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Managing New Groundwater Irrigated Lands in Egypt Using GIS

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Abstract

Geographic information technology is very important in the worldwide organizations due to its efficiency. Developments in different information systems and computer especially water resources data management systems, directly affect GIS. This technology can be used in Egypt which is an arid country to manage the water resources especially groundwater from both renewable and nonrenewable aquifers. The sustainable water management is one of the most important issues Egypt faces in reclamation lands, Water savings in agriculture in these new lands are an important objective of Egypt's water strategy. Based on that the magnitude of potential water savings in agriculture and best achieve such savings and management is very important issue. In this study, the scope of the problem is how to manage the available groundwater resources in reclamation lands especially the most of reclamation land is far from the center of decision makers so there is a need to a remote management system. Therefore, it is necessary to develop an appropriate Spatial Decision Support System which quickly enables the decision makers to decide upon different planning and management issues and determine the optimal use of these resources without depletion. This research aims at building new water resources management tool to manage and control the groundwater resources by using a Web GIS in order to explore means of increasing water resources using efficiency in reclamation lands management based on dynamic maps and current data.

Keywords: Egypt, New Lands; Management; ArcGIS; Water Resources, Web GIS; Groundwater.

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1. Introduction

Development of GIS bring out new solutions for managing and monitoring water resources related data especially in land reclamation. For decades, Egypt has tried to increase its agricultural area through reclamation of desert land. GIS offers a set of functions to display, analyze and relate spatial data. GIS analysis tools can be used to support real-time management of geographic related data and the distribution of updates to all relevant organizations in a timely manner. This improved access to the current and updated data. In the new lands, water resources constitute the major determinant of reclamation and development. Therefore, the economic philosophy of using land and water resources to maximize the returns per feddan needs to take into consideration water consumption in relation to returns. Other problems include the absence of clear objectives for reclamation, selection of reclamation sites, lack of integration of project implementation phases, inability to choose the best mode of the newly-reclaimed land use and other obstacles such as management, energy, security, and labor. With regard to future prospects of land reclamation in Egypt, emphasis was laid on the proper selection of reclamation sites. One of the reasons behind the crisis in Egyptian agriculture is the relatively low investments directed to the agricultural development, particularly in the fields of land reclamation and modernization of irrigation systems [1]. Figure (1) shows the changes in cultivated area in Egypt with time till 2017, and Table (1) shows Projected newly reclaimed areas till 2030.

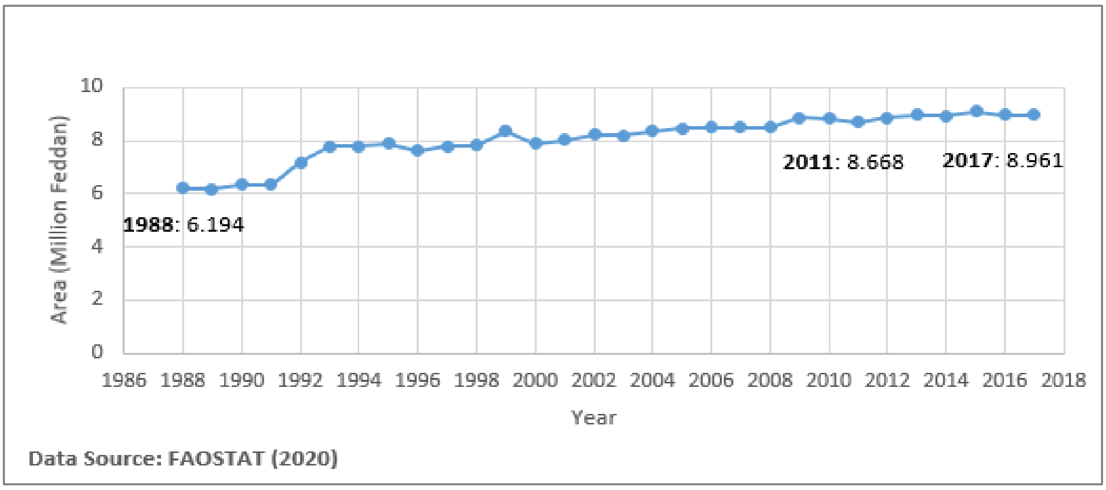

Figure 1: The Agricultural Area in Egypt With Time

Table 1: Cultivated and reclaimed agricultural land up to 2030 [2]

Type of land	Area (Million) feddan
Total cultivated area in 2011	8.6
Cultivated old lands (surface) in 2011	6.5
Reclaimed lands (modern) in 2011	2.1
Projected newly reclaimed areas till 2030	3

In new lands, Groundwater is an important source of fresh water. Although in terms of quantity the contribution of groundwater to the total water supply in Egypt has been very moderate, groundwater is important source of water for people living in the desert areas. Because of limited options to increase the Nile water availability, there has been an increasing interest during the last decade to further develop the groundwater resources. The major groundwater systems in Egypt are in Table (2).

Table 2: The main aquifers in Egypt with modification – Source [3]

Aquifer	Distribution	Productivity	Main Features
Nile Valley and Delta	Extensive	High	87% of the total groundwater in Egypt, with a productivity of 100-300 cubic meters / hour
Coastal Aquifers	Local	Moderate to high	It is located on the northern and western coasts and recharged from rain
Nubian Sandstone Aquifer	Extensive	Moderate to high	Covering an area of 2 million square kilometers. The total stored water is about 150,000 billion cubic meters
Fissured carbonate Aquifer	Extensive	Moderate	It covers 50% of Egypt area, with productivity from 5 cubic meters / hour to more than 300 cubic meters / hour
Moghra Aquifer	Extensive	Low to moderate	It is located from Al Natroun valley to Al Farigh valley
Hardrock Aquifer	Local	Low	It is located in the Eastern Desert and South Sinai. It is recharged with small amounts of leaked rain water

Figure (2) shows the groundwater aquifers in Egypt. The renewable groundwater aquifer is distributed between the Nile Valley and the Delta and its water is part of the Nile's water resources. The amount of water withdrawn from this aquifer was 6.5 billion cubic meters in 2006. the maximum safe water withdrawal rate from it is estimated to be 7.5 billion m^3 according to the estimates of the Research Institute of Groundwater. It is also characterized by a good quality of water with a salinity 300-800 ppm in the southern Delta regions. The non-renewable groundwater aquifers are extending under the eastern desert, western desert and the Sinai Peninsula. The Nubian sandstone reservoir in the Western Desert is the most important non-renewable groundwater aquifer with amount of water about 40 thousand billion m3. the maximum safe water withdrawal rate from this aquifer is 2.5 to 3 billion m^3 [4].

Water management analyses and availability of data for water resources especially groundwater in land reclamation is a point of concern, especially in areas that are located away from the decision-makers headquarter. In this study Web-based GIS is used as an important tool to provide spatially and temporally consistent information required for efficient water resources management in new irrigation projects in Egypt.

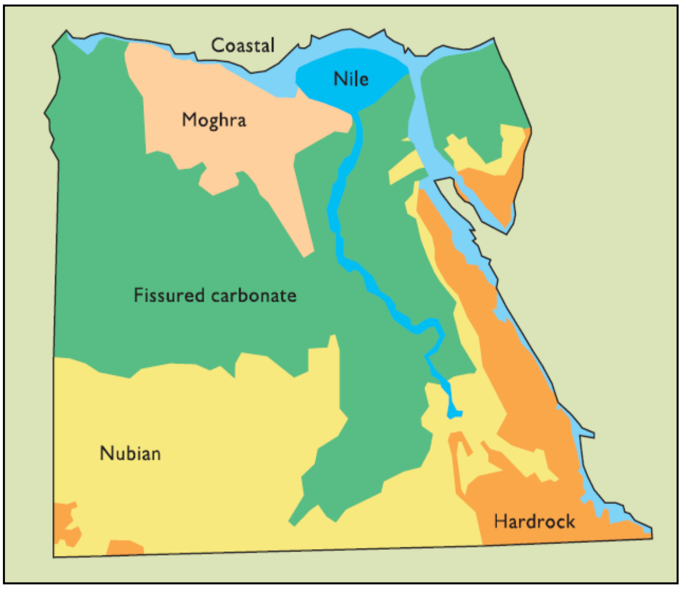

Figure 2: Groundwater systems in Egypt [5]

2. Research Objectives

Egypt is facing Water scarcity challenge. Thus, a sustainable development of new lands requires the sustainable use of groundwater resources. Groundwater monitoring provides information to water resources management decision makers. Therefore, in this research, water resources management tool is developed to be used in new irrigation projects in land reclamation in Egypt as a unified integrated system based on GIS web applications to show the optimal use of groundwater without depletion.

The primary objective of this research is to have an insight into groundwater resources management system to assess and evaluate the irrigation water practices. The following are the main objectives of this research:

- Provide a new tool for water resources management in new lands by building a model for maximizing water- use efficiency, including water- management options.
- Help decision makers to understand the current status by giving a complete picture for available water resources in reclamation lands that promotes the following:
  - Maximize efficient use of available groundwater resources
  - Manage land and water
  - Improve food security
- Support and enhance capabilities for monitoring and controlling water resources in new lands.

3. Tools for Analysis

There are many definitions for the GIS. However, the most widely accepted definition which covers almost all functionalities of GIS is: "A system of computer hardware, software, geographic data, people, organizations, and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the Earth, " particularly in case of environmental process [6]. The geospatial world is moving increasingly toward an open geospatial infrastructure that connects producers and users of authoritative source datasets via the web. Commercial GIS is evolving to support mapping and charting organizations in their missions and in their participation in this new world by enabling them to improve the speed and accuracy of their data, maps, and charts without increasing resources—good, fast, and cost-effective [7]. Figure (3) shows how GIS abstracts real world objects into layers.

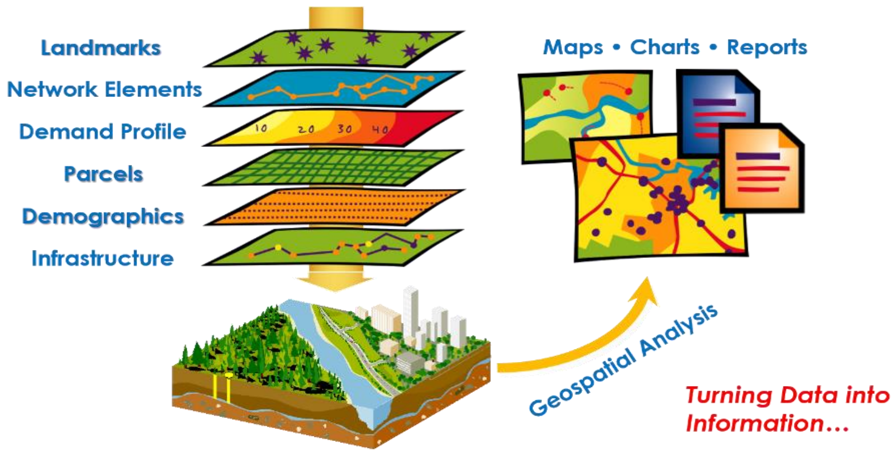

Figure 3: GIS Abstracts Real World Objects into Layers

Geographic information system (GIS) is a tool for data input, storage, retrieval, manipulation, analyzing and output the spatial data [8] as shown in Figure (4). It can play a major role in spatial decision-making. Considerable effort is involved in information collection for the suitability analysis for crop production. The information should present both opportunities and constraints for the decision maker [9]. GIS has the ability to perform numerous tasks utilizing both spatial and attribute data stored in it. The ultimate aim of GIS is to provide support for spatial decisions making process [10].

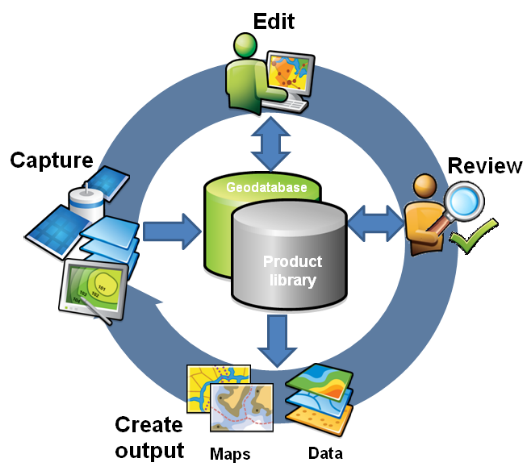

Figure 4: Map Production in GIS [11]

Traditionally, GIS has been a technology used by analysts to perform spatial analysis and generate custom map products that meet the specific needs of their organizations. Although it was considered a niche technology, in recent years the concept and importance of spatial location have become more mainstream, and GIS awareness is now becoming more prominent in many organizations. The geographic approach benefits organizations of all sizes, the following are the benefits which generally fall into five basic categories [12]:

- Cost saving resulting from greater efficiency
- Better decision making and improved communication
- Better geographic information record keeping
- Geographic management

One of the most important potential contributions of GIS in relation to water management is clearly as a means of display and visualization. The importance of maps in this respect should not be underestimated: they are extremely persuasive and informative tools. They provide a means of bringing together a large volume of data and synthesizing it within a relatively simple and often readily accessible form. They can add value to the data by helping to show spatial patterns and relationships. In some cases, they may also contribute to tests of such relationships, by providing a first-step opportunity to examine possible spatial correlations [13]. On the other hand, GIS technologies is used on the Internet through Web GIS, it is the process of using the maps delivered by geographic information systems in World Wide Web. According to Esri (2019) [14], Web GIS is a type of distributed information system, comprising at least a server and a client, where the server is a GIS server and the client is a web browser, desktop application, or mobile application. In its simplest form, web GIS can be defined as any GIS that uses web technology to communicate between a server and a client. Web GIS introduces distinct advantages over traditional desktop GIS, including the following:

- A global reach: As an ArcGIS user, user can present web GIS applications to the world, and the world can access them from their computers or mobile devices. The global nature of web GIS is inherited from HTTP, which is broadly supported. Almost all organizations open their firewalls at certain network ports to allow HTTP requests and responses to go through their local network, thus increasing accessibility.
- A large number of users: In general, a traditional desktop GIS is used by only one user at a time, while a web GIS can be used by dozens or hundreds of users simultaneously. Thus, web GIS requires much higher performance and scalability than desktop GIS.
- Better cross-platform capability: The majority of web GIS clients are web browsers: Internet Explorer, Mozilla Firefox, Apple Safari, Google Chrome, and so on. Because these web browsers largely comply with HTML and JavaScript standards, web GIS that relies on HTML clients will typically support different operating systems such as Microsoft Windows, Linux, and Apple Mac OS.
- Easy to use: Desktop GIS is intended for professional users with months of training and experience in GIS. Web GIS is intended for a broad audience, including public users who may know nothing about GIS. They expect web GIS to be as easy as using a regular website. Web GIS is commonly designed for simplicity, intuition, and convenience, making it typically much easier to use than desktop GIS.
- Unified updates: For desktop GIS to be updated to a new version, the update needs to be installed on

every computer. For web GIS, one update works for all clients. This ease of maintenance makes web GIS a good fit for delivering real-time information.

Groundwater mapping and satellite data is one of the main tools for controlled development and managing of groundwater resources. These maps are used by decision makers in order to allocate, improve and manage groundwater in Egypt. Abdalla (2012) identified the most important related parameters that show the groundwater potential in Wadi El Laqeita in the Central Eastern Desert and its surroundings as one of the most hopeful areas for agricultural reclamation in Egypt. To describe the location of the proposed groundwater zones, different thematic maps were prepared from topographic and geological maps. The thematic map of each parameter was produced using GIS and RS. These input layers were combined using the Raster Calculate Module in a GIS model to produce the final groundwater expected zones of the investigated area [15]. Amer and his colleagues (2012) evaluated quality, quantity and possibilities uses for groundwater in the Central Eastern Desert of Egypt as a case study for groundwater utilization in arid regions. Field studies and RS data were integrated with a GIS-based modeling to estimate the groundwater budget of sedimentary sub-basins and use these estimates to propose locations for new wells. the study result is integrated tool to evaluate the source of water in different aquifer types and propose management policies for groundwater use [16]. Omran (2008) performed an interpretation approach that integrates data obtained from RS and GIS to identify groundwater resources for the determine of candidate well locations in Sohag region. Groundwater potential zones have been divided by integration of aquifer thickness derived from surface electrical resistivity survey and drilling data with the different thematic layers; hydro geomorphology, slope, drainage and depth to aquifer using model developed through a GIS technology. The weights for each parameter and groundwater potential zone map generated through this model was verified with the yield data to check the validity of the model developed. Total weights were assigned to the different layers depending on suitability [17].

4. The Developed Web GIS

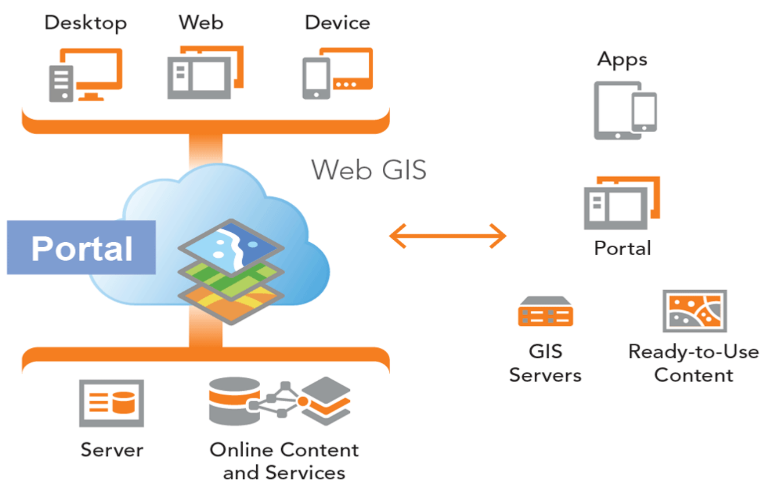

Figure 5: Web GIS General Concept [18]

The developed web-based GIS tool in this research is built by ArcGIS Online to create and share interactive web map applications as shown in Figure (5). ArcGIS Online is powered by ArcGIS Server and deeply integrated with ArcGIS software. It is a set of map and image services in use by ArcGIS Desktop and ArcGIS Server users. These services are designed to be easily integrated within Esri GIS applications. Basemaps, such as imagery for the world, a world street map, shaded relief, and topographic maps, are available as Web services in the management tool, enabling quickly connect to these maps and globes and apply them as the foundation for the applications map. Using the management tools applications which built on ArcGIS Online, different users types can access the content they need like shapefiles, geodatabases, imagery, or other GIS services and perform an analysis.

Web GIS applications are widely usable and helpful in many areas like Irrigation, water resources management, environment conservation, disaster management, and so on. Web GIS is a pattern for delivering GIS capabilities. It is at the center of Esri's strategic direction for implementing GIS as a platform. The key concept behind web GIS is that all members of an organization can easily access and use geographic information within a collaborative environment. Web GIS provides a platform for integrating GIS with other business systems and promotes cross-organizational collaboration. Consequently, web GIS extends the reach of GIS to everyone in an organization, enabling better decision making. The developing of the geographic web applications of management tool in this research includes activities to establish and maintain the spatial database, the development of the application solutions, the preparation and building of digital data. The establishment of the management tool and the creation of a unique database will result in rationalization, integration, and decision-making optimization in multiple sectors and give an efficient data exchange within the entire enterprise. The development of this tool can be seen through the following phases:

- centralization, and presentation of all spatial data;
- Modeling of business processes (related to spatial data).
- Functional and non-functional specification of the system.
- System design: system architecture, software architecture and data model.
- Implementation development of the tool interfaces.
- Development of an integral Web GIS application that will allow access to all available spatial data sets.

The web applications for the management tool enables data synchronization and integration with any existing systems to manage the water resources, to facilitate the flow of information about existing wells and new lands, in addition to the empowerment of analysis capabilities for decision makers to study the current situation. As a first step to build the proposed web application data model in this research, the SQL Server Management Studio is used to build the data model in Figure (6) which is the heart of the management tool in order to perform the geodatabase tasks like making maps, querying databases and performing site suitability analyses. Because the types of analyses that can be undertaken are strongly influenced by the way the real world is modeled.

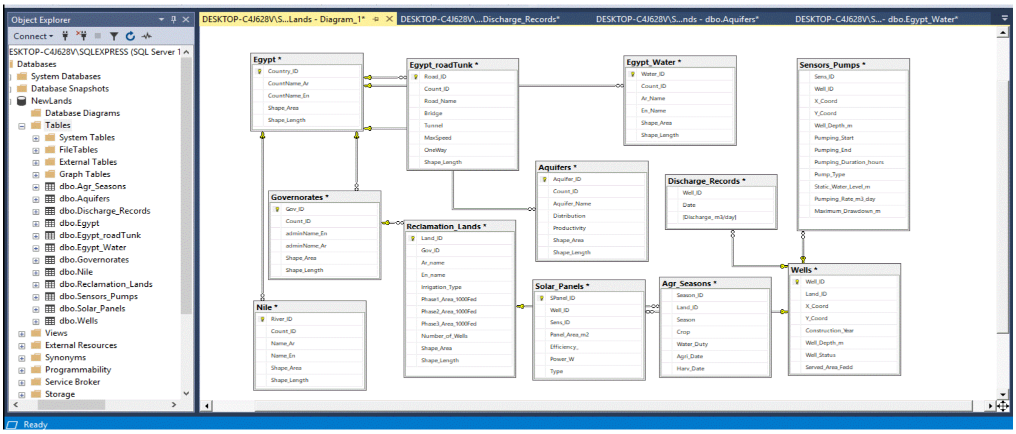

Figure 6: Web Application Data Model in SQL Server

5. Results

The management tool includes a dashboard application which supports collaboration by providing a common operating view of key performance indicators (KPIs) to help decision makers understand what is working well and what needs attention. Accordingly, ArcGIS Online Dashboard is applied to one and a half million feddan case study areas to build a monitoring application with different goals such as showing the new areas location over all Egypt and its related data by displaying charts and Key Performance Indicators (KPIs) that can show the current status for these lands, observing withdrawal from the wells in every location of the project, shows crop pattern in charts, pumps status, solar banal data and many other data that can be shown in the dashboard interface which gives spatial optimal allocation of land and groundwater resources. The developed dashboard shown in Figure (7) is interactive, it includes a dynamic map that allows the decision makers to check the everyday processes and procedures outputs of groundwater and new lands management to ensure everything is running easily. Also, it gives a simple visual display of the most significant data to fix issues and deal with the current situations before they become problems and affect performance of management process.

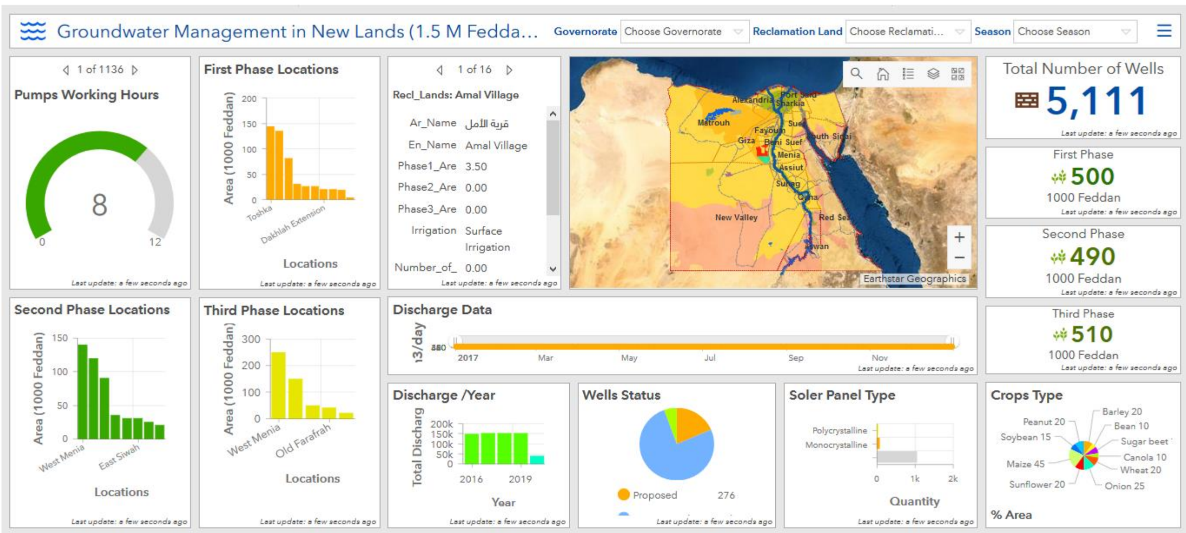

Figure 7: Developed Dashboard Interface

The operations dashboard includes many KPIs which is a measurable value to analyze, track and display information like lists, line charts, bar charts and gauges which used to monitor the groundwater resources in new lands. The user can choose and maximize any chart or KPI from the dashboard for detailed data which changes according to the selection lists of governorates or new lands. The following is a list of KPIs shown in Figure (7):

- The gauge for pumps working hour which allows user to display the pumps one by one to monitor any change in withdrawal hours from the well.
- Bar chart for the information about the first phase of 1.5 million feddan project. It shows the proposed cultivated area (feddan) in each area of reclamation.
- Bar chart for the information about the second phase of 1.5 million feddan project. It shows the proposed cultivated area (feddan) in each area of reclamation.
- Bar chart for the information about the third phase of 1.5 million feddan project. It shows the proposed cultivated area (feddan) in each area of reclamation.
- List for project locations to shows all available information in the geodatabase about any selected location.
- Line chart for the daily discharge (m^3/day) for any selected well in a specified new land location.
- Bar chart for cumulative discharge (m^3/year) for any selected well.
- Pie chart shows the total numbers of wells in the selected location and the current status of these wells (constructed, proposed and under construction).
- Bar chart for the total numbers of solar panel for the selected location (polycrystalline – monocrystalline).
- The right section of the developed dashboard includes some interactive indicators for the total numbers of wells and area in feddan for each new land location.
- Pie chart for the crop pattern as a percentage of area classified based on season (winter – summer-other) for any selected new land.

As example of applying the dashboard, the user can choose any governorate to show the proposed reclamation lands list and KPIs indicators for its related data like the total area for this land and its number of wells. Also, the user can choose any well to display a line chart of groundwater withdrawals with time, which helps to monitor and retrieve the historical data for any well and compare the actual discharge and with the proposed based on crops consumption to give an indicator about if there any overdrawing or not. This helps decision makers to determine the optimum crop pattern and helps in future planning and evaluation. Figure (8) shows some maximized KPIs.

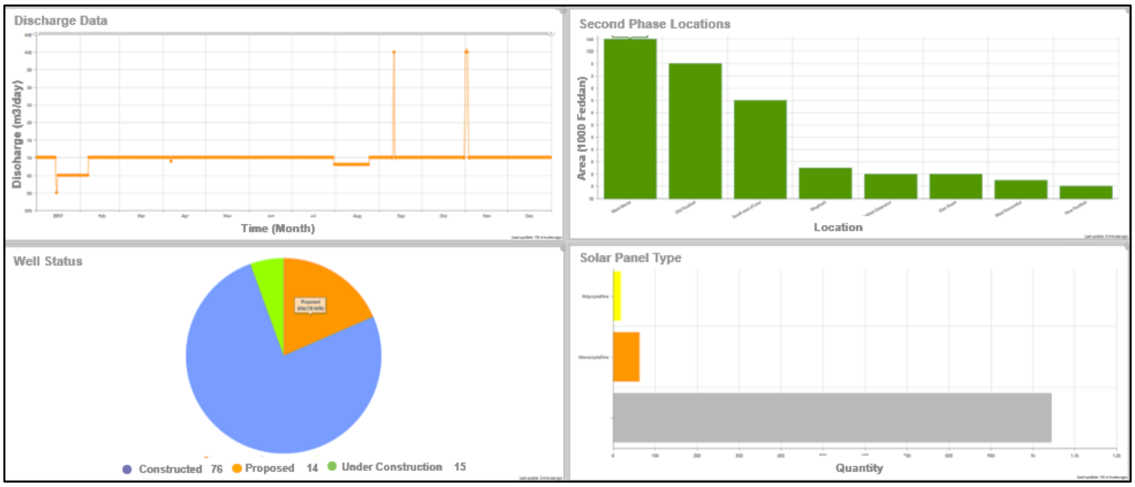

Figure 8: Interactive KPIs Show Reclmation Lands and Wells Status and Discharge

In its core, the tool allows the integration with existing systems such as sensors system, CCTV surveillance systems and SCADA system. It helps extend the benefits of data gathered through existing systems. these systems are all about real time monitoring of wells in the field. As integration with the pumps sensors data shown in Figure (9), the gauge in the dashboard displays the working hours of any selected pump to monitor any increasing in the number of scheduled working hours and give an alert by changing the color of gauge from green to red. This alarm helps decision makers to take the necessary action with the system availability of making automatic pump shut down.

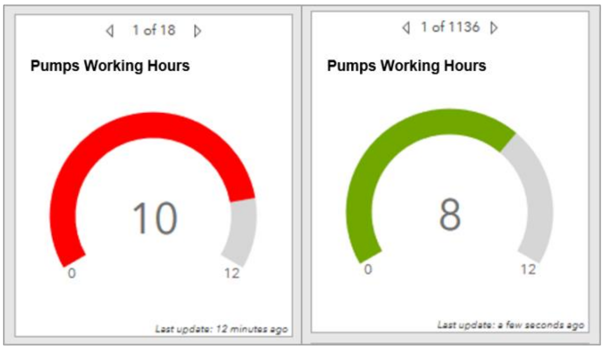

Figure 9: Changing the Color of Gauge to Red in case of Exceeding scheduled working hours

One of the most important specifications of management tool Application is the synchronization, which means that any update in any data will be appeared in dashboard. So in case of permissible values are exceeded for any data, this will be shown through a different color as an alert in the dashboard.

6. Conclusions

This research work aims at developing a spatial decision support system for optimal use of land and groundwater resources in agricultural projects in new lands. The evaluation tool for managing ground water in new lands is designed to be a Real-Time GIS that can give the users in different levels the ability to tap into, analyze, and display streaming data from many sensor and device. Real-time monitoring will allow the decision maker to automatically and simultaneously send alerts to key personnel, detect and focus on the most important events, monitor thresholds for the operations, improve safety, and respond faster to emergencies. The developed web-based GIS can provide decision-makers with the best groundwater information in the shortest time. Therefore, decision-makers get prepared to make better and faster decisions which can reduce the damage of the natural events and minimize the loss. The tool designed in this study can easily be expanded and integrated to other systems because of its structure and flexibility. It can easily be transformed into other systems which has different purpose. The data required for the development of the water resources management tool were collected for the case study area from various resources and stored in both map and tables form. Some of this data were collected from internet survey, some from the web site of Ministry of Water Resources and Irrigation MWRI, some from the literature and the satellite images while some of tabular data are hypothetic data. The tool provides web-based applications. with the following capabilities:

- Provide a single source of common data and information through centralized geodatabase
- Support the decision-makers with real time Information
- Access by everyone and everywhere over the internet which reduce time and minimize the effort to reach data
- Produce reports based on user specified parameters

For future researches, the system can be integrated with other models and systems. As example of these models, CROPWAT which is a is a decision support tool developed by the Land and Water Development Division of FAO for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. In present scenario, besides the pervious data collected for developing the groundwater resources management tool in new lands, exploration the effect of any related data like meteorological, water quality, environmental data will be added value. Also, there is a very important needs for establishment the tool applications on premises using ArcGIS Server Enterprise instead of using ArcGIS Online for the case of sensitive data that cannot be uploaded and stored in the cloud.

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