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IMPACT OF CLIMATE CHANGE ON WHEAT WATER CONSUMPTION IN SOME EGYPTIAN REGIONS

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ABSTRACT: Wheat is considered one of the most important strategic crops cultivated in Egypt. It is one of the crops that are affected by climate change especially for their water requirements. Therefore, it takes particular attention, especially under the conditions of water scarcity available for irrigation.

This work aims to measure the extent of wheat's water consumption affected by climate changes in three governorates representing the Nile Delta and Valley from the north to south of Egypt, namely Gharbia, Assiut, and Aswan. To achieve this goal, coordinates of specific climatic stations were determined to represent climatic zones characteristic of Egypt using the Climwat program. Then, some necessary climatic data were collected to calculate the reference crop evapotranspiration through the modified Penman equation over a period of 40 years started from 1982 up to 2021, using data from the NASA website, and dividing the climatic periods into four epochs, each lasting ten years. Subsequently, all the collected data were entered into the Cropwat program to calculate both the reference and actual evapotranspiration and irrigation schedule for the wheat crop planting in three soil types (sandy, loamy, and clay) in the three subjected governorates. This was done to determine the water requirements and plan for scheduling wheat irrigation scientifically. The results indicated an overall increase in the water requirements for wheat in recent years, especially in the south governorate of Egypt. The research recommends the application of the Cropwat program for scheduling wheat irrigation.

Key words: Wheat, Climate Change, Water Requirements, Egypt, Cropwat Program, Evapotranspiration, Irrigation Scheduling, NASA.

INTRODUCTION

Egypt's sustainable agricultural expansion is vital for its economy, but water supplies have declined due to factors like arid terrain, climate change, and inefficient irrigation. Over-irrigation and farmers' reluctance to rationalize irrigation water are exacerbated by a lack of research on irrigation water management.

A six present (6%) rise in temperatures and a 30% drop in precipitation are projected by the climate simulation model, which will have a negative impact on crop yields. Reduced wheat and barley yields are a predictable outcome of future climate change. The negative impacts on agricultural sustainability can be mitigated with proper management (Shayanmehr *et al.*, 2022). Climate change is expected to reduce agricultural land productivity, crops, and water resources by 2030 (Manasa and Shivapur, 2016). Efficient soil water management is crucial for conserving water and maintaining plant output. The Cropwat application, launched by the FAO (2009), estimates water and irrigation requirements for crops based on soil, climate, and crop factors. However, the application faces issues like data requirements, complexity, initial cost, weather variability, and crop variety limits.

This work aims to determine the effects of climate change on various meteorological parameters, crop evapotranspiration and irrigation scheduling for wheat crop planting in three soil types (sandy, loamy and clay) of three governorates distributed from the north to the south of Egypt namely Gharbia, Assiut, and Aswan.

MATERIALS AND METHODS

Three Egyptian weather stations were chosen representing the north (Tanta, Gharbia), centre

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(Assiut), and south (Aswan) of Egypt to provide the data of national climate differences.

Climwat program is downloaded from the next link: https://www.fao.org/land-water/databases-and-software/climwat-for-cropwat/en/. A specified coordinates are chosen representing the selected three weather stations of Tanta (Gharbia), Assiut, and Aswan. These coordinates are inserted into POWER NASA website (https://power.larc.nasa.gov/data-access-viewer/) and the meteorological data for 40 years (from 1/1/1982 to 31/12/ 2021) was downloaded from NASA (2021) in the form of an excel file. Also, Cropwat program is downloaded from the link: https://www.fao.org/land-water/databases-and-software/cropwat/en/.

The forty (40) years meteorological data was divided into 4 decades (each decade has 10 years). A general average was calculated for chosen six climatic factors, which are required for computing evapotranspiration. Table (1) shows the stations and decades.

Table 1: The three weather stations and decades.

Weather Stations	Decades			
	DECADE (1)	DECADE (2)	DECADE (3)	DECADE (4)
Tanta (Gharbia)	1982-1991	1992-2001	2002-2011	2012-2021
Assiut				
Aswan				

After including the weather data (Table, 2) for desired three weather stations, the application first calculates radiation and then estimates reference evapotranspiration using the FAO-Penman-Monteith (FPM) equation.

The following equations show the general computation procedure followed in calculation:

$ETc=ET_0*Kc$

Irrigation requirements =ETc - Effective rain

Gross irrigation= net irrigation ÷ irrigation efficiency

Net irrigation= ET_C-(Pe+Ge+Wb) +LR

Where:

ET_c = Crop evapotranspiration (mm).

Pe = Effective dependable rainfall (mm).

Ge = Groundwater contribution from water table (mm).

Wb = Water stored in the soil at the beginning of each period (mm).

LR = Leaching requirement (mm).

The procedure and calculations were done according to FAO (1986), FAO (1998), FAO (2009) and Balasaheb and Biswal (2020).

Table 2: The weather parameters with desired units.

Inputs	Outputs
Minimum Temperature (°C)	Radiation (MJ/m²/day) ET_0 (mm/day)
Maximum Temperature (°C)	
Relative Humidity (%)	
Wind Speed (km/day)	
Sun hours (hours)	

The spring wheat crop was chosen to symbolize the crop grown in Egypt since its growth stages and duration are the same as those of the Egyptian crop. In addition, black clay, red loamy, and red sand were chosen because research indicated that these soil types—heavy, medium, and light texture soils were most like Egyptian soils in terms of field capacity and irrigation frequency for particular crops. The Cropwat program's icons were clicked, and the necessary data was manually entered. The program then computed the remaining data automatically. For instance, after specifying the date of cultivation, the program estimates the date of harvest, and so forth. Lastly, the program simulates complete irrigation scheduling for the chosen crop under various soil and climate conditions (i.e., zone and time).

RESULTS AND DISCUSSION

The average evapotranspiration (ET_0) values of the three governorates of Egypt (Gharbiya, Assiut, and Aswan) over the four decades are presented in Table (3).

Table 3: Average evapotranspiration (ET_0) of the chosen governorates in Egypt through the period (1982-2021).

Governorate	**ET_0 (mm/decade)**			
	1982-1991	**1992-2001**	**2002-2011**	**2012-2021**
Gharbiya	5.49	5.46	5.56	5.55
Assiut	6.91	6.95	7.08	6.93
Aswan	7.77	8.04	8.08	8.09

ET_0, expressed as millimetres per decade, over the course of four decades, from 1982 to 2021, in the three governorates of Egypt. These variables are crucial for water resource management, particularly in dry regions like Egypt, and are an important part of agricultural and hydrological studies.

Data in Table (3) show that, the average evapotranspiration rate in Gharbiya governorate is relatively increased from 5.49 mm in the first decade (1982-1991) to 5.56 mm in the third decade (2002-2011) then decreased to 5.55 in the last decade (2012-2021). This relatively stable ET_0 trend over 40 years suggests that, evapotranspiration-affecting climate has remained consistent in this region.

Assiut has a slightly different ET_0 pattern which starting with 6.91 mm in the first decade (1982-1991) increased up to 7.08 in the third decade (2002-2011) then it decreased to 6.93 in the last one (2012-2021). Minor changes in regional climate or agricultural practices may affect evapotranspiration rates.

In Aswan (south of Egypt with aridity climate) evapotranspiration rates increased clearer, from 7.77 mm in the first decade (1982-1991) up to 8.09 mm in the last one (2012-2021). Aswan's ET_0 has been rising due to rising temperatures and possibly lower humidity, which are common in arid climates, highlighting how climate change affects evapotranspiration.

These findings emphasize the importance of evapotranspiration as a monitoring for Egyptian water resource management. ET_0 is affected by temperature, humidity, wind speed, and solar radiation, so the observed trends may indicate broader climatic changes in these regions. Thus, understanding these trends is essential for developing strategies to reduce water scarcity, optimise irrigation, and ensure sustainable agricultural productivity in changing climates.

Over decades, the potential evapotranspiration is clearly increased in all the three governorates. This suggests higher water demand in these areas due to rising temperatures and climate change. Rising ET_0 increases irrigation demand and affecting agriculture. Farmers may need to adjust their irrigation practices to handle higher ET_0 values, which could affect the environment and economy. Soil and plants lose more water with higher ET_0.

Egypt relies on the Nile River, which can strain regional water resources. It emphasizes efficient water resource management and sustainable water infrastructure. Higher ET_0 values are linked to climate change and rising temperatures. This data supports the global climate change trend, which can affect ecosystems, agriculture, and water availability.

These findings may influence local climate adaptation policies. This may include encouraging water conservation, climate-resilient agriculture, and efficient irrigation. The derived ET_0 also varies across the three regions, reflecting weather differences. According to the climate analyses, Gharbia is the coldest region, Assiut is middle, whereas Aswan is the warmest one.

In this regard, Omran (2000) conducted a comparison of six evapotranspiration models that are utilized in field experiment in clay soil in Egypt to schedule irrigation for green pepper. The results of the study indicated that, the Penman model could be effectively utilized to calculate ET_0 using meteorological data. Moreover, Omran (2005 and 2013) planned maize and clover irrigation scheduling. Soil water data were utilized in lieu of evapotranspiration.

Figs (1 to 6) depict the relationship between the various climatic factors rquired for FPM equation to calculate ET_0. The relationship between ET_0 and the various main weather parameters used in the FPM equation was investigated, and R^2 values were calculated.

The obtained resultes showed in Figs (1-6) can be reviewed as follows:

For example, Fig (1) shows the relationship between maximum temperature and ET_0 in the three different governorates (Gharbiya, Assiut, and Aswan) over the four decades, divided into ten-year periods. The relationship is expressed through regression equations, and the goodness of fit is measured by the coefficient of determination (R^2). The regression equation is in the form of $y=mx+b$, where: y represents potential evapotranspiration (ET_0) in mm/day; x represents maximum temperature in ^oC; m is the slope; and b is the intercept.

The results revealed that, the overall trend was similar across the all three stations The next graphs depict the most closely related weather parameters to ET0 in the three weather stations studied. Hereher *et al.* (2016) found significant climate changes in Egypt by analyzing land surface temperature (LST) variability over the previous decade. The study examined 276 satellite images from 2003 to 2014 and discovered a temporal increase of 0.3-1.06 °C per decade, with more pronounced changes in the south.

The analysis of the data for each weather station and decade reveal that, the maximum temperature, sun hours, relative humidity, and solar radiation are the most strongly correlated climate variables with ET_0. A satisfactory linear relationship was discovered between them. So ET_0 could be calculated using the resulting regression equations with any of the previously mentioned factors.

In Gharbia governorate, skewed data points and R^2 values produced unsatisfactory results for wind speed and minimum temperature. This result suggests that Tanta (Gharbia) experiences low wind speeds, unlike the maximum temperature, which is very effective in the ET process, the minimum temperature has a smaller effect on evaporation and transpiration. However, at the Assiut and Aswan stations, wind speed and minimum temperature affect both the reference and actual ET. R^2 values were notably correlated with maximum temperature, relative humidity, sunlight hours, and radiation. These findings indicate that ET_0 can be accurately estimated from each of the previously mentioned parameters using the desired regression equation at Tanta Station (Gharbia). Evapotranspiration in Assiut and Aswan can be calculated using the previously mentioned factors, as well as wind speed and minimum temperature.

According to the research conducted by Mazhayskiy *et al.* (2021), a multitude of variables have a substantial impact on water usage. These variables consist of total radiation, radiation balance, air humidity deficit, duration of sunshine, temperature, humidity, wind speed, evaporation from the water surface, precipitation, and soil temperature. According to a study by Smith *et al.* (2002), the FAO Cropwat model predicts water stress effects with precision; however, calibration is necessary for agricultural parameters. The model has the capability to improve experimental procedures, detect discrepancies, and offer a more systematic evaluation of findings. Additionally, it facilitates the consistent presentation of data and enhances the compatibility of outcomes. Models are highly effective tools for extrapolating field observations to real-world scenarios and enabling the prediction of deficit irrigation scheduling across diverse conditions. Fadl *et al.* (2013) emphasize the significance of wheat cultivation in ancient Egypt, where Triticum dicoccum (wheat) has been the principal crop since antiquity.

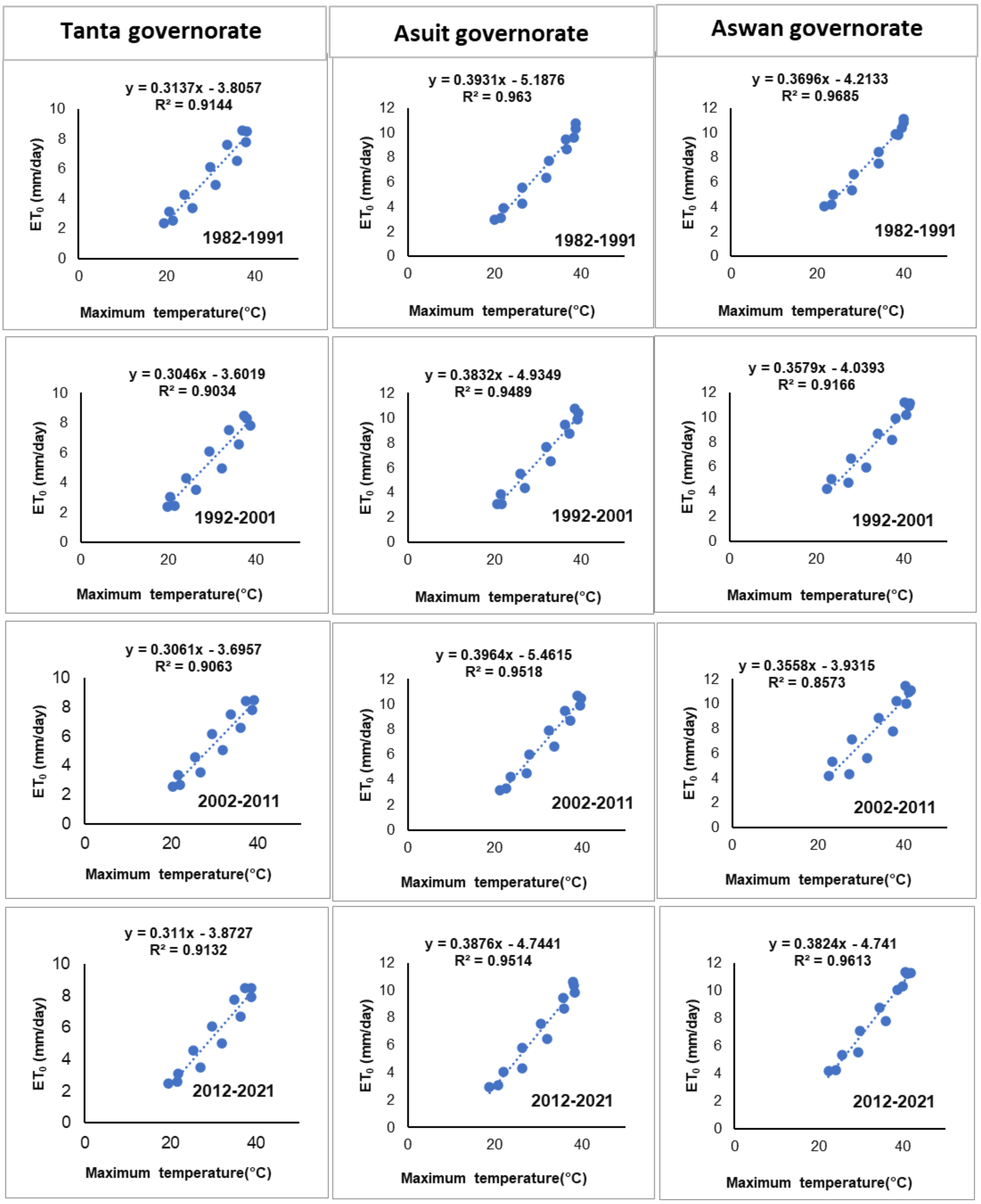

Fig 1: Linear regression between maximum temperature and ET_0 for different stations and decades.

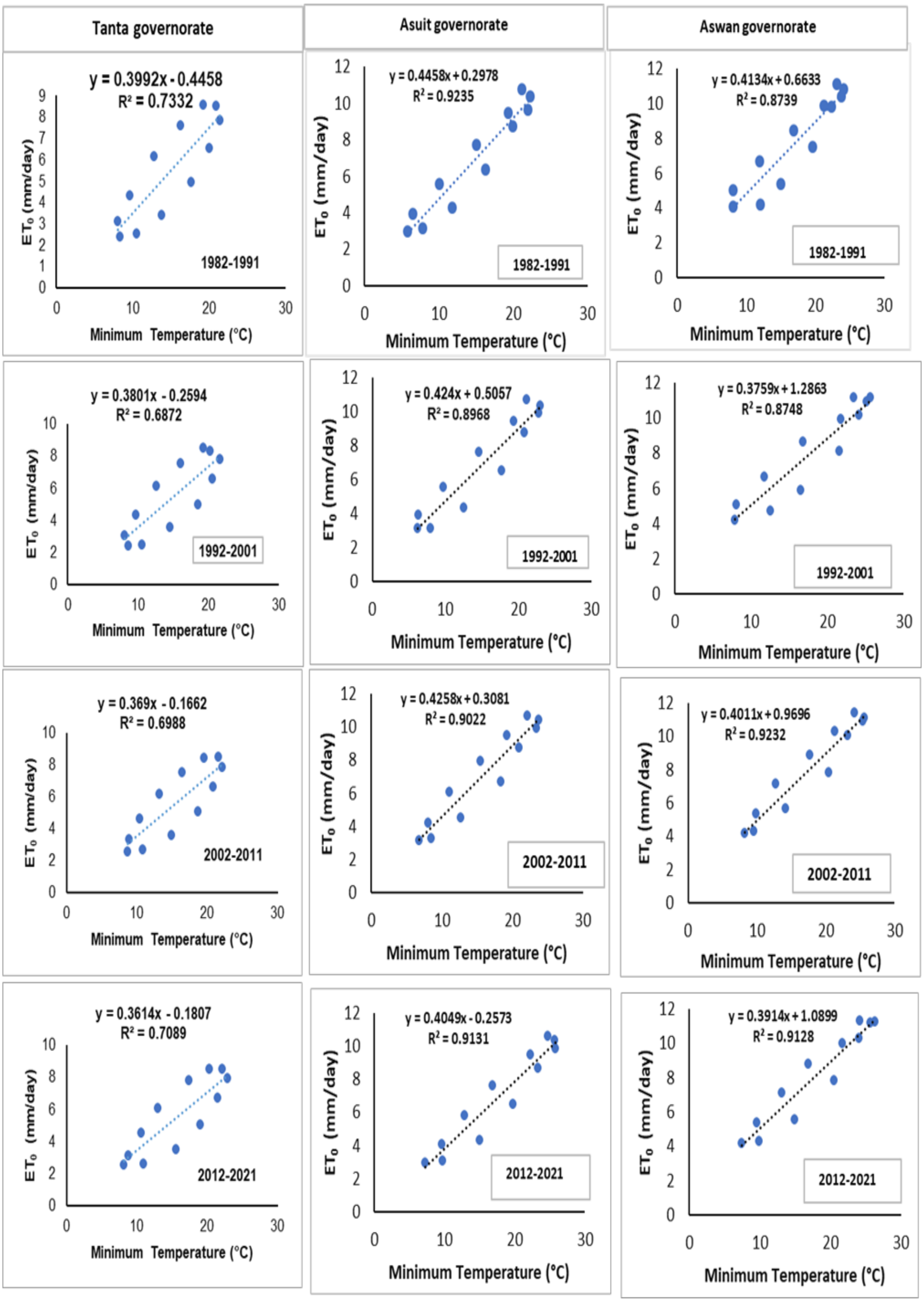

Fig 2: Linear regression between minimum temperature and ET_0 for different stations and decades.

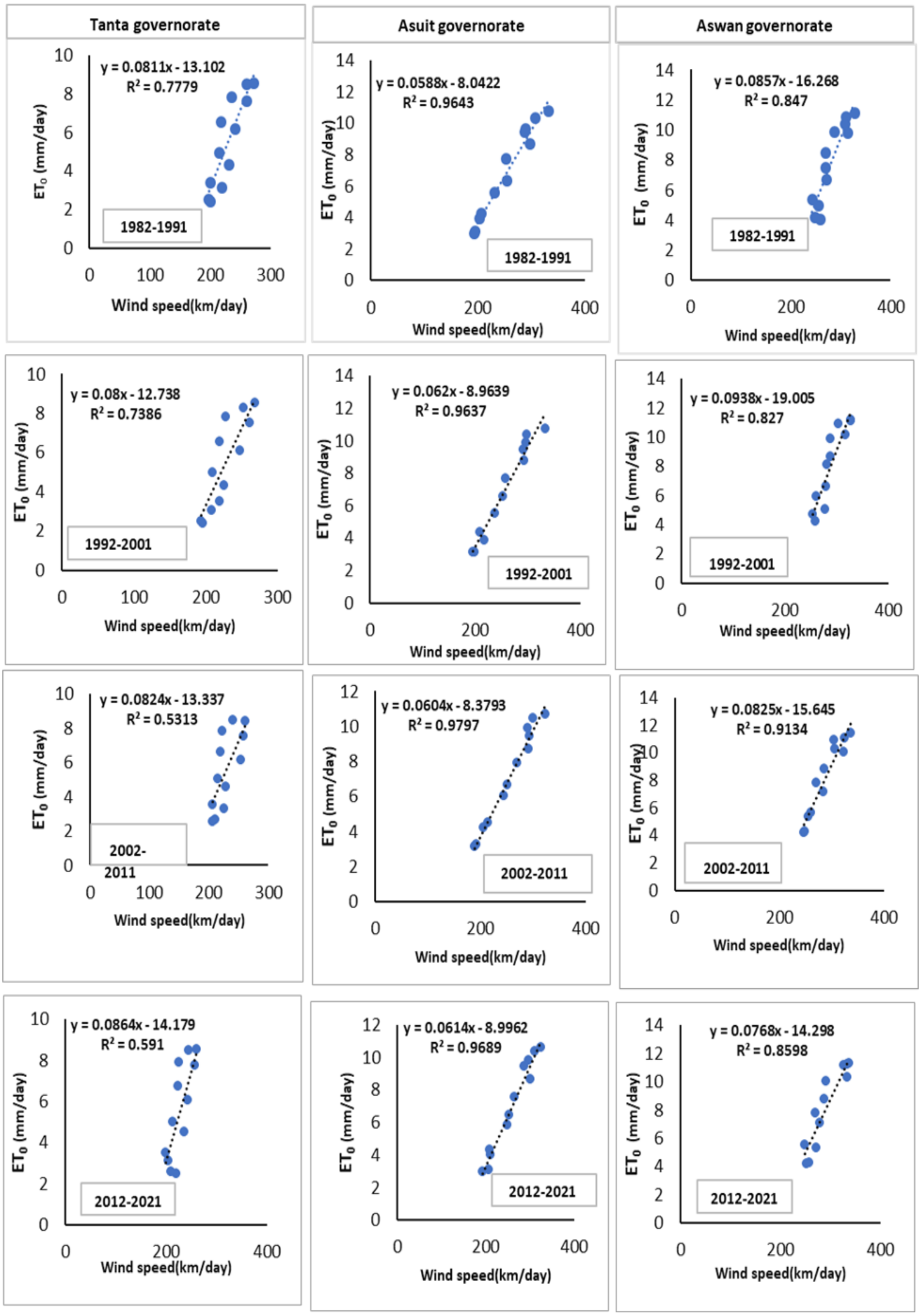

Fig 3: Linear regression between Wind speed and ET_0 for different stations and decades.

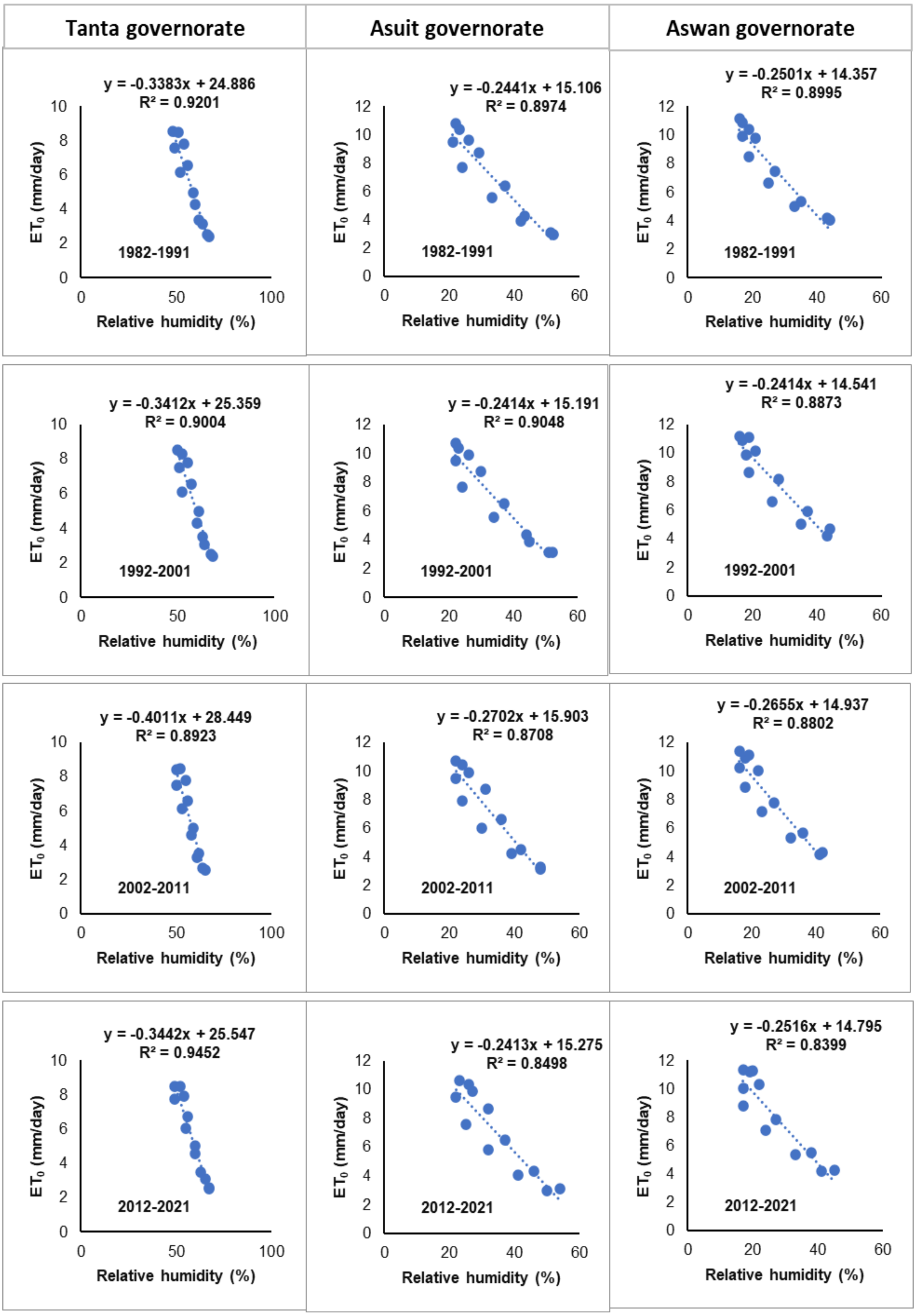

Fig 4: Linear regression between relative humidity and ET for different stations and decades.

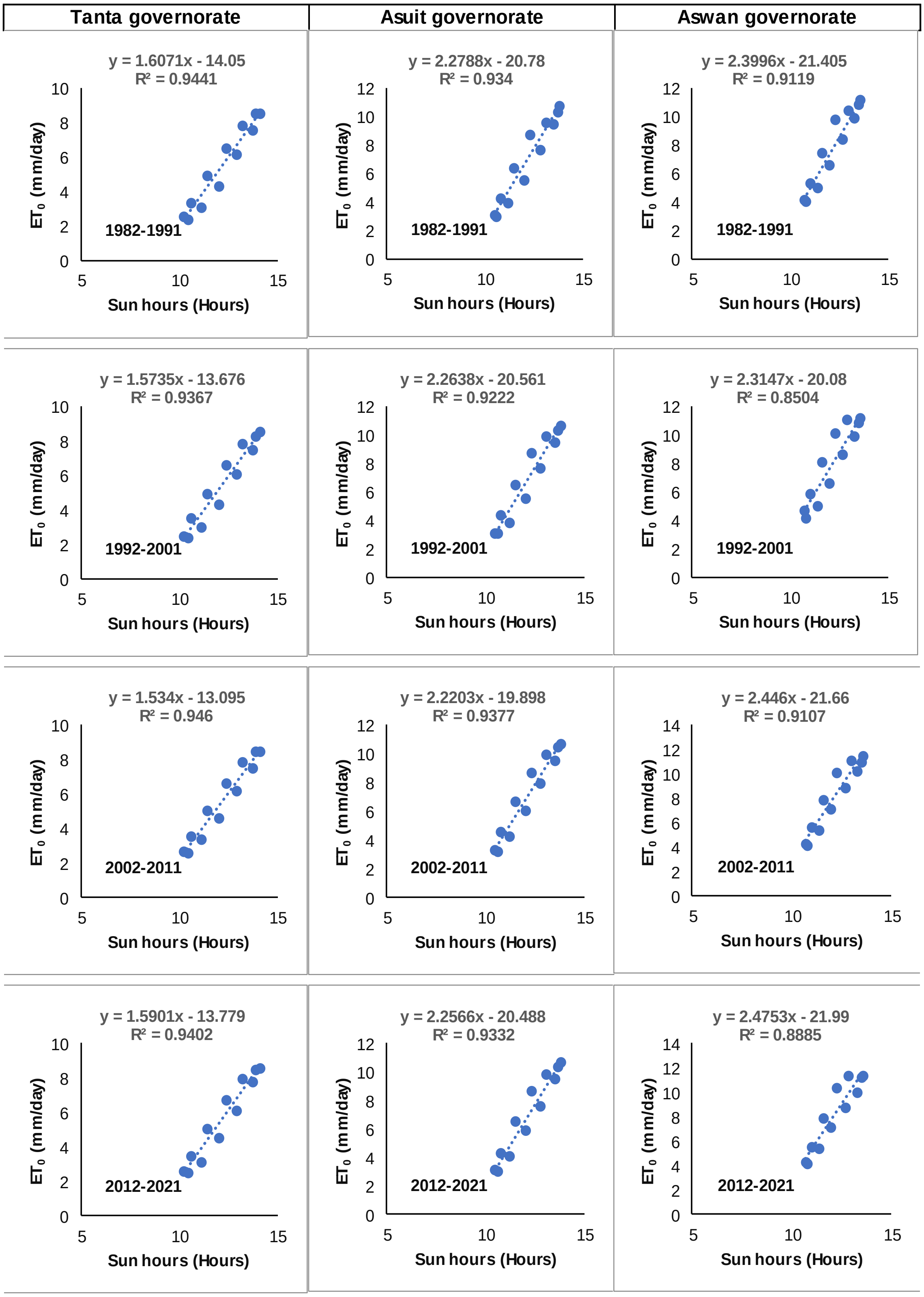

Fig 5: Linear regression between sun hours and ET for different stations and decades.

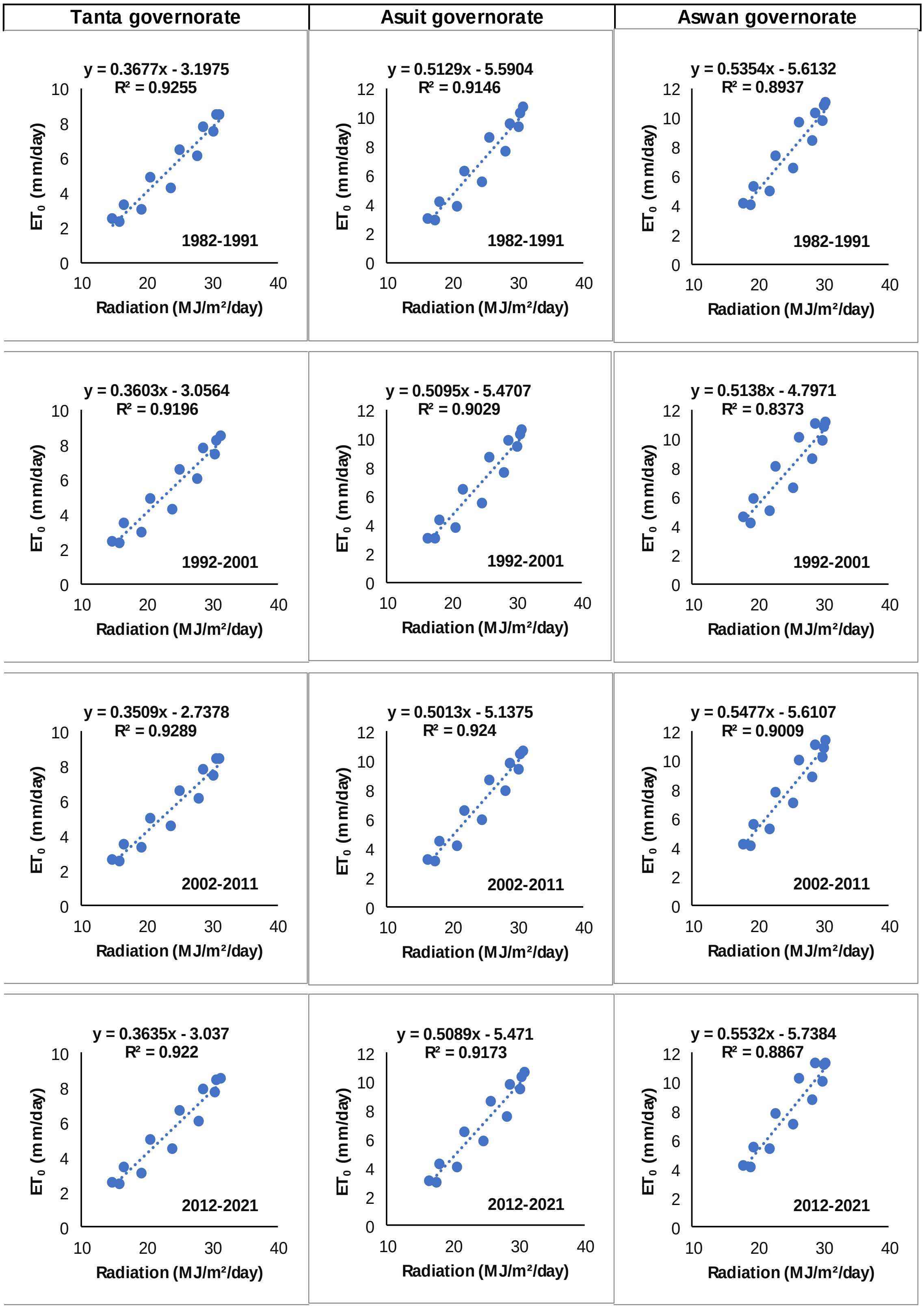

Fig 6: Linear regression between radiation and ET for different stations and decades

Water requirements for Wheat over 40 years in different Egyptian regions

The next section (Table, 4) discusses the water requirements for wheat over 40 years in the studied Egyptian regions (Gharbiya, Assiut, and Aswan governorates).

In this case, the actual crop ET is considered equal to the crop's water demands because the rainfall values used in the program were supposed to be zero.

Table (4) provides a detailed dataset that spans the initial development (Init) to late development (Late) stages of wheat growth, with an indication of the intensity of the climate change impact with respect to time and regions. The data also shows how different growth stages (GS) and crop coefficients (CC) affect the water requirements for wheat.

Table 4: Wheat water requirement at the governorates of Gharbiya, Assiut, and Aswan in forty years period divided into four decades.

GS	CC	Gharbiya governorate				Assiut governorate				Aswan governorate			
		Water requirement (mm/10 days)											
		1982-1991	1992-2001	2002-2011	2012-2021	1982-1991	1992-2001	2002-2011	2012-2021	1982-1991	1992-2001	2002-2011	2012-2021
Init	0.3	7.2	7.5	7.7	7.2	8.5	9.1	9.5	8.9	10.4	10.9	11.6	10.8
Init	0.3	10.9	11.3	11.8	11.1	13.2	13.8	14.5	13.7	16.3	16.8	17.9	16.9
Dev	0.3	9.6	9.8	10.8	10.2	12.0	12.2	12.9	12.5	15.1	15.5	16.3	15.7
Dev	0.36	10.2	10.2	11.9	11.2	13.0	13.1	13.9	13.6	17.0	17.1	18.0	17.6
Dev	0.67	20.4	20.6	23.6	22.4	26.1	26.6	28.1	27.9	34.8	35.5	37.0	36.6
Mid	0.99	27.0	27.5	30.6	29.2	34.6	35.9	37.5	37.7	47.0	48.5	50.1	50.1
Mid	1.21	32.1	32.8	36.5	35.0	41.2	43.4	44.9	45.8	56.9	59.4	61.0	61.6
Mid	1.22	41.2	40.7	46.5	43.5	52.1	53.5	56.5	57.3	69.4	71.5	74.7	75.4
Mid	1.22	43.0	41.4	48.3	43.4	53.6	53.9	58.0	58.5	69.2	70.5	74.9	75.5
Late	1.22	47.8	44.9	53.4	46.9	59.1	58.5	63.7	64	74.5	75.2	81.0	81.6
Late	1.14	40.2	38.9	44.6	41.0	50.0	49.8	54.1	54.5	61.7	61.8	66.3	66.7
Late	0.87	42.6	42.1	46.9	45.0	53.0	53.1	57.5	58.0	64.3	64.0	68.4	68.8
Late	0.56	30.3	30.5	33.2	32.6	37.7	38.0	41.0	41.4	45.0	44.6	47.5	47.7
Late	0.35	8.5	8.7	9.1	8.9	10.3	10.4	11.0	11.0	11.7	11.8	12.3	12.3
Total		371	367	415	388	464	471	503	505	593	603	637	637

Note: Because of the time involved in cultivation and harvesting, the period in the first and last values may be shorter than ten days.

The minimum water requirement is 7.2 mm/10 days during the initial growth stage in the 1982-1991 decade at Al-Gharbiya governorate. This indicates the initial stages of wheat growth have the lowest water demands.

The maximum water requirement recorded is 81.6 mm/10 days during the late growth stage in the 2012-2021 decade at Aswan governorate. This highlights the significant increase in water needs as the wheat crop approaches maturity, especially under higher crop coefficients.

There's a noticeable increasing trend in water requirements over the decades across all the three governorates. This trend is more pronounced at higher crop coefficients, reflecting the increased water demand of wheat with progression in its growth stages.

The CC plays a significant role in determining the water requirements. Higher CC values, which indicate more advanced stages of growth or varieties with higher water needs, are associated with increased water requirements. This suggests the critical importance of considering the GS and variety in water management for wheat cultivation.

The three governorates exhibit distinct patterns in water requirements, with Aswan consistently showing the highest demand. This can be attributed to regional differences in evapotranspiration rates and possibly the wheat varieties cultivated, which may have higher crop coefficients.

The analysis over four decades shows a consistent increase in water requirements for each subsequent decade, indicating not just the impact of advancing wheat growth stages but also possibly reflecting changes in agricultural practices or shifts in wheat varieties towards those with higher water demands.

The overall increase in total water requirement from 1982 to 2021 underscores the escalating challenge of meeting the water needs of wheat cultivation. This trend is particularly stark in Aswan, followed by Assiut, and then Gharbiya, suggesting that regions with inherently higher crop coefficients or more advanced stages of crop development face more significant challenges in water resource management.

In conclusion, the analysis reveals that, both the crop's development stage and its inherent water demand (as indicated by the crop coefficient) are crucial factors influencing the water requirements for wheat cultivation over time and across different regions. These insights highlight the importance of strategic water resource management and the selection of crop varieties adapted to the specific water availability conditions of each region to ensure sustainable agricultural practices in the face of growing water demands.

The subsequent section details the wheat crop's irrigation schedule (quantity and frequency) for various soil types. The irrigation schedule for wheat grown in clay soil in the three governorates under study is detailed in Tables 5, 6, and 7.

The data pertaining to the irrigation scheduling of wheat grown in clay soil within the Gharbiya governorate for a span of four decades is presented in Table (5). The document provides information on the soil water depletion percentages (Depl.%) and gross irrigation requirements (GI in millimetres) at various wheat growth stages (GS), including Initial (Init), Development (Dev), Mid, End, and Harvest.

Table 5: Irrigation scheduling for wheat cultivated in clay soil in Gharbiya governorate for 40 years divided in 4 decades.

Date	No. of Days	GS	1982-1991		1992-2001		2002-2011		2012-2021	
			Depl. (%)	GI (mm)	Depl. (%)	GI (mm)	Depl. (%)	GI (mm)	Depl. (%)	GI (mm)
17 Nov	3	Init	55	54.5	56	54.8	56	54.9	55	54.6
25-Dec	41	Dev	55	144.9	56	146.3	55	137	56	143.9
30-Jan	77	Mid	56	193.2	55	189	56	193.4	56	193
05-Mar	111	End	65	223	66	225.4	57	195.6	59	202.9
24-Mar	130	Harvest	24		22		52		37	
Total				615.6		615.5		580.9		594.4

Note: GS = growth stage; Depl. = Soil Water Depletions; GI = gross irrigation

Table 6: Irrigation scheduling for wheat cultivated in clay soil in Assiut governorate for 40 years divided in 4 decades.

Date	No. of Days	GS	1982-1991		1992-2001		2002-2011		2012-2021	
			Depl. (%)	GI (mm)	Depl. (%)	GI (mm)	Depl. (%)	GI (mm)	Depl. (%)	GI (mm)
17-Nov	3	Init	56	55.5	57	55.9	57	39.3	57	55.8
19-Dec	36	Dev	55	132.5	55	130.1	55	87.7	56	131
17-Jan	66	Mid	55	189.8	56	193	57	136.4	57	193.7
11-Feb	92	Mid	56	190.7	56	190.9	55	132.5	57	194.1
09-Mar	111	End	-	-	-	-	-	158	68	234.7
24-Mar	130	Harvest	77		79		66		23	
Total				568.5		569.9		791.3		809.3

Table 7: Irrigation scheduling for wheat cultivated in clay soil in Aswan governorate for 40 years divided in 4 decades

2012-2021		2002-2011		1992-2001		1982-1991		GS	No. of Days	Date
GI (mm)	Depl. (%)	GI (mm)	Depl. (%)	GI (mm)	Depl. (%)	GI (mm)	Depl. (%)			
52.4	56	52.7	56	52.4	56	52.2	55	Init	2	16-Nov
109.1	55	107.6	56	108.8	55	111.7	55	Init	27	11-Dec
169.7	55	175.5	57	175.6	56	177.4	56	Dev	54	07-Jan
197.8	58	196.3	57	190.7	56	193.4	56	Mid	76	29-Jan
191.7	56	190.2	55	191.6	56	191.3	56	Mid	95	17-Feb
226.1	66	224.5	65	239.8	70	257	75	End	123	17-Mar
	38		38		20		9	Harvest	130	24-Mar
946.8		946.8		958.9		983		Total		

The amount of water removed from the soil in relation to its field capacity is shown by depletion percentages. These percentages exhibit slight variations over the course of four decades at various growth stages, suggesting a reasonably consistent pattern of water usage by the wheat crop over time. Notably, the Harvest stage exhibits the lowest soil water depletion (ranging from 22% to 52%), while the End stage exhibits the highest (ranging from 57% to 66%). Gross irrigation amounts reflect the total amount of water used during each growth stage. Irrigation requirements gradually increase from the Initial to the End stage, with no irrigation requirement reported at Harvest, most likely because irrigation is not typically applied so close to harvesting. The Initial stage shows very slight variations in both soil water depletion and gross irrigation across the decades, indicating a consistent start to the wheat growing season.

During the Development stage, there's a slight increase in both depletion percentage and gross irrigation in the 1992-2001 decade, followed by a decrease in the 2002-2011 decade and an increase again in the 2012-2021 decade. This fluctuation could reflect changes in climate patterns or irrigation practices. The Mid and End stages show a more consistent requirement for gross irrigation across the decades, with a notable increase in soil water depletion in the final decade during the End stage. The Harvest stage does not provide irrigation data but shows a significant variance in soil water depletion, indicating varying conditions at the time of harvest over the years.

The total gross irrigation requirement has a minor fluctuation across the decades, with the earliest (1982-1991) and the latest (2012-2021) decades showing slightly lower and higher total irrigation requirements, respectively. The total gross irrigation reflects the cumulative water applied across all stages, excluding the Harvest stage, and indicates the overall trend of water application to wheat crops over the years. Overall, there is stability in the irrigation needs of wheat crops in clay soil, with minor fluctuations that could be attributed to variations in weather patterns, advancements in irrigation technology, or changes in farming practices over the 40 years. There's a notable increase in both soil water depletion and gross irrigation needs at the End stage, emphasizing the critical need for water as the wheat approaches maturity.

The data suggests consistent irrigation practices have been maintained over the decades, with adjustments reflecting either improved understanding of wheat water needs or responses to external environmental conditions. In this respect, FAO (2000) studied irrigation scheduling for maximum net profit. They found that one, two, or three 60mm irrigations produce high yields of winter wheat.

Similar to Table (5), Table (6) lists the duration of each growth stage and correlates these stages with the gross irrigation amounts and soil water depletion percentages for the governorate of Assiut. From the first planting stage to the harvest, there are various stages. The irrigation practices and water depletion percentages are remarkably consistent between the decades 1982-1991 and 1992-2001. Gross irrigation amounts are similar, with minor variations, indicating stable irrigation practices and possibly consistent climatic conditions.

The decade 2002-2011 shows a substantial decrease in soil water depletion percentages during the mid-season, implying improved irrigation efficiency, changes in rainfall patterns, or changes in wheat varieties that influence water usage. However, the total gross irrigation amount decreases significantly, indicating a change in irrigation strategy or external factors influencing water availability.

Like earlier decades, the most recent decade (2012-2021) has witnessed a return to higher soil water depletion percentages, but with the highest gross irrigation amount, most notably during the End and Harvest stages. This may suggest alterations in agricultural practices, climate conditions, or irrigation technologies with the objective of optimizing crop production.

There has been a noticeable trend of increasing gross irrigation amounts over the decades, implying adjustments to either compensate for increased crop water demand or adapt to less favourable climatic conditions. The data show a particular anomaly or data gap for the End and Harvest stages in the last three columns, with no information provided for the 1982-2001 periods and a significant increase in irrigation at the End stage from 2012 to 2021. This could reflect changing agricultural practices or the introduction of new wheat varieties with varying water requirements.

Implications of Water Resource Management: The data-driven evolution of irrigation practices emphasizes the importance of continuous adaptation in water resource management strategies. The change in gross irrigation amounts and soil water depletion percentages over time reflect responses to changing environmental conditions, technological advancements, and possibly economic considerations for wheat production in the region.

Table (7) displays the irrigation schedule for wheat cultivated in clay soil in Aswan governorate. The total irrigation volumes over the decades show a slight decrease, moving from 983 mm in the 1982-1991 decade to 946.8 mm in both the 2002-2011 and 2012-2021 decades. This trend might suggest low impact of climate change in irrigation need for wheat in clay soil in Aswan. The consistent soil water depletion percentages across the decades indicate a stable approach to water management in the region, despite the potential for climatic variability and evolving agricultural technologies. Additionally, the gross irrigation amounts reflect a comprehensive understanding of the water needs of wheat in clay soil conditions, ensuring the crop receives adequate moisture throughout its growth stages to maximize yield and quality.

A study by Elbeltagi *et al.* (2021) assessed evapotranspiration in the Egyptian Nile Delta between 1997 and 2017. The study proposes that, for sustainable water management, land use and land cover changes should be integrated with geographic data.

Table (8) shows the scheduling of irrigation for wheat cultivation in sandy soil of Gharbiya governorate as opposed to clay soil, much like Table (5). For the decades 1982-1991 and 1992-2001, the irrigation metrics show very similar soil water depletion percentages and gross irrigation amounts. This consistency may be due to stable climatic conditions or unchanged agricultural practices over these time periods.

Table 8: Irrigation scheduling for wheat cultivated in sandy soil of Gharbiya governorate for 40 years divided in 4 decades

Date	**No. of Days**	**GS**	**1982-1991**		**1992-2001**		**2002-2011**		**2012-2021**	
			Depl. (%)	**GI (mm)**	**Depl. (%)**	**GI (mm)**	**Depl. (%)**	**GI (mm)**	**Depl. (%)**	**GI (mm)**
29-Dec	45	Dev	56	77.8	56	76.9	56	72.3	56	74.3
21-Jan	68	Mid	56	95.2	58	99.5	56	96.5	56	96.2
07-Feb	85	Mid	56	96.6	58	100.2	59	101.1	57	96.9
22-Feb	100	Mid	59	101.1	56	96.8	59	101	57	97.5
15-Mar	121	End	73	125.7	76	129.7	63	107.7	68	116.8
24-Mar	130	Harvest	18		11		65		40	
Total				496.4		503.1		478.6		481.7

Note: GS = growth stage; Depl. = Soil Water Depletions; GI = gross irrigation

Compared to prior decades, the decade 2002–2011 shows a minor drop in the gross irrigation amount, but an intriguing rise in the percentage of soil water depletion during the mid-season. It alludes to a possible change in irrigation effectiveness or reaction to changing environmental circumstances. The most recent ten years 2012–2021 show a consistent pattern of somewhat lower gross irrigation amounts than preceding years, combined with a moderate adjustment in the percentages of soil water depletion. This may point to a continuous adaptation to water-saving measures or modifications to wheat varieties for optimal water consumption.

A gradual decrease in total gross irrigation amounts is observed over the decades, suggesting improvements in irrigation efficiency, possibly due to technological advancements or the adoption of more water-efficient wheat varieties.

Soil water depletion percentages show minor fluctuations across the decades but remain relatively consistent, indicating stable water demand by the wheat crops throughout their growth stages. The data highlights the importance of adjusting irrigation practices to suit the changing demands of growing wheat in sandy soil. There has been a general movement toward improving agricultural water use, as shown by the change in overall irrigation amounts and small changes in soil water depletion percentages. For water management to be sustainable, these tendencies are essential, particularly in areas where water scarcity is a problem.

Table (9) elucidates the irrigation scheduling for wheat cultivated in sandy soil of Assiut governorate through 40-year spanning from 1982 to 2021. The lowest GI was observed in the second decade (1992- 2001). GI value was 572 mm in the first decade (1982-1991), while the highest GI requirement was recorded in the last decade (2012-2021) at 681.6 mm, indicating an increase in water needs over time.

Table 9: Irrigation scheduling for wheat cultivated in sandy soil of Assiut governorate for 40 years divided in 4 decades

Date	No. of Days	GS	1982-1991		1992-2001		2002-2011		2012-2021	
			Depl. (%)	GI (mm)	Depl. (%)	GI (mm)	Depl. (%)	GI (mm)	Depl. (%)	GI (mm)
16-Dec	32	Dev	55	64.8	55	61.3	55	55	43.3	61.8
08-Jan	55	Dev	57	94.5	56	91.6	56	56	63.5	90.7
23-Jan	70	Mid	58	100.3	55	94.8	58	57	68.9	98.5
05-Feb	83	Mid	56	96	55	94.9	58	59	70.9	101.3
16-Feb	94	Mid	59	101	57	97.6	56	56	67.6	96.6
27-Feb	105	End	67	115.4	65	110.6	60	61	73.3	104.6
16-Mar	122	End	-	-	-	-	73	75	89.7	128.1
24-Mar	130	Harvest	51		69		27	21		
Total				572		550.8		477.2		681.6

Note: GS = growth stage; Depl. = Soil Water Depletions; GI = gross irrigation

The lowest depletion percentage recorded was during the harvest stage on 24-Mar, at 27% in the second decade and 21% in the last decade, indicating minimal water stress at the end of the growth cycle. The highest depletion percentage and GI were observed in the last decade, specifically on 16-Mar at the end of the growth cycle, with a depletion of 73% and a GI of 128.1 mm, reflecting increased water demand during this period.

Table (10) outlines the irrigation scheduling for wheat grown in sandy soil of Aswan governorate. Across the study, the highest GI requirement was observed in the latest decade (2012-2021) with a total of 851.7 mm, indicating an increasing trend in water demands over the years. The lowest GI requirement was noted in the second decade (1992-2001) with 726.3 mm, suggesting variations in water needs possibly due to changes in climate, wheat varieties, or irrigation practices over time.

The lowest soil water depletion percentages were generally observed at the initial and harvest stages, indicating lower water stress at the start and end of the wheat's lifecycle. For example, at harvest on 24-Mar, depletion was down to 32%, the lowest recorded, underscoring minimal water stress at this stage. Conversely, high depletion percentages during critical growth periods, like the end-season, highlight the need for more precise water management to prevent stress and optimize growth.

Table 10: Irrigation scheduling for wheat cultivated in sandy soil in Aswan governorate for 40 years divided in 4 decades.

Date	No. of Days	GS	1982-1991		1992-2001		2002-2011		2012-2021	
			Depl. (%)	GI (mm)	Depl. (%)	GI (mm)	Depl. (%)	GI (mm)	Depl. (%)	GI (mm)
03-Dec	19	Init	56	48.9	55	46.2	56	44.4	55	46.3
28-Dec	44	Dev	57	80.3	56	76.9	57	75.4	57	78.7
11-Jan	58	Dev	56	96	59	100.1	58	95.6	57	94.6
22-Jan	69	Mid	59	101.9	56	95.8	56	96.8	58	98.8
01-Feb	79	Mid	60	103.5	55	94.4	57	97.1	58	98.9
10-Feb	88	Mid	60	102.6	60	102.1	56	96.3	57	97
19-Feb	97	Mid	57	97.3	57	97	60	103.2	61	104.8
28-Feb	106	End	69	117.6	66	113.8	62	106	62	107
14-Mar	120	End	-	-	-	-	72	123.1	73	125.6
24-Mar	130	Harvest	56		77		39		32	
Total				748.1		726.3		837.9		851.7

Note: GS = growth stage; Depl. = Soil Water Depletions; GI = gross irrigation

The data illustrates a gradual increase in irrigation requirements for wheat in sandy soils over four decades, with the most substantial needs seen in the 2012-2021 decade. This trend may reflect evolving agricultural practices, climatic variations, or advancements in wheat cultivation technologies. Adapting irrigation schedules based on these insights could significantly influence wheat productivity and sustainability in arid regions like Aswan governorate.

Based on wheat productivity, irrigated agriculture provides Egypt with half of its 20 million tons of required wheat. Wheat yields are predicted to be largely impacted by climate change, notwithstanding recent technological advancements. The amount of water required for irrigation will increase from 6 to 20 billion m^3, but more water is still required for salt leaching and efficiency. Egypt will have difficulties producing enough grain and supplying water for irrigation in the future (Asseng *et al.*, 2018). The increase in water need could be partially offset by improving irrigation technologies and conveyance systems in the eastern Mediterranean (Fader *et al.*, 2016).

Research conducted by Sharshar (2010), Al Tahar *et al.* (2011), El hag (2011), Zafarnaderi and Mohammadi (2013), and Omar *et al.* (2014) demonstrated that various irrigation numbers influenced various plant parameters, including days to heading, days to maturity, plant height, number of spikes/m^2, grain yield, straw yield, harvest index, number of grains/spikes, and 1000-grain weight. Additionally, they concluded that the values underlying the mentioned traits increased as the number of irrigations increased and decreased as the number of irrigations decreased.

Conclusion

Climate change affects Aswan and Assiut's weather patterns, such as increasing temperatures and fluctuating wind speeds. Aswan saw the largest increase in wind speed, followed by Assiut, while Al-Gharbiya saw stability. It is anticipated that Aswan and Assiut will continue to see rising temperatures and winds. There is a significant correlation between reference evapotranspiration in Al-Gharbiya and variables like maximum temperature, sunshine hours, solar radiation, and relative humidity. Over the past 40 years, changes in climatic conditions have caused a shift in the percentages of soil water depletion and gross irrigation amounts. The percentages of soil water depletion decreased during the last ten years (2012–2021), but there was a notable increase during the final irrigation event prior to harvest, indicating that irrigation tactics should be changed to maximize wheat growth and yield. The importance of precise irrigation scheduling based on the growth stage of wheat, ensuring optimal water use efficiency and supporting sustainable agricultural practices in the face of changing environmental conditions.

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تأثير التغير المناخي على الاستهلاك المائي لمحصول القمح في بعض مناطق مصر

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الملخص العربي

يعد القمح من أهم المحاصيل الاستراتيجية التي تزرع في مصر، كما يعتبر من ضمن المحاصيل التي من المتوقع أن تتأثر احتياجاتها المائية بالتغيرات المناخية، التي يجب الاهتمام بدراستها خصوصا في ظل ظروف ندرة المياه المتاحة للري.

وتهدف هذه الدراسة الي قياس مدي تأثر الاستهلاك المائي لمحصول القمح بالتغيرات المناخية في بعض المحافظات الممثلة لوادي ودلتا نهر النيل في مصر، ولتحقيق هذا الهدف تم تحديد احداثيات محطات مناخيه معينة لتمثيل ثلاث مناطق مناخية ممثلة لمصر، تبدأ من الشمال بمحافظة الغربية إلى الوسط حيث محافظة أسيوط وتنتهي في الجنوب بمحافظة أسوان، ولقد تم دراسة الخصائص المناخية لهذه المناطق باستخدام برنامج Climwat ، ثم تم تجميع بعض البيانات المناخية اللازمة لحساب البخر نتح المرجعي من خلال معادلة Penman المعدلة وذلك خلال فترة زمنية مقدارها أربعون عاماً تبدأ من ١٩٨٢ حتى ٢٠٢١ باستخدام بيانات موقع وكالة ناسا على شبكة المعلومات الدولية، مع تقسيم الفترات المناخية الي أربع عقود زمنية كل منها ١٠ سنوات، ثم تم ادخال البيانات المستخرجة كلها على برنامج الـ Cropwat لحساب البخر نتح المرجعي، والفعلي، وجدولة الري لمحصول القمح الذي يزرع في ثلاث أنواع من الترب (الرملية، والطميية، والطينية) في المحافظات الثلاثة تحت الدراسة (الغربية، واسيوط، واسوان)، مع عمل محاكاة لتلك الحسابات فيها وذلك لتحديد الاحتياجات المائية، والتخطيط لجدولة ري محصول القمح بشكل علمي سليم.

وقد دلت النتائج علي زيادة الاحتياجات المائية بشكل عام للقمح خلال السنوات الأخيرة خصوصا في جنوب مصر، ويوصي البحث بتطبيق استخدام برنامج Cropwat لجدولة ري محصول القمح.

كلمات مفتاحية: القمح – التغير المناخي – الاحتياجات المائية – مصر – برنامج كروبوات – البخرنتح – جدولة الري – موقع ناسا.