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IMPROVED WATER MANAGEMENT IN THE MAIN CANAL COMMAND AREA BY USING SPATIAL MODELING OF WATER BALANCE. "CASE STUDY - ISMAILIA CANAL" EAST DELTA

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الملخص العربى :

في مصر ، تخضع إدارة الموارد المائية لتحديات تعيق توفير المياه والتنمية المستدامة. هذه التحديات هي النمو السكاني السريع ، والتوسع في الأنشطة الزراعية ، والتصنيع ، وتغير المناخ من أجل مواجهتها وتأمين المياه للأجيال الحالية والقادمة ، وقد تم اعتماد نهج الإدارة المتكاملة للموارد المائية .(IWRM) ومع ذلك ، لا يزال يعاني من صعوبات كبيرة. أحد هذه الأسباب هو الافتقار إلى الأدوات التي يمكنها تفعيل الأفكار والجمع بين العناصر الاجتماعية والاقتصادية والمادية الديناميكية لأنظمة الموارد المائية. تهدف هذه الورقة إلى تقديم نظام مكاني جديد كأداة فنية لتحقيق التوازن المائي على مستوى زمام الترع الرئيسية على أساس نهج الإدارة المتكاملة للموارد المائية. يقدر النموذج فجوات المياه ويحقق التوازن بين العرض والطلب مع مراعاة الحفاظ على البيئة. يمكنه التنبؤ بالتطورات المستقبلية لمدة 10 إلى 20 عاما. يمكن أن يدعم صانعي القرار المسؤولين عن الإدارة المتكاملة للموارد المائية في أوقات نقص المياه. لديها 3 مكونات رئيسية ؛ واحد من أجل معالجة قاعدة البيانات الجغرافية ونظام المعلومات الجغرافية ، والآخر لنماذج المحاكاة المكانية ، والثالث لواجهة المستخدم الرسومية. تم تطوير النموذج باستخدام لغة برمجة Python وبناء نموذج ArcGIS لاستخدام سطح المكتب. من أجل التحقق من النموذج ، تم تطبيقه على زمام ترعة الاسماعيلية لتنظيم عملية العرض / الطلب على المياه. كان للمنطقة مجموعات بيانات قياسية متاحة لمدة 10 سنوات للهيدرولوجيا والتشكل وكمية المياه. يمكن أن يحقق النموذج توازنا مقبولا بين العرض والطلب على المياه. وبالتالي ، تم التوصل إلى أنها أداة موثوقة لنمذجة ورصد وتقدير العرض / الطلب على المياه وزيادة مشاركة المعلومات بين أصحاب المصلحة.

الكلمات المفتاحية: إدارة الموارد المائية (WRM) ، التوزيع المكاني ، توازن العرض / الطلب ، نمذجة المياه ، كفاءة استخدام المياه.

ABSTRACT:

In Egypt, water resource management is subject to challenges that impede water provision and sustainable development. These challenges are the rapid population growth, expansion of agricultural activities, industrialization, and climate change in order to confront them and secure water for the current and coming generations, the integrated water resource management (IWRM) approach has been adopted. However, it still suffers major difficulties. One such is the lack of tools that can operationalize the ideas and couple the dynamic social, economic, and physical elements of water resources systems. This paper aims to introduce a new spatial system as a technical tool to achieve a water balance within canal catchment areas based on the IWRM approach. The model estimates water gaps and achieves a balance between supply and demand considering environmental conservation. It can predict future developments for 10 to 20 years. It can support the decision-makers responsible for IWRM in times of water shortage. It has 3 major components; one for Geo-database and GIS processing, another for spatial simulation models, and a third for graphical user interface. The model has been developed using the Python Programming Language and ArcGIS Model Building for Desktop Use. In order to verify the model, it has been applied to a canal command area to regulate the water supply/demand process. The area had 10-year record datasets of hydrology, morphology, and water quantity available. The model could achieve an acceptable water supply/demand balance. It was, therefore, concluded that it is a reliable tool to model, monitor, and estimate water supply/demand and further share information among stakeholders.

Keywords: Water Resources Management (WRM), Spatial Distribution,Supply/Demand Balance, Water Modeling, Water-Use Efficiency.

1. Introduction

Egypt faces severe water scarcity and climate change, with its water resources being limited to 55.5 BCM/ year from the Nile River, 1.6 billion m3 from precipitation, 2.4 billion m3 from non-renewable deep groundwater, and 6.5 billion m3 from shallow groundwater. The country's water supply is 66 billion m3, but the total water demand is 79.5 BCM/ year, resulting in a water availability-needs gap of approximately 13.5 BCM/ year [15]. The country's rapid urbanization and population growth have increased the stress on water resources, necessitating better development and management of water, land, and energy resources to meet the growing population's demands [9].

IWRM is a comprehensive approach to water management that focuses on planning, implementing, and managing water systems to meet human and environmental needs and protect against risks. It faces challenges in implementing its ideas and connecting social, economic, and physical aspects of water systems. The Systematic Design Method (SDM) approach has been used to solve water resource management problems, but it lacks spatial system elements and spatial variability. Water management requires a thorough understanding of the geographical area, including water sources, land cover, human activities, rainfall, temperature, soil condition, geology, and environmental data. Understanding terrain morphology is crucial for understanding and modeling hydrological processes. This study aims to create a spatial water balance system based on the IWRM approach so that it can manage water in canal command areas efficiently and adequately. The model estimates the water gaps and their potential according to any change and achieves a balance between supply and demand. This tool is also designed to support the decision-makers in charge of water resource planning, specifically in times of water shortage. Additionally, it can help irrigation engineers, agronomists, and agro-meteorologists to plan, operate, and manage irrigation systems more efficiently. The models are developed using the Python Programming Language and Model Builder for Esri ArcGIS desktop 10.6. Arc Hydro tools 10.6 is also utilised for preliminary processing and producing some of the datasets needed for analysis. Then, sub-models that compute water budgets and estimate water gaps were created using a combination of Python Scripts and Model Builder.

Both the balance and quantity indices created have successfully assessed the state of water resources. And determining the areas and the amount of water deficit in the research area. According to simulation data, the research area is experiencing a water supply deficit. Its range is between 5% and 28%, and it is expected to increase with time, posing a threat to economic and social development. However, this deficiency can be addressed, and the required water balance can be achieved through integrated and careful planning. The model is a powerful tool to support water managers and decision-makers in applying the principles of IWRM. This tool also allows the management of spatial and non-spatial information and data about land use and water resources.

Review IWRM Approaches and Different Applications for Water Resources Management

The IWRM approach aims to address water problems in country politics by improving water allocation and involving all stakeholders in decision-making. This literature review evaluates the effectiveness of system dynamics modeling (SDM) and various modeling methods for water resource management. RIBASIM, MODSIM, and WEAP are widely used models that can impact organizational setups and management issues in specific river basin water resource systems. These 0D models use a node-link network to represent the simulated water resource system, with the linking storage node concept modifying stream and river reach volumes and flow.

The RIBASIM simulation principle states that water balance is solved for each node in downstream order per the time step. The RIBASIM model was used to simulate Fayoum Governorate's water resources. Different scenarios were assessed under optimistic, pessimistic, and intermediate settings. Three scenarios illustrated different rates of implementation of the tested activity [16]. The MODSIM model has water allocation processes in a river basin by solving the following network flow optimization issue sequentially for each time period. Also, numerous nations, including the United States, Mexico, Brazil, Germany, Ghana, Burkina Faso, Kenya, South Africa, Mozambique, Egypt, and Israel, have used the Water Evaluation and Planning (WEAP) model to evaluate and improve their water resources. WEAP was used to evaluate water resource development alternatives in Tanzania's Pangani Catchment Area [16].

Additionally, "Ref. [17]" employed the WEAP model to determine the potential impacts of the TK5 dam project on the flow yield of the Atbara sub-basin. Atbara is the final major tributary feeding the Nile River before it enters the Mediterranean Sea. Their results showed that the construction of the TK5 Dam in the basin's upstream region did not boost the yearly flow production of the Atbara Basin. As well as the results showed that the flow regulating mechanism used by TK5 Dam enhances the electricity output from Khashem El Girba Dam. In South Africa, a Water Resources Planning Model (WRPM) was developed for assessing water distribution within catchments. Surface water, groundwater, and inter-basin transfers are all simulated by the model [18]. The Centre for Advanced Decision Support for Water and Environmental Systems (CADSWES), University of Colorado, created the river basin modelling system (RiverWare). This model uses the Policy Language (RPL) to create operational policies for river basin management and operations. In order to simulate complex river basin operations, users can enter logical expressions in RPL that define the rules by which objects behave as well as the relationships between objects [19]. The SDM has been applied in many scientific domains. It has many advantages in the field of water resource management. First, it enables the inclusion of environmental and socio-economic factors in the calculations. Second, it establishes a direct link between a system's structure and behavior, allowing for a more thorough examination of system structure changes and their effects on behavior. SDM is one of the methods used in IWRM because it can depict complex relations among all subsystems of the water resources management system [7]. "Ref. [3]" used the SDM in a project to manage urban water in Las Vegas, USA. By 2025, urban water demand is expected to exceed availability. As a result, the local water authorities had to persuade the people of the importance of water conservation.

"Ref. [11]" presented an overview of using the SDM approach for water resource management. They concluded that this concept had been successfully used for a wide range of water issues, including regional planning, river basin management, floods, urban water management, and irrigation. SDM was employed by [10] to investigate the impacts of climate change on Colorado River flows and their effects on the management of local water resources. "Ref. [12]" the SDM was used to create the integrated water scenario analysis for the trans boundary Saskatchewan River Basin's Saskatchewan part. This has contributed to expanding the existing IWRM model by introducing an irrigation sub-model to account for the dynamic irrigation demand and another economic sub-model that provides an economic perspective of water use in various sectors.

Limitations of SDM:

Although SDM has been widely applied to many IWRM problems, such as scarce water resource management, drought management studies, dam reservoir operation, flood management, hydrologic studies under climate change, and others, it still suffers a significant limitation. It can't depict spatially distributed biological, chemical, or physical processes. "Ref. [13]" contrasted the compartmental spatial system dynamics (CSSD) model with a process-based Albuquerque basin groundwater dynamics model created in MODFLOW. They found that CSSD is not an appropriate technique for situations requiring a deep examination of groundwater dynamics and the like, based on a comparison of the respective results. "Ref. [5]" developed a model which consists of two components; a semi-distributed hydrological component and another that describes the relevant socio-economic processes basin-wide. Several notable attempts to add the spatial component of SDM have been made as the technology has become more frequently employed in recent years, and the range of applications has broadened. According to [4], spatial modeling is used to comprehend geographical shapes and processes through the use of spatial data and linkages. "Spatialized" SDMs should replicate the system structure in its natural state, which is heterogeneous in space, and investigate how spatial relationships affect system behavior.

Choosing a suitable system archetype is critical since it determines the spatial and temporal scales of an SDM. Different techniques fundamentally alter spatial models' structure, composition, and behavior to represent space (network, zonal, or grid). According to "Ref. [2]", zonal models provide a limited solution in the presence of strong environmental and geographic system heterogeneity and are used to predict global system behavior. In order to solve this problem, "Ref. [1]" proposed an innovative approach which is designated as Spatial System Dynamics (SSD). This approach has been used to develop a new model that couples SDM and geographic information system (GIS) through a data exchange link. This model selects an area of interest and divides it into cells. Through a series of feedback linkages, the SDM communicates with such cells. This reciprocal interaction depicts changes in parameter values seen at every place in space as a function of an average of parameter values in nearby cells. A similar method was proposed by "Ref. [6]" to construct a Python-edited software that combines SDM and GIS. This method achieves the essential capacity for SDM and GIS two-way interaction activities. They concluded that the spatial model's findings are influenced by the raster resolution as well as the spatial structure.

In summary, the SDM's major limitation is that it does not explicitly represent spatial system elements and spatial variability within a modeled system. It doesn't define the spatial and temporal scales either. The authors created a new spatial system as a technical tool to improve water management by achieving integrated water balances in major canal catchment areas. This system takes into account spatial elements and scaling to create a spatial dynamics model, and it has the advantage of applying to the catchment canal scale (medium scale).

2. Material and methods:

Development of a Spatial Integrated Water Balance System

In general, a spatial integrated water balance system consists of three major components, as shown in Figure 1. They are as follows:

A. Component (1) is represented by geo-database and GIS thematic information layers, including all the data related to conventional and non-conventional water resources, water-consuming activities,
B. Component (2) comprises spatial simulation model developed to link sectors demands with water supply to predict supply and demand trends.
C. Component (3) is a graphical user interface

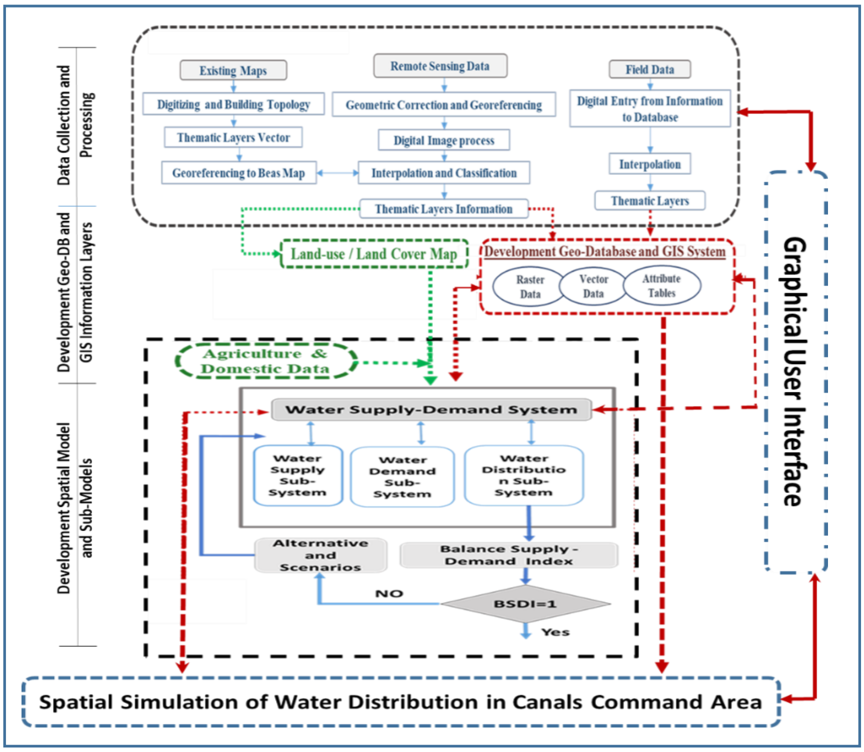

Figure 1: Flowchart of the Stages of Developing the Spatial System

Development Geo-Database and GIS Thematic Information Layers

A spatially integrated water balancing system involves gathering data about available water resources in an area, including supply and demand data and monitoring information for all sectors of water usage. This data is stored in a spatial database with static and dynamic information linked to geographical locations. The main purpose of developing a Geo-Database is to create tools for data entry and storage, including vector, raster, and table data formats. Data is collected from various sources and formats, including hardcopy maps, digital maps, tabular data, and field survey data. Three types of maps are considered for thematic maps relevant to GIS implementation: hydro-geologic, topographic, and land-use.

Datasets from various sources must be processed before being stored in the Geo-Database component. For example, hardcopy maps must be scanned, digitized, rectified, and geo-referenced before being converted to thematic information layers. The maps should have an information layer for each feature, such as irrigation canal networks, drainage networks, canal command areas, drainage catchments, groundwater observation wells, GW aquifers, reuse pump stations, irrigation network monitoring stations, drainage network monitoring sites, industries, drinking and wastewater treatment plants, and land use.

Development of Land Use/Land Cover (LULC) Map Using Remote Sensing Data and Geospatial Analysis:

Land use modeling is crucial for assessing land use and land cover change, aiding in water and agriculture management, monitoring land use change (LULC), and understanding human-environment interactions. A tool was developed by combining remote sensing data with GIS technology and field surveys to classify land cover characteristics and create a land-use map (LULC) for the study area. This map is a key input parameter in the spatial system framework, considering the impact of LULC characteristics on surface water flow, runoff, and water consumption calculations. The study used satellite images from the USGS to map land use and land cover in a study area. The images were chosen for their low cloud distortion and representation of the year's major vegetation growing seasons. The data was then supervised and mapped using Esri ArcGIS desktop software. The map was modified based on ground verification of questionable locations and proper classification. At least fifteen points were assigned to each class, such as agriculture, water bodies, barren land, and built-up land. GPS surveys were conducted, and accuracy was determined using the same ground reference data used for image classification. The LULC map validation and accuracy assessment are crucial for determining its dependability. Accuracy assessment evaluates the quality of classification results and ensures data usage correctly. A specimen of pixels from the categorised image is chosen and its category identification is matched with ground reference data. Experts recommend a minimum accuracy of 85% for land use classification.

Development of the Main Model of the Spatial Water Balance System and its Sub-Models.

The research has developed a new spatial water balance model to calculate water balance elements at the main canal catchment scale. The model evaluates water resources and consumption, determines water deficit areas, and proposes solutions. It consists of four main items: resources, variables, flows (inflow and outflow), and feedback. The goal is to simulate these items simultaneously to bring the whole system to a state of equilibrium.

Water balance in any natural area is usually achieved by calculating the total inflows to the selected hydrological unit (e.g., canal catchment), the total outflows from the hydrological unit, and changes (loss/gain) in water storage during the investigation period. The basic equation for building a water balance model is:

Inflow = outflow ± Change in Storage…………………… (1)

In general, the left side of the equation includes some terms such as precipitation (P) for the time interval Δt (mm), surface water inflow, subsurface water inflow, and artificial import (reuse). The right side includes evaporation (E.T.) from (surface water/land areas), surface runoff, and subsurface outflow (rate of infiltration (I)) (mm/month). Elements in equation (1)] are expressed in volume units per unit of time, such as (m^3/month, m^3/year).

The water balance equation is calculated using mathematical equations and sub-models to simulate the system's equilibrium. A water supply/demand balance model was developed to assess water resources by creating indicators. Researchers developed the Arc Supply-

Demand Balance Tool as a planning tool for water resource management during a water shortage. This tool connects water supply sources and demands, evaluates the current status of supply sources and demand centers, and allows for rapid judgment of future effects of changes in supplies and demands on the supply/demand balance. This study's spatial water supply/demand balance model comprises three sub-models (modules). They are presented below in the order of their implementation. They include all the equations, logical rules, and algorithms that constitute the model. The models were developed using the Python Programming Language and Model Builder for Esri ArcGIS 10.6. Arc Hydro 10.6 tools were also used for preliminary processing and the production of some datasets needed for analysis. Then, using a combination of Python Scripts and Model Builder, sub-models were created to calculate water budgets and estimate water gaps. There were three subsystems in the developed modeling toolset: one for assessing water supply, another for assessing water demand, and a third for achieving water balance. First, system dynamics analysis software was used to obtain the relationships between the various variables necessary to construct this toolset. Then, based on the analysis of these relationships, subsystems were created. It acts as an accurate measure of the ability of an irrigation directorate to provide sufficient water for the different demands. The water supply for the system comes from surface water inflow from the canal distribution network, groundwater extraction by agriculture wells, drinking water treatment plants, and other non-conventional water sources. Therefore, equation (2) calculates the total water supply amounts in the canal command area (Q ($_{T.S}$.)). On the other hand, water demand in the system includes the amount of water needed for domestic, industrial, and agricultural uses. Therefore, equation (3) is used to calculate the consumed water volume in a canal command area (Q $_{(T.D.)}$). An imbalance in available water resources can be detected by analyzing demand and supply. Accordingly, optimal solutions provided.

$$Q_{(T.S.)} = W.S._{(Sur)} + W.S._{(Gro)} + W.S._{(Reuse)} + W.S._{(Des)} \ldots\ldots\ldots\ldots \ldots \qquad (2)$$

<u>Where:</u> $Q_{(T.S.)}$ = total water supply for the interval time Δt (MCM); $W.S._{(Sur)}$ = surface inflow; $W.S._{(Gro)}$ groundwater extraction; $W.S._{(Reuse)}$ = amount of wastewater that is related to water quality; $W.S._{(Des.)}$ = amount of desalinated water.

$$Q_{(T..D.)} = W.D._{(Irr.)} + W.D._{(Dom.)} + W.D._{(Ind.)} + Losses \quad \ldots\ldots\ldots\ldots\ldots \qquad (3)$$

<u>Where:</u> $Q_{(T..D.)}$ = total water demand for the interval time Δt (MCM); $W.D._{(Irr.)}$ = irrigation water demand; $W.D._{(Dom.)}$ = domestic water demand; $W.D._{(Ind.)}$ = industrial water demand.

Supply- Demand Balance Index (BSDI): This module predicts the index of supply and demand balance (BSDI) using spatial statistical analysis of data records from the last ten years. This balance index is an indicator of the water shortage degree. Also, it is used to measure the ability to secure sufficient water that can meet various demands. Therefore, the balance index can mainly act as a basis for developing and protecting water resources. This index is defined by the ratio of total water available to total water consumption for diverse uses within a canal catchment area, as shown in equation (4):

$$BSDI = Q_{(T.S.)} / Q_{(T.D.)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

If the BSDI is greater than 1.0, supply is greater than demand. It means that the area has no shortage of water. If the BSDI value is between 0.9 and 1.0, supply is smaller than demand, and the study area has a small water shortage. If BSDI lies between 0.6 and 0.9, supply is smaller than demand, and, therefore, the study area has a mild water shortage. In this case, production and development processes may be greatly affected. If the BSDI is less than 0.5, supply is half the demand. Accordingly, the study area suffers from a critical water shortage. Production may be stopped due to sharp water deficits in such a case. So, it is said that the lack of water in the study area is affecting the area's growth.

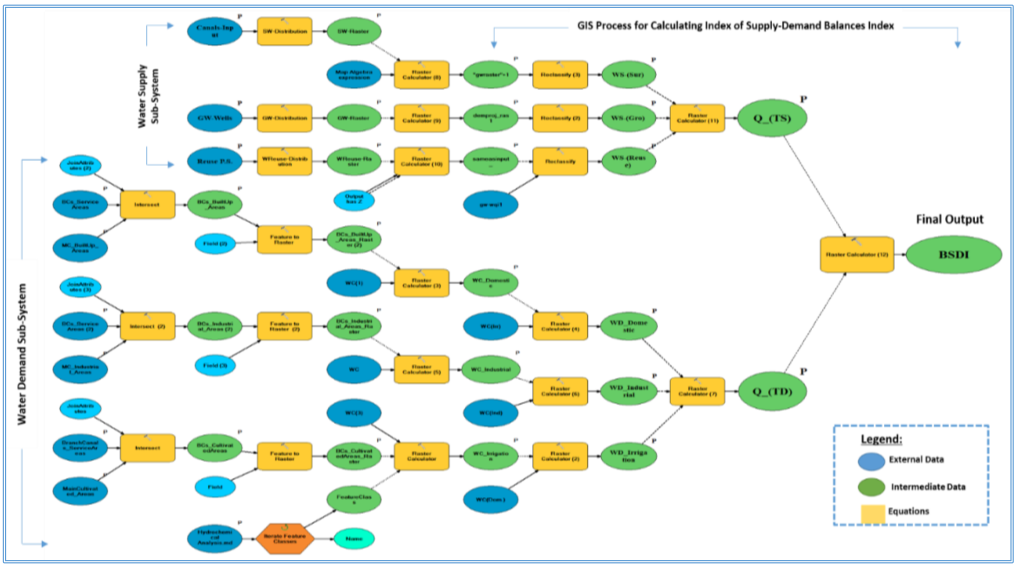

Figure 2: A GIS-Processes Flow Diagram for Building an Arc Supply-Demand Modeling Toolset

Development of a Dynamic User Interface (DUI):

The third component is a dynamic user interface (DUI), created to connect the system's different components (modeling toolset and geodatabase). It's also how the user interacts with the application and may efficiently manage data and information, as well as get the system's results and outputs.

3. Results and discussion

Study Area

A new spatial system has been applied to the Ismailia canal's command area. It is one of the most significant canals in the Nile Delta's eastern region. This region was chosen because it is Egypt's most vibrant and rapidly developing area. It has a variety of land cover/land use and is in heavily populated areas; it also has several water-intensive

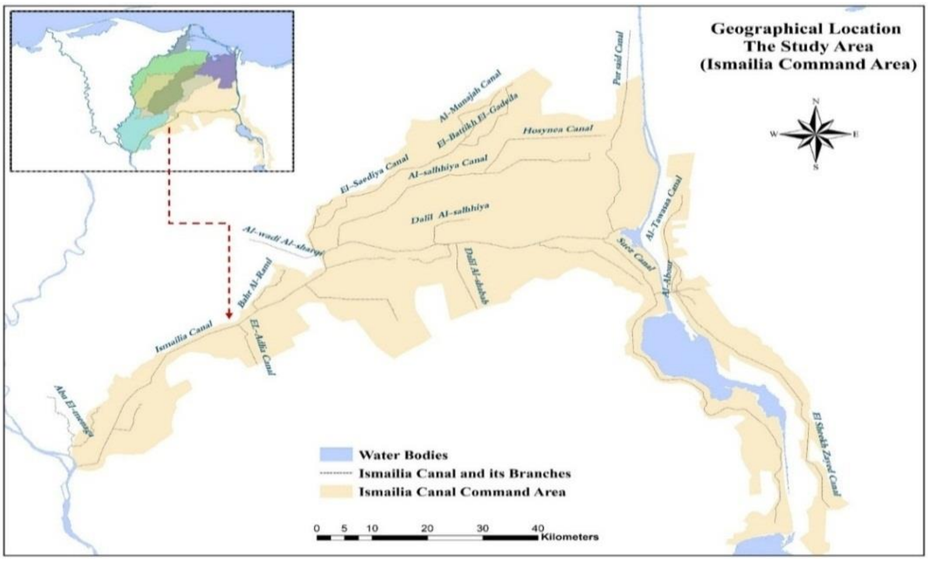

Figure 3: Study Area (Ismailia Canal's Command Area)

projects. The Ismailia Canal and the El-Salam Canal are in this region. They are the main water sources for major national projects for land reclamation in the eastern Delta and northern Sina and the establishment of big urban centers. The Ismailia Canal is located in Cairo's northeastern outskirts, east of the Damietta Branch, which goes upstream from the Nile Delta Barrages. The Ismailia Canal, which has a length of about 136 km, runs northeast to the desert's edge and then drops eastward to the city of Ismailia; it is divided into numerous branches to supply fresh water to the operational region. It splits into two branches: a 90 km north branch to Port Said and an 87 km south branch at Suez before Ismailia city. It then ends in Timsah Lake, as depicted in Figure 3. The Ismailia Canal serves a total area of 330492 hectares, divided into two irrigation directorates: The Salhiya irrigation directorate, which includes 185167 hectares, and the Ismailia irrigation directorate, which consists of 122417 hectares.

Application of the Developed Model for Analysis Water Supply-Demand System

The above steps are performed sequentially within the ArcGIS environment. The user does not need to come out of the system at any stage. Once the main canal system is selected, the model is run using input data, and the entire process is done automatically. The Ismailia canal system was chosen to implement the model, with a service area of 342999 ha. Historical data for 2019 was used to get the water status and determine the required water released each month. Then the outcomes came as follows;

Analysis Water Supply System

The outputs of this stage are used to estimate the system's water supply from various sources and create water supply maps, as shown in Figure 4. Which can be explained:

- The results that appear on map 4 (A) illustrate that the total surface water ($SW_{(Sur)}$) entering the research area is 5885 MCM. The Ismailia Canal and its branches are the principal sources of surface water supply, providing 5615 MCM, i.e., 95.5% of the total surface water supply in the study area. At the same time, the Abu Al-Manja Canal provides 270 MCM, i.e., 4.5% of the total.

- Map 4 (B) results illustrate the geographical distribution of groundwater extraction rates in the Ismailia canal catchment. This concluded that the total groundwater extraction ($SW_{(Gro)}$) in the research area is 244.55 MCM, which included extraction for irrigation, residential, industrial, and other uses.The results on map 4 (C) illustrate the geographical distribution of the reuse sites and summarize the amount of drainage water reuse in the command area. This concluded that the total drainage water reuse is 238.83 MCM.

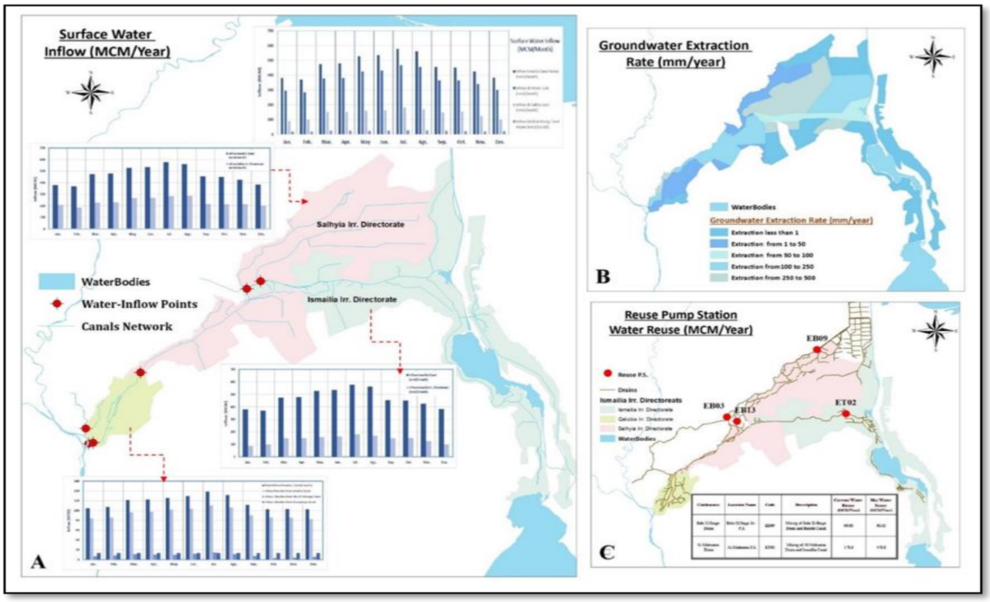

Figure 4. Shows Water Supplies (WS) from Different Sources in the Ismailia Command Area (MCM)

Analysis Water Demand System

The outputs of this stage are used to calculate the water requirements in the domestic, irrigation, and industrial sectors as well as create water demand maps, as shown in Figure 6. Which can be interpreted as follows:

- Map 5(A) illustrates the geographical distribution of the main crops cultivated per year in the Ismailia command area. As well as map 5(B) illustrates the geographical distribution of the water consumption of crops and the total irrigation water demand (WD (Irr.)) for 2019 in the Ismailia command area. According to these results, the total crop water consumption reached 2985 MCM, while the total irrigation water demand (WD (Irr.)) is about 4111 MCM.
- The module results also clarify the domestic and industrial water requirements inside the Ismailia command area. Based on these results, the total residential area was 38206 ha, i.e., 14.8% of the entire study area. The total population is about 116,741,500 people. Then, the total domestic water demand (WD (Dom.)) amounted to about 1195.50 MCM, i.e., 17.21% of the study area quota.

– The water consumption rate for industrial units (WD (Ind.)) in the study area was estimated by analysing data collected by the EEAA for the different factories. This data includes the geographical location of the factory, the type of industry, the water source, the amount of water used per m3/day, the amount of wastewater produced, and the source of waste disposal. Based on the output of the modeling tool, the current amount of water provided to the industrial user is 729 MCM, i.e., 7.5% of the study area quota.

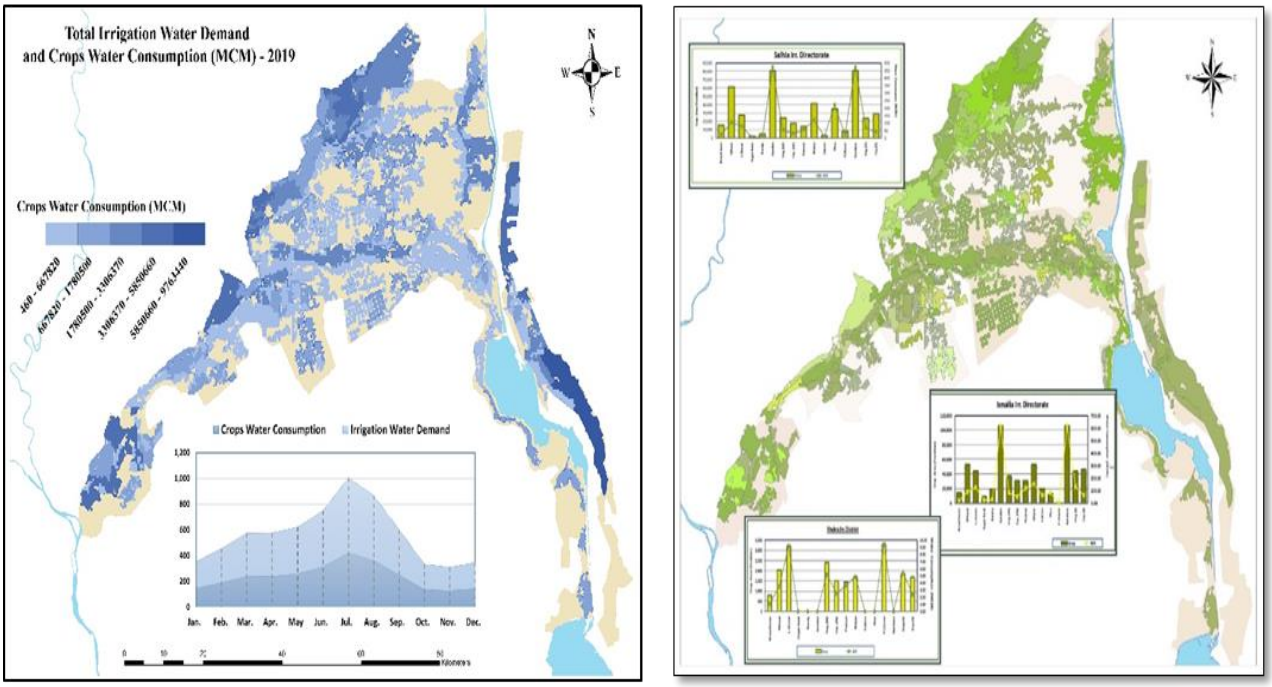

Figure 5. Irrigation Water Demand in Ismailia Canal Command Area

Supply-Demand Balance Index (SDBI):

The last procedure is to forecast the Supply and Demand Balance Index (SDBI). This balance indicator is determined as the ratio of total water supply (Q (T.S.)) to total water demand (Q (T.D.)). This index has values ranging from 1 to 0, as illustrated in figure (6). According to BSDI in the Ismailia Command Area, the index value ranges from 1 to 0.9 in Shubra, East Belbis, Abu Hammad, Faqous, El-Mallak, and South Salhyia, El-tal El-Kabeer, El-Ismailia, and North El-Ismailia Irrigation Districts. This means that supply is less than demand, and the irrigation districts have a small water shortage. The index value ranges from 0.9 to 0.7 in the irrigation districts of El-Tolombat, North Salhyia, El Suez, East El-bohirat, and El Sheikh Zayed . This means that supply is less than demand, and, therefore, the irrigation districts have a mild water shortage. Here, production and development processes may be affected.

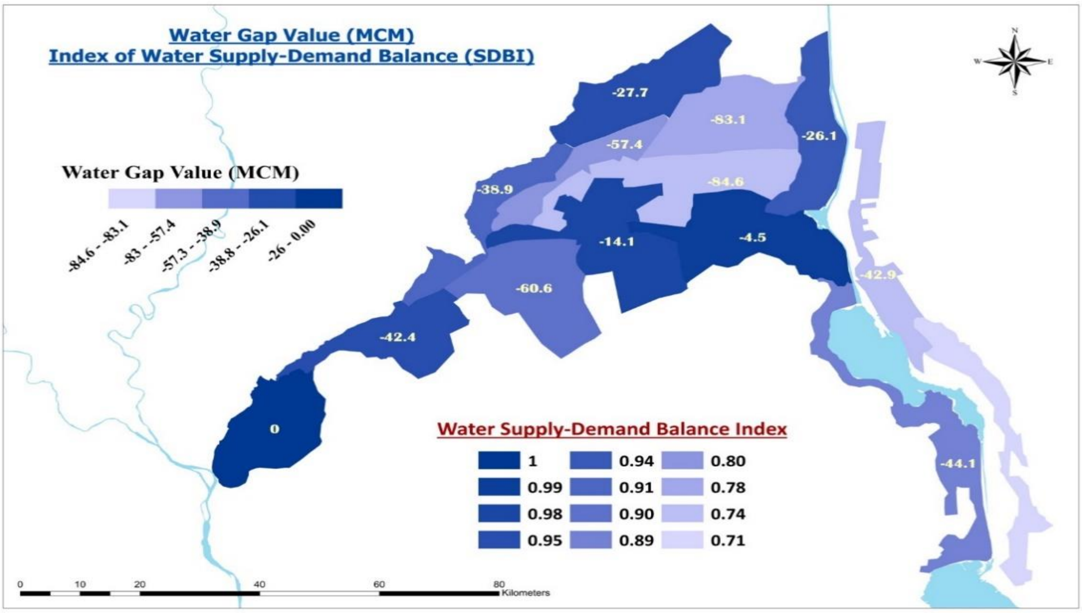

Figure 6. Water Shortage at Irrigation Distracts in Ismailia Canal Command Area

Model Calibration

SIWBS simulated the current situation at the Ismailia Canal command area, based on the input data. This was considered an action toward calibrating the model to the water system in the main canal command area. Agricultural demand was 4.11 BCM/year during the calibration process, residential consumption was 1.19 BCM/year, and industrial demand was 0.73 BCM/year. The overall annual demand from all sectors was 6.04 MCM. Furthermore, the 2019 field measurements were added to the calibration procedure. Actual agricultural, domestic, industrial, and total demand were 4.65, 1.50, 0.75, and 6.90 billion cubic metres per year, respectively. The current simulation's Mean Percentage Relative Error (%) was determined as follows.

$$\textbf{MPRE (\%)} = \frac{\sum \left(\frac{\textbf{Model Result} - \textbf{field measurment}}{\textbf{Field measurment}}\right) * \textbf{100}}{\textbf{Number of result}}$$

From calculating MPRE (%) find that the model underestimated home demand by 0.83% and industrial demand by 1.22% compared to the actual field data. In addition, the model overstated agricultural demand by 1.95% and total demand by 1.33%. As a result, it was obvious that the SIWP model could perform well in simulating future demands.

4. Conclusions

The current study has developed a spatial model that can achieve water balance within the main canal command areas. The model is a powerful tool to support water managers and decision-makers in applying the principles of IWRM. This tool also allows the management the spatial and non-spatial information and data about land use, as well as water resources. Moreover, it can analyze the state of water resources in order to detect areas of water deficit and problems and areas of good environmental status. The model can predict the events and developments expected to occur within 10 to 20 years in the future. Suggested water resources management measures can be evaluated, as well as their effects can also be assessed and represented on maps.

5. REFERENCES

[1] S. Ahmad, "An Intelligent Decision Support System for Flood Management: A Spatial System Dynamics Approach", Doctoral Dissertation, Department of Civil and Environmental Engineering, The University of Western Ontario, London, 2002.

[2] L. Anselin, "Under the Hood: Issues in the Specification and Interpretation Spatial Regression Models", Agric Econ, vol. 27, no. 3, pp. 247–267, 2002.

[3] K.A. Stave, "A System Dynamics Model to Facilitate Public Understanding of Water Management Options in Las Vegas, Nevada", J. Environ Manag, vol. 67, pp. 303–313, 2003.

[4] T. BenDor, N. Kaza, "Theory of Spatial Reference Modes and System Archetypes" System Dynamics Winter Conference in January 2011, Austin Texas.

[5] P. Prodanovic, and S.P. Simonovic, "An Operational Model for Integrated Water Resources Management of A Watershed", J. Water Resour Manag, vol. 24, no. 6, pp. 1161–1194, (2010).

[6] C. Neuwirth, A. Peck, and S.P. Simonovic, "Modeling Structural Change in Spatial System Dynamics: A Daisyworld Example", Environ Model Softw, vol. 65, pp. 30–40, March 2015. https://doi.org/10.1016/j.envsoft.2014.11.026

[7] P. Prodanovic, and S.P. Simonovic, "Development of Rainfall Intensity Duration Frequency Curves for the City of London Under the Changing Climate". Water Resources Research Report No. 058, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Canada, 2007, 51 p,

[8] S. Ludwig, K. De Ruyter, D. Mahr, M. Wetzels, "Take their Word for it: the Symbolic Role of linguistic Style Matches in User Communities", J. Management Information Systems Quarterly, vol. 38, no. 4, pp. 1201-1217, 2014.

[9] Srijana Dawadi and Sajjad Ahmad, "Changing Climatic Conditions in the Colorado River Basin: Implications for Water Resources Management", Journal of Hydrology, vol. 430–431, no. 2, pp. 127-141, April 2012. https://doi.org/10.1016/j.jhydrol.2012.02.010.

[10] Ines Winz, Gary Brierley, and Sam Trowsdale, "The Use of System Dynamics Simulation in Water Resources Management", J. Water Resource Manage, vol. 23, pp.1301–1323, 2009. https://www.researchgate.net/publication/225776221.

[11] H. Elmira, A. Elshorbagy, H. Wheater, and P. Gober" Managing Water in Complex Systems: An Integrated Water Resources Model for Saskatchewan, Canada", J. Environmental Modelling & Software, vol. 58, pp. 12-26, August 2014. https://doi.org/10.1016/j.envsoft.2014.03.015.

[12] J J. Roach, and V. Tidwell, "A Compartmental–Spatial System Dynamics Approach to Ground Water Modeling", vol. 47, no.5, pp. 686-698, October 2009. https://doi.org/10.1111/j.1745-6584.2009.00580.

[13] Arab Republic of Egypt, Ministry of Water Resources and Irrigation. Water Scarcity in Egypt; February 2014. [accessed August 31, 2014], mfa.gov.eg

[14] Omar M. Evaluation of actions for better water supply and demand management in Fayoum, Egypt using RIBASIM. Water Sci. 2013;27:78–90. https://doi.org/10.1016/j.wsj.2013.12.008

[15] Arranz R, McCartney MP. Application of the water evaluation and planning (WEAP) model to assess future water demands and resources in the Olifants Catchmen, South Africa. In: International Water Management Institute (IWMI), South Africa; 2007, Working Paper 116. p. 91.

[16] Monem RHA, Soliman ESA, ElAzizy I. Assessment Of Atbara Basin Under The Future Development Plans. In: The 8th International Conference on Technology and Sustainable Development in the Third Millennium; 2014.

[17] Mwaka B. Developments in DSS to Enhance equitable participation in water resources systems operation. In: CPWF: Proceedings of the working conference January 23–26, Nazareth, Ethiopia; 2006.

[18] Frevert D, Fulp T, Zagona E, Leavesley G, Lins H. Watershed and river systems management program – an overview of capabilities. J Irrig Drain Eng (J Irrig Drain Eng) 2006, 10.1061/ (ASCE) 0733–9437. 132:2(92), 92–97.