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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 (ETo) values during current and future conditions were found in Luxor and Aswan governorates; while the lowest ETo 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 m2), 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 (Farag *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 CO2 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 CO2 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

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

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

$$IR = (ETo * Kc) + LR * Ea * 4.2$$

Where:

IR= irrigation requirement for sugarcane m3 / feddan/ day
Kc= Crop coefficient [dimensionless].
ETo= Reference crop evapotranspiration [mm/day].
LR= Leaching requirement LR (%) (assumed 20% of the total applied water).
Ea= 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 m2)

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 m3/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 differences 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

	Current	RCP 3			RCP4.5			RCP 6			RCP 8.5		
month	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*

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

	Current	RCP 3			RCP4.5			RCP 6			RCP 8.5		
month	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
P-Value		*	*	*	*	*	*	*	*	*	*	*	*

**** 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 8618.8m3/feddan (RCP3 at 2011-2040 in Menia using a gated pipe) to 16768 m3/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	2011-2040	2041-2070	2071-2100
Menia													
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
P-Value		*	*	*	*	*	*	*	*	*	*	*	*
Asyut													
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
P-Value		*	*	*	*	*	*	*	*	*	*	*	*
Sohag													
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
P-Value		*	*	*	*	*	*	*	*	*	*	*	*
Qena													
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
P-Value		*	*	*	*	*	*	*	*	*	*	*	*
Luxor													
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
P-Value		*	*	*	*	*	*	*	*	*	*	*	*
Aswan													
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
P-Value		*	*	*	*	*	*	*	*	*	*	*	*

Significant at P < 0.05

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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 colour (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-

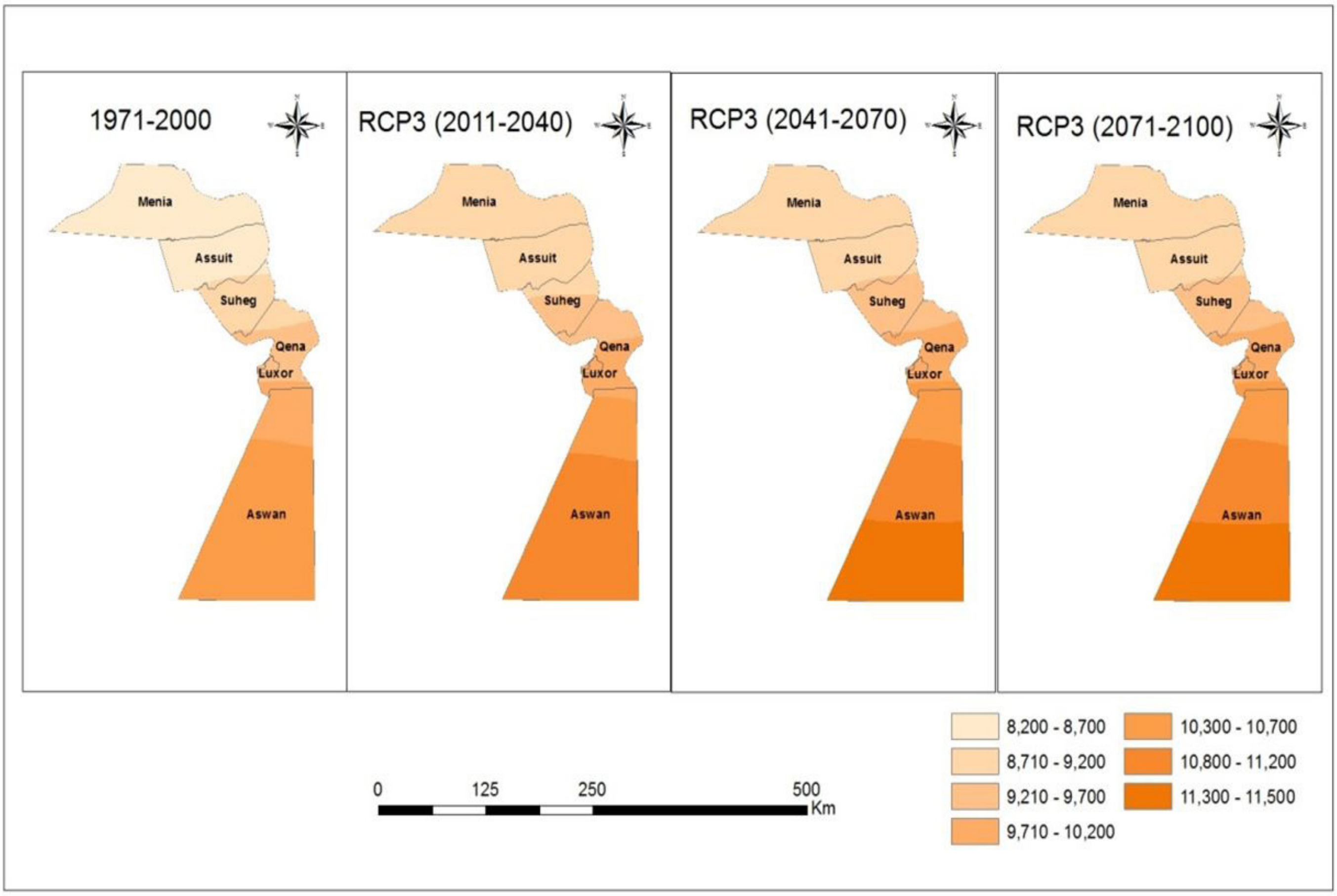

Fig. 1. Interpolation maps of total irrigation requirement values for sugarcane under current (1971 – 2000) and RCP3 conditions at 2011-2040, 2041-2070 and 2071 - 2100.

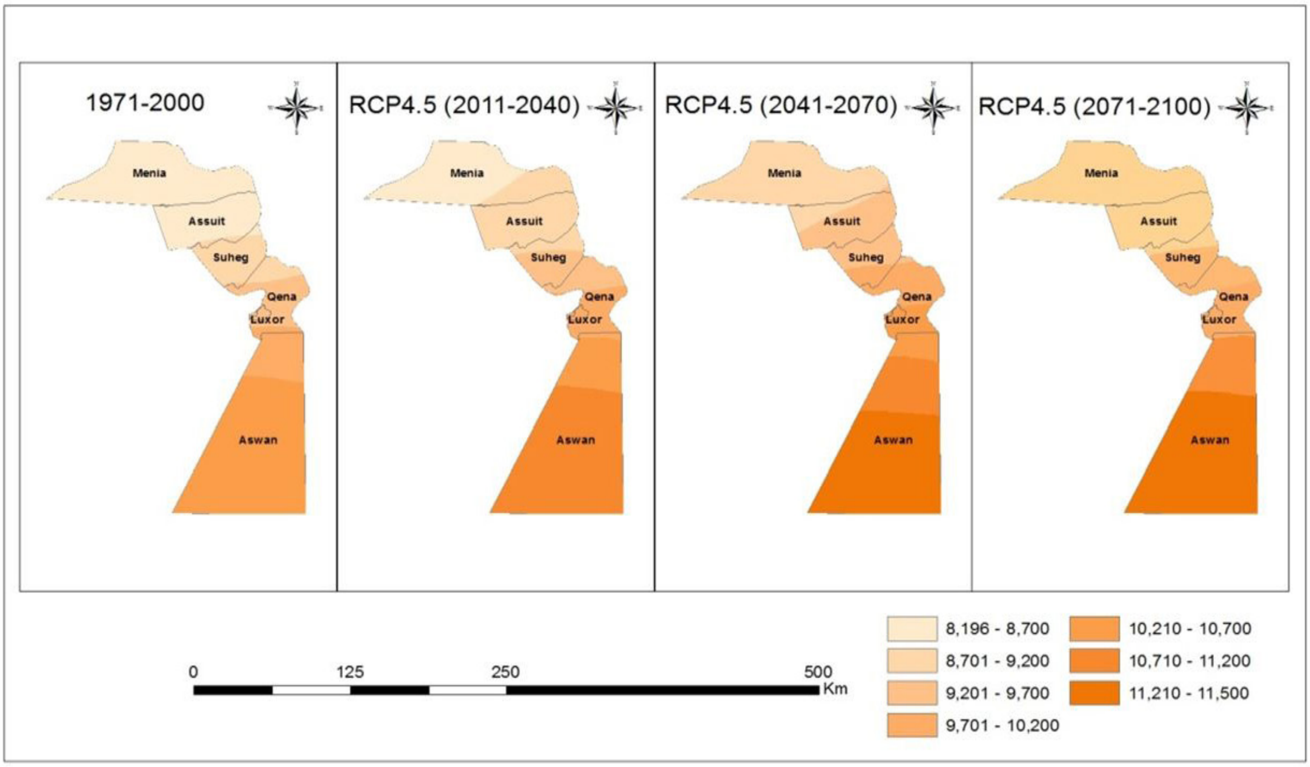

Fig. 2. Interpolation maps of total irrigation requirement values for sugarcane under the current (1971 – 2000) and RCP4.5 conditions at 2011-2040, 2041-2070 and 2071 - 2100.

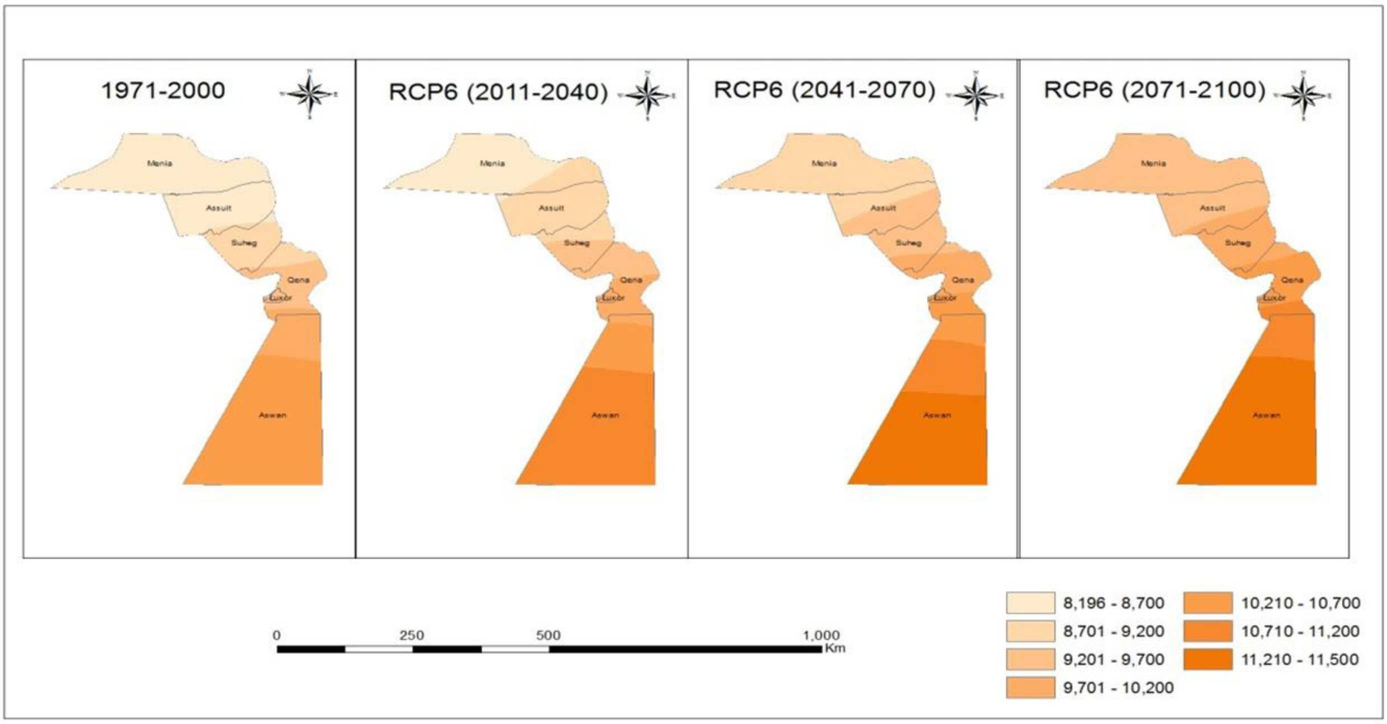

Fig. 3. Interpolation maps of total irrigation requirement values for sugarcane under the current (1971 – 2000) and RCP6 conditions at 2011-2040, 2041-2070 and 2071 - 2100.

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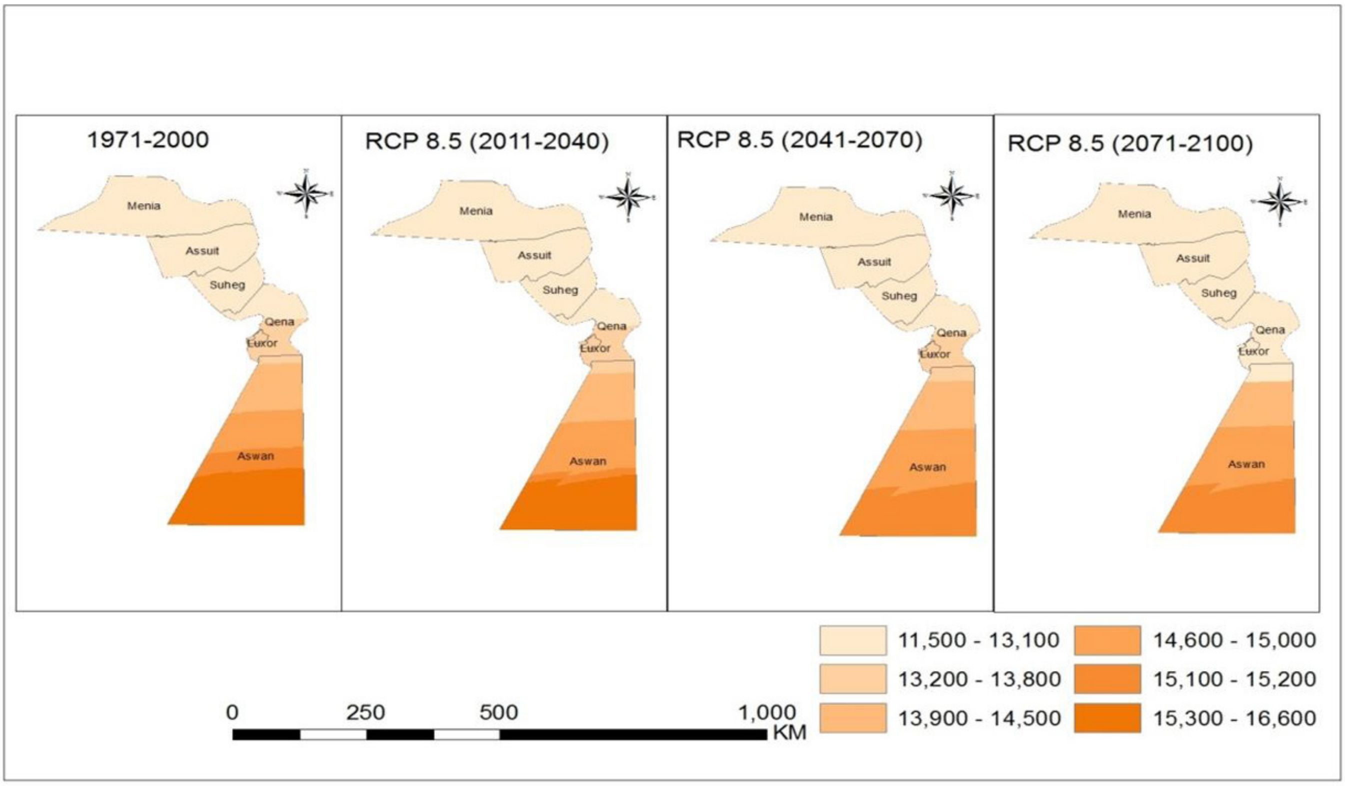

Fig. 4. Interpolation maps of total irrigation requirement values for sugarcane under the current (1971 – 2000) and RCP8.5 conditions at 2011-2040, 2041-2070 and 2071 - 2100.

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
Menia													
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
Asyut													
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
Sohag													
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
Qena													
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
Luxor													
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
Aswan													
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 Renascence 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

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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	flood irrigation system						gated pipes irrigation system					
Governorate	Menia	Asyut	Sohag	Qena	Luxor	Aswan	Menia	Asyut	Sohag	Qena	Luxor	Aswan
(1971-2000)												
Current conditions	1404	1438	1520	1566	1671	1826	1003	1027	1086	1118	1194	1304
(2011-2040)												
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%**
(2041-2070)												
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%**
(2071-2100)												
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%**

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