Article

Potential Climate Change Impacts on Water Resources in Egypt

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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/ScenGen 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

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 CO₂ 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 CO₂ 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 (CO₂), methane, and others. Globally, the emissions of CO₂ 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 CO₂ 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 m³ 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 km². 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 m²).

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).
CROPWAT 8.0 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].

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 ($E_{\text{To}}$)

The $E_{\text{To}}$ was calculated by FAO Penman–Monteith method, using the decision support software CROPWAT 8.0 developed by FAO, based on Allen et al. [20]. The equation used for calculating $E_{\text{To}}$ is described as follows:

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

(1)
where $E_{To}$ is the reference crop evapotranspiration (mm day$^{-1}$), $R_n$ 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 ($^\circ$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), $\Delta$ is the slope of the pressure-temperature curve (kPa $^\circ$C$^{-1}$), and $\gamma$ is the psychrometric constant (kPa $^\circ$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 ($E_{To}$), by crop coefficient ($K_c$):

$$\text{ETc} = K_c \times E_{To}$$

where: ETc is the crop evapotranspiration (mm day$^{-1}$), $K_c$ is the crop coefficient (dimensionless), and $E_{To}$ is the reference crop evapotranspiration (mm day$^{-1}$).

3.1.3. Calculation of the Irrigation Water Requirements (IWR)

$$\text{IWR} = \frac{\text{ETc}}{\text{IE}}$$

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 pat-
terns 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/SCENGEN 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.
Average irrigation water requirements (IWR) for some main winter crops in Middle Egypt under current and climate change conditions over 30 years.

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.

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 5423 to 7420 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.
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 m³/ha for cotton; 9362 and 12,517 m³/ha for maize; 6308 and 8790 m³/ha for sunflower; 7002 and 10,400 m³/ha for potato; and 11,180 and 15,535 m³/ha for tomato. However, in 2050, the values varied from 11,888 to 16,538 m³/ha for cotton; 9782 to 13,107 m³/ha for maize; 6585 to 9218 m³/ha for sunflower; 7360 to 10,962 m³/ha for potato; and 11,700 to 16,330 m³/ha for tomato.

In 2100, they ranged from 12,367 to 17,273 m³/ha for cotton; 10,178 to 13,665 m³/ha for maize; 6842 to 9610 m³/ha for sunflower; 7690 to 11,513 m³/ha for potato; and 12,182 to 17,073 m³/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 m³/ha for potato and 10,567 to 14,142 m³/ha for tomato. Concerning the values in 2050, the amounts varied from 9963 to 13,222 m³/ha for potato and 11,077 to 14,858 m³/ha for tomato. In 2100, the values ranged from 10,382 to 13,797 m³/ha for potato and 11,560 to 15,525 m³/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.
Table 1. Impacts on Water Resources in Egypt.

| Crop          | Area (ha) (Current) | IWR (2050) | IWR (2100) | IWR (2050) | IWR (2100) |
|---------------|---------------------|------------|------------|------------|------------|
| Cotton        | 654                  | 3,284,969  | 5358       | 3,503,950  | 5667       |
| Maize         | 5023                 | 3,284,969  | 5358       | 3,503,950  | 5667       |
| Sunflower     | 1,132                | 1,549,611  | 1,957      | 1,916      | 1,916      |
| Potato (S)    | 11,974               | 15,525     | 19,388     | 19,388     | 19,388     |
| Tomato (S)    | 140.9                | 154.2      | 193.9      | 193.9      | 193.9      |

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.
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 m³ 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 m³ in 2050, and 13.4, 3.7, 1898.4, 73.4, and 81.0 million m³ 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 71.5 million m³; 147.9, 3032.6, 10.7, 49.1, and 73.4 million m³ in 2050; and 154.2, 3164.0, 10.7, 51.5, and 76.7 million m³ 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).

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 m³ under current conditions; 3.4, 0.45, 85.8, 3.1, and 35.1 million m³ in 2050; and 3.6, 0.48, 90.3, 3.3, and 37.1 million m³ 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 m³ for current conditions; 82.0, 1.18, 1.95, and 47.1 million m³ in 2050; and 85.6, 1.23, 2.05, and 49.2 million m³ 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.

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