Towards Development of Open Source Models of Decision Support Systems for Water Demand Management in Egypt

Mohamed Ghareeb, Ahmed Khaled Seif

Abstract: Managing the increasing water demands in Egypt, with limited water resources, urges Egypt to find innovative and sustainable approaches for management and for decision support systems. Taking into consideration the cost of building such management systems, and make use of the information and communication technologies (ICT) to build decision support systems (DSS). The main objective of this paper is to develop a DSS tools, using open-source and free modeling and GIS software, to facilitate Water Resource planners to effectively manage water demands in the agriculture sector, which consumes more than 80% of water resources in Egypt. Several open-source software tools were investigated, utilized, developed and integrated, to support modeling water resources (WR) and estimating water demands (WD). Open-source software was adopted to make use of its technical and social advantages and to facilitate the dissemination of GIS knowledge and technology at the different individual and organizational levels. In addition, it also saves the high costs of the commercial software, and allows more opportunities for learning and employment in the ICT services fields for the water management sector and other sector later. The study concluded that the developed open-source GIS and DSS tools are capable of modeling, monitoring, and estimating agriculture water demands. It can also analyze and optimize different scenarios for cropping patterns, based on different objectives, considering the fluctuation in the available water resource. The developed optimization model results in saving up to 5% of the agriculture water consumption, by re-allocating crops to the least water consumption locations, which proves better WR management.

Keywords: DSS, Evapotranspiration, Open-Source Software, Remote Sensing, Egypt.

I. INTRODUCTION

Egypt is a country located in North East Africa at Geographic coordinates: 27 00 N, 30 00 E, covering an area of about 1,001,450 square kilometers. The population in Egypt is about 100.3 million (2019 Census) and it is expected to reach 160 million capita before the year 2050 [1]. This poses great stresses on satisfying water demand for agricultural, domestic, and industrial uses. The water resources are not expected to increase with the same high rate of population growth which was tripled in the last 6 decades. In the year 1900, the population was nearly 10 million, arable land per capita was 0.5 feddan per capita and available water per capita was 5100 m³. In the year 2000, the arable land per capita decreased to be less than 0.12 feddan and available water <1000 m³, alarming for water scarcity. More than 95% of the population lives in a small band alongside the Nile River in the Nile valley, in the Nile delta and in coastal areas, on only 5% of the country’s area (figure 1). Agriculture is a key sector in the Egyptian economy, it consumes more than 80% of water resources; while it contributes less than 12% of the Gross Domestic Product (GDP) and commodity exports, and about 30% of the overall employment [2]. About 55% of Egypt’s population lives in rural areas. The arid climate of Egypt characterized by high evaporation rates (1500-2400 mm/year), and very low rainfall (5-200 mm/year) leaves the River Nile as the main freshwater resource. Egypt gets its share of freshwater, as about 55.5 BCM (km³), through Nasser Lake and the River Nile as a sole major resource. Cultivation is generally dependent or fully irrigated.

Fig. 1. Land use, Cultivated areas, and Waterbodies in Egypt.

The moderate climate of Egypt around the year is ideal for a wide variety of crops. This made it possible to adopt an intensive cropping system and thus permitted the production of more than one crop per year in most of the cultivated area. The crop acreage is much greater than the actual cultivated area, which is about 9 million feddans, making a sum of total about 15 million feddans during the three agricultural seasons every year (winter, summer, nili) [3].

II. BACKGROUND

The National Water Resources Plan (NWRP) has been developed within the framework of the NWRP project, carried out by the Ministry of Water Resources and Irrigation (MWRI) with support of the Government of the Netherlands. The main objective of NWRP is to describe how Egypt will safeguard its water resources in the future, both with respect to
quantity and quality, and how it will use these resources in the best way from a socio-economic point of view [4]. The NWRP-Decision Support System (NWRP-DSS) is the main planning tool to assess the impacts of different strategies on the water resources system for a selected combination of demand and supply scenarios.

DSSs for water demands management have been studied with the advancement in the open-source tools and technologies for other domains. The DSS models have been adopted in Egypt since 1980’s, but not frequently used. The effectiveness of such systems was not corresponding to its relatively high cost. In the water management sector, The NWRP - DSS consists of a set of databases, models, and tools for simulation and analysis and presentation of results. The databases mainly contain model-related data, such as time series on cropping patterns and water quality monitoring, and data that describe the characteristics of the water resources system. The Agricultural Sector Model for Egypt (ASME) is a simulation model, among several models in the NWRP – DSS. ASME determines the optimum cropping pattern and other agroeconomic and socio-economic parameters. ASME Model is an example of such models that are not frequently used with MWRI [5]. To use ASME, a huge amount of data should be required such as crop characteristics, labor force, commodity consumption, imports and exports, crop production, crop water requirements, available water and land. The ASME model is written with GAMS language, has no friendly interface for input data or for results output. It is used through the command line and ASCII files and its steps should be followed strictly.

Water demands in Egypt could be classified into two main categories, withdrawals, and non-withdrawals demands. The withdrawal de-mands are agriculture (including livestock and fish farming), municipal, and industrial, while the non-withdrawal demands are hydropower generation, navigation, and regulators levels.

III. ROBLEM IDENTIFICATION

The internal renewable freshwater resource in Egypt is only 3.1% of the whole available water [6]. This fact puts great stress on satisfying water demand for irrigation, domestic, and industrial uses, where water resources are not expected to increase in parallel to the population growth which was tripled in the last 6 decades. This stress extends not only for water resources, but the same concern should be applied for all resources in Egypt such as economic, social and environmental resources.

Water management is fragmented among several ministries and authorities, each making either a direct or indirect contribution to water resources management [7]. The policy of the Ministry of Water Resources and Irrigation (MWRI) is responsible for providing water in adequate quantity and quality to the country’s demand sectors (agriculture, domestic, industrial, etc). There is no well-established mechanism for coordination or for information dissemination among the different water users in Egypt, particularly with the local communities and farmers.

Recently, Egyptian government is under pressure and blames (locally and internationally) for not developing new resources or using their water resources efficiently. Although domestic and industrial water supplies are suffering huge wastes, the agricultural water demand is still the main water consumer in Egypt and most of blame focus on it. The agricultural sector had been completely liberalized since 1993, in terms of the governmental control of farm and out-put prices, crop areas and procurement quotas, the private sector as regards the imports, exports and distribution of inputs, subsidies on farm inputs and the financial services of Principal Bank of Development & Agricultural Credit (PBDAC), and the governmental ownership of arable land. The “New land” was sold to the private sector, and the role of the Ministry of Agriculture was limited to agricultural research, extension, legislation and economic policies, and the land tenancy system was modified over time.

These reforms had (to some extent) a positive impact on crop production. They improved the value and profitability of the crop rotation, resulting in an increase in the more profitable crops at the expense of crops with lower profitability. But, the global liberalization of agriculture needs to be adjusted nationally according to the recent circumstances and threats of water shortenings. It is quite clear that the personal objective of farmers, to cultivate more profitable crops, contradicts with the national objective of cultivating strategic crops, aside from the crop water requirements and imports and exports prices.

Information and Communication Technology (ICT) infrastructure became an essential component for any successful management. In Egypt, although there is widespread of GIS and Internet technology in many organizations and decision-making centers, the benefit of using this technology is not as expected and it is not fully utilized in a productive and effective way [8]. This indicates wasting re-sources on acquiring and adopting these tools. Many concerns were outlined on the cost of proprietary GIS packages, that include costs of purchasing, development, upgrading and maintenance, and limited capabilities of modulation and distribution, following the rights of the commercial software limit the flexibility of developing DSS systems and keeping it alive. When software publishers talk about “enforcing” their "rights" or "stopping piracy," what they actually say is secondary [9]. In the other side, open source and free software allow more opportunities for learning and knowledge creation, from its open source; more integration and security in development and save costs of purchasing.

Open source is a development method for software that harnesses the power of distributed peer review and transparency of the process. The fundamentals of open source are more involvement, higher reliability, more flexibility, more functionality, and lower cost.

It is a fact that most of the GIS software used in Egypt is commercial, and it is mainly ESRI reputable software, and it is used in different GIS and DSS projects.
We need to reconsider the DSS developments using commercial software, where its cost is definitely high for a country like Egypt, especially if there are other alternatives available, like Free and Open-Source tools when it satisfies our real needs. According to the American chamber of commerce in Egypt, the total imports of ICT technologies from USA only exceeded 800 Million USD in 2018, this amount could be easily minimized if open-source and free tools will be adopted for use, whenever it works adequately. It is worth mentioning that the cost of one license for GIS commercial software may exceed 20,000 USD; while a complete single system may need more than 5 modules and 5 licenses for full capability.

IV. APPROACH

Information and Communication Technologies (ICT) and geo-ICT, such as (GIS) and Remote Sensing (RS), became an essential infrastructure for any successful management. GIS and RS have effectively demonstrated the ability to deliver powerful applications for decision-support/information management in different domains of development, planning, modeling, and monitoring. There are no doubts about GIS and RS capabilities in modeling, manipulating, analyzing and representing spatial patterns in digital forms.

The decision-making process for water demands management becomes is complex process, which needs to bridge between varieties of interests from different stakeholders. The modern management approach encourages integrating of different sciences and disciplines with ICT technologies, believing that ICT tools is capable to facilitate such complex processes in an effective way.

Different ICT tools were investigated to develop the proposed decision support system (DSS) modules and building-blocks for water demands management using open-source and free tools. These modules will be in the framework of the previous experiences in DSS development in Egypt (NWRP-DSS), and in the context of the modern and new ICT open trends. Moreover than its low price, open standard software and open format are more transparent and it permits users to transfer the knowledge, improve the software and to redistribute it freely in modified or unmodified forms.

V. METHODOLOGY

The structure of modern decision support environment become very complex due to the new concepts of Business Intelligence applications and technologies like Data mining and intelligence. In this respect DSS development process are not simple and needs a dynamic methodology or framework able to manage different tools and platforms to achieve user requirements [10]. The DSS development process could be summarized in three fundamental axioms as follows:

1. Use cases development, to model the users and stakeholders’ requirements, in terms of data and processes.
2. System Architecture development, to develop and describes how the system is broken down into components, and how those components interact and deployed.
3. An iterative and incremental approach, to break the project into small subprojects that deliver system functionality in modules, leading to a fully functional system.

The prototype development methodology was adopted in this research rather than the traditional waterfall method. The prototype methodology - in such a research - facilitate making a workable sample of system components, and validate its functional essence and make essential changes before creating the authentic final solution. The DSS development process will be an iterative set of activities and operations to develop each system component, and before the integration and validation of such components at the end of the research.

Analyzing the water demand system in Egypt produced the block diagram in figure 2, which states the procedure to estimate these demands, the parameters and data required for the computations [11]. A focus was placed on examining the use-case of computing the crop water requirement in the agricultural water demand in Egypt according to the annual cropping pattern. Free and open-source software were used to develop a DSS for the defined water demand case, utilizing the capabilities of open-source concept and technologies, and saving the costs of purchasing commercial systems. Figure 2 shows a global view for all water demands computation and estimates, in terms of data required and estimation procedure. Data of the cropping pattern, evapotranspiration parameters, and crop water requirements per crop stage were extracted mainly from FAO site [13], [14].

![Fig. 2.Water Demands in Egypt (estimate parameters and required data). [11]](image-url)
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The DSS design specifications is derived from the system model (figure 3). Based on the complex structure of WDM decision support environment, the DSS development process is not a simple task and needs a dynamic methodology able to manage different aspects to achieve the principal requirements.

The design of the key-functions of the proposed DSS was carried out in repeated cycles of open-source software development to achieve the desired functionalities which are:

1. Modeling the data of the cropping pattern and parameters of evapotranspiration in a numeric, attribute and spatial forms, allowing the user to update and modify the input parameters.
2. Modeling the equation that computes the crop evapotranspiration, and the cropping pattern water requirement in a friendly interface, allowing to estimate the water demand per any combination of crops/area/month and agricultural season.
3. Displaying the results in numeric/chart/map forms, and on the internet to allow information dissemination among different partners.
4. Facilitate the generation of different scenarios for cropping pattern, with different strategies and to minimize crop water consumption by choosing the crop best location.

Fig. 3. Architecture of the DSS for WDM – composed of 3 main modules (one desktop and two web-based)

The proposed architecture of the DSS (Figure 3) has two main sides; the server-side which is operated by administrators and composed of 3 main modules (one desktop and two web-based), and the client-side (users) which needs only a browser. All the building blocks are compliant to the Open-geospatial Consortium Standards (www.opengeospatial.org). The 3 modules which compose the server are as follows:

a. Module 1: Desktop Applications (QGIS) for data preparation and processing (WR and WD data). This module for administrators and specialists
b. Module 2: Web Application (PHP Drupal) for data entry, modelling, computing the agriculture WD, and analyzing the results in numeric and chart forms (figure 4). This module for data collector and field surveyors.
c. Module 3: GIS server Application (Geoserver and Openlayers) for publishing the data and results with map formats on the web (figure 5). This module mainly for decision makers.

Fig. 4. Data Entry Table of cropping pattern data over Egypt governorates.

Fig. 5. Module3 visualizing the results.

VII. FINDINGS AND RESULTS

Computing the Potential Evapotranspiration (ET0) for each crop per unit area (1 feddan) was initially developed, producing a map for the best locations to cultivate the crop with least water consumption, in ascending order (figure 6). The cropping pattern data for a specific year (2005), and evapotranspiration parameters from FAO site [13] [14], were entered to the Model, for validation, and to compute the crop water requirements (figure 7).

Several scenarios of cropping patterns were tested and computing the relevant water requirements. Based on the results, and for the given cropping pattern; fixing the same total areas for each crop without any changes; and to minimize the crop water consumption, making use of the differences in ETc for the same crop in several locations. The developed system facilitates re-allocating crops to the least water consumption locations. This allowed to minimize the overall water consumption and improve the efficiency of water use.

This optimization model was applied on two major crops in the different seasons, wheat and long clover in winter, and maize and rice in summer. Re-allocating the 2 crops over their area and at the least difference ETc by distributing the crop with more ETc (long clover or rice) at the areas with minor difference in ETc. after distributing the whole area of the crop with more ETc, the competent crop (wheat or maize) with minor ETc than (long clover or
rice) will be distributed over the remained area. This model, by re-allocation, saved sum of water ranges between 2.5 to 5% of the total water consumption of the two crops (figure 8).

![Fig. 6. The Potential evapotranspiration map for wheat.](image)

Comparing the results of this research with the previous and related research works would assert that the technologies investigated in this research work are the state of the art in DSS, and ICT development. Also, this research was undertaken from a national perspective and with reference to a unique situation in Egypt, it is to be mentioned clearly that there are no negative impacts or drawbacks (social, economic and technical) from adopting this research approach.

![Fig. 7. Computing the evapotranspiration for different scenarios](image)

VIII. CONCLUSIONS AND RECOMMENDATIONS

This paper is focusing on the development of open source and free DSS tools for water demands management in Egypt, Matching the needs of the WDM with the ICT open-source capabilities, trying to facilitate the dissemination of DSS and GIS tools. The developed system resulted an enhanced tools make it easier for stakeholder participation, and improve the efficiency of WD management. The system allows data preparation, cropping pattern scenario modeling and computations, and visualizing the results on the web for different stakeholders. The prototype methodology adopted in developing the proposed system facilitates developing functional components for the system, and make it easy to integrate such components in an interoperable way at end of the research.

Also, the proposed system avoiding the cost of purchasing when using commercial Software while available open-source tools are feasible and free alternative.

The study concluded that the developed Open-source GIS and DSS tools are effective, and data is efficient, for modeling, and estimating the agriculture water demands. The system allows exchanging the information among different involved water partners and stakeholders. It allows developing different scenarios for cropping pattern (based on different strategies and with reference to the fluctuation in water resource). It also facilitates minimizing the water consumption by re-allocating crops to the least water consumption location over all the arable land in Egypt, saving amounts of 2.5% to 5% of the total crop water requirements. It is believed that such DSS, 100% free, available and feasible, will achieve better institutional coordination and is highly needed to overcome the fragmented responsibilities in the field of integrated water resources management in Egypt.
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REFERENCES


AUTHORS PROFILE

Dr. Mohamed Ghareeb conducted his higher studies and researches in geomatics engineering and water resources management. He earned his BSc and PhD from Civil Engineering Department - Faculty of Engineering- Ain Shams University; and he obtained his MSc with distinction degree, from ITC Faculty of Geo-Information Science and Earth Observation, University of Twente. Dr. Ghareeb works as assistant professor in geomatics engineering in Jouf University-KSA. Dr. Ghareeb supervised Civil Engineering projects developed by the Egyptian ministry of communication, and he is a consultant in Quality management and Biddings. Also, he worked at the Egyptian Cabinet of Ministries as project manager; he supervised and participated in several GIS and Remote Sensing Applications and Projects. Dr. Ghareeb possesses extensive experience on GIS and Image processing packages, in addition to the open-source packages.

Ahmed Khaled Seif, PhD Degree, M.Sc. Degree, and B. Sc. Degree in Civil Engineering. More than 17 years of working experience in the field of Hydrological analysis using different hydrological models including those with GIS application. Do statistical analysis to determine the design storm and return periods. Design protection works, like dams and different hydraulic structures. Write technical reports of different studies. Carry out many studies for protection against flash floods in Egypt and abroad. Valuable experience in teaching as well as research in the fields of surface water hydrology, water resources management, and environmental impact assessment related to water resources and river morphology.