



# Climate change impact on economic and irrigation requirements for sugarcane crop in Egypt

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Availability of irrigation water is considered one of the major challenges faced by Egypt currently and will become increasingly difficult in the future due to the limited water resources and linear increase of population. The current study investigates irrigation demand for sugarcane cultivation areas in the Middle and Upper Egypt Governorates (Menia, Asyut, Sohag, Qena, Luxor and Aswan) during present times and under representative concentration pathways (RCP) scenarios. The data was collected within the period between 1971 and 2000, and the RCP data were collected for different scenarios (RCP 3, RCP 4.5, RCP 6 and RCP 8.5) during three-time series (2011-2040, 2041-2070 and 2071-2100). The highest evapotranspiration (ET<sub>o</sub>) values during current and future conditions were found in Luxor and Aswan governorates; while the lowest ET<sub>o</sub> values were recorded in Menia and Asyut. All RCPs scenarios were significantly higher than the current conditions. Moreover, the highest irrigation requirements under RCP scenarios were recorded in Aswan and Luxor under RCP 8.5 during 2071-2100 time series. While Menia, under RCP3 at 2011-2040 recorded the lowest irrigation water needs under climate change. Interpolated maps were done for the clear appearance of the difference between water requirements under different climatic condition. The advantage of the current work was to give a clear vision related to the economic status of irrigation water management under current and future conditions for one of the major crops in Egypt.

## 1. Introduction

Sugarcane is considered the main ingredient source for the sugar and molasses industry in Egypt. Besides, Egyptian consume it fresh or as juice, and the industry by-products are used in the ethyl alcohol, active yeast, citric and acetic acid, paper and pulp industries (El-Kholi, 2008). The agriculture sector is considered to be one of the most prominent water-consuming sectors, totalling 82% of all consumption or 75 billion cubic meters. Irrigation water is a vital element in agriculture and the basis for agricultural expansion.

Therefore, the problem of limited water resources and the subsequent low efficiency of irrigation limits the possibility of more land reclamation. Egypt is classified as a water-poverty country, which means that it is unable to provide food and employment opportunities (Yasmen, 2015). The limited water resources weigh negatively on the cultivation of sugarcane that needs nearly 13-15 thousand cubic meters of water per feddan (one feddan equal 4200 m<sup>2</sup>), compared to 2.5-3.0 thousand cubic meters for the sugar beet.

Agriculture is the basis for Egypt's economy, and one of the primary sources of income for almost half of the Egyptian population and therefore plays a vital role in sustainable economic development. Also, the agricultural sector provides raw materials for industrial purposes. The sustainability of these roles requires economic development derived from two main factors, increase the productivity per water unit and increase the cultivated area (Farak *et al.*, 2017). Current and future water resources are the limiting factor among the other economic production factors (Raouf, 1996). The economy in Upper Egypt is heavily dependent on refined sugarcane sugar. The cultivation of sugarcane in Upper Egypt is directly connected with the livelihoods of 200,000 families (sugarcane farmers). Almost 5.3 million people are dependent on sugarcane growing and sugar production. Nearly 300,000 families are connected to the sugarcane business indirectly (Omar and Tate, 2019). Furthermore, sugarcane is preferred over beets in the climate change scenario because of the attractive price offered by the government, making it the cash crop (Elasraag, 2019).

However, high temperatures are likely to negatively affect water management practices for agriculture under the current climate conditions. An increase in water demand for irrigation is projected under a warmer climate (Krol & Bronstert, 2007). Climate change will increase the average daily air temperature for each climate region, which leads to increased daily evaporation and then increased irrigation water needs. It is well known that climate change is considered a challenge for irrigation system capacity to meet the anticipated increase in net daily evaporation. Higher evaporation due to high temperatures can result in drought stress in sugarcane fields; higher irrigation quantities with more frequent irrigation events will have to be done to meet higher irrigation water demands (Chandiposha, 2013).

The RCPs are called 'Representative Concentration Pathways' because they were developed to be 'representative' of possible future emissions and concentration scenarios published in the IPCC's fifth assessment report (IPCC, 2013). Irrigation water requirements were projected to increase by around 50% in developing regions and 16% in developed regions. Knox *et al.* (2010) used the DSSAT-Canegro model to predict that expected climate change in the 2050s could increase sugarcane irrigation requirements in

Swaziland by +9%, and sucrose yields by about 15%. Conventional irrigation methods are not appropriate to sugarcane with limited irrigation water availability; the irrigation sector in Egypt faces a rapid decline in the availability of irrigation water and low water-use efficiency in the flood irrigation method (conventional) (Hanafy *et al.*, 2008).

Water pumps are often used continuously over hours, and as a result, they account for a large part of fuel consumption and CO<sub>2</sub> emission of general-purpose. Therefore, the fuel consumption of such pumps should be improved. Previous studies forecasted that water pumps would account for 85% of fuel consumption and CO<sub>2</sub> emissions of agriculture machinery (tractor, mower, power carrier, tiller and water pump) (Naohiro & Takahide, 2015). The increase in diesel price led to renewed interest in conducting efficiency evaluations method of diesel irrigation pumping (Henggeler *et al.*, 2004). The target of this study is to estimate the trend of temperature, reference ETo and water irrigation demands for sugarcane crop under climate change conditions according to IPCC fifth assessment report (RCP scenarios) in six governorates.

## 2. Material and methods

### 2.1. Study area

Egypt has several recognised agro-climatic regions according to climatic data. Upper Egypt and south of Middle Egypt are considered the most critical agro-climatic regions for sugarcane production. The studied area from North to South contained six governorates: Menia, Asyut, Sohag, Qena, Luxor and Aswan. The daily historical climate data of minimum and maximum air temperature, relative humidity, wind speed and solar radiation were collected from the Central Laboratory for Agricultural Climate and Egyptian Authority of Meteorology. The average monthly data from 1971 to 2000 were estimated from the collected daily data. The data for different locations were collected from meteorological stations of the different regions. The coordinates of the concerned automated weather stations are presented in Table (1).

### 2.2. Climate change scenarios

The IPCC released a set of climate change scenarios based on representative concentration pathways



**Table 1.** The coordinates of automated weather stations used in this study

| No. | Station | Latitude (°N) | Longitude (°E) | Altitude (m) |
|-----|---------|---------------|----------------|--------------|
| 1   | Menia   |               |                |              |
| 2   | Asyut   | 28.5          | 30.4           | 44           |
| 3   | Sohag   | 27.3          | 31.2           | 56           |
| 4   | Qena    | 26.6          | 31.6           | 68           |
| 5   | Luxor   | 26.1          | 32.7           | 72           |
| 6   | Aswan   | 25.4          | 32.5           | 80           |
|     |         | 24.0          | 32.9           | 108          |

(RCPs) (Ritchie & Dowlatabadi, 2017). The RCP scenarios involve widely differing emissions pathways, reflecting different levels of effectiveness in tackling emissions and climate change (IPCC, 2013).

### 2.3. Data and Projections

The data projection was customised to the Middle and Upper Egypt regions in six governorates (Menia, Asyut, Sohag, Qena, Luxor and Aswan), downscaled climate data for these governorates were drawn from ClimaScope website <http://climascope.tyndall.ac.uk>.

### 2.4. ETo calculation

ETo is a measure of crop water use and was calculated, for both, current and future conditions using the Food and Agricultural Organization (FAO-56) Penman-Monteith (PM) procedure presented by Allen *et al.* (1998). The FAO Penman-Monteith equation predicts the evapotranspiration from a hypothetical grass reference surface that is 0.12 m in height having a surface resistance of 70 s m<sup>-1</sup> and albedo of 0.23. The equation provides a standard to which evapotranspiration can be computed. The evapotranspiration from other crops can be related in different periods of the year or other regions.

### 2.5. Irrigation requirement for sugarcane

The irrigation requirements for sugarcane are calculated according to Allen *et al.* (1998). The irrigation requirement for sugarcane was estimated according to the following equation:

$$IR = (ET_o * K_c) + LR * E_a * 4.2$$

Where:

IR= irrigation requirement for sugarcane m<sup>3</sup> / feddan/ day

K<sub>c</sub>= Crop coefficient [dimensionless].

E<sub>To</sub>= Reference crop evapotranspiration [mm/day].

LR= Leaching requirement LR (%) (assumed 20% of the total applied water).

E<sub>a</sub>= efficiency of the irrigation application (50% flood irrigation and 80% gated pipes)

4.2= to convert water requirements from millimetre per day to cubic meter per feddan per day (Feddan = 4200 m<sup>2</sup>)

### 2.6. Interpolation technique (GIS)

The ordinary kriging interpolation method is a standard technique for spatial interpolation (Farag *et al.* 2014). It provides each cell with a local, optimal prediction and an estimation of the error that depends on the variogram and the spatial configuration of the data. Kriging with external drift incorporates secondary information into the kriging system when the main and second variables are correlated (Esri, 2012). In our case, altitude was evaluated as a secondary variable. Although similar to universal kriging, it uses an ancillary variable, which varies smoothly in space, to represent the trend instead of the spatial coordinates (Goovaerts, 2000).

### 2.7. Estimate pumping water cost per hour

Pumping costs: Pumping water costs were divided into two main categories: (i) fixed cost and (ii) operating costs, which vary directly with the number of operating hours. The calculation assumed the pumps to have 150 -200 m<sup>3</sup>/h discharge, engine power 8 horsepower, and fuel consumption of 0.12 L/horsepower/hour (L/hp/h). The value of these costs can be estimated by making a few assumptions about machine



life, annual use, fuel and labour prices (Thompson *et al.*, 2002). Fixed costs included depreciation, interest (opportunity cost), taxes, insurance, and housing facilities. Variable costs included repairs, maintenance, fuel, lubrication, and operator labour. The average cost of pumping one cubic meter of water was estimated by 0.12 L.E. (Egyptian pound) according to Hanafy *et al.* (2008).

### 2.8. Statistical analysis

Statistical analysis was carried out using SAS software. The paired t-test was used to establish whether there exist significant differences in the current ETo from 1998 to 2007 and estimated ETo under climate change in the 2050s, 2100s at significant level 0.05 (SAS, 2000).

## 3. Results and discussion

### 3.1. Trend of ETo, current and future

The average monthly ETo values for the concerned governorates under current and future (2011-2040, 2041-2070 and 2071-2100) conditions are presented in Tables (2 and 3). Table 2 represents the Menia governorate or Middle Egypt governorates whereas Table 3 represents the Aswan governorate or the Upper Egypt governorate. The other studied governorate is tabulated in the annexe. There were significant differ-

ences among the irrigation requirement under current and future scenarios.

Data indicated that the highest monthly ETo values during current and future conditions was found in Luxor and Aswan; while the lowest ETo values were recorded in Menia. The highest monthly ETo values for the concerned region under the current situation was recorded during the summer months (June, July and August), while the lowest monthly ETo was recorded in the winter months (December, January and February). Concerning the monthly ETo in the different studied time series (2011-2040, 2041-2070 and 2071-2100), all scenarios expected significant increase of ETo values in different studied time series compared to current climatic conditions.

The lowest ETo values were projected under RCP3; while the highest was expected under RCP8.5 in all governorates. All ETo values under climate change scenarios were significantly higher than the current conditions. We can conclude that all RCP scenarios were significantly higher than the current conditions. Moreover, the highest ETo under RCP scenarios was recorded in Aswan and Luxor under RCP 8.5 during 2071-2100 time series. In contrast, the lowest ETo under climate change were found in Menia under RCP3 during 2011-2040 time series.

**Table 2.** Average reference ETo under current and future conditions at Menia Governorate

| month   | Current   |           | RCP 3     |           | RCP4.5    |           |           | RCP 6     |           |           | RCP 8.5   |           |           |
|---------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|         | 1971-2000 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 |
| Jan     | 2.71      | 2.89      | 3.12      | 3.36      | 2.88      | 3.01      | 3.09      | 2.87      | 2.99      | 3.15      | 2.89      | 3.12      | 3.36      |
| Feb     | 3.37      | 3.64      | 3.87      | 4.13      | 3.61      | 3.76      | 3.85      | 3.59      | 3.75      | 3.92      | 3.64      | 3.87      | 4.13      |
| Mar     | 5.60      | 5.96      | 6.31      | 6.68      | 5.96      | 6.13      | 6.22      | 5.94      | 6.09      | 6.34      | 5.96      | 6.31      | 6.68      |
| Apr     | 8.08      | 8.46      | 9.07      | 9.71      | 8.44      | 8.76      | 8.98      | 8.44      | 8.75      | 9.11      | 8.46      | 9.07      | 9.71      |
| May     | 10.52     | 10.96     | 11.60     | 12.34     | 10.95     | 11.28     | 11.49     | 10.93     | 11.22     | 11.73     | 10.96     | 11.60     | 12.34     |
| Jun     | 10.92     | 11.58     | 12.25     | 13.15     | 11.47     | 11.95     | 12.18     | 11.39     | 11.87     | 12.45     | 11.58     | 12.25     | 13.15     |
| Jul     | 10.16     | 10.73     | 11.56     | 12.47     | 10.67     | 11.17     | 11.42     | 10.66     | 11.06     | 11.65     | 10.73     | 11.56     | 12.47     |
| Aug     | 9.17      | 9.76      | 10.59     | 11.50     | 9.76      | 10.24     | 10.44     | 9.73      | 10.14     | 10.74     | 9.76      | 10.59     | 11.50     |
| Sep     | 7.69      | 7.98      | 8.49      | 9.04      | 7.95      | 8.24      | 8.40      | 7.92      | 8.19      | 8.54      | 7.98      | 8.49      | 9.04      |
| Oct     | 5.80      | 6.15      | 6.61      | 7.12      | 6.14      | 6.37      | 6.52      | 6.10      | 6.33      | 6.65      | 6.15      | 6.61      | 7.12      |
| Nov     | 3.66      | 3.95      | 4.24      | 4.55      | 3.93      | 4.09      | 4.18      | 3.91      | 4.08      | 4.26      | 3.95      | 4.24      | 4.55      |
| Dec     | 2.60      | 2.82      | 3.04      | 3.29      | 2.81      | 2.92      | 3.00      | 2.79      | 2.90      | 3.06      | 2.82      | 3.04      | 3.29      |
| average | 6.69      | 7.07      | 7.56      | 8.11      | 7.05      | 7.33      | 7.48      | 7.02      | 7.28      | 7.63      | 7.07      | 7.56      | 8.11      |
| P-Value |           | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         |

\* Significant at P < 0.05



**Table 3.** Average reference ETo under current and future conditions at Aswan Governorate

| month          | Current   |           | RCP 3     |           | RCP4.5    |           | RCP 6     |           | RCP 8.5   |           |           |           |           |
|----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                | 1971-2000 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 |
| Jan            | 3.24      | 3.45      | 3.55      | 3.55      | 3.48      | 3.70      | 3.82      | 3.45      | 3.69      | 3.95      | 3.50      | 3.88      | 4.33      |
| Feb            | 5.60      | 5.89      | 6.01      | 5.99      | 5.90      | 6.14      | 6.27      | 5.89      | 6.12      | 6.42      | 5.95      | 6.39      | 6.79      |
| Mar            | 6.80      | 7.18      | 7.36      | 7.36      | 7.21      | 7.54      | 7.70      | 7.18      | 7.52      | 7.89      | 7.25      | 7.78      | 8.43      |
| Apr            | 10.80     | 11.19     | 11.37     | 11.37     | 11.22     | 11.62     | 11.89     | 11.19     | 11.59     | 12.06     | 11.23     | 12.00     | 12.84     |
| May            | 12.40     | 12.85     | 13.00     | 13.00     | 12.86     | 13.00     | 13.00     | 12.82     | 13.00     | 13.00     | 12.88     | 13.00     | 13.00     |
| Jun            | 14.00     | 14.00     | 14.00     | 14.00     | 14.00     | 14.00     | 14.00     | 14.00     | 14.00     | 14.00     | 14.00     | 14.00     | 14.00     |
| Jul            | 13.48     | 14.06     | 14.30     | 14.30     | 14.06     | 14.61     | 14.84     | 14.04     | 14.52     | 15.00     | 14.08     | 15.00     | 15.00     |
| Aug            | 12.26     | 12.98     | 13.00     | 13.00     | 12.99     | 13.00     | 13.00     | 12.96     | 13.00     | 13.00     | 13.00     | 13.00     | 13.00     |
| Sep            | 11.02     | 11.40     | 11.57     | 11.56     | 11.40     | 11.82     | 12.05     | 11.39     | 11.76     | 12.23     | 11.42     | 12.13     | 12.96     |
| Oct            | 9.71      | 9.99      | 10.17     | 10.13     | 9.99      | 10.43     | 10.63     | 9.99      | 10.34     | 10.77     | 10.09     | 10.69     | 11.41     |
| Nov            | 5.91      | 6.26      | 6.37      | 6.36      | 6.29      | 6.55      | 6.70      | 6.25      | 6.55      | 6.83      | 6.29      | 6.80      | 7.33      |
| Dec            | 4.20      | 4.43      | 4.56      | 4.55      | 4.44      | 4.67      | 4.81      | 4.43      | 4.64      | 4.93      | 4.49      | 4.86      | 5.33      |
| average        | 9.12      | 9.47      | 9.61      | 9.60      | 9.49      | 9.76      | 9.89      | 9.47      | 9.73      | 10.01     | 9.51      | 9.96      | 10.37     |
| <i>P-Value</i> |           | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         |

\* Significant at  $P < 0.05$

### 3.2. Irrigation requirements for sugarcane under current and future conditions

Data in Table (4) show the irrigation requirement values under the current and different RCP scenarios in major areas of sugarcane production in the Middle and Upper Egypt governorates. The irrigation requirement values (cubic meter/feddan/season) for sugarcane under RCPs scenarios ranged between 8618.8m<sup>3</sup>/feddan (RCP3 at 2011-2040 in Menia using a gated pipe) to 16768 m<sup>3</sup>/feddan (RCP 8.5 at 2071-2100 in Aswan using flood irrigation). Concerning the RCPs scenarios and time series, Aswan governorate had the highest irrigation requirements, followed by Luxor and Qena. In contrast, Menia and Asyut had the lowest irrigation requirements for sugarcane. It could be concluded that the highest predicted irrigation requirements for sugarcane were found in the Upper Egypt governorates during different time series, while the lowest water requirement was found in Middle Egypt Governorate (Menia). Generally, the predicted irrigation requirement gradually increased with time series (2011-2040, 2041-2070 and 2071-2100) under different RCPs scenarios to reach the maximum predicted values during 2071–2100. The RCP 8.5 scenario had the highest irrigation requirements for sugarcane crop

under the different governorates compared to the other RCPs scenarios.

Finally, flood irrigation (conventional irrigation method) had a higher irrigation requirement than the gated pipe irrigation system under all tested scenarios and time series. Irrigation requirement under gated pipe irrigation system was lower than flood irrigation system by about 28.56%. This result can be one of the adaptation options for the management of irrigation water for sugarcane under climate change conditions. These results agreed with Abdrabbo *et al.* (2013), Abdrabbo *et al.* (2015), and Farag *et al.* (2014). They reported that air temperature under climate change will be higher than current conditions and that irrigation requirements will be higher under different agro-ecological zones by uneven rates. Nour El-Din, (2013) concluded that low irrigation efficiency of conventional flood irrigation system increases the vulnerability of the water sector in Egypt because more water is needed to irrigate the cultivated crop. Under this study, using a gated pipe irrigation system is considered one of the solutions for low water use efficiency for the irrigation system. Abdrabbo *et al.* (2015) mentioned that ETo would be increased by 10-12% in the Nile Delta and will be increased by about 20% in



Upper Egypt, meaning that Upper Egypt will be more vulnerable to the irrigation water availability (Farag *et al.* 2014). Irrigation performance in Egypt is the overall result of existing climatic conditions, irrigation systems and availability of investment (Hamdy, 2007).

The projected future temperature rises under climate change scenarios are likely to increase irrigation demands, thereby directly decreasing irrigation water use efficiency for all crops. The increase in the ETo in Egypt is projected to augment the national irrigation-demands by 10-20% during the 2100s. The

availability of irrigation water is considered a regional problem under projected climate change. Climate assessment reports for the southern Africa region confirm that the region will become warmer and drier. The air temperature is predicted to increase by 2-5oC over coming decades (IPCC, 2007) and increasingly varied rainfall is anticipated, with the region becoming generally drier, especially in the east. The consequence of these combined impacts of climate change is expected to reduce the productivity of several crops (Lobell *et al.*, 2008).

### 3.3. Interpolation for irrigation water requirement

**Table 4.** Water requirements (cubic meter per feddan /season) for sugarcane in the Middle and Upper Egypt governorates using flood or gated pipe irrigation system under current and future conditions.

|                  | Current   | RCP3      |           | RCP4.5    |           | RCP 6     |           | RCP 8.5   |           |           |       |       |       |
|------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-------|-------|-------|
|                  | 1971-2000 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 |       |       |       |
| <b>Menia</b>     |           |           |           |           |           |           |           |           |           |           |       |       |       |
| flood irrigation | 11500     | 12066     | 12257     | 12245     | 12085     | 12543     | 12804     | 12049     | 12474     | 13058     | 12135 | 12932 | 13843 |
| Gated pipes      | 8214      | 8619      | 8755      | 8747      | 8632      | 8960      | 9146      | 8607      | 8910      | 9327      | 8668  | 9237  | 9888  |
| <b>P-Value</b>   |           | *         | *         | *         | *         | *         | *         | *         | *         | *         | *     | *     | *     |
| <b>Asyut</b>     |           |           |           |           |           |           |           |           |           |           |       |       |       |
| flood irrigation | 11776     | 12301     | 12519     | 12489     | 12316     | 12817     | 13070     | 12268     | 12777     | 13335     | 12381 | 13246 | 14211 |
| Gated pipes      | 8412      | 8786      | 8942      | 8921      | 8797      | 9155      | 9336      | 8763      | 9126      | 9525      | 8844  | 9461  | 10151 |
| <b>P-Value</b>   |           | *         | *         | *         | *         | *         | *         | *         | *         | *         | *     | *     | *     |
| <b>Sohag</b>     |           |           |           |           |           |           |           |           |           |           |       |       |       |
| flood irrigation | 12455     | 12893     | 13067     | 13049     | 12895     | 13388     | 13530     | 12865     | 13331     | 13848     | 12975 | 13709 | 14585 |
| Gated pipes      | 8897      | 9209      | 9334      | 9321      | 9211      | 9563      | 9665      | 9189      | 9522      | 9892      | 9268  | 9792  | 10418 |
| <b>P-Value</b>   |           | *         | *         | *         | *         | *         | *         | *         | *         | *         | *     | *     | *     |
| <b>Qena</b>      |           |           |           |           |           |           |           |           |           |           |       |       |       |
| flood irrigation | 12826     | 13294     | 13553     | 13543     | 13329     | 13855     | 14138     | 13265     | 13754     | 14433     | 13381 | 14267 | 15025 |
| Gated pipes      | 9162      | 9496      | 9681      | 9673      | 9521      | 9897      | 10099     | 9475      | 9824      | 10309     | 9558  | 10191 | 10732 |
| <b>P-Value</b>   |           | *         | *         | *         | *         | *         | *         | *         | *         | *         | *     | *     | *     |
| <b>Luxor</b>     |           |           |           |           |           |           |           |           |           |           |       |       |       |
| flood irrigation | 13693     | 14276     | 14390     | 14390     | 14320     | 14678     | 14988     | 14242     | 14644     | 15104     | 14336 | 15076 | 15893 |
| Gated pipes      | 9781      | 10197     | 10279     | 10279     | 10229     | 10484     | 10706     | 10173     | 10460     | 10788     | 10240 | 10769 | 11352 |
| <b>P-Value</b>   |           | *         | *         | *         | *         | *         | *         | *         | *         | *         | *     | *     | *     |
| <b>Aswan</b>     |           |           |           |           |           |           |           |           |           |           |       |       |       |
| flood irrigation | 14955     | 15478     | 15696     | 15692     | 15502     | 15913     | 16114     | 15466     | 15877     | 16283     | 15540 | 16221 | 16769 |
| Gated pipes      | 10682     | 11056     | 11212     | 11209     | 11073     | 11366     | 11510     | 11047     | 11340     | 11631     | 11100 | 11587 | 11978 |
| <b>P-Value</b>   |           | *         | *         | *         | *         | *         | *         | *         | *         | *         | *     | *     | *     |

\* Significant at  $P < 0.05$

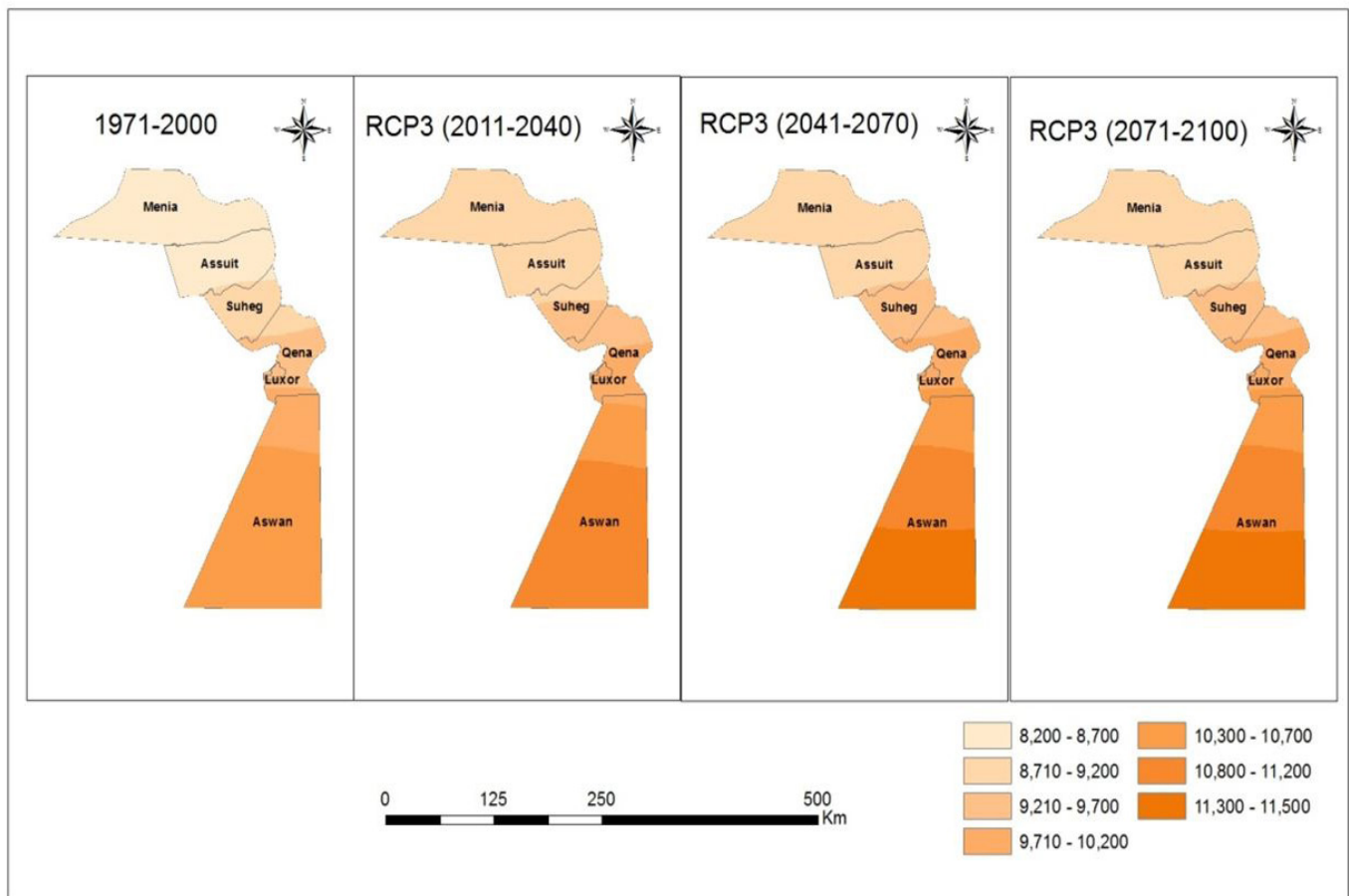
## for the sugarcane

Figures 1, 2, 3 and 4 show the interpolation maps of total seasonal irrigation requirement (cubic meter per feddan) values for the major sugarcane production governorates in Middle and Upper Egypt. Each governorate was represented in the maps by using their corresponding coordinates. The interpolated maps created regions based on the similar irrigation requirement values; the same colour represents the value of irrigation requirement in the range of this region. Menia governorate had the lowest irrigation requirement value in comparison to the other locations, and it was recognised by the lighter colour. In contrast, Aswan governorate had the highest irrigation requirement values under current and RCPs scenarios. The interpolated maps confirmed that also the irrigation requirement values under different time series (2011-2040, 2041-2070 and 2071-2100) were higher than those values under the current situations. The interpolation indicated that the area of the dark col-

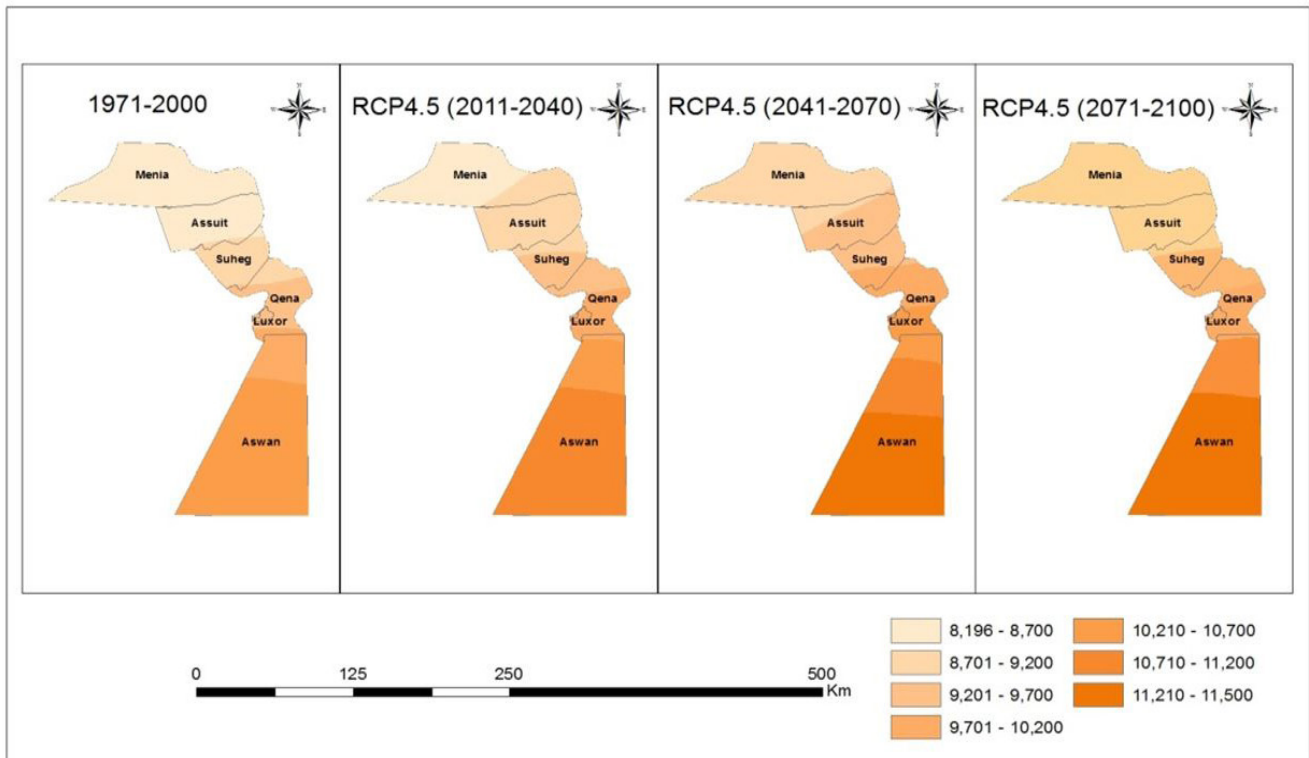
our (highest irrigation requirements) in Upper Egypt which contained Aswan and Luxor become larger under RCP 8.5 and under time series 2071-2100. This data confirm the finding above. The irrigation requirements in Aswan are higher than the other studied governorates, and RCP 8.5 had the highest water requirements in 2071-2100 time series. These results agreed with Farag *et al.* (2014) who reported that using interpolation technique helps demonstrate the climatic data under current conditions and climate change to help the decision-makers draw an accurate plan for future irrigation water management.

### 3.4. Fuel requirements for sugarcane crop under current and future conditions

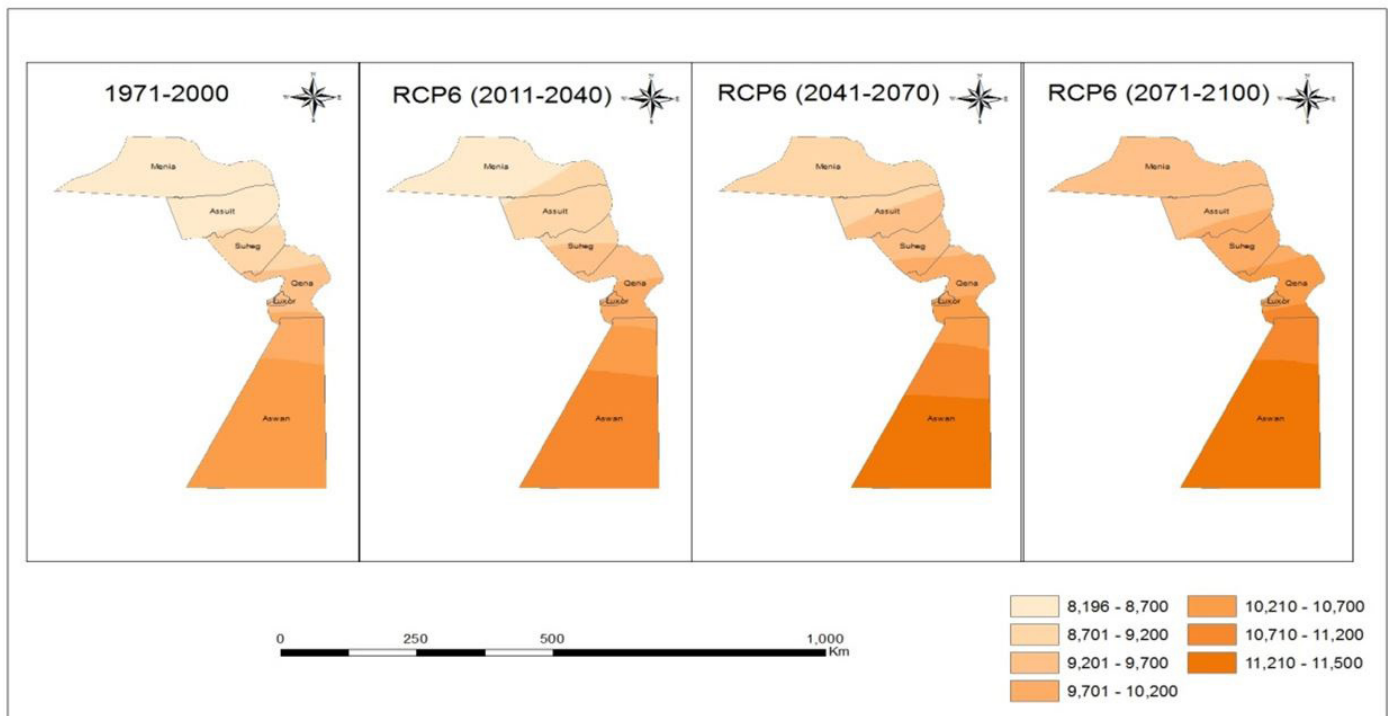
Data in Table (5) show that the total fuel requirement for sugarcane will increase under all RCPs scenarios in comparison with the current conditions. Total fuel requirement in Upper Egypt governorates was higher than in Middle Egypt governorates. Fuel require-



**Fig. 1.** Interpolation maps of total irrigation requirement values for sugarcane under current (1971 – 2000) and RCP3 conditions at 2011-2040, 2041-2070 and 2071 - 2100.

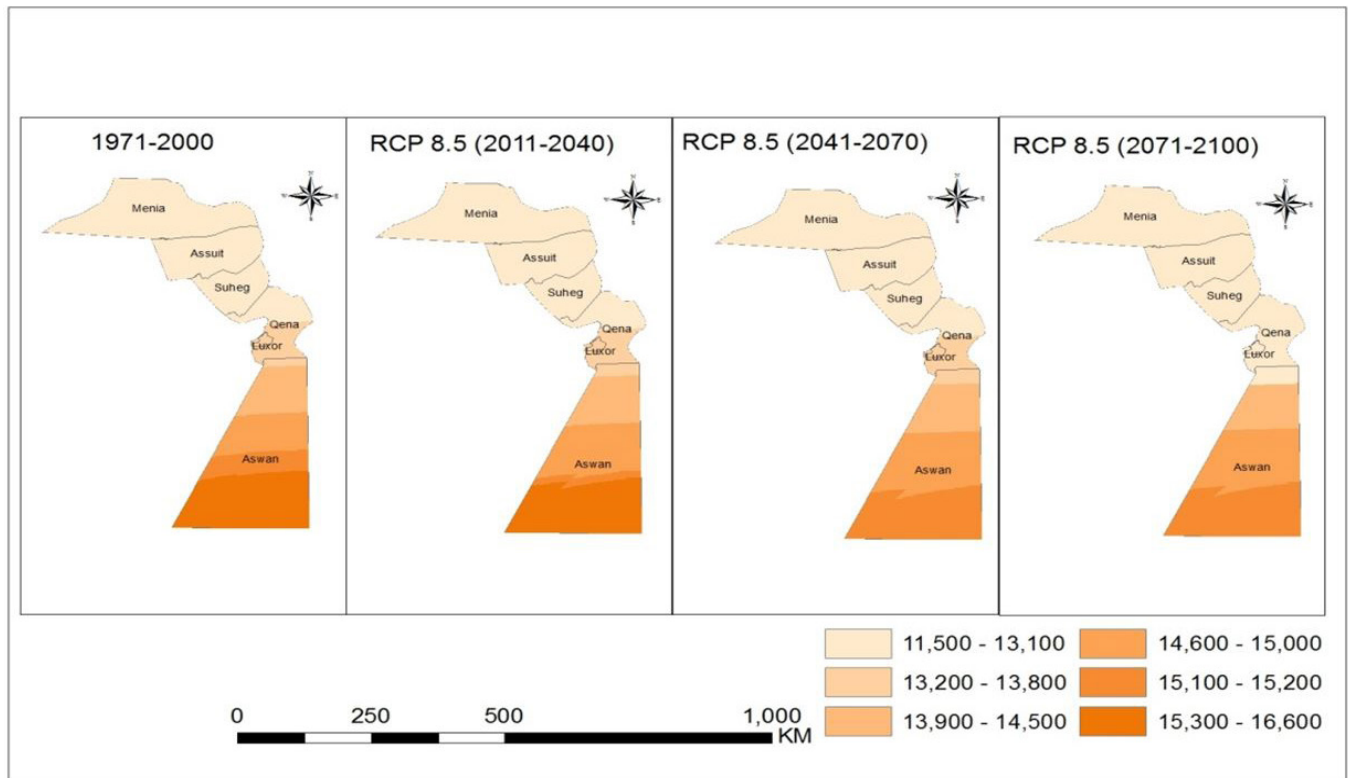


**Fig. 2.** Interpolation maps of total irrigation requirement values for sugarcane under the current (1971 – 2000) and RCP4.5 conditions at 2011-2040, 2041-2070 and 2071 - 2100.



**Fig. 3.** Interpolation maps of total irrigation requirement values for sugarcane under the current (1971 – 2000) and RCP6 conditions at 2011-2040, 2041-2070 and 2071 - 2100.





**Fig. 4.** Interpolation maps of total irrigation requirement values for sugarcane under the current (1971 – 2000) and RCP8.5 conditions at 2011-2040, 2041-2070 and 2071 - 2100.

ment increased under all RCPs scenarios as follow: RCP3 increase by 5%, RCP4.5 increase by 8%, RCP6 increase by 10% and RCP8.5 increase by 12% compared to the fuel requirements under current conditions. The highest fuel requirement was found under RCP8.5 at time series 2071–2100. This data agreed with Naohiro and Takahide (2015) and Henggeler *et al.* (2004), who concluded that the consumption of fuel would increase gradually with increasing air temperature and water consumption. The same authors added that the operation period would increase with increasing water need, and the fuel consumption will increase due to the impacts of high temperature under climate change based on climate change scenarios.

### 3.5. Cost of irrigation for sugarcane crop under current and future conditions

Data in Table (10) shows the seasonal water pumping cost (diesel cost + fixed cost + operating cost) of a flood irrigation system in the six governorates (Menia, Asyut, Sohag, Qena, Luxor and Aswan). The average water pumping costs were around 1571 L.E in the tested governorates under current conditions. The

highest pumping cost was recorded in Aswan governorate followed by Luxor, Qena, Sohag, Asyut, and Menia (1826, 1671, 1566, 1520, 1438, and 1404 L.E, respectively). Also, Table (10) shows that the average cost (L.E/fed./season) of pumping water was around 1122 L.E under gated pipes system. Aswan governorate had the highest cost, followed by Luxor and Qena. Flood irrigation had higher pumping costs than gated pipe system by about 29% under current and future conditions. RCP8.5 scenarios had the highest pumping cost compared to the other RCP scenarios for all other time-series. Aswan governorate was highest in cost, followed by Luxor, Qena, Sohag, Asyut, and Menia (1735-1690-178-1696-1940-2047, respectively). The percentage of cost increase for RCP8.5 compared to current conditions for Aswan, Luxor, Qena, Sohag, Asyut, and Menia was 21%, 20%, 17%, 17% 16% and 12%, respectively.

It can be concluded that Aswan governorate had the highest pumping cost compared to the other governorates and thus higher production cost of sugarcane because of higher evapotranspiration than the other studied governorates. Regarding RCP scenarios,



**Table 5.** Fuel requirements (liter of diesel per feddan /season) for sugarcane in the Middle and Upper Egypt governorates using flood or gated pipe irrigation system under current and future conditions.

|                  | Current  |           | RCP3      |           | RCP4.5    |           | RCP 6     |           | RCP 8.5   |           |           |           |           |
|------------------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                  | 1971-000 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 | 2011-2040 | 2041-2070 | 2071-2100 |
| <b>Menia</b>     |          |           |           |           |           |           |           |           |           |           |           |           |           |
| flood irrigation | 62.2     | 65.3      | 66.3      | 66.2      | 65.4      | 67.9      | 69.3      | 65.2      | 67.5      | 70.6      | 65.6      | 70.0      | 74.9      |
| Gated pipes      | 44.4     | 46.6      | 47.4      | 47.3      | 46.7      | 48.5      | 49.5      | 46.6      | 48.2      | 50.5      | 46.9      | 50.0      | 53.5      |
| <b>Asyut</b>     |          |           |           |           |           |           |           |           |           |           |           |           |           |
| flood irrigation | 63.7     | 66.5      | 67.7      | 67.6      | 66.6      | 69.3      | 70.7      | 66.4      | 69.1      | 72.1      | 67.0      | 71.7      | 76.9      |
| Gated pipes      | 45.5     | 47.5      | 48.4      | 48.3      | 47.6      | 49.5      | 50.5      | 47.4      | 49.4      | 51.5      | 47.8      | 51.2      | 54.9      |
| <b>Sohag</b>     |          |           |           |           |           |           |           |           |           |           |           |           |           |
| flood irrigation | 67.4     | 69.7      | 70.7      | 70.6      | 69.8      | 72.4      | 73.2      | 69.6      | 72.1      | 74.9      | 70.2      | 74.2      | 78.9      |
| Gated pipes      | 48.1     | 49.8      | 50.5      | 50.4      | 49.8      | 51.7      | 52.3      | 49.7      | 51.5      | 53.5      | 50.1      | 53.0      | 56.4      |
| <b>Qena</b>      |          |           |           |           |           |           |           |           |           |           |           |           |           |
| flood irrigation | 69.4     | 71.9      | 73.3      | 73.3      | 72.1      | 75.0      | 76.5      | 71.8      | 74.4      | 78.1      | 72.4      | 77.2      | 81.3      |
| Gated pipes      | 49.6     | 51.4      | 52.4      | 52.3      | 51.5      | 53.5      | 54.6      | 51.3      | 53.1      | 55.8      | 51.7      | 55.1      | 58.1      |
| <b>Luxor</b>     |          |           |           |           |           |           |           |           |           |           |           |           |           |
| flood irrigation | 74.1     | 77.2      | 77.9      | 77.9      | 77.5      | 79.4      | 81.1      | 77.0      | 79.2      | 81.7      | 77.6      | 81.6      | 86.0      |
| Gated pipes      | 52.9     | 55.2      | 55.6      | 55.6      | 55.3      | 56.7      | 57.9      | 55.0      | 56.6      | 58.4      | 55.4      | 58.3      | 61.4      |
| <b>Aswan</b>     |          |           |           |           |           |           |           |           |           |           |           |           |           |
| flood irrigation | 80.9     | 83.7      | 84.9      | 84.9      | 83.9      | 86.1      | 87.2      | 83.7      | 85.9      | 88.1      | 84.1      | 87.8      | 90.7      |
| Gated pipes      | 57.8     | 59.8      | 60.7      | 60.6      | 59.9      | 61.5      | 62.3      | 59.8      | 61.4      | 62.9      | 60.0      | 62.7      | 64.8      |

RCP8.5 had the highest pumping cost followed by RCP6 while the lowest pumping cost was estimated under current conditions. Moreover, the highest pumping cost was found under time series 2071–2100, followed by 2041–2070 while the lowest pumping cost under climate change was estimated under time series 2011–2040. This data agreed with Abdrabbo *et al.*, (2015), and Naohiro and Takahide (2015) who mentioned that the water requirements would increase under RCPs scenarios compared to the current conditions and then the cost of pumping water would increase gradually with the increasing water needs. The production of sugarcane in the upper region area faces many problems such as a conventional farm irrigation system with high irrigation quantities, the low income per unit area compared with cash crops, higher cost of fuel compared with 2012 season and competition between sugarcane and sugar beet (Farag *et al.*, 2017). Climate change issues will increase the challenges which impact the sustainable production of sugarcane in Upper Egypt (Abdrabbo *et al.*, 2015).

Cultivating alternative crops in such area is not an easy undertaking because there is a lack of knowledge in terms of good agricultural practices for such crops. The current work gives the decision-maker in the irrigation sector an accurate estimation of the irrigation

requirements for sugarcane in the main cultivation area, which can help strategic measurements for future sugarcane cultivation. Alternatively, the sugarcane area from Aswan and Qena could be moved to Menia and Asyut, where there are lower evapotranspiration and lower irrigation water needs. On the other hand, Egypt already encounters a crisis related to the availability of freshwater due to linear increase in Egyptian population with limited irrigation water resources from the Nile River (Farag *et al.*, 2014). An issue which will become increasingly complicated with the construction of the Renaissance Dam by Ethiopia (Nour El-Din, 2013). The decision-maker will need such results to determine the different available options to build strategic and contingent plans that take into consideration the socioeconomic aspect related to sugarcane production in Upper Egypt. Over the last ten years, there have been many efforts on to improve water use efficiency for this area through demonstration farms that use different irrigation methods such as gated pipes or drip irrigation system to enhance the productivity of unit of water (Osaman, 2002). The primary purpose of such strategy is to conserve a significant amount of water for cultivation area expansion and to enhance the food security of Egyptian people through proper irrigation water management as well as reduce the cost of production which means higher



profits for farmers (Abdel-Raheem *et al.*, 2016).

#### 4. Summary and conclusion

The expected climate changes in Egypt, according to the RCP scenarios, will cause an increase in the ETo of all sugarcane cultivation areas. Irrigation requirements increased depending on climate change scenarios data. The expected climate changes in Egypt according to the RCP scenarios will also cause an increase in seasonal irrigation requirement for sugarcane under future climate change conditions. Using interpolated maps is an easy way to illustrate the irrigation requirements for sugarcane under climate changes for decision-makers to allow the building of future management plans. The economic study of the cost of irrigation concluded that fuel requirements

would increase with increasing irrigation requirements under all RCP scenarios, which mean an increase in the cost of sugarcane production. Further studies are needed to study the effect of irrigation efficiencies on climate-proofing sugarcane production.

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#### Conflict of Interest

**Table 6.** The costs (L.E/feddan/season) of pumping water for sugarcane in the Middle and Upper Egypt governorates using flood or gated pipe irrigation system under current and future conditions.

| Irrigation systems<br>Governorate | flood irrigation system |       |       |      |       |       | gated pipes irrigation system |       |       |      |       |       |
|-----------------------------------|-------------------------|-------|-------|------|-------|-------|-------------------------------|-------|-------|------|-------|-------|
|                                   | Menia                   | Asyut | Sohag | Qena | Luxor | Aswan | Menia                         | Asyut | Sohag | Qena | Luxor | Aswan |
| <b>(1971-2000)</b>                |                         |       |       |      |       |       |                               |       |       |      |       |       |
| Current conditions                | 1404                    | 1438  | 1520  | 1566 | 1671  | 1826  | 1003                          | 1027  | 1086  | 1118 | 1194  | 1304  |
| <b>(2011-2040)</b>                |                         |       |       |      |       |       |                               |       |       |      |       |       |
| RCP3                              | 1473                    | 1502  | 1574  | 1623 | 1743  | 1889  | 1052                          | 1073  | 1124  | 1159 | 1245  | 1350  |
| differences %                     | 5%                      | 4%    | 4%    | 4%   | 4%    | 3%    | 5%                            | 4%    | 3%    | 4%   | 4%    | 4%    |
| RCP4.5                            | 1475                    | 1503  | 1574  | 1627 | 1748  | 1832  | 1054                          | 1074  | 1124  | 1162 | 1249  | 1352  |
| differences %                     | 5%                      | 5%    | 4%    | 4%   | 5%    | 0%    | 5%                            | 5%    | 3%    | 4%   | 5%    | 4%    |
| RCP6                              | 1471                    | 1498  | 1570  | 1619 | 1738  | 1888  | 1051                          | 1070  | 1122  | 1157 | 1242  | 1349  |
| differences %                     | 5%                      | 4%    | 3%    | 3%   | 4%    | 3%    | 5%                            | 4%    | 3%    | 3%   | 4%    | 3%    |
| RCP8.5                            | 1481                    | 1511  | 1584  | 1633 | 1750  | 1897  | 1058                          | 1080  | 1131  | 1167 | 1250  | 1355  |
| differences %                     | 5%                      | 5%    | 4%    | 4%   | 5%    | 4%    | 5%                            | 5%    | 4%    | 4%   | 5%    | 4%    |
| <b>(2041-2070)</b>                |                         |       |       |      |       |       |                               |       |       |      |       |       |
| RCP3                              | 1496                    | 1528  | 1595  | 1654 | 1757  | 1916  | 1069                          | 1092  | 1139  | 1182 | 1255  | 1369  |
| differences %                     | 7%                      | 6%    | 5%    | 6%   | 5%    | 5%    | 7%                            | 6%    | 5%    | 6%   | 5%    | 5%    |
| RCP4.5                            | 1531                    | 1565  | 1634  | 1691 | 1792  | 1942  | 1094                          | 1118  | 1167  | 1208 | 1280  | 1387  |
| differences %                     | 9%                      | 9%    | 8%    | 8%   | 7%    | 6%    | 9%                            | 9%    | 7%    | 8%   | 7%    | 6%    |
| RCP6                              | 1523                    | 1560  | 1627  | 1679 | 1788  | 1938  | 1088                          | 1114  | 1162  | 1199 | 1277  | 1384  |
| differences %                     | 8%                      | 8%    | 7%    | 7%   | 7%    | 6%    | 8%                            | 8%    | 7%    | 7%   | 7%    | 6%    |
| RCP8.5                            | 1579                    | 1617  | 1673  | 1742 | 1840  | 1980  | 1128                          | 1155  | 1195  | 1244 | 1315  | 1414  |
| differences %                     | 12%                     | 12%   | 10%   | 11%  | 10%   | 8%    | 12%                           | 12%   | 10%   | 11%  | 10%   | 8%    |
| <b>(2071-2100)</b>                |                         |       |       |      |       |       |                               |       |       |      |       |       |
| RCP3                              | 1495                    | 1525  | 1593  | 1653 | 1757  | 1916  | 1068                          | 1089  | 1138  | 1181 | 1255  | 1368  |
| differences %                     | 6%                      | 6%    | 5%    | 6%   | 5%    | 5%    | 6%                            | 6%    | 5%    | 6%   | 5%    | 5%    |
| RCP4.5                            | 1563                    | 1595  | 1652  | 1726 | 1830  | 1967  | 1116                          | 1140  | 1180  | 1233 | 1307  | 1405  |
| differences %                     | 11%                     | 11%   | 9%    | 10%  | 10%   | 8%    | 11%                           | 11%   | 8%    | 9%   | 9%    | 8%    |
| RCP6                              | 1594                    | 1628  | 1690  | 1762 | 1844  | 1988  | 1139                          | 1163  | 1207  | 1258 | 1317  | 1420  |
| differences %                     | 14%                     | 13%   | 11%   | 13%  | 10%   | 9%    | 14%                           | 13%   | 12%   | 14%  | 12%   | 9%    |
| RCP8.5                            | 1690                    | 1735  | 1780  | 1834 | 1940  | 2047  | 1207                          | 1239  | 1272  | 1310 | 1386  | 1462  |
| differences %                     | 20%                     | 21%   | 17%   | 17%  | 16%   | 12%   | 20%                           | 21%   | 17%   | 17%  | 16%   | 12%   |

The authors have no conflict of interest.

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