PREDICTION OF TOTAL WATER REQUIREMENTS FOR AGRICULTURE IN THE ARAB WORLD UNDER CLIMATE CHANGE

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ABSTRACT

In this paper, prediction equations were developed to calculate total water requirements needed to support irrigation in each country in the Arab world in 2025 under the expected increase in temperature by 2.0ºC. Data for actual and future amounts of water required for agriculture were obtained from "Arabic Center for Dry and Arid Zones Studies". Data for mean annual temperature of 100 years for each country was regressed on future amounts of water required for agriculture to develop the equations. The results showed that the Arab Countries can be divided into three groups according to the temperature range. Group (1): Oman, Yemen, Djibouti, Sudan, Somalia, Egypt and Libya, where the "range" is less than 2.0 ºC. In this group, Egypt was found to have the highest percent increase water requirements in 2025 (33%) and both Djibouti and Sudan will have the lowest percentage (13%). Group (2): Tunisia, Algeria, Maraca and Mauritania, where the temperature range between 2.0-2.6ºC. Algeria will have the highest percent increase water requirements in 2025 (15%), whereas Tunisia will have the lowest percentage (6%) in the group. Group (3): Jordan, Syria, Iraq, Palestine, Lebanon, United Arab Emirates, Bahrain, Saudi Arabia, Qatar, and Kuwait, where the temperature range was higher than 2.6ºC. In this group, Kuwait will have the highest percent increase water requirements in 2025 (29%) and Lebanon will have the lowest percentage (8%). Thus, in 2025 the demand for irrigation water will increase in all the Arab countries and that will create a problem in allocation of water resources between different sectors. Therefore, the Arab governments need to use adaptation measures to conserve water and avoid the wasteful use of water resources.

Key words: Arabic countries, total required water for agriculture, prediction equations.

INTRODUCTION

Most of the Arab countries are located in arid and semi-arid zones known for their scanty annual rainfall, very high rates of evaporation and consequently extremely insufficient renewable water resources. The per capita water share of renewable water resources in the Arab Region is less than 10% of the global average (Al-Weshah, 2008 [1]). Sustainable management of water resources is a must as water scarcity is becoming more and more a development constraint impeding the social and economic development of many countries in the region (AbuZeid and AbdelMegeed, 2004 [2]).

The Arabic region is considered one of the most vulnerable regions to climate change impacts, on account of its water scarcity, which is the highest in the world (Elasha, 2010 [3]). Giorgi (2006) [4] identifies North Africa and the Mediterranean among the most physically sensitive regions to climate change. Climate models are projecting hotter, drier and less predictable climate, resulting in a drop in water run-off by 20% to 30% in most of region by 2050, mainly due to rising temperature and lower precipitation (Milly 2005 [5]), in addition to increase the frequency and intensity of extreme weather events such as droughts and floods (El-Quesy, 2009[6]). The fragile water situation in the region is more sensitive to climate change which may cause economic, social and environmental effects. One of the major drawbacks of research in and on the Arab region is data availability: regular measurements, continuous monitoring and neutral evaluation of the water status in the area is either missing or only available in isolated surveys that might be separated by long time spans with unavailable records. This adds to the uncertainty of the effect of climate change on water resources in most of the Arab countries (El-Quesy, 2009 [6]), which in turn will affect the future of agriculture.

In the Arab countries, the agricultural sector consumes over 83% of the water in the region and 37% of an economically active population of 126 million, were engaged in agriculture in 2006 (IFAD, 2009 [7]). Because agriculture is an activity developed under climatic condition, the impacts of climate change could affect a large segment of the population. Furthermore, agriculture is under pressure to produce more food to help reduce the Arab countries' enormous food imports bill, which equivalent to US$ 28 billion in 2006 (UNDP, 2008 [8]). Previous research was done in Egypt on the effect of climate change on water requirements for crops. It revealed that it will increase by 16% for summer crops compared to their current requirements under current conditions. Furthermore, climate change conditions could decrease water demand for winter crops up to 2% in the year of 2050 (Eid and El-Mowelhi, 1998 [9]). In this context, management of water supply and water demand are equally critical. In order to ensure long-term adaptation to climate change and scarcer water availability, new approaches and policy frameworks, together with innovative solutions, are essential (IFAD, 2009 [7]).

Therefore, it is important to determine how will the amount of water required to support agriculture in the Arab countries be affected by climate change conditions. It is expected that the required water for agriculture will increase under climate change condition as a direct effect of increasing evapotranspiration of the growing crops (Gardner et al., 1985 [10]). The quantification of that effect is hard to do using modeling techniques in each country as a result of lack of trained staff. However, a simpler, yet accurate procedure could be used to do the assessment, i.e. prediction equations resulted from regression analysis (Draper and Smith 1987 [11]).

The objective of this paper was to determine the percentage of increase in the required water for agriculture in all Arabic countries under the expected climate change in 2025.

MATERIALS AND METHODS

1. Source of data

Required water for agriculture for 21 Arabic countries was obtained from a report prepared by "The Arabic Center for Dry and Arid Lands" in 1997 [12]. In this report, agricultural water requirements quantities for each Arabic country were predicted in 2010 and 2025. Furthermore, mean temperature data in centigrade was obtained from "Climatic Research Unit" in the United Kingdom from the following web site: http://www.cru.uea.ac.uk/~timm/cty/obs/TYNCY11.html [13]. The data was values of mean temperature in a period of 100 years from 1901-2000.

Data on area, population, total renewable water resources and water withdrawal for agriculture for each Arabic country was obtained from AQUASTAT. AQUASTAT is FAO's global information system on water and agriculture, developed by the Land and Water Division. The main mandate of the program is to collect, analyze and disseminate information on water resources, water uses, and agricultural water management worldwide. This allows interested users to find comprehensive and regularly updated information at global, regional, and national levels. FAO-AQUASTAT can be access in the following web site http://www.fao.org/nr/water/aquastat/gis/index3.stm [14].

2. Statistical analysis

2.1. Descriptive statistics was done for the mean temperature values to determine the mean value of each year and the mean of the 100 years. Furthermore, the temperature range, which is the difference between highest and lowest value of yearly mean of temperature was calculated for the 100 years (Snedicor and Cochran, 1980 [15]). The Arabic countries were classified according to temperature range into three groups to be used as indication of the vulnerability of these countries to climate change.

2.2. Multiple linear regression (Draper and Smith, 1987 [11]) was used to fit a line through the set of observations, and test how the value of irrigation water requirements for agriculture in each country is affected by the value of its annual mean temperature. As a result, a prediction equation, coefficient of determination (R^2) and standard error of estimates (SE%) were obtained. Coefficient of determination is the amount of variability due to all independent variables, and standard error of estimates is a measurement of precision i.e. closeness of predicted and observed value to each other.

Both irrigation water quantities in 2025 and annual mean temperature values of each country were used to develop a regression equation to predict the value of irrigation water required for agriculture under climate change. The amount required in 2010 was used as a base amount to determine the percentage of increase in 2025. The accuracy of these equations in predicting water required for agriculture in each country was judged by several parameters, i.e. high value of R^2, low value of SE%, the significance of the regression in the ANOVA table, the significance of regression coefficient for mean temperature (MTemp) and regression coefficient for mean temperature lies within confidence interval.

3. Prediction of total water requirements for agriculture under climate change

The developed prediction equations were use to predict the required amount of irrigation water for agriculture in 2025. The IPCC report (2001) [16] estimates an increase in temperature in the Arab region of up to 2°C in the next 15-20 years. Thus, 2.0ºC was added to mean temperature to represent the change in climate in 2025 and irrigation water required for agriculture was predicted in each country using its developed prediction equation.

RESULTS AND DISCUSSION

1. Brief description of the Arab countries

The Arabic countries are divided into four geographic regions: The Eastern Arabic region, the Arabic Island region, the Middle Arabic and the Western Arabic region (Figure 1 and Table 1).

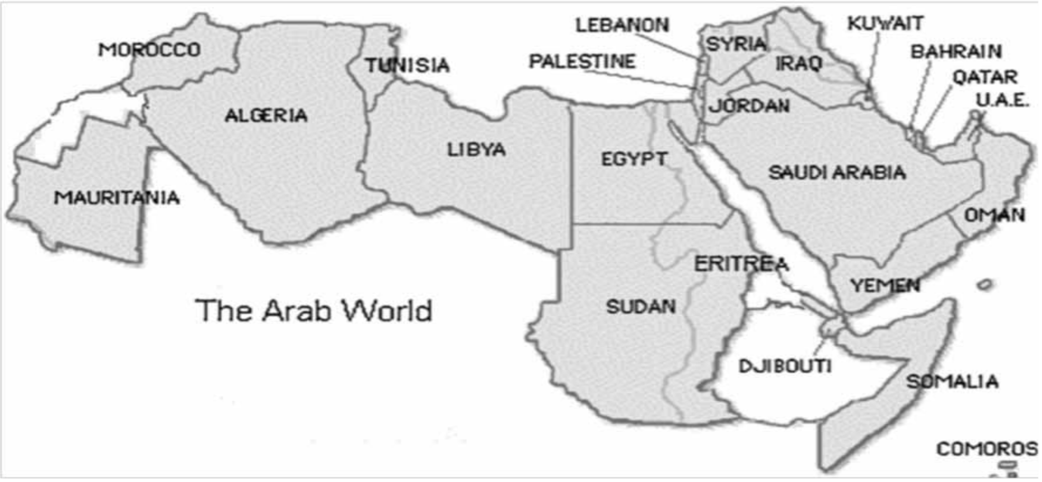

Figure (1): Map of the Arabic countries.
Source: Arab Bay.com, http://www.arabbay.com/arabmap.htm

1. The Eastern Arabic region

This region is located in the East of the Mediterranean Sea in Asia (Figure 1 and Table 1). Five countries are exist in it: Jordan, Syria, Iraq, Occupied Palestine and Lebanon. Iraq has the largest area and the largest population, with water withdrawal percentage for agriculture equal 79%. The highest amount of total renewable water resources exists in Lebanon, 60% of it is withdraw for agriculture. Syria has the largest water withdrawal percentage for agriculture, i.e. 88%.

Table (1): Total area, population and total renewable water in the Eastern Arabic region in 2005.

Arab Countries	Area (km^2)	Population (10^6 inhabitant)	TRWR (10^6 m^3/year)	% WWA
Jordan	88,780	5.7	682	65
Syria	185,180	19.0	4300	88
Iraq	438,320	28.8	3520	79
Occupied Palestine	6,020	3.7	837	45
Lebanon	10,400	3.6	4800	60

TRWR= total renewable water resources; % WWA= % of water withdrawal for agriculture.

2. The Arabic Island region

This region is composed of 7 countries located in Asia between east of the Red Sea and the Arabic Gulf (Figure 1 and Table 2). Saudi Arabia has the largest area, the largest population and the largest total renewable water resources. Yemen has the highest percentage of water withdrawal for agriculture.

Table (2): Total area, population and total renewable water resources in the Arabic Island region in 2005.

Arab Countries	Area (km^2)	Population (10^6 inhabitant)	TRWR (10^6 m^3/year)	% WWA
United Arab Emirates	83,600	4.5	150	83
Bahrain	710	0.7	4.0	45**
Saudi Arabia	2,150,000	24.6	4200	88
Oman	309,500	2.6	1400	88
Qatar	11,000	0.8	58.1	59
Kuwait	17,820	2.7	20*	44
Yemen	527,970	21.0	2100	90

TRWR= total renewable water resources; % WWA= % of water withdrawal for agriculture.
* Ground water inflow.
** The value for Abu Dhabi Emirate only.

3. Middle Arabic region

This region is located in east of Africa and composed of 4 countries: Djibouti, Sudan, Somalia and Egypt (Figure 1 and Table 3). Sudan has the largest area and the largest total renewable water resources. Sudan and Somalia have the highest percentage of water withdrawal for agriculture, i.e. 99%.

Table (3): Total area, population and total renewable water resources in the Middle Arabic region in 2004.

Arab Countries	Area (km^2)	Population (10^6 inhabitant)	TRWR (10^6 m^3/year)	% WWA
Djibouti	23,200	0.7	300	13
Sudan	2,500,000	34.3	149000	99
Somalia	637,660	6.8	1420	99
Egypt	1,000,000	73.4	5730	86

TRWR= total renewable water resources; % WWA= % of water withdrawal for agriculture.

4. The Western Arabic region

Five Arabic countries in this region are existed in the Western part of Africa (Figure 1 and Table 4). These countries are Tunisia, Algeria, Libya, Morocco and Mauritania. The largest area was found for Algeria, which also has the largest population. The largest total renewable water resources exist in Morocco. Moreover, the highest percentage of water withdrawal for agriculture is observed in Mauritania.

Table (4): Total area, population and total renewable water resources in the Western Arabic region in 2004.

Arab Countries	Area (km^2)	Population (10^6 inhabitant)	TRWR (10^6 m^3/year)	% WWA
Tunisia	163,610	9.9	4600	82
Algeria	2,400,000	32.3	11300	65
Libya	1,760,000	5.7	200	83
Morocco	446,550	31.0	29000	87
Mauritania	1,025,520	3.0	11100	88

TRWR= total renewable water resources; % WWA= % of water withdrawal for agriculture.

A common trend existed in the Arabic countries, which is irrigation water withdrawal normally far exceeds the consumptive use of irrigation because water lost in its distribution from its source to the crops (FAO-AQUASTAT [14]. Therefore, improving conveyance efficiency could play an important role in reducing irrigation water losses, especially under the relatively high percentage of water withdrawal for agriculture in most of the Arabic countries.

2. Vulnerability of the Arabic countries to the impact of climate change

Vulnerability is the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes (IPCC, 2001 [17]). The range of the annual mean temperature over the studied period (1901-2000) was used to classify the Arabic countries into three groups to determine its vulnerability to climate change.

2.1. Vulnerable Arabic countries

There are 10 countries in this group, all of them located in Asia, where temperature range over 100 years is higher than 2.6°C. This result implied that these countries are more vulnerable to climate change (Table 5), compared with the rest of the Arab countries. Figure (2) showed that all the Asian Arabic countries are experience a rise in the temperature around 2°C in the period of 1974-2004, except for Yemen and Oman.

Mean temperature in this group was between 16.3-27.0°C. The highest mean temperature was observed in Bahrain, i.e. 27.0°C, which also has the highest range in this group, i.e. 3.6°C. The lowest mean temperature existed in Lebanon, where it was 16.3°C. However, its temperature range was relatively high 2.9°C (Table 5).

Table (5): Vulnerable Arabic countries to climate change according to temperature range in the period between 1901-2000

Arab Countries	Mean Temperature average of 100 years (°C)	Temperature range over 100 years (°C)
Jordan	18.2	3.0
Iraq	21.3	2.9
Lebanon	16.3	2.9
United Arab Emirates	26.8	2.7
Saudi Arabia	24.6	2.9
Kuwait	25.2	2.8
Occupied Palestine	19.1	3.1
Syria	17.7	3.1
Qatar	27.0	3.3
Bahrain	27.0	3.6

2.2. Arabic countries with intermediate vulnerability

Temperature range over 100 years in this group was between 2.0 and 2.5°C (Table 6). This group contains 4 countries located in North East of Africa, i.e. Algeria, Morocco, Tunisia and Mauritania. These countries are also vulnerable to climate change as it shown in Figure (2).

Regarding to mean temperature, it was between 17.1-27.5°C. The lowest mean temperature was found in Morocco, i.e. 17.1°C, with temperature range equal 2.4°C. The highest mean temperature was observed in Mauritania, where it was 27.5°C and temperature range was 2.5°C (Table 6).

Table (6): Intermediate Vulnerable Arabic countries to climate change according to temperature range in the period between 1901-2000.

Arab Countries	Mean Temperature average of 100 years (°C)	Temperature range over 100 years (°C)
Algeria	22.4	2.0
Morocco	17.1	2.4
Tunisia	19.0	2.5
Mauritania	27.5	2.5

2.3. Less vulnerable Arabic countries

All the countries in this group are located in North West and West of Africa, except Yemen and Oman. Temperature range was less than 2.0°C (Table 7). Figure (2) showed that these countries are less vulnerable to climate change.

In this group, mean temperature was between 21.9-28.7°C. Djibouti has the highest mean temperature equal to 28.7°C and its temperature range was 1.7°C. Whereas, Libya has the lowest mean temperature equal to 21.9°C, with temperature range equal to 1.6°C (Table 7).

Table (7): Less Vulnerable Arabic countries to climate change according to temperature range in the period between 1901-2000

Arab Countries	Mean Temperature average of 100 years (°C)	Temperature range over 100 years (°C)
Somalia	27.1	1.4
Yemen	23.7	1.6
Libya	21.9	1.6
Djibouti	28.7	1.7
Oman	25.4	1.7
Sudan	26.8	1.9
Egypt	22.3	1.9

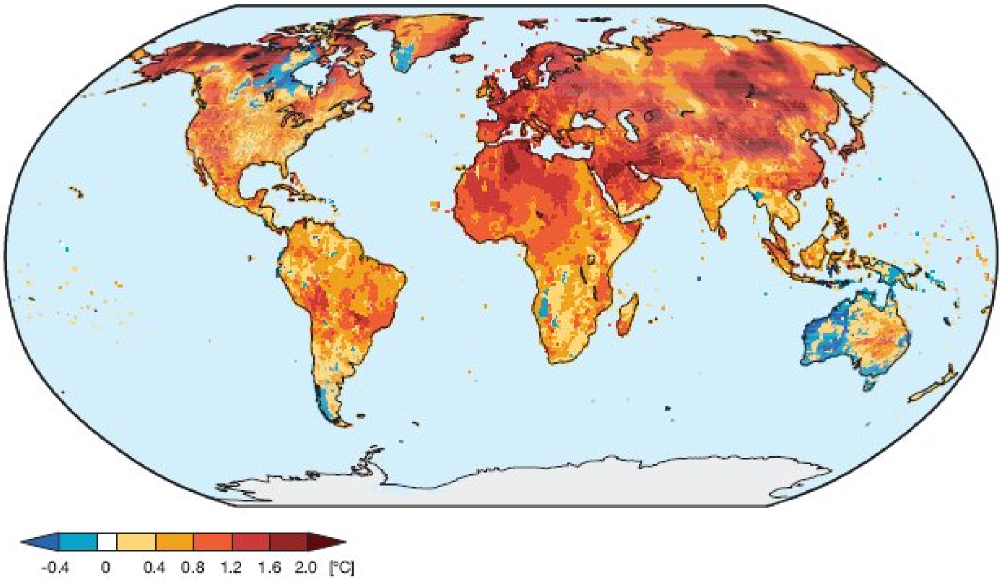

Figure (2): Linear temperature trends for the period 1974-2004.
Source: WBGU1, data Potsdam Institute for Climate Impact Research (PIK) climate database.

3. The developed prediction equations

Prediction equations, coefficient of determination, standard error of estimates, in addition to confidence interval for regression coefficient of mean temperature are included in Table (8) for vulnerable Arabic countries. Results in that table implied that the developed prediction equations could predict the amount of required irrigation water for agriculture with high degree of accuracy as a result of high value of R^2, low value of SE%, the significance of regression coefficient for mean temperature (MTemp) and regression coefficient for mean temperature lies within the confidence interval.

Table (8): Prediction equation, coefficient of determination and standard error of estimates for vulnerable Arabic countries.

Arab Countries	Prediction equations	R^2	SE%	CI (95%)
Jordan	Y^= 8837.50 + 20.14(MTemp)**	0.86	0.05	21.77-18.51
Iraq	Y^= 48499.47 + 47.64(MTemp)**	0.92	0.02	44.79-50.48
Lebanon	Y^= 3948.29 + 45.69(MTemp)**	0.93	0.02	43.15-48.22
United Arab Emirates	Y^= 984.11 + 60.14(MTemp)**	0.93	0.32	56.48-63.80
Saudi Arabia	Y^= 26496.04 + 60.13(MTemp)**	0.91	0.04	56.26-64.00
Kuwait	Y^= 2809.42 + 53.60(MTemp)**	0.92	0.19	50.53-56.67
Palestine	Y^= 3921.35 + 45.78(MTemp)**	0.92	0.02	43.08-48.47
Syria	Y^= 38422.37 + 44.74(MTemp)**	0.93	0.02	42.26-47.22
Qatar	Y^= 673.4 + 49.83(MTemp)**	0.91	1.34	46.57-53.09
Bahrain	Y^= -517.44 + 45.47(MTemp)**	0.89	1.32	42.34-48.60

Y^= amount of required water for agriculture ($10^6 m^3$); MTemp= mean temperature from 1901-2000 (ºC); R^2= coefficient of determination; SE%= standard error of estimates; CI= confidence interval for regression coefficient of mean temperature at 95% level of significant.

Furthermore, similar situation was observed for the prediction equations for Arabic countries with intermediate vulnerability to climate change and less vulnerable Arabic countries for climate change in Table (9) and (10), respectively.

Table (9): Prediction equation, coefficient of determination and standard error of estimates for Arabic countries with intermediate vulnerability.

Arab Countries	Prediction equations	R^2	SE%	CI (95%)
Algeria	Y^= 48621.16 + 59.49(MTemp)**	0.95	0.01	56.76-62.22
Morocco	Y^= 40123.22 + 60.29(MTemp)**	0.93	0.02	56.97-63.61
Tunisia	Y^= 1788.24 + 58.23(Mtemp)**	0.92	0.24	46.34-51.57
Mauritania	Y^= 1788.24 + 58.23(Mtemp)**	0.92	0.24	54.82-61.63

Y^= amount of required water for agriculture ($10^6 m^3$); MTemp= mean temperature from 1901-2000 (ºC); R^2= coefficient of determination; SE%= standard error of estimates; CI= confidence interval for regression coefficient of mean temperature at 95% level of significant.

Table (10): Prediction equation, coefficient of determination and standard error of estimates for less vulnerable Arabic countries.

Arab Countries	Prediction equations	R^2	SE%	CI (95%)
Somalia	Y^= 11767.89+110.49(MTemp)**	0.87	0.07	101.82-119.16
Yemen	Y^= 16894.33+ 93.92(MTemp)**	0.87	0.05	86.93-100.91
Libya	Y^= 9582.92 + 76.15(MTemp)**	0.96	0.05	93.21-79.08
Djibouti	Y^= -1574.63 + 89.78(MTemp)**	0.92	0.81	84.47-95.05
Oman	Y^= 228.52 + 96.14(MTemp)**	0.91	0.32	90.04-102.24
Sudan	Y^= 54076 + 61.86(MTemp)**	0.97	0.00	59.69-64.03
Egypt	Y^= 125369 + 63.60(MTemp)**	0.97	0.00	61.35-65.86

Y^= amount of required water for agriculture ($10^6 m^3$); MTemp= mean temperature from 1901-2000 (ºC); R^2= coefficient of determination; SE%= standard error of estimates; CI= confidence interval for regression coefficient of mean temperature at 95% level of significant.

3. Prediction of the effect of climate change on required water for agriculture

3.1. Vulnerable Arabic countries

The amount of required water for agriculture in 2025 under 2ºC increase in temperature for the group of vulnerable Arabic countries is expected to increase by an average of 24%. The highest percentage of increase is expected to be in Kuwait, where the value is 32% (Table 11). This high percentage could be explained by the fact that the per capita water consumption in Kuwait is high (FAO-AQUASTAT [14]).

On contrast, the lowest percentage is projected to be in Lebanon, i.e. 11% (Table 11). In Lebanon, the share of water withdrawal for agriculture is likely to decrease over the coming years as more water will have to be diverted for municipal and industrial purposes (FAO-AQUASTAT [14]).

Table (11): Predicted total required water amount for agriculture in 2010 under current climate and in 2025 under temperature increase by 2ºC for vulnerable Arabic countries.

Arab Countries	Amount in 2010 ($10^6 m^3$)	Amount in 2025 ($10^6 m^3$)	Percent increase in the amount in 2025
Lebanon	4246	4787	11
Qatar	589	722	18
Iraq	40198	49652	19
Jordan	7266	9244	21
Bahrain	619	801	23
Palestine	3900	5289	26
Syria	29135	39304	26
United Arab Emirates	1929	2716	29
Saudi Arabia	19649	28126	30
Kuwait	2881	3691	32
Average	11041	14433	24

3.2. Arabic countries with intermediate vulnerability

The predicted amount of required water for agriculture in 2025 under 2ºC increase in temperature for this group is ranged between 9-19%, with an average of 13% (Table 12). Algeria will have the highest percentage of required water amount for agriculture, i.e. 19%, where it has the largest total area in this group (Table 4).

On the contrary, Tunisia will have the lowest percentage equal to 9% (Table 12), where it has the smallest total area (Table 4).

Table (12): Predicted total required water amount for agriculture in 2010 under current climate and in 2025 under temperature increase by 2ºC for Arabic countries with intermediate vulnerability.

Arab Countries	Amount in 2010 ($10^6 m^3$)	Amount in 2025 ($10^6 m^3$)	Percent increase in the amount in 2025
Tunisia	10932	12038	9
Mauritania	3073	3506	12
Morocco	35830	41275	13
Algeria	40343	50073	19
Average	18438	21783	13

3.1. Less vulnerable Arabic countries

The highest percentage of required water amount for agriculture for this group in 2025 under 2ºC increases in temperature will occur in Egypt, where the percentage will be 36% (Table 13). This high percentage could be explained by the high percentage of water withdrawal for agriculture, i.e. 86% (Table 4). Furthermore, the high population growth rate estimated by 1.8 (FAO-AQUASTAT [14]) put pressure on the agricultural sector to produce more food to attain food security.

Sudan will have the lowest percentage of required water amount for agriculture, i.e. 17% (Table 13) as a result of low population density, i.e. 14 inhabitant/km^2 (FAO-AQUASTAT [14]).

Table (13): Predicted total required water amount for agriculture in 2010 under current climate and in 2025 under temperature increase by 2ºC for less vulnerable Arabic countries.

Arab Countries	Amount in 2010 ($10^6 m^3$)	Amount in 2025 ($10^6 m^3$)	Percent increase in the amount in 2025
Sudan	46207	55858	17
Somalia	12246	14983	18
Yemen	16780	22567	18
Djibouti	1051	1303	19
Oman	2170	2863	24
Libya	8308	11403	27
Egypt	80636	126915	36
Average	23914	33699	23

CONCLUSION

The majority of Arab countries are considered among the world's most water scarce, and in many places demand for water already exceeds supply. Higher temperatures and less rainfall will reduce the flow of rivers and streams, slow the rate at which aquifers recharge, and make the entire region more arid. The presented data showed that in 12 countries of 21 Arabic countries, the percentage of water withdrawal for agriculture was higher than 80% (Tables 5, 6 and 7). These previous changes will have a series of effects, particularly on agriculture, energy and food security.

Climate change is expected to affect food security through its impact on agriculture and food production systems. According to the IPCC 2007 [17], by the 2080s, agricultural potential in the developing world could fall by 9% under climate change condition. A study by the World Bank (2007) [18]) concluded that, under climate change, for the Arabic region as a whole, agricultural output will decrease 21% in value terms by 2080, with peaks of an almost 40% decrease in countries like Algeria and Morocco.

The approach developed in this study relies both on the countries' statistics, on temperature and on modeling to provide a more reliable database for each Arabic country. Thus, the developed prediction equation could be very important tool to assess the impact of increasing temperature on the amount of water assigned for agriculture. Our results showed that under temperature increase by 2ºC, the total required water for agriculture in the Arabic countries will be increased by a percentage between 9% and 36%. The large variation in the previous percentage is mainly due to population growth and increasing demand for water assigned for agriculture. As a result, in 2025, the demand for irrigation water will increase in all the Arab countries and that will create a problem in allocation of water resources between different sectors. The availability of such information will increase the ability of the policy makers in each Arabic country to prepare the appropriate developmental plans.

The Arab governments need to use adaptation measures to conserve water and avoid the wasteful use of water resources. Improving irrigation efficiency in Arabic countries using surface irrigation and improving agricultural practices techniques could help in preserving irrigation water. Similarly, improving water harvesting techniques in Arabic countries using rain fed irrigation could also an important procedure to sustain water resources.

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