



Impact of climatic changes on future irrigation water requirement in the Middle East and North Africa's region: a case study of upper Egypt

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Abstract

Freshwater shortages in the Middle East and North Africa's region (MENA) cause serious issues, while climate change causes even more issues. The current study examines how climate change may impact future irrigation requirements in Egypt's Upper Region using the medium greenhouse emission RCP 4.5 and high emission RCP 8.5 scenarios. Based on the Intergovernmental Panel on Climate Change (IPCC) and the Fifth Assessment Report, the climatic projections for RCPs 4.5 and 8.5 for the years 2023–2080 and 2081–2100 were used to determine the patterns of temperature and rainfall in the upper Egypt territory. The CROPWAT model was employed to estimate reference evapotranspiration (ET_0) and net irrigation water requirement (NIWR) for the upper Egypt territory key crops sugar cane, potatoes, berseem clover (alfalfa), dry bean, wheat, cotton, maize, and tomato based on the predicted meteorological conditions. Five different scenarios for the key crops' future irrigation needs were calculated. The results reveal that under RCP 4.5 greenhouse emission for the periods 2023–2080 and 2081–2100, respectively, the overall NIWR for all examined crops increases by 5.1 and 5.9% in comparison to the current (2022) total NIWR for all crops. The total NIWR for all crops analyzed increases by 7.7 and 9.7% under the RCP 8.5 greenhouse emission scenario for the periods 2023–2080 and 2081–2100, respectively, in contrast to the current total NIWR for all crops. It is important to consider changes in water resource management in the MENA region, such as applying modern irrigation systems, using crop pattern rotation strategies with minimal water demands, and changing crop calendars or the times and locations of cropping activities.

Keywords Water resources · Climate change · Crop irrigation · Greenhouse gases · Egypt

Introduction

The majority of nations today are putting unheard-of pressure on water supplies. According to projections, the world will experience a 40% deficit between expected demand and the available supply of water by 2030 if current practices continue. The world's population is expanding rapidly. Moreover, catastrophic weather (such as floods and droughts) and chronic water scarcity are seen as some of the largest dangers to world peace and prosperity. More people are becoming aware of how drought and a lack of water are

escalating fragility and violence. It will take a 50% increase in agricultural production (which currently uses 70% of the resource) and a 15% increase in water withdrawals to feed 10 billion people by 2050. Figures estimate that about 40% of the world's population lives in water scarcity places, and around 0.25 of the world's GDP is subject to this difficulty. One in four kids would reportedly reside in regions with severe water shortages by the year 2040. Water security is a significant—and frequently expanding—concern for many nations today. By changing hydrological cycles, making water more unpredictable, and increasing the frequency and severity of floods and droughts, climate change will make the issue worse. The Sustainable Development Goals (SDGs) are at risk as a result of the rising demand for food and water (SDGs 2014). The SDGs, especially those that address poverty, hunger, and environmental sustainability, are seriously threatened by climate change, population expansion, water scarcity, and urban sprawl. Climate change

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is expected to have a greater impact on agriculture in the coming years because of changes in precipitation intensity, volume, and distribution as well as changes in the amount of atmospheric water vapor, the water content of the soil, and higher temperatures that will ultimately lead to increased evapotranspiration. The amount of irrigation water needed will be significantly impacted by this, especially in semi-arid areas (Masia et al. 2021; El-Rawy et al. 2023; Alotaibi et al. 2023). The Middle East is being profoundly impacted by climate change. Policymakers need to move away from top-down paradigms and involve a larger segment of their populace in climate adaptation in order to better prepare their societies to endure its shocks (Namdar et al. 2021). Climate change will have severe, far-reaching effects on the Middle East and North Africa (MENA), a region where elites and governments have long minimized or disregarded it. It will exacerbate already-existing governance issues and sharpen socioeconomic disparities while also bringing about new upheavals. The cascading effects of climate change are yet another daunting set of problems for nations already dealing with the aftermath of the pandemic, civil wars and conflict-related displacement, population growth, and a long-term decline in the demand for the oil that underpins many MENA economies (Al-Saidia et al. 2016). In addition, Egypt has been confronted with significant issues as a result of population growth, limited water resources, and insufficient agricultural production. Egypt's population surpassed 111 million in early 2022 (<https://www.worldometers.info/world-population/egypt-population/>, accessed August 2022), a 60% rise from the early 2000s (CAPMAS 2022). Since the agreement between Egypt and Sudan in 1959, the Nile River has provided 55.5 km³ annually, accounting for 94% of all renewable water resources in Egypt (Gabr 2022; Li et al. 2022). However, with the start of the Grand Ethiopian Renaissance Dam (GERD), there are concerns about the future availability of this resource, which may diminish Egypt's water share during the filling period. One of the most fundamental criteria for farm crop planning and the design of any irrigation project is calculating the irrigation water requirements of crops (Gabr 2021, 2023). In order to address difficulties with future food security and the sustainability of water resources, it is essential to comprehend the effects of climate change on crop water requirements (CWR) (Sunil et al. 2021; Noha and Jagath 2020). The Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report (AR5) (IPCC 2014; Zamani et al. 2020) provides climate projections for four representative concentration trajectories (RCPs), namely RCP 2.6, RCP 4.5, RCP 6, and RCP 8.5, up to 2100. Several scholars have used the RCP scenarios to model the influence of climate change on water resources in various parts of the world throughout the last decade (Elhoussaine et al. 2019; Allani et al. 2020). Water resources are significantly impacted by climate change in a

particular area. Several studies have been carried out to ascertain the variations in reference evapotranspiration (ET_0) and crop water demand CWR values that come from variations in climatic parameters, such as temperature and precipitation, under various RCP scenarios. Examining variations in ET_0 and local agricultural water needs took place in China's Hetao Irrigation District (HID) using predicted temperature and precipitation data. The results show that the anticipated rise in temperature and precipitation extremes has directly caused future ET_0 levels in the HID to rise by 4–7% (Zhou et al. 2017). In the Siwa region of the Western Desert of Egypt, Noha and Jagath (2020) used various climate models under the two typical concentration paths (RCPs) of RCP 4.5 and RCP 8.5 for the project to reclaim 30,000 acres as a part of a national project to reclaim and cultivate 1.5 million acres to increase agricultural production. The highest increase in summer temperature under RCP 4.5 and RCP 8.5 is 1.68 ± 1.64 °C in 2060 and 4.65 ± 1.82 °C in 2100, respectively. The increase in agricultural water requirements is predicted to be between 6 and 8.1% for RCP 4.5 and between 9.7 and 18.2% for RCP 8.5. Maximum reductions in strategic crop yield under RCP 4.5 range from 2.9% to 12.8% in 2060, but maximum reductions under RCP 8.5 range from 10.4% to 27.45% in 2100. Because of this, the nonrenewable Nubian Sand Stone Aquifer (NSAS), a transboundary aquifer shared by Egypt, Libya, Sudan, and Chad, is the main source of water in the National Project to reclaim 1.5 million acres in the western desert of Egypt. Abdrabbo et al. (2015) used many RCPs, including RCP 2.6, RCP 4.5, RCP 6, and RCP 8.5, throughout three time periods: 2011–2040, 2041–2070, and 2071–2100, to assess ET_0 in Egypt over time. In the Delta region, ET_0 can rise by around 5% to 20.1%, and in the Middle of Egypt, it can rise by about 4.7% to 19.65, according to a comparison of the results and actual data from 1971 to 2000. The increase in ET_0 in southern Egypt might be between 11.8 and 26.8%. Penman–Monteith (1988), a method that was suggested as an internationally standard approach for identifying and quantifying reference crop evapotranspiration, is one of the methods frequently used to calculate ET_0 . Several studies have looked at the spatial dispersion of the measured ET_0 utilizing the Penman–Monteith–FAO system and system. On the other hand, alternative methods of computing ET_0 were employed (Salama et al. 2015; Khalil et al. 2015; Khaydar et al. 2021). The CROPWAT 8.0 simulations, created by Smith (1991) and based on the Penman–Monteith method as well, are widely utilized in the field of water management all over the world. The current study uses the medium emission RCP 4.5 and high emission RCP 8.5 scenarios to examine how climate change would affect future irrigation needs in Egypt's Upper Territory, which comprises the governorates of Sohag, Qena, Luxor, Aswan, and the Red Sea. For the key crops (sugar cane, potatoes, berseem clover (alfalfa),

dry bean, wheat, cotton, maize, and tomato), ET_0 and NIWR were calculated using the FAO CROPWAT 8.0 model (FAO 2022). For future irrigation planning and reservoir operation modeling for Egypt's regions, the estimates of crop water requirement changes can be used appropriately as recommendations. To achieve the study objectives, (1) the recent studies that anticipated the adverse effects of rising temperatures on crop water requirements and crop yield are reviewed, (2) the Intergovernmental Panel on Climate Change (IPCC 2014) Fifth Assessment Report (AR5) served as the basis for the climatic projections for RCPs 4.5 and 8.5, which were used to estimate the patterns of temperature and rainfall in the upper Egypt territory, (3) ET_0 and NIWR for upper Egypt territory key crops sugar cane, potatoes, berseem clover (alfalfa), dry bean, wheat, cotton, maize, and tomato are estimated using CROPWAT 8 model, based on the predicted climatic parameters were used as an input into the CROPWAT model for future irrigation demand estimation for five scenarios: (1) current climate conditions 1990–2022; (2) temperature and rainfall change in 2023–2080 for RCP 4.5; (3) temperature and rainfall change for RCP 4.5 for 2081–2100, (4) temperature and rainfall change in 2023–2080 for RCP 8.5 and (5) temperature and rainfall change for RCP 8.5 for 2081–2100.

Materials and methods

MENA region, scarcity of water, droughts, and increasing sea levels

The most prominent impact of climate change in the MENA region has been water shortage; experts frequently refer to this area as "the world's most water-stressed." Other climate effects that are anticipated to have an impact on MENA residents, particularly those in rural areas and urban peripheries, migrants and refugees, informal sector workers, and other vulnerable communities, include desertification, population movements (both within the region and from elsewhere), food insecurity, and rising temperatures and their detrimental effects on health and productivity (UNHCR 2021). Concerningly, the MENA area is predicted to be among the first places in the world to "effectively run out of water," as water resources are being consumed more quickly than precipitation can replace them. In a region where there is already a shortage of water, climate change intensifies the constraints already put on water supply by population growth and is likely to continue to reduce total and per capita water availability to dangerously low levels. This is particularly true in nations like Iraq where irrigated agriculture is a substantial industry. This has caused countries to overdraw water from rivers and aquifers, weakening already limited water resource bases. For instance, in Western Iraq, desertification

and sandstorm frequency have significantly increased during the past 20 years. Desertification poses a range of deleterious effects on air quality, human health, land productivity, and ecosystem dynamics. Governments, businesses, and multilateral organizations have responded by implementing a variety of measures in the area, including reforestation, afforestation, and new agriculture projects, to both stop desertification and lower atmospheric carbon levels (Namdari et al. 2021; Kong et al. 2022). But these actions have elicited skepticism from some scholars who consider them counterproductive and ecologically damaging.

In the MENA area, internal renewable water, which is defined as rivers and aquifers supplied by precipitation, would be reduced by about 4% by 2050 as a consequence of climate change and less precipitation rates (Frederic and Ninar 2022). By 2025, between 80 and 90 million people in the region are expected to experience some sort of water stress; Iran has already experienced demonstrations due to water shortages. Governments are being compelled by the increased demand for water resources to pursue costly desalination projects or to divert water away from agriculture, both of which have the potential to exacerbate already-existing economic disparities and expand the urban–rural divide (IPCC 2019). The MENA region is expected to experience temperatures much above this estimate, even if global warming is only projected to boost temperatures by 2 °C. If greenhouse gas emissions continue to climb at their current rate, the region's temperatures are predicted to rise by at least 4 °C by 2050, and the frequency of heat waves is predicted to increase tenfold by that time (Kong et al. 2022). Future temperatures in the area are predicted to rise over the point at which people can adapt, which will result in greater mortality rates for young people and the elderly (Hertig and Trambly 2017). In Kuwait, for instance, wealthy citizens and locals frequently use air conditioning to avoid the effects of rising temperatures, while non-Kuwaiti workers from developing countries work outdoors and are up to three times more likely to perish on extremely hot days (El-Rawy et al. 2021). By the end of the century, the average global sea level is predicted to rise 30–122 cm (1–4 feet), making the MENA region one of the region's most susceptible to the effects of increasing sea levels brought on by climate change. As a result, there are many effects, including the possibility that as sea levels rise, seawater will seep into coastal aquifers and wells, saline the water, and cause havoc on agricultural communities along the coastline (Frederic and Ninar 2022). The flooding of coastal areas could potentially render several waterfront cities and villages in the MENA region uninhabitable, adding to the already burdensome governments' economic and migration-related challenges (Fusco 2022). The towns of Algiers, Benghazi, and Alexandria in particular will be vulnerable to even minor rises in sea level by 2050, making the countries of North Africa, particularly

in danger in terms of the overall population threatened by sea level rise.

Description of study area

Egypt is located at the northeastern tip of Africa, with coordinates of $30^{\circ} 06' N$ and $31^{\circ} 25' E$, respectively (Fig. 1). Egypt experiences low precipitation, a high ET_0 rate, and an arid or semi-arid environment throughout the year (Gabr et al. 2023). The land surface heights vary between (-400 and 2500 m) above the normal sea main level. Egypt has a total area of about one million km^2 , of which only a small portion (8%) is fertile land and the rest is an arid desert. Nearly 97% of arable land is occupied by more than 105 million people, who are mostly concentrated in the Nile Valley

and Delta, as well as the northern coastal zone along the Mediterranean Sea (Gabr et al. 2022). The Eastern Desert, Western Desert, North West Coast, Sinai Peninsula, and Nile Valley and Delta are physiographic areas. Among the different soil types in Egypt are alluvial soils in the Delta and Valley, desert soils in the Eastern and Western Deserts, calcareous soils along the Egyptian coast, and soils in the Sinai Peninsula (Gabr 2021).

Meteorological data

The climate data regarding temperature and rainfall for the period 1990–2022 were collected from Suhag, Qena, Aswan, and Red Sea climate stations. Suhag station: Altitude 61 m, latitude ($26.56^{\circ} N$), longitude ($31.7^{\circ} E$), Qena station:

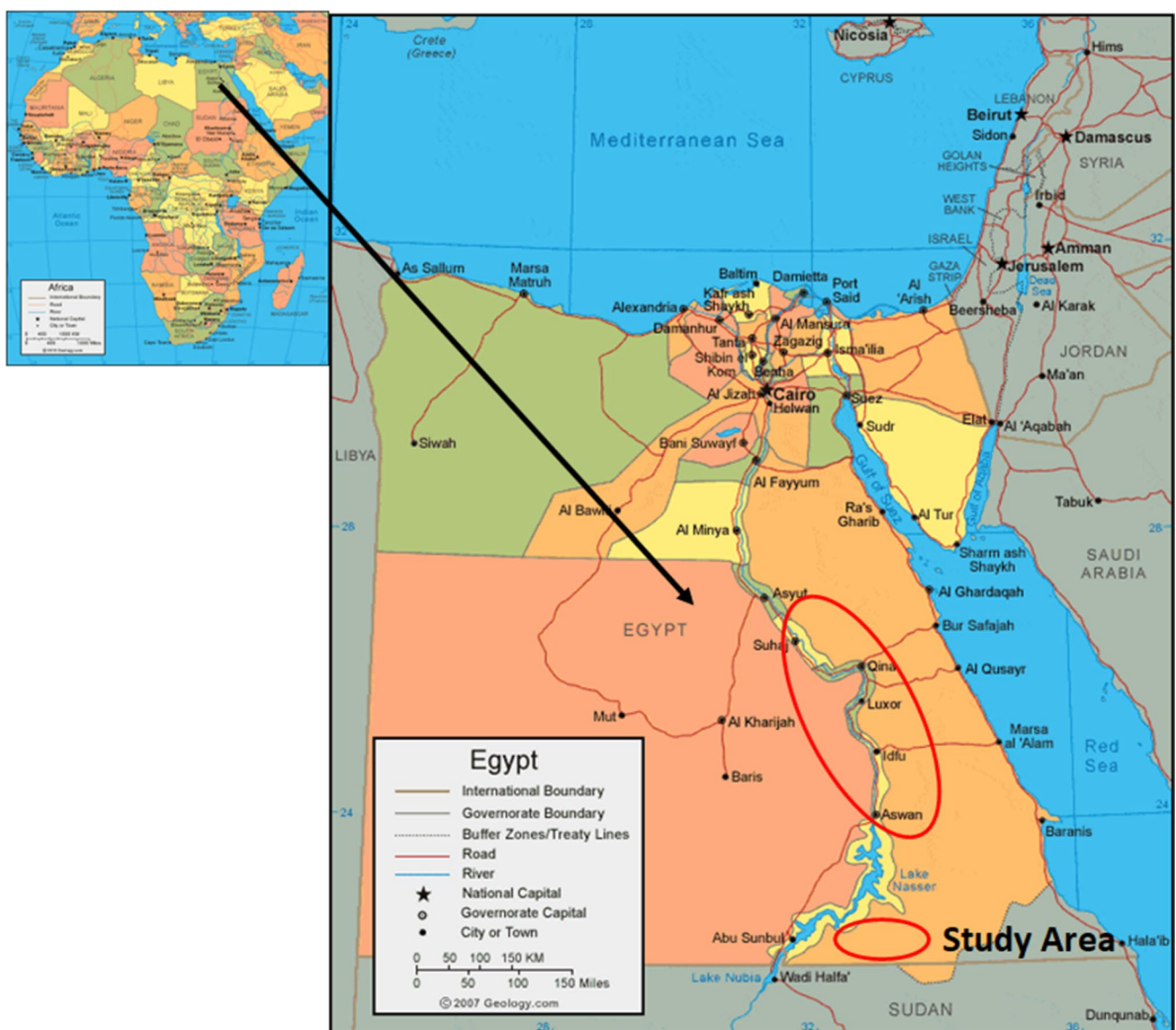


Fig. 1 Map of Egypt

Altitude 78 m, latitude (26° N), longitude (32.25° E), Aswan station: Altitude 194 m, latitude (23.96° N), and longitude (33.26° E), and Red Sea station: Altitude 11 m, latitude (27.19° N), longitude (33.87° E) climate stations and the average values were computed to represent the upper Egypt territory as shown in Fig. 2. In addition, the climate data regarding the relative humidity, wind speed, sunshine, and

solar radiation for the period 1990–2022 for Suhag station were collected to be used in the Cropwat 8 model (Table 1).

The Intergovernmental Panel on Climate Change (IPCC 2014) Fifth Assessment Report (AR5) served as the basis for the climatic projections for RCPs 4.5 and 8.5 for the periods 2023–2081 and 2081–2100 which were used to estimate the patterns of temperature and rainfall in the upper

Fig. 2 Currently climate data (1990–2022) for the Suhag, Qena, Aswan, and Red Sea climate stations: **a** maximum temperature, **b** minimum temperature, and **c** rainfall

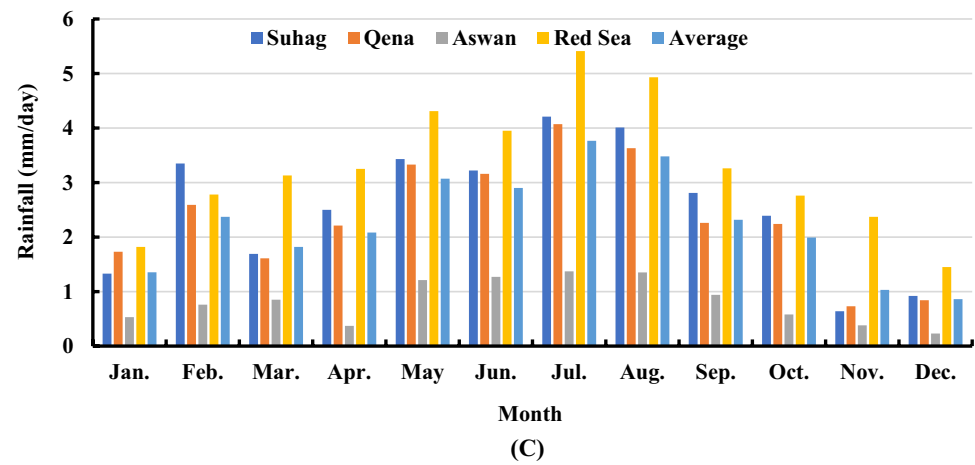
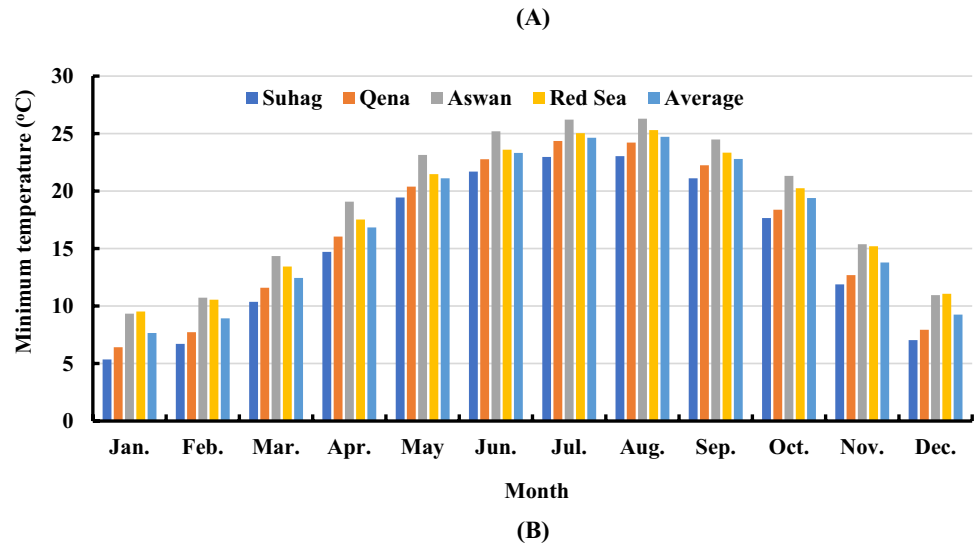
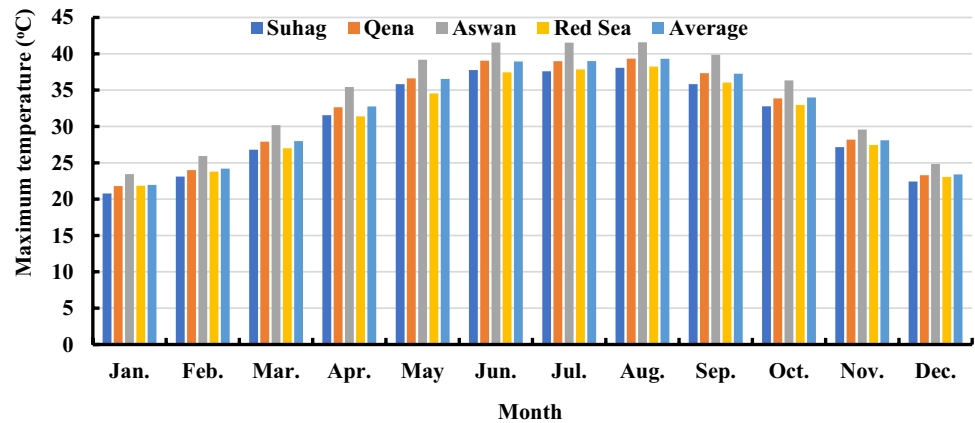


Table 1 Current (1990–2022) relative humidity, wind speed, sunshine, and solar radiation climate data for Suhag station

Month	Relative humidity (%)	Wind speed (km/day)	Sunshine (h)	Solar radiation (MJ/m ² /day)
January	58	285	7.9	14.6
February	51	285	8.7	17.7
March	45	285	8.9	20.5
April	35	285	9.2	22.9
May	30	285	10.2	25.2
June	31	285	11.1	26.7
July	37	285	11	26.4
August	43	285	10.8	25.4
September	45	285	9.9	22.5
October	44	17	9.1	18.8
November	51	17	8.4	15.5
December	58	17	8.1	14.1
Average	44	218	9.4	20.9

Egypt territory. The average maximum and minimum temperatures, and rainfall for the Suhag, Qena, Aswan, and Red Sea climate stations were computed to represent the upper Egypt territory. Figure 3 shows the climate data for RCP 4.5: (2023–2080) for the Suhag, Qena, Aswan, and Red Sea climate stations: (a) maximum temperature, (b) minimum temperature, and (c) rainfall. In addition, Fig. 4 shows the climate data for RCP 4.8: (2081–2100) for the Suhag, Qena, Aswan, and Red Sea climate stations: (a) maximum temperature, (b) minimum temperature, and (c) rainfall.

Soil and crop data

To evaluate the water needs of the eight main crops farmed in the Upper Egyptian region—tomato, dry bean, wheat, cotton, berseem clover (alfalfa), potatoes, and sugar cane—soil and crop data were gathered. Data on crops and soil in the various regions were gathered using a combination of field observations, interviews with farmers and stakeholders, and the Ministry of Agricultural and Land Reclamation (MALR 2022) handbook for agricultural operations in Egypt. The crop variety, first and final planting and harvesting dates, first and last irrigation application depths, irrigation application frequencies and intervals, duration of plant growth stages, and rooting depth are among the information included (MWRI 2017). Table 2 summarizes the soil and crop data in the study area as the predominant soil is heavy clay.

CROPWAT 8 model

Using data on rainfall, soil, crops, and climate, the decision-support computer program CROPWAT 8.0 by FAO

determines ET_o , crop net irrigation water requirement, and irrigation schedules. The reference evapotranspiration (ET_o) was computed based on Penman Montith's 1998 method and Effective rainfall was computed according to the USDA soil conservation method (FAO 2022; Smith 1991). The flowchart for simulating the water requirements for crop irrigation is shown in Fig. 5.

ET_o was the primary factor used to estimate crop evapotranspiration (ET_c) (Alotaibi et al. 2023; Gabr 2021). In typical circumstances (limitless crop growth, adequate water availability, and disease and pest-free crops), ET_c was estimated as the value of ET_o and crop coefficient (K_c) (Sunil et al. 2021). From ET_o and crop coefficient (K_c), the ET_c value was calculated using Eq. 1 (Ewaid et al. 2019).

$$ET_c = K_c ET_o \quad (1)$$

The net irrigation water requirement (NIWR) and the gross irrigation requirement were calculated as:

$$NIWR = ET_c - R_{eff} \quad (2)$$

where R_{eff} is the effective rainfall (mm).

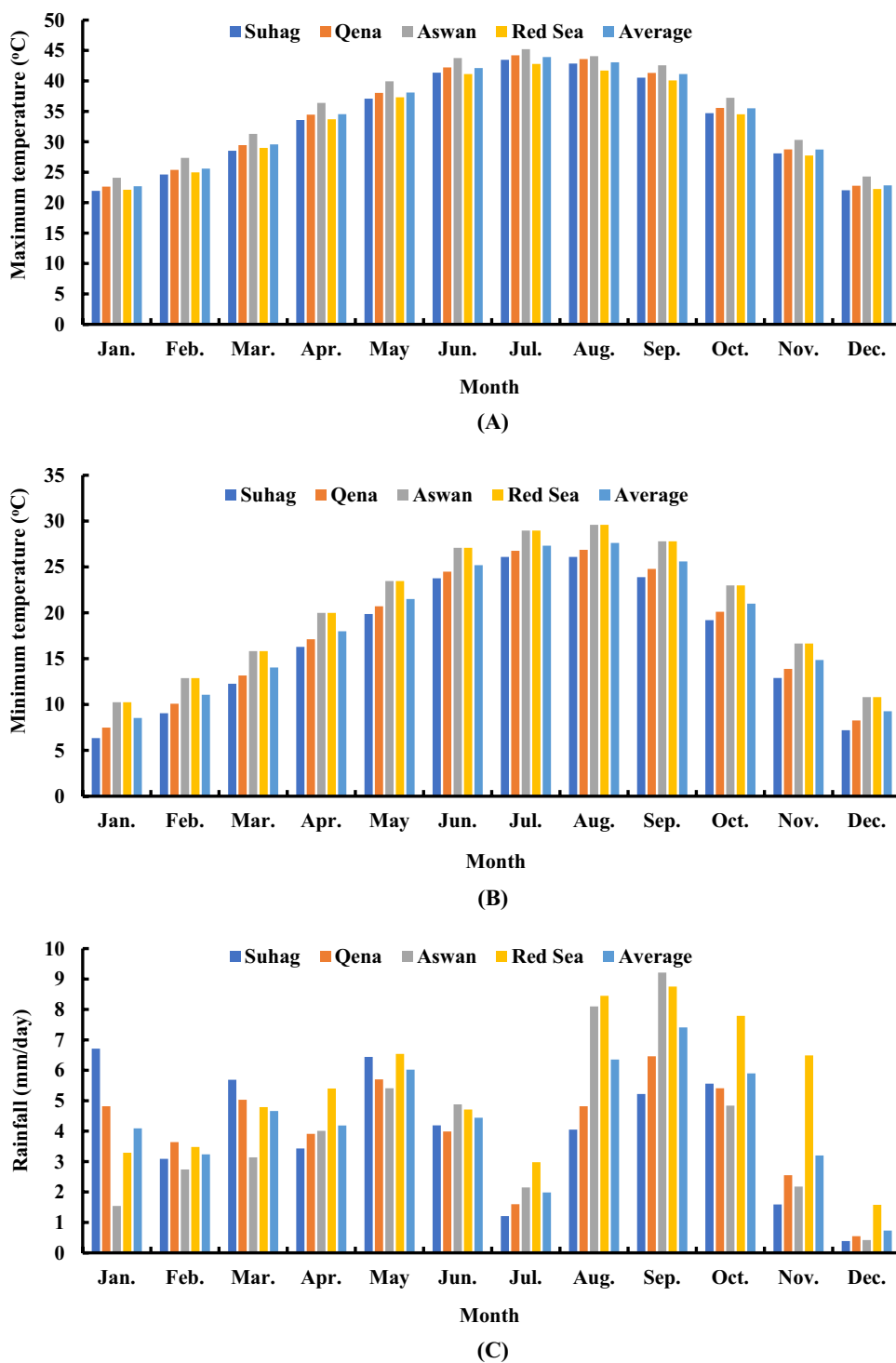
$$GIWR = NIWR/I \quad (3)$$

where I refer to the field irrigation efficiency.

Results

In comparison to the current situation (2022), Table 3 lists the average, range, difference, and change in rainfall, maximum, and minimum temperatures for the four models under RCP 4.5 and 8.5 for 2080 and 2100. For the current scenario (2022), the average maximum temperature is 32 °C, with a range of 39.3 °C in August to 22 °C in January. Whereas, for RCP 4.5: 2023–2080, the maximum temperature range is 43.9 °C in July to 22.7 °C in November, with an average of 34 °C. Additionally, RCP 4.5: 2081–2100 has an average maximum temperature of 19 °C with maximum temperatures ranging from 43.5 °C in July to 22.4 °C in November, which represent increases of 6.3 and 7.2%, respectively, from the current situation. However, according to RCP 8.5, the maximum temperature changes for the years 2081 and 2100 are 10 and 12.8% higher, respectively, than they are for the present scenario (2022). On the other hand, for the current scenario, the average minimum temperature is 17.1 °C, with a maximum value of 24.7 °C in August and a minimum value of 7.7 °C in January. For the RCP 4.5: 2023–2080, the minimum temperature range is 27.6 °C in August to 8.5 °C in January, with an average of 18.7 °C. Moreover, the average minimum temperature for RCP 4.5: 2081–2100 is 19 °C, with a range of 27.9 °C in August to 8.6 °C in January. In addition, the minimum temperature change for RCP

Fig. 3 Climate data for RCP 4.5: (2023–2080) for the Suhag, Qena, Aswan, and Red Sea climate stations: **a** maximum temperature, **b** minimum temperature, and **c** rainfall

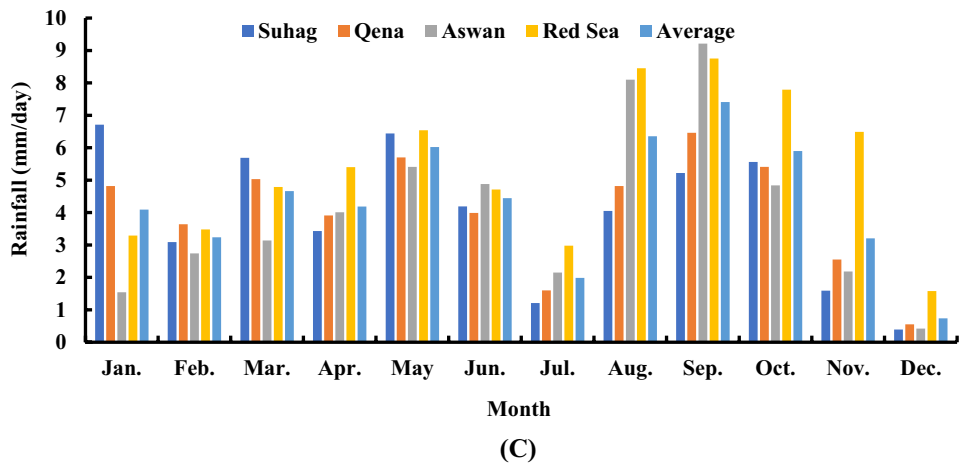
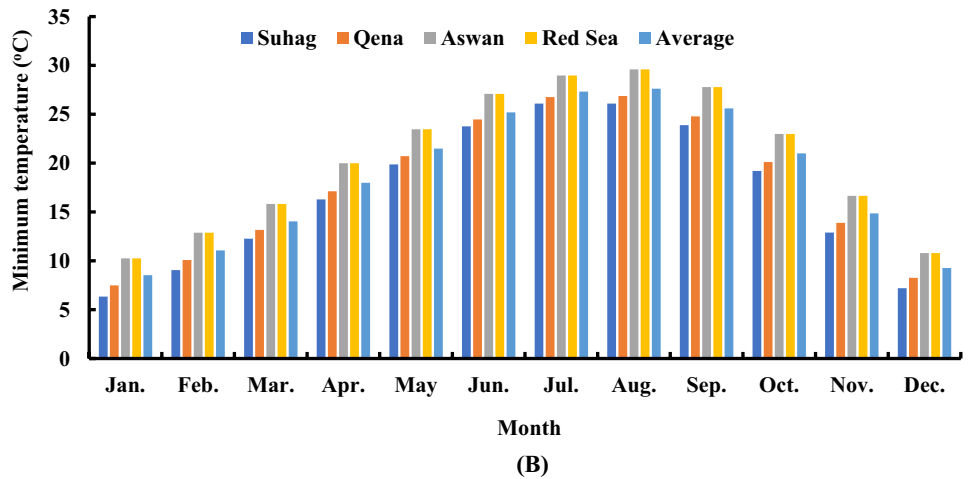
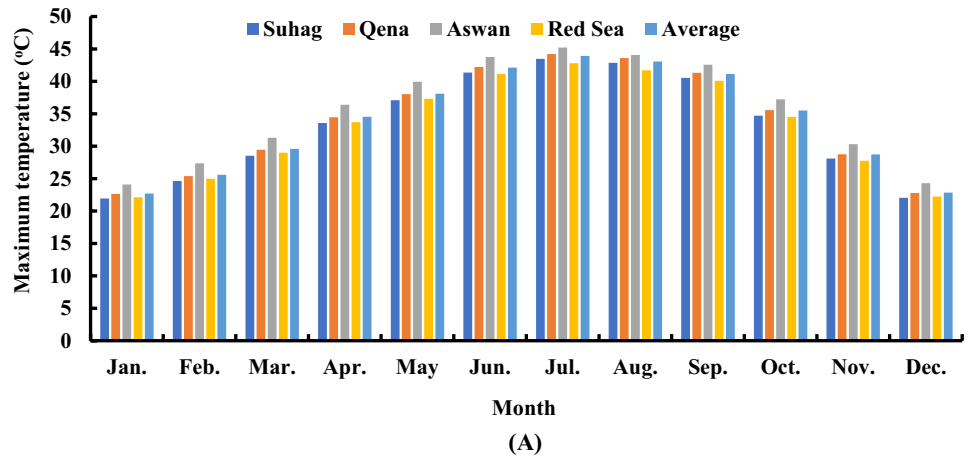


4.5: 2023–2080 and 2081–2100 indicates an increase of 9.4 and 11.1%, respectively compared to the current scenario. However, according to RCP 8.5: 2023–2080 and 2081–2100, the minimum temperature changes are 13 and 20.3% higher, respectively, than the present scenario.

For the current scenario, the average monthly rainfall is 2.3 mm, it is ranged from 0.9 mm in December to

3.8 mm in July. RCP 4.5: 2023–2080 rainfall range from 7.4 mm in September to 0.7 mm in December, with an average of 8.2 mm. Moreover, the average rainfall for RCP 4.5: 2081–2100 is 9.5 mm, a range of 10.6 mm in August to 0.9 mm in December. For the years 2080 and 2100, the rainfall change predicted by RCP 4.5 shows a rise of 256.5 and 313%, respectively. The rainfall changes

Fig. 4 Climate data for RCP 8.5 for the Suhag, Qena, Aswan, and Red Sea climate stations: (2081–2100): **a** maximum temperature, **b** minimum temperature, and **c** Rainfall



for the years 2080 and 2100, as compared to the current scenario (2022), are 221.7 and 273.9% higher, respectively, according to RCP 8.5.

Reference evapotranspiration (ET₀)

Table 4 summarizes the daily ET₀ for the Upper Egypt region for the four models (2080 and 2100) under RCP 4.5 and 8.5, as well as the current situation (2022). Therefore,

Table 2 Soil and crop data in the study area

Sr. no.	Soil parameter	Value
Heavy soil (clay)		
1	Total available soil moisture (FC-WP)	200 mm/m
2	Maximum infiltration rate	40 mm/day
3	Maximum rooting depth	250 cm
4	Initial soil moisture depletion	0%
5	Initial available soil moisture	200 mm/m
Crop	Planting date	Harvest date
Crop data (planting and harvest dates)		
Sugar cane	1-September	31-Augst
Potatoes	1-September	8-October
Berseem clover	15-October	27-May
Dry bean	1-October	18-January
Wheat	1-November	10 March
Cotton	1-May	11-November
Maize	20-April	22-Augst
Tomato summer	6-June	28-October

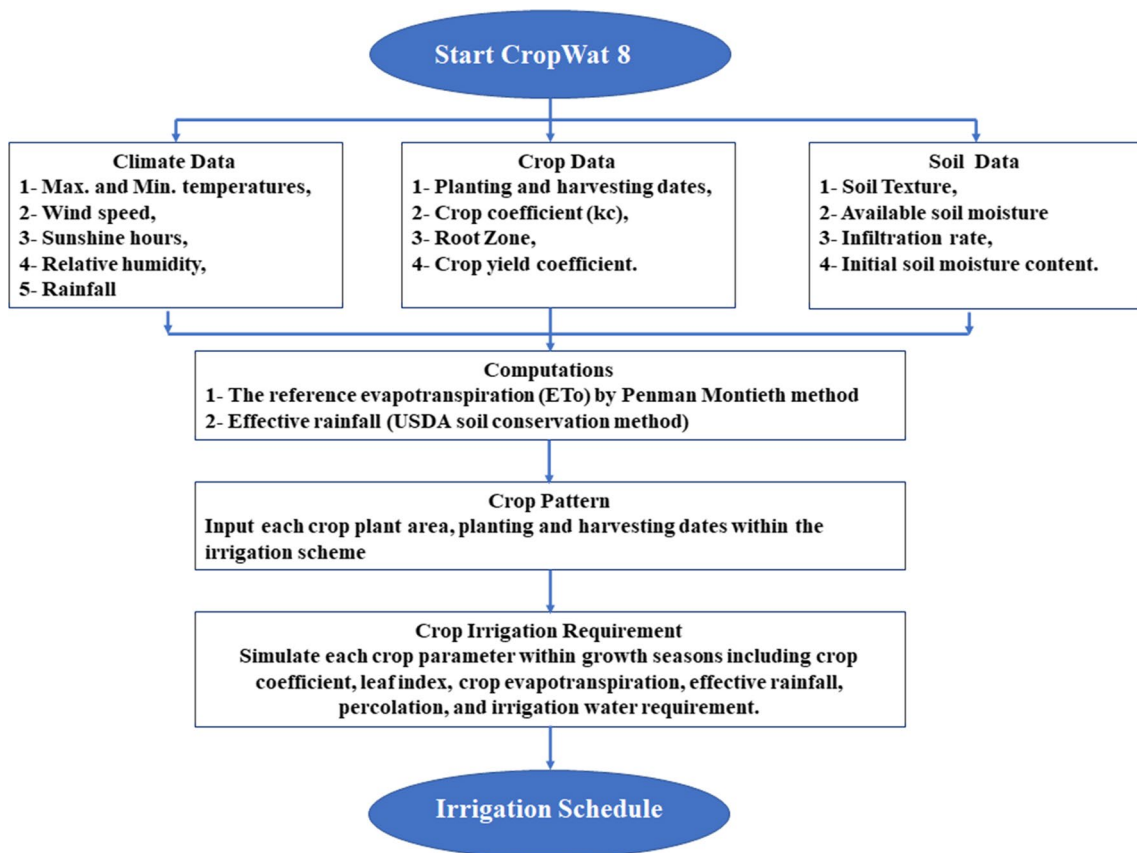


Fig. 5 Diagram of the methods for simulating the water requirements for crop irrigation

Table 3 Monthly maximum and minimum temperatures and rainfall variations (average, range, difference, and change) for the future four models (2080 and 2100) under RCP 4.5 and 8.5, and current condition (2022) for Upper Egypt territory

	Current (1990–2022)	2023–2080	2081–2100
Monthly max. temp. (°C)			
RCP 4.5			
Average	32	34	34.3
Range	39.3 (Aug.)–22 (Jan.)	43.9 (Jul.)–22.7 (Nov.)	43.5 (July)–22.4 (Dec.)
Difference (ΔT)	–	2.00	2.30
Change (%)	–	6.3	7.19
RCP 8.5			
Average	32	35.2	36.1
Range	39.3 (Aug.)–22 (Jan.)	44.8 (July)–24.8 (Dec.)	46.1 (July)–23.7 (Dec.)
Difference (ΔT)	–	3.2	4.1
Change (%)	–	10.00	12.81
Monthly min. temp. (°C)			
RCP 4.5			
Average	17.1	18.7	19
Range	24.7 (Aug.)–7.7 (Jan.)	27.6 (Aug.)–8.5 (Jan.)	27.9 (Aug.)–8.6 (Jan.)
Difference (ΔT)	–	1.6	1.9
Change (%)	–	9.4	11.11
RCP 8.5			
Average	17.7	20	21.3
Range	24.7 (Aug.)–7.7 (Jan.)	29.2 (Aug.)–9.1 (Jan.)	31.1 (Aug.)–10.3 (Jan.)
Difference (ΔT)	–	2.3	3.6
Change (%)	–	13	20.34
Monthly rainfall (mm/month)			
RCP 4.5			
Average	2.3	8.2	9.5
Range	0.9 (Dec.)–3.8 (July)	0.7 (Dec.)–7.4 (Sep.)	1.6 (Dec.)–8.4 (Sep.)
Difference (ΔR)	–	5.90	7.20
Change (%)	–	256.5	313
RCP 8.5			
Average	2.3	7.4	8.6
Range	0.9 (Dec.)–3.8 (July)	0.7 (Dec.)–6.7 (Sep.)	0.9 (Dec.)–10.6 (Aug.)
Difference (ΔR)	–	5.1	6.3
Change (%)	–	221.7	273.9

Table 4 Daily ET_o for (average, range, difference, and change) for the four models (2080 and 2100) under RCP 4.5 and 8.5, and current condition (2022) for Upper Egypt territory

	Current (2020)	2080	2100
ET_o (mm/day)			
RCP 4.5			
Average	5.95	6.29	6.32
Range	1.72 (Dec.)–9.36 (June)	1.71 (Dec.)–9.96 (July)	1.77 (Dec.)–9.98 (June)
ΔT	–	0.34	0.37
Change (%)	–	5.71	6.2
RCP 8.5			
Average	5.95	6.46	6.6
Range	1.72 (Dec.)–9.36 (June)	1.82 (Dec.)–10.14 (July)	1.186 (Dec.)–10.4 (July)
ΔT	–	0.51	0.24
Change (%)	–	8.6	10.9

the average ET_o is 5.95 mm/day, it is ranged from 1.72 mm/day in December to 9.36 mm in June. RCP 4.5: 2023–2080 ET_o range from 1.71 mm/day in December to 9.96 mm/day in July, with an average of 6.29 mm/day. Moreover, the average ET_o for RCP 4.5: 2081–2100 is 6.32, a range of 1.77 mm/day in December to 9.98 mm/day in June. For the years 2080 and 2100, the ET_o change predicted by RCP 4.5 shows a rise of 5.71 and 6.2%, respectively. The ET_o changes for the years 2023–2080 and 2081–2100, as compared to the current scenario (2022), are 5.6 and 10.9% higher, respectively, according to RCP 8.5.

Figure 6 shows the ET_o fluctuation for the current scenario greenhouse emissions and the RCP 4.5 and 8.5 emissions over the time periods 2023–2080 and 2081–20,100, respectively.

Crop evapotranspiration (ET_c) and Net irrigation water requirement (NIWR)

Table 5 summarizes the NIWR for the main crops in Upper Egypt (Current scenario 2022) in terms of planting date, harvest date, period of crop growth, ET_c , effective rainfall, and

Crop area. Figure 7 shows the ET_c fluctuation for the current (2022) greenhouse emissions and the RCP 4.5 and 8.5 emissions over the time periods 2023–2080 and 2081–2100, respectively. Net irrigation water requirement (NIWR). The ET_c values for the crops in the current scenario, listed in ascending order, are dry bean, wheat, potatoes, alfalfa, maize, summer tomato, cotton, and sugar cane. These values are 214.1, 329.6, 360.4, 872.1, 968.6, 1059.3, 1317.3, and 2325 mm/season respectively. In comparison to the current total NIWR for all crops, the total NIWR for all examined crops increases by 5.1 and 5.9% under RCP 4.5: 2080 and 2100, respectively. On the other hand, for the RCP 8.5: 2080 and 2100, respectively, the total NIWR for all investigated crops increases by 7.7 and 9.7% in comparison to the current total NIWR for all crops (Fig. 8).

Discussion

One of the most difficult environmental problems facing growth is climate change, particularly in arid and semi-arid areas. The study results coincided with Noha and

Fig. 6 ET_o variation for the current (2022) and RCP 4.5 and 8.5 greenhouse emissions for the periods 2023–2080 and 2081–2100 in for Upper Egypt territory

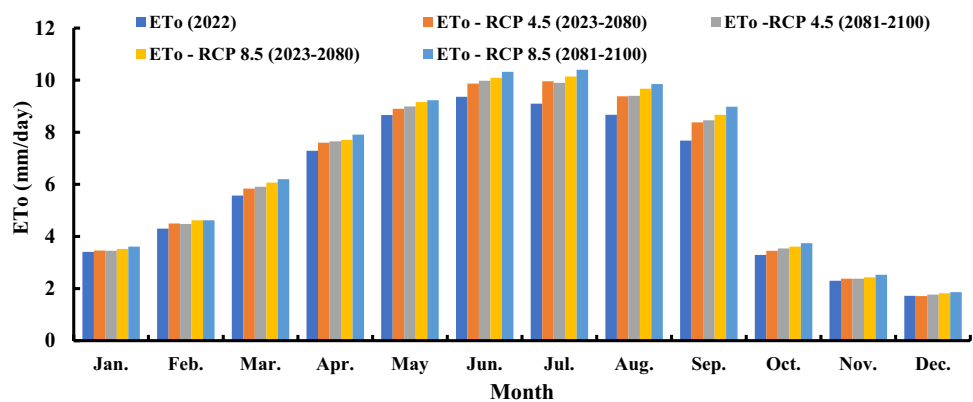


Table 5 Crop water use for Upper Egypt territory (current scenario 2022)

Crop	Planting date	Harvest date	Period of crop growth (days)	ET_c (mm)	Eff. rain (mm)	NIWR (mm)	Crop area (ha)	Total NIWR (MCM)
Sugar C	1st Sep	31st Aug	365	2325	0.0	2325	137,019	3185.69
Potatoes	1st Sep	8th. Jan	130	360.4	0.0	360.4	887.9	3.20
Alfalfa	15th Oct	27th. May	225	872.1	0.0	872.1	3883.7	33.87
Bean D	1st Oct	29th. Dec	110	214.1	0.0	214.1	2061	4.41
Wheat	1st Nov	10th. Mar	130	329.6	0.0	329.6	124,380	409.96
Cotton	1st May	11st. Nov	195	1317.3	0.0	1317.3	181	2.38
Maize	20th Apr	22nd. Aug	125	968.6	0.0	968.6	41,961	406.43
Tomato S	1st Jun	23rd. Oct	145	1059.3	0.0	1059.3	10,598	112.27
Total							320,971	4158.21

ET_c , crop evapotranspiration; Eff. Rain, effective rain; NIWR, net irrigation water requirement; MCM, million m^3 of water

Fig. 7 ET_c variation for the current scenario (2022) and RCP 4.5 and 8.5 greenhouse emissions for the periods 2023–2080 and 2081–2100 for Upper Egypt territory

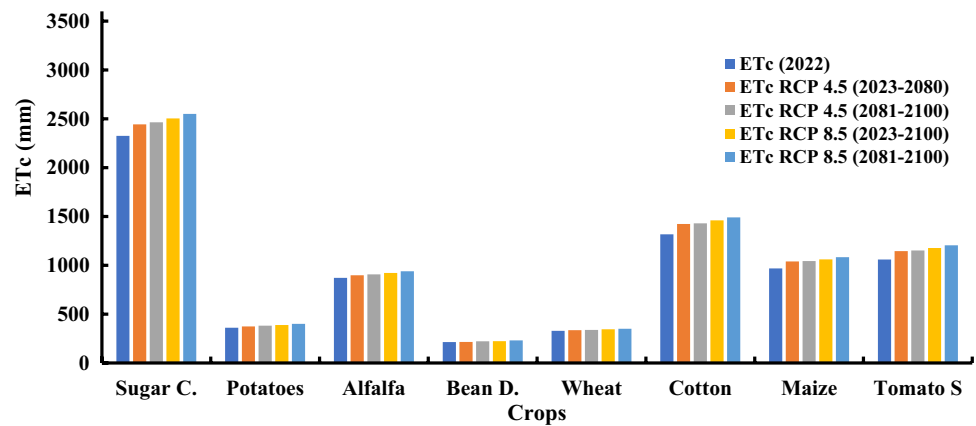
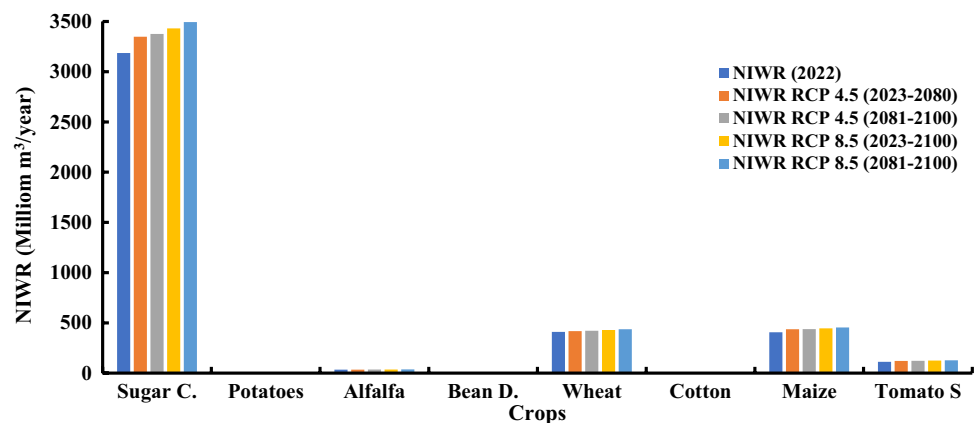


Fig. 8 NIWR variation for the current (2022) and RCP 4.5 and 8.5 greenhouse emissions for the periods 2023–2080 and 2081–2100 for Upper Egypt territory



Jasath (2020). Therefore, for the Siwa region in Egypt's Western Desert (arid region), where 30,000 acres will be reclaimed to boost agricultural productivity, they used various climate models for RCP 4.5 and RCP 8.5 for the years 2060 and 2100. Under RCP 4.5 and RCP 8.5, the increase in agricultural water needs is expected to range from 6 to 8.1% and from 9.7 to 18.2%, respectively. However, maximum yield reductions under RCP 8.5 range from 10.4% to 27.45% in 2100, while maximum yield reductions under RCP 4.5 range from 2.9 to 12.8% in 2060.

In addition, the study results coincided with El-Rawy et al. (2023), who investigated the expected adverse impacts of climate change on water irrigation management in Saudi Arabia (arid region). The results showed that, during the 2100s, the annual average ET_o increases predicted by the Shared Socioeconomic Pathways (SSP)2–4.5 and SSP5–8.5 scenarios were 0.35 mm/day (6%) and 0.7 mm/d (12.0%), respectively. For the current, SSP2–4.5, and SSP5–8.5 scenarios, the net irrigation water requirement (NIWR) and growth of irrigation water requirement (GIWR) for the primary crops in the Al Quassim region were evaluated. According to SSP5–8.5, the GIWR is anticipated to rise by 2.7, 6.5, 8.5, and 12.4%, respectively,

in the 2040s, 2060s, 2080s, and 2100s compared to the present situation (1584.7 million m^3). As a result, under SSP5–8.5, main crops will experience larger deficits in 2100, with deficits of 15.1%, 10.7%, 8.3%, 13.9%, and 10.7%, respectively, in the crop areas of wheat, clover, maize, other vegetables, and dates. In the context of population and technological change, Fader et al. (2016) evaluated how irrigation needs in the Mediterranean region may be impacted by climate change and increases in atmospheric CO_2 concentrations. The Mediterranean region revealed a signal of rising net irrigation needs, without the benefits of higher CO_2 concentrations in the atmosphere, when using some climate models at 3 °C global warming and above. Also, Driouech et al. (2020) used the Regional Climate Model ALADIN-Climate to investigate anticipated changes in temperature, precipitation, and associated severe events in the middle east and North Africa (MENA) region. According to the study's findings, the warming rates over the land range from 0.2 to 0.5 °C/decade, depending on the scenario. The predicted heat waves are predicted to last longer and be more intense. There will likely be more drought in the region's northern half. In addition, according to Zittis et al. (2021), global

climate predictions point to a marked escalation in the MENA region's summer heat extremes. On a business-as-usual trajectory, they said, the second part of this century will see the emergence of previously unheard-of super- and ultra-extreme heatwave conditions. These phenomena include exceptionally high temperatures (up to 56 °C and greater) and will last for a long time (a few weeks), potentially endangering human life. Over 600 million people, or roughly half of the MENA population, might experience frequent, super- and ultra-extreme heat waves by the end of the century. As a result, planning and management for agriculture are significantly impacted by climate change. Increased irrigation efficiency through intelligent irrigation technologies (El-Rawy et al. 2021) strategic crop planting, or crop patterns that use less irrigation water can all help to lessen the future impact of climate change on water irrigation requirements in the upper Egypt region. These actions will improve the management of the available water resources.

Conclusion

The Cropwat 8 program was used to simulate the current and future NIWR for the main crops (dry bean, wheat, potatoes, alfalfa, maize, summer tomato, cotton, and sugar cane) in the Upper Egypt territory. The representative concentration path (RCP) 4.5 and 8.5 for greenhouse gas emissions for the periods 2023–2080 and 2081–2100 predicts that climate change will have a significant impact on the net irrigation water requirement (NIWR) for the studied crops. The computed current (2022) evapotranspiration (ET_0) indicates an average value of 5.95 mm/day. The ET_0 values based on RCP 4.5 greenhouse emission for the periods 2023–2080 and 2081–2100 indicate an increase of 5.71 and 6.2% respectively compared to the current scenario. On the other hand, The RCP 8.5 greenhouse emission for the periods 2023–2080 and 2081–2100 indicates an increase of 5.6 and 10.9% respectively. The current ET_c values in ascending order were 214.1, 329.6, 360.4, 872.1, 968.6, 1059.3, and 1317.3 mm/season for dry beans, wheat, potatoes, alfalfa, maize, summer tomato, cotton, and sugar cane respectively. The overall NIWR for all investigated crops rise by 5.1 and 5.9% under RCP 4.5 greenhouse emission for the periods 2023–2080 and 2081–2100, respectively, in contrast to the total NIWR for all crops as it is right now. On the other side, the total NIWR for all crops analyzed increases by 7.7 and 9.7% for the RCP 8.5 greenhouse emission for the periods 2023–2080 and 2081–2100, respectively, in contrast to the current scenario of the total NIWR for all crops. Water resources management adaptations should be considered such as using crop rotation strategies with low water demands, applying modern irrigation techniques

(adjustments to quantity, timing, or technology), and modifying crop calendars or the times and locations of cropping activities. This study could be useful for managing water resources and reducing the negative effects of climate change on crop water requirements in the Middle East and North Africa (MENA) region.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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