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A Water Management Software Tool for Estimating Water Requirements under Current and Climate Change Conditions

Abdrabbo, M. A. A.[1], Rasha El-Morshedy[1] and Eid S. F. M. [2]

[1]On Farm Irrigation Research Dept., Agricultural Engineering Research Institute, Agricultural Research Center, Egypt (AEnRI), P. O. Box 256, Cairo, Dokki – Giza – Egypt.

[2] Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center, Egypt 6, Dr. Michiel Bakoum St., El Dokki, Giza, Egypt, 12411

Abstract: *The aim of this work is to develop a software program that is capable of predicting water irrigation requirements in the field based on climatic data, soil data and crop data. The software program (called Water Management software (WMS) for different field and horticulture crops.) The software can auto update based on the inputs information such as, climate data, soil analysis and crop coefficient. The developed software can be used by researchers, farmers and irrigation system designers. In order to verify the outputs produced from the software, a field experiment data were gathered for this purpose during 2010/11 and 2011/12 for irrigation management of wheat under four irrigation levels (60, 80 , 100 and 120 % of evapotranspiration (ET). The irrigation water requirement of WM was the same like 100% of ET. The results of wheat productivity and water productivity was higher under 100% of ET than the other irrigation water treatments. Moreover, prediction of irrigation water requirement of wheat under climate change conditions (2050s) showed that the evapotranspiration under 2050s will be higher than current condition by different values ranged by 4 – 12 % under the different climate change scenarios. The highest increasing percentage of "evatpotraspration" was predicted under RCP 8.5 scenario followed by RCP 6.0 scenario while the lowest increasing percentage of ET was predicted under RCP 2.6 scenario. This paper recommended developing a new software for water management considering climate change conditions to provide accurate information for decision makers related to water status in Egypt under climate change particularly for the major strategic crops.*

1. INTRODUCTION

Agriculture is the major consumer of water in Egypt, accounting for about 80 to 85% of the total net demand in the country. Because of Egypt's arid climate, nearly all agriculture depends on irrigation water (Karajeh, 2011).
Growing land and water scarcity are the two main structural challenges to Egypt's sustainable agricultural development. Egyptian agricultural production is almost entirely dependent on irrigation, and irrigation mostly depends on a single source, the river Nile. In addition, the amount of arable land available in the country is almost fixed, with limited capacity to expand it. Hence, the Egyptian government strategy has focused on the sustainable use of existing agricultural land, reclaiming desert areas, and increasing productivity through improved irrigation and cultivation methods. The government could also consider devoting scarce land area to grow crops higher in economic value but lower in water use, which would then increase exports and foreign exchange available for staple imports (this option is feasible depending on additional conditions, such as availability of markets, harmonization of safety and quality standards, etc.) (Tellioglu & Konandreas, 2017).

Egypt faces the water scarcity with the fact that its share in the Nile waters is predetermined. Also, its water-use efficiency is low, due to high water losses. Water conveyance efficiency is estimated at 70%, and the mean efficiency of field irrigation systems is estimated at only 50%. Hence, one of the main components of the agricultural development strategy is to achieve a gradual improvement of the efficiency of irrigation systems to reach 80% in an area of 8 m feddans, and to reduce the areas planted to rice from 1.673 m feddans (2007) to 1.3 m feddans by (2030) in order to save an estimated 12.4 billion cubic meters of water (MALR, 2009).

The increases in the consumption of water for domestic use, industry, and tourism will undoubtedly affect agriculture. In order to overcome this difficulty, agriculture has to come up with innovative ideas with respect to both cropping and irrigation systems. Although water is not treated as an economic commodity in Egypt, the country has to use water according to its value rather than its price. Crops are, therefore, cultivated according to their market value rather than local needs and consumption (Karajeh, 2011).

Management of irrigation is one of the most important aspects of cultivation production. Farmers do not have the required information to minimize water usage without reducing plant productivity, Optimize the basic irrigation water usage requires an expert to support farmers by the exact necessary water at exact time to irrigate their crops. Those experts are hard to get when farmers need their help. Also, it isn't common to establish a communication channel with them in most of Egypt villages. That required using the available information and communication technology to develop systems that manage water usage which will help in enhancing the irrigation water usage efficiency in most of the Egyptian villages. Expert systems technology can be used to transfer knowledge from irrigation experts to both agricultural engineers/officers and farmers which lead to enhance water usage in Egypt (Mahmoud, 2009).

Developing an application easy to apply to agricultural crops will help planters in faster dissemination of expert advice for different locations at the same time and will guide them to take decision into different aspects of crop management (Dath & Balakrishnan, 2013). A developed software application can offer a good solution for the management of irrigated water due to the lack of existence of irrigation experts and difficulties in obtaining them when required. The application can ease the transfer of knowledge to the farmer appropriately, serving them to irrigate their crop in the most efficient way approved by the irrigation specialists. The goal of the irrigation software application is to determine the exact amount of required water and the exact timing for applying it. The amount of water applied is determined depending on the consumer state of affairs (Nada, Nasr, & Hazman, 2014).

Software applications are believed to be the one of the most fitting tools for the solution of challenging problems like pump selection (Freeman & Ayers, 1989). Models developed for crop irrigation requirements and found some differential aspect between reality and the suggested by the model considering different climatic conditions were reviewed in (Beshir, 2017). In (Ghandour, 2017), an alternative approach for calculating Crop Evapotranspiration and Informing the beneficiary the Crop Coefficient in Egypt was developed, and a new concept that will provide the farmers accurate rate of crops water requirements was presented in (Parvathi, Shubha Lakshmi, Arjun, & Shivakumar , 2017). The paper claims it will turn into one of the major basis for planning, designing and managing of irrigation system in present practice to determine crop water requirement by using modified penman method. Finally, (Eid & Abdrabbo, 2018) aimed to build, prove, and confirm the developing of a computer application that consider working under arid conditions of Egypt.

This research aims to develop and test a software tool that developed by the Agricultural Engineering research Institute to facilitate the estimation of irrigation requirement and, then, the development of the irrigation management for different stakeholders in the agriculture and water fields.
Following the introduction, the remainder of this paper is organized as follows: Section 2 outlines the underlying methodology of this work while Section 3 provides detailed description of the developed software. Experiments and results are provided in Section 4 followed by conclusions in Section 5.

2. METHODOLOGY

2.1 Description

A standard software development lifecycle (SDLC) was implemented that consisted of six phases: (1) Identify: the need/problem was identified – inputs from various stakeholders (researchers and decision makers) were gathered pointing out the weaknesses of current practice and the need for the proposed software tool; (2) Plan: work plan was developed to define the requirements of the new software and determines the cost and resources required; (3) Design: this includes turning the software specifications into a Design Specification; (4) Development: the software tool was developed by generating all the actual code; (5) Test: the tool was examined for possible defects and deficiencies and these discovered were fixed accordingly; (6) Deploy; the tool is used to predict water requirements for various crops.

2.2 Underlying system of equations

Different outputs included in this software are calculated according to Food and Agricultural Organization (FAO) Penman- Monteith (PM) procedure, FAO 56 (Allen, Pereira, Rase, & Smith, 1998).

3. WMS

The Water Management software application (WMS) was written using visual basic 6 programming software to help people plan irrigation management of crops. The model use weather data, kc of the crop at each growth stage, soil moisture constants and depletion of soil water from root zone to determine the amount of water needed to be applied for individual irrigation and the time of its application.

3.1 Software Architecture

As Figure (1) depicts, the presented software has: (1) two main databases - Climatic data an Crops data; (2) two user forms – the first of selecting different parameters and the second for selecting irrigation system; (3) processing engine; and (4) results are feedback to user through the user forms.

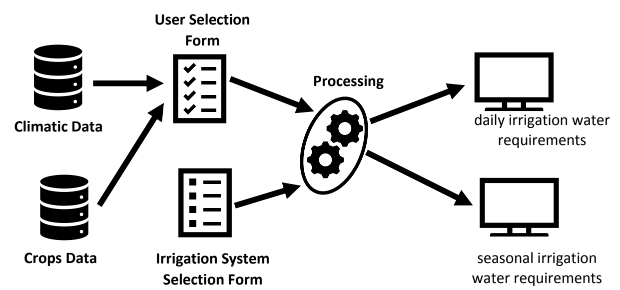

Figure (1) Software Architecture – Schematic Illustration

3.2 Functionality

The main aim of the developed software tool is to accurately calculate the usage of irrigated water for different crops taking into consideration the avoidances of excess, misuse or lack of adequate water supply. First step – as shown in Figure 2 – is enter to the software climatic factor via select the climatic station and then program data base retrieve all the climatic data related to the selected weather station, select the crop type and crop name, and then enter the soil analysis of selected farm or location.

The developed software tool can give an accurate recommendation in terms of water requirements for field and horticultural crops and irrigation interval based on soil physical analysis. Furthermore, the developed software tool can calculate the leaching requirements for the soil based on

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the soil chemical analysis. The user – as shown in Figure 3 – should provide the program with required information such as crop type, crop age, farm location, soil analysis to have an accurate data, when user don't have such information the program retrieve data for clay and sand normal data for soils in Egypt. In our experiment the developed software tool used to calculate irrigation water requirements for wheat crop. Below are the inputs and outputs provided through each of the two forms.

Inputs

Main Form

1. Climatic Region – the user can change among three alternatives: Delta, Middle Egypt, or Upper Egypt
2. Season – winter/summer
3. Crop – a drop list containing several crops; wheat, maize, …
4. Governorate – based on the selected Climatic Region, a list of governorates within that region is availed to user to select one
5. Plant age -
6. Soil type -
7. Climate Data under climate change – whether current or historical
8. Climate change scenario – determines the type of the used scenario
9. Climate scenario covered period of time
10. ….

Secondary Form – irrigation system

11. Irrigation system type – drip, flood, or sprinkle.
12. Cultivated area – to determine the covered area with the plant

Outputs

1. The daily irrigation water requirements
2. Seasonal irrigation water requirements
3. Irrigation requirements – system discharge, intervals, …

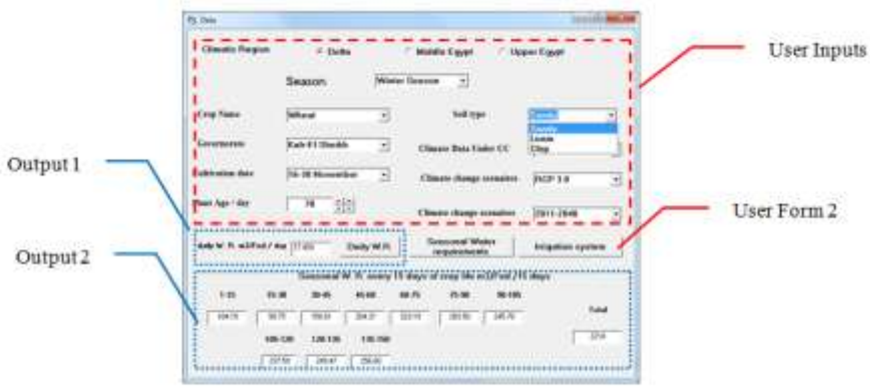

Figure (2) Main Form

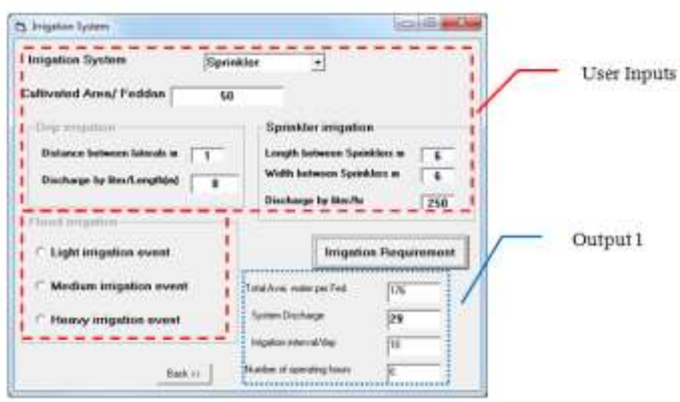

Figure (3) Secondary Form – irrigation system

4. Experiments, Results, and Discussions

4.1 Setup and Data

Validation analysis in this paper is based on data from previous experiments conducted during 2010/11 to 2011/12 at El- Dokki Protected Agriculture Site, Giza Egypt –Egypt (Eid & Abdrabbo, 2018) under the following conditions: (1) sowing was done at three different dates 1st, mid of November and 1st of December; (2) four irrigation levels were tested 60, 80, 100 and 120% of evapotranspiration according to the collected climatic data; (3) plot size was 10.5 m2 (3 m length x 3.5 m width); (4) sprinkler irrigation was used during all experimental period; (5) the applied sprinkler discharge was 750 liters/ hour; (6) the distance between each two sprinkler devices was 8 meters; (7) the radius of sprinklers was 6 meters; and (8) the sprinkler was raised by one meter by using PVC raisers.

The average total applied irrigation volume of 1.00 of WR in experimental location was 3161, m3/season per feddan for the. Table (1) shows the measured climatic factors during the experimental period; these data collected from automated weather station allocated at the experiments' location. The total amount of phosphorus (Super phosphate form) was applied with the soil preparation (150 kg P2O5/ feddan). Ten kilograms of K2O (Potassium Sulphate form) and Twenty five kilograms of N (Ammonium Sulphate form) per feddan were applied as starter fertilizer added also with soil preparation; remained quantity of N (200 kg Ammonium nitrate form per feddan) and K fertilizers (50 kg Potassium Sulphate form per feddan) was injected into irrigation system by using venture during the season. The same fertilization schedule was added for the different planting dates. Twenty cubic meters per feddan of cattle manure were added to the soil with the starter mineral fertilizers one week before cultivation. All fertilizers applications were finished before heading stage. The collected data from this experiment was compared with the output of The developed software tool.

Table (1) Soil chemical characteristics of the experimental location

Dokki											
Depth	SP	pH	ECe (dS/m)	meq /l							
				Cations				Anions			
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	CO_3^{--}	HCO_3^{-}	SO_4^{--}
0- 30cm	43	7.75	0.6	2.2	1.71	1.83	0.27	1.35	-	2.09	2.57
30- 60cm	45	7.7	0.7	3	2.37	1.3	0.37	1.35	-	1.9	3.79
60- 90cm	48	7.7	0.5	2	1	1.76	0.27	1.35	-	0.95	2.73

4.2 Irrigation water requirements under climate change for wheat

The average agro-meteorological data were collected for the concerned governorates to calculate the average data for each agro-climatic zone. The maximum and minimum temperature in the current (1971 to 2000) and different time series [(2011-2040), (2041-2070) and (2071 - 2100)] for different RCPs scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) were downscaled from ClimaScope internet website http://climascope.tyndall.ac.uk/. The projected data was according to HadCM3, Bern model. Whereas, the Daily historical data of relative humidity, wind speed, precipitation and solar radiation were collected from automated weather stations of the Central Laboratory for Agriculture Climate (CLAC) to calculate the evapotranspiration of each agro-climatic zone.

4.3 Results - validation of The developed software tool

Irrigation was rescheduled under the three sowing dates using an irrigation scheduling model called WM (irrigation schedule management). The model was run using the required input for wheat planted in the three sowing dates under current weather conditions. A new irrigation schedule was developed. The total amount of water for each schedule was calculated and compared with the amount of water measured in the field. Results for the wheat cultivated in Dokki Location showed good agreement between measured and predicted irrigation water requirement. This agreement was reflected by low percentage of difference between measured and predicted values, low mean square error and high Willmott index of agreement (Table 2).

Table (2): Monthly applied and predicted water requirements for wheat in Dokki location.

Months	Predicted	m^3/feddan/month Applied	PD %	STDV
November	220	218	2.70	**1.41**
December	356	354	2.81	**1.41**
January	489	487	3.06	**1.41**
February	727	725	1.11	**1.41**
March	845	841	2.42	**2.83**
April	524	523	3.59	**0.71**
RMSE	0.35			
WI	0.97			

RMSE= Root mean square error; WI= Willmott index of agreement; PD% = percent difference between measured and predicted values; STDV = standard deviation between estimated and predicted.

4.4 Climate change scenarios

Four climate change scenarios were used to determine the effect of climate change in four time series, i.e. 2040, 2060, 2080 and 2100. Four climate change scenarios were used RCP2.6, RCP4.5, RCP6.0 and RCP8.5 (IPCC, 2013). The values in Table (3) were developed for Egypt. The highest temperature increase was recorded by RCP8.5 climate change scenario followed by RCP6.0; while the lowest temperature increase under RCP2.6 for different tested time series.

Table (3): Annual average increase in monthly mean temperature under four RCP's scenarios compared with current conditions for Giza governorate.

Month	2011-2040	2041-2070	2071-2100
RCP8.5	1.74	2.47	3.09
RCP6.0	1.92	2.84	4.17
RCP4.5	1.31	2.18	2.66
RCP2.6	1.38	2.08	2.39

4.5 Estimating Future Irrigation Requirements for Wheat under Climate Change Conditions

The predicted temperature data was entered to WMS to estimate evapotranspiration under climate change conditions and, then, irrigation water requirements was estimated under climate change for Giza governorate based on the WMS hypothesis.

Table (4) Irrigation requirement for wheat under different RCPs scenarios under climate change.

Months	current	RCP2.6	RCP4.5	RCP 6	RCP8.5
			m3/feddan/month		
			2011-2040		
Nov	220	231	233	238	247
Dec	356	372	378	387	402
Jan	489	511	519	529	551
Feb	727	757	761	775	799
Mar	845	871	877	893	918
Apr	524	538	544	551	573
Total	3161	3280	3313	3373	3490
P-Value		*	*	*	*
			2041-2070		
Nov	220	238	244	243	251
Dec	356	384	393	391	407
Jan	489	527	540	537	558
Feb	727	781	798	798	819
Mar	845	900	920	915	938
Apr	524	555	564	564	582
Total	3161	3384	3460	3447	3556
P-Value		*	*	*	*
			2071-2100		
Nov	220	238	248	254	269
Dec	356	384	402	411	437
Jan	489	527	553	563	598
Feb	727	781	810	824	868
Mar	845	898	933	950	997
Apr	524	555	579	586	622
Total	3161	3381	3524	3588	3791
P-Value		*	*	*	*

* Significant at P < 0.05

The predicted irrigation requirement (Table 4) at time series 2041-2070 show that irrigation requirements will be increase by 7, 9, 8 and 11 percentages under RCP2.6, RCP4.5, RCP6, and RCP8.5, respectively. Data revealed that the maximum increase of irrigation requirement will be under RCP8.5 at time series 2071 – 2100. The lowest monthly and seasonal irrigation requirements were obtained from predicted data under RCP26 at different tested time series. From this data, we can conclude that to cultivate the same land in the future Egypt needs much water; the climate change challenges will increase the needs for water for Egyptian people. With increase Egyptian population, the needs for food will be increase, then the water resources should increase to allow Egyptian agriculture sector to meet such demands.
Table (5) shows the quantities of total irrigation water requirement for wheat under current and climate change conditions (RCP4.5 at 2041-2070) for five locations North Sinai (Arish), Nubaria, Menia, El-Moghra, and East of Owinat for sprinkler irrigation. The objective of this step was to reveld the increase percentage of irrigation water under climate change for different location in Egypt.
Data revealed that water requirements under climate change conditions will be increase at 2041-2070. The higher water requirements under climate change conditions will be increased due to increasing air temperature by 1.5- 2.5 °C depending on the location and then increasing Evapotranspiration. The difference between current and future water requirement for wheat crop varies between 7.9-15.4% depending on the location. This data can help the decision maker to prepare a proper strategy plan for irrigation water requirement during the next decades.

Table (5) Irrigation water requirement for wheat under current and future conditions RCP4.5 at 2041-2070 under sprinkler irrigation.

Location	Current	RCP4.5	% Difference
Arish	2989	3288	8.8%
Nubaria	3157	3278	8.5%
Menia	3463	3437	13.7%
El-Moghra	2954	3261	7.9%
East of Owinat	3509	3489	15.4%

5. Conclusions

WM program software could be used to predict irrigation water nutrient requirements for wheat under current and future climate change and then help decision maker to draw contingency as well as emergency plan for Egyptian to obtain optimum crop strategy in future. On the other hands, this software is vital for designer manager of irrigation system. The presented software tool provides several benefits. First, it can be easily customized to fit the different needs of the local customers and the local atmospheric conditions. Second, although it may lack the adequate knowledge and required proficiency to create sophisticated software capable of handling all the tasks the user require but it is very simple to use and employ and easy to update according to users requirements. Third, it will not cost much to install and employ. And, finally, it will be easier to contact the developer asking for guidance and help.

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