Radwan, G.; Ellah, A. Water resources in Egypt and their challenges, Lake Nasser case study. *Egypt. J. Aquat. Res.* **2020**, *46*, 1–12.
27. Khordagui, H. Climate change in ESCWA region: Reasons for concern. In Proceedings of the Expert Group Meeting on Trade and Environment Priorities in the Arab Region, Cairo, Egypt, 11–13 November 2007.
28. IPCC. *Climate Change 2007: The Physical Science Basis, Summary for Policy Makers. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, WMO*; UNEP: Nairobi, Kenya, 2007; 18p.