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Assessment of the Water Supply and Demand Management System in Fayoum using WEAP

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Abstract: Fayoum Governorate faces numerous water-related issues, including adjusting for water shortages and limiting the volume of drainage water effluents entering Qarun Lake. Fayoum Governorate now faces a water scarcity, which is anticipated to worsen over time. Currently, this water scarcity is offset by drainage reuse, which degrades water quality. Numerous activities can be taken to address these water-related concerns using a water resources management approach. These measures are divided into two categories: water resources (supply management) and properly managing current water resources (demand management). The paper examines the application of the WEAP model as a decision-making tool for water sector planning and management, as well as the most appropriate future initiatives. WEAP was used to simulate current conditions in 2017 and future scenario in 2050. WEAP results show a water shortage of 1.3 and 2.67 BCM (billion cubic meters annually) for the various simulated scenarios. Because Fayoum is a miniature of Egypt. This study offers ideas for enhancing Egypt's water resources system, considering both natural and water systems. This study can serve as recommendations for improving Fayoum's water resources system.

Keywords: Water resources; Supply management; demand management; WEAP; Water shortage.

1. Introduction

The water sector in Fayoum Governorate faces severe challenges in terms of water sources and utilization. The water supply is being depleted and its quality is declining as a result of unregulated use, particularly by the agricultural sector. On the user's side, in the municipal sector, per capita water consumption is relatively high and the irrigation efficiencies in the agricultural sector are low. Data and information on the industrial sectors are not detailed. Moreover, the water sector is fragmented institutionally, leading to sectoral water planning and management with minimum coordination among the various water agencies as well as between the water sector and other water-related sectors such as energy and food. The efficiency of the water management sector is not high, and its sustainability is in question under the current conditions.

Water scarcity is a big issue facing many countries today. Sustainable and efficient water usage is vital for nations facing water scarcity, as water distribution is unequal globally. Sustainable development aims to manage water resources sustainably and ensure that everyone has access to safe, clean water [1]. Egypt is a classic example, with a rapidly rising population and improvements in various industries, including constructing a new capital [2]. Egypt is the country farthest downstream in the Nile Basin. The majority of its freshwater intake (about 97%) comes from beyond its limits [3-4]. Egypt's national plan for 2037-2050 identifies a yearly water scarcity of around 21 billion cubic meters (BCM) across several sectors, which is expected to increase. Before 2030, per capita annual water availability is expected to be only 500 cubic meters, indicating absolute water shortage [5-7].

All available water resources are being used to meet the demands of all sectors. Water resources are employed across all sectors to suit their needs. Egypt's current national plan represents a shift away from traditional approaches to demand management. Water resource management has also shifted from a local to a national focus. To ensure the sustainability of water resources, it's important to examine the negative impacts of population growth, urbanization, and national and local objectives [8]. Water managers can analyze management possibilities by modeling various modifications with this data-processing tool [9-12].

This tool in water resource management involves using a spatial geodatabase in a geographic information system (GIS) and has been widely used by administrators and scholars worldwide [14-16] despite lacking the ability to calculate distinct water balances [13]. The program has been used in several studies [17-20].

The WEAP model in river systems establishes mass flow balance while permitting inflows and abstractions [21]. Each demand location is assigned a priority ranging from 1 to 99, where 1 is the greatest and 99 is the lowest. In the case of a water crisis, this algorithm gradually decreases water allocation to low-priority demand areas. For further information on the model [10,14,15].

Many studies have employed the WEAP program. In order to understand the Water–Energy–Food–Environment (WEFE) nexus for climate change adaptation in the Urmia Lake Basin in northwest Iran, Nasrollahi et al. studied the Water-Energy-Food-Environment (WEFE) nexus and its impact on climate change adaptation in the Urmia Lake Basin in northwest Iran. The LEAP and WEAP models were used to evaluate probable future climatic scenarios [20]. The WEAP model supports decision-making and integrates water resource management with policy analysis. It allows the simulation of water demand and supply. A full analysis of Egypt's water system at various sizes is possible by considering agricultural water requirements and other characteristics [22-23]. WEAP's water quality modeling was utilized to study water reuse processes in the Segura River Basin in Spain and Europe, employing a virtual tracer technique [24].

Jaramillo et al. used the QUAL2K and WEAP models to investigate the relationship between quantity and quality in Colombia's Vieja river basin [25]. Ramadan et al. used WEAP to analyze the water deficit in Egypt's Sharkia province [26]. WEAP software, available at www.weap21.org, supports several case studies worldwide.

The WEAP model and a GIS were the two models employed in this investigation. To inform the strategy to solve seasonal water shortfalls in Fayoum, western Egypt, mathematical verifications were assessed. To help with the development and planning of evaluation procedures, this study intends to shed light on the possible application of hydrological and WEAP models as a decision-support tool for managing and planning the water sector in regions where water resources are already under a great deal of strain. The study's suggestions and actions can help to strengthen Fayoum's water resources infrastructure. The plausible future scenarios till 2050 and the current condition in 2017 were both simulated using WEAP.

2. METHODOLOGY

2.1 MODEL DESCRIPTION

The WEAP Model refers to Water Evaluation and Planning. Several countries, notably the United States and Egypt, have utilized it to examine and develop their water resources, as shown in Figure 1. It simulates water demand, supply, flow, storage, pollutant generation, treatment, and disposal. It evaluates a variety of water development and management options while considering the different and competing needs of water systems. The system is illustrated as a node-link network. Each connection/node is determined by what it represents in the basic equation of WEAP, which applies the water balance equation in its general form: Input (I) - Output (O) = Change in Storage (CS), where inputs include precipitation, groundwater influent, and runoff. While the output includes losses. The components are estimated as follows:

- Rainfall gauges measure precipitation.
- The allowable volume of groundwater influent varies by region and basin.
- Runoff is estimated based on the duration of precipitation.
- Irrigation use is approximated based on consumption, field application, distribution, and conveyance losses.
- Evaporation is estimated based on changes in water levels in evaporation pans.

2.2 STUDY AREA DESCRIPTION

Fayoum Governorate is a vast depression in Egypt's western desert, 90 kilometers south-west of Cairo. Fayoum Governorate is located astronomically at latitude 29° 18' 35.82" north, and longitude 30° 50' 30.48" east, as depicted in Figures 2a and 2b. Fayoum's principal water supply is the Bahr Youssef Canal which is 312 kilometers long and branches off the Al-Ibrahimia Canal, which in turn branches off the Nile River. The Lahun barrage controls water flow through Bahr Youssef, totaling around 2.56 billion cubic meters per year. Fayoum's irrigation and drainage network consists of approximately 324 canals totaling 1,296 km and 222 drains totaling 924 km. Desalination is not considered a water resource in the governorate because the Fayoum Company for Mineral Salts primarily desalinates water for internal use. In addition, water is drained into two ecologically significant lakes, Lake Qarun and Wadi Rayan. As the available water is fixed and the demand for water is increasing, it is vital to manage the water resources in a sustainable way [27].

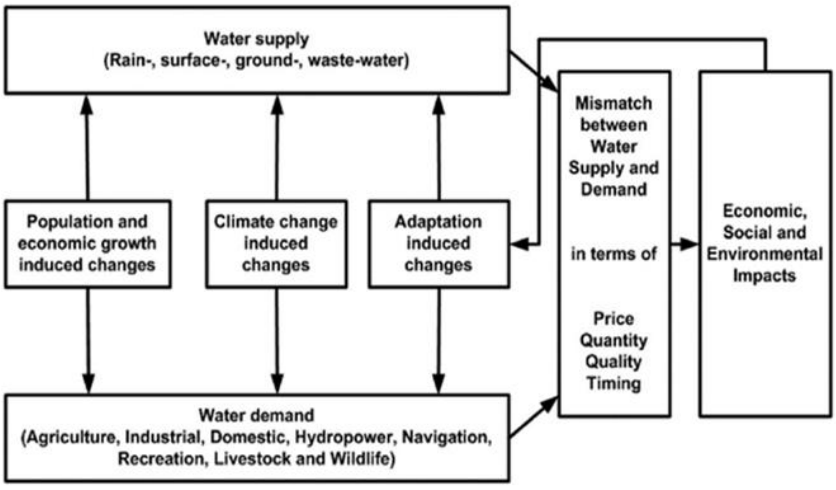
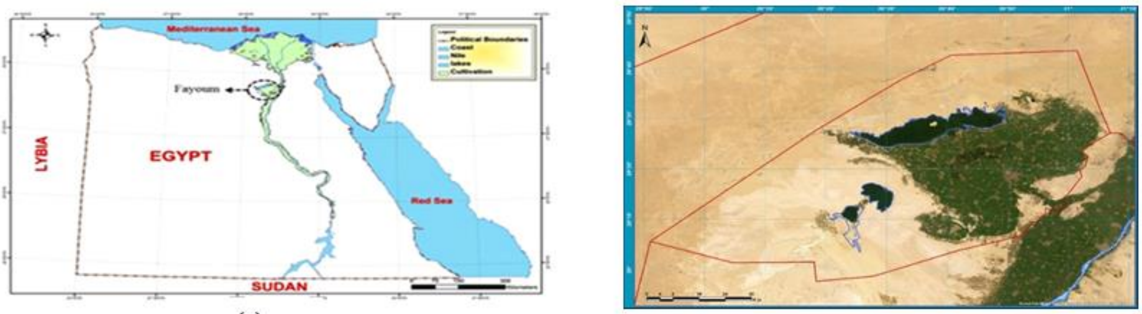


FIGURE 1. The Main Parts of the WEAP



(a) (b)

FIGURE 2. Location of Fayoum in Egypt [27].

Several visits were made, including to the Water Resources Unit, the Fayoum Irrigation Directorate, the Fayoum Agriculture Directorate, and the Fayoum Water and Wastewater Treatment Holding Company. Population numbers and growth, total agricultural area and cropping patterns, total agricultural area of new lands in the surrounding deserts and irrigation systems, capacities of all drinking water plants, capacities of primary and secondary wastewater treatment plants, the number of factories and total industrial demand, and total irrigation volumes discharged into agricultural lands were among the information gathered.

The Fayoum water balance was developed for water resources analysis based on site evaluations and data collection as shown in Table 1. The water balance includes both inputs and outputs. It also displays the overall amount of water utilized by each sector, as well as the amount of water returned to the system. Here is a summary of Fayoum's water balance:

- Imports include discharge from Bahr Youssef Canal through Lahon Dam, rainfall, and shallow groundwater.
- Outputs include evaporation, water consumption for various sectors, and drainage to Qarun Lake and Rayan Valley.

2.3 MODEL DATA AND ASSUMPTIONS

The data concerning water balance in Fayoum Governorate 2017 was utilized in the modeling process to simulate and calibrate the WEAP model as shown in Table1.

The model development includes the following crucial data and assumptions: The real leakage of the drinking water network, as reported by the Ministry of Housing, Utilities, and Urban Communities and the Holding Company for Water and Wastewater, is around 30.1%. The model considers the demands for annual water allocation [28].

Water sector indicators for the second national water resources plan in the Fayoum governorate from 2017 to 2037 were considered. The area under cultivation determines the agriculture sector's water use. The water requirement was defined as follows: the agriculture sector consumed 3437 million cubic meters, while the industrial and municipal sectors used 299 million. The WEAP model considers Nile water, shallow groundwater, agricultural drainage water reuse, and treated wastewater reuse as the principal water sources in the Fayoum governorate. The municipal, industrial, and agricultural sectors are all being considered. Figure 3 displays the water system as a hypothetical dynamic graphic, with demand sector represented by red dots and groundwater resources represented by green squared. Red arrows represent returned flows and the blue line represents Bahr Youssef (conventional water Supply). Green links show the transfer of water resources to user locations [29].

The high population growth in the Fayoum governorate is acknowledged as the key factor impacting water demand, as shown in Figure 4 (a and b). In agriculture, a modeling approach is used to achieve 60% irrigation efficiency. WEAP inputs for domestic and industrial demand include the total population (3.615 million capita), population growth rate (2.42%), average water consumption (195 l/capita/day), and distribution water losses (30%) [29].

TABLE 1. Water balance in Fayoum, MWRI 2017

Water supply		Volume (BCM)	Water Demand	Volume (BCM)
Conventional water Source	Lahoun	2.636	Drinking and Industry	0.299
Unconventional water Source	Shallow groundwater	0.500	Agricultural	3.437
	Reuse of agricultural wastewater	0.800	Fish farms	0.200
Total supply		3.936	Total demand	3.936

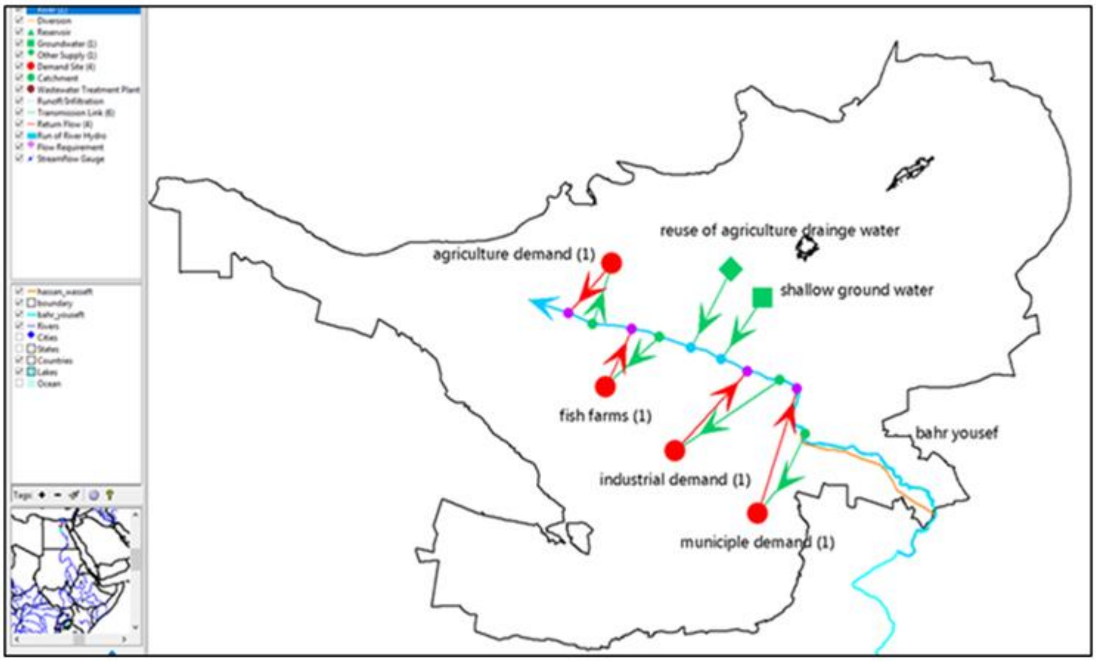
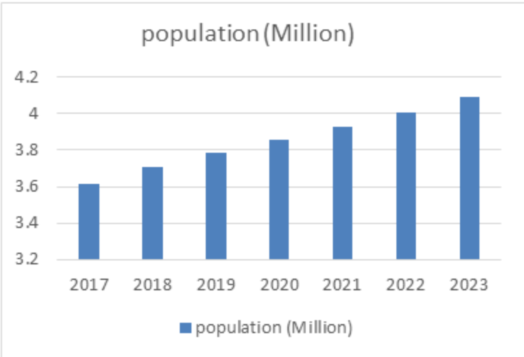


FIGURE 3. Conceptual dynamic diagram of the water system in Fayoum governorate



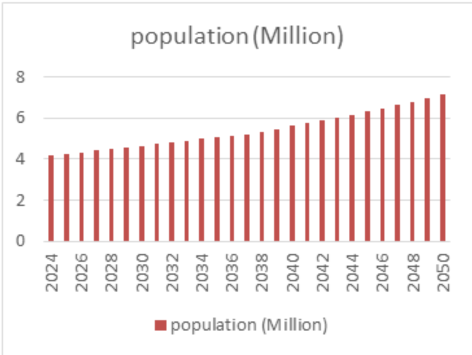


FIGURE 4. a) The actual population of Fayoum **b)** The projected population of Fayoum

2.4 MODEL CALIBRATION

To accurately simulate the water system in Fayoum, historical observations were used to calibrate the model. The calibration was based on available data for the period 2017-2050. Calibration is performed using the actual population until 2023 and the projected population from 2023 to 2050. The simulated water data is performed using the WEAP model [30-31]. The model's results were compared to the actual (till 2023), projected (2023-2050), and simulated (using WEAP) values for the same years. Municipal water demand is calibrated based on the per capita water rate. The obtained simulated results using WEAP are presented in Figures 5, 6, and 7 showing projected water requirements for agriculture, municipalities, and industries from 2023 to 2050. The figures show calibrated agricultural, municipal, and industrial water requirements with the Mean Percentage Relative Error values of 0.8, 0.87, and 0.9 respectively indicating good results for both agricultural and overall water supply demands. Figure 8 compares projected and simulated total water demands, with an MPRE of 0.85. Thus, the WEAP model effectively simulates demand.

The following formula was used to determine the Mean Percentage Relative Error (MPRE) (%) for the water demands for agriculture, industry, and municipal water demands through the calibration process.

$$MPRE = \frac{\sum\left[\left(\frac{Numerical\ result - Field\ measurement}{field\ measurement}\right) x\ 100\right]}{Number\ of\ results} \quad (1)$$

3. RESULTS

From the simulation results in Figure 5 concerning the year 2017, the agricultural, domestic, and industrial demand was 3.437, 0.295, and 0.004 BCM/yr. The unmet water demand in the year 2017 was 1.3 BCM/yr. Which was compensated by water reuse and shallow groundwater. As for future scenarios, the water shortage in 2050 would be 2.668 BCM/yr. The demands for the agricultural, domestic, and industrial sectors in the year 2017 were 3.437, 0.296, and 0.004 BCM/year. The demands for the agricultural, domestic, and industrial sectors in the year 2050 were 4.726, 0.573, and 0.005 BCM/year. The total demand of all sectors in 2050 would be 5.753 BCM/yr and water shortage in 2050 would be 2.668 BCM/year (i.e. 1.289, 0.278, and 0.001 BCM/year) for agricultural, industrial, and municipal water demand. These obtained results using WEAP are presented in Figure 9. The figures and tables represent the values for the water demand, Demand Coverage, Unmet Demand in each sector from 2017 to 2050.

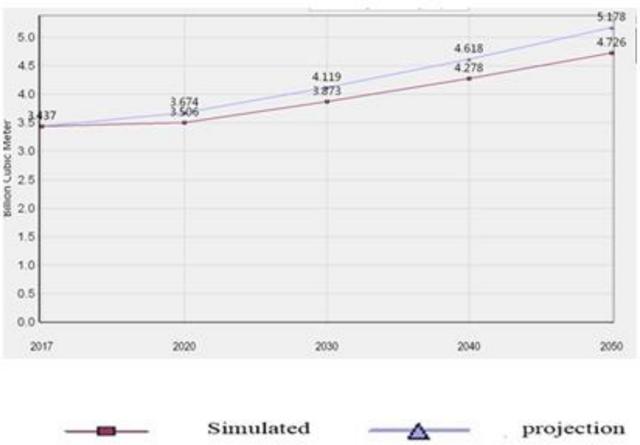


FIGURE 5. Comparison between Simulated and Projection in Agriculture Demand

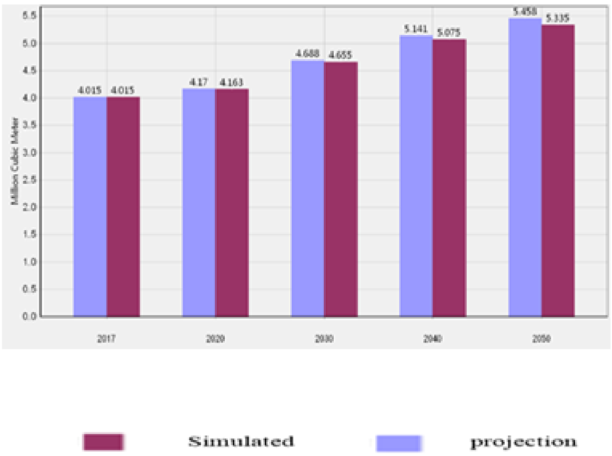


FIGURE 6. Comparison between Simulated and Projection in Industry Demand

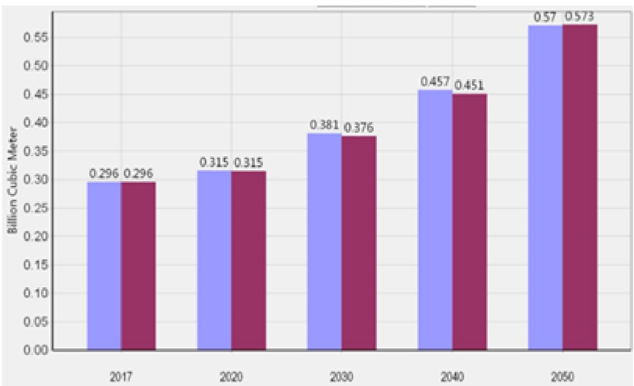


FIGURE 7. Comparison between Simulated and Projection in Municipal Demand

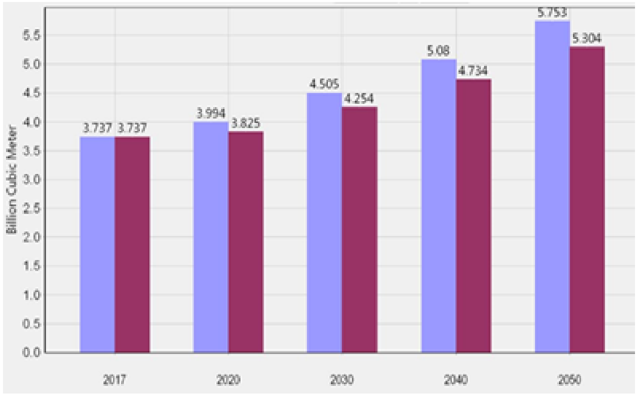


FIGURE 8. Comparison between Simulated and Projection in Total Water Demand

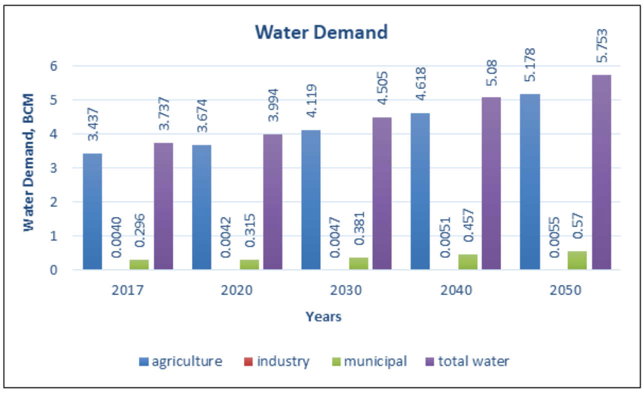


FIGURE 9. Water Demand (Billion Cubic Meter)

Regarding the results, unmet demand was in the agricultural sector. In contrast, it was not evident in the municipal or industrial sectors. The agricultural unmet demand occurred throughout the summer months. Unmet demand for agriculture is covered by reusing agricultural wastewater and shallow groundwater. The results obtained using WEAP are presented in Tables 2 and 3 showing the percentage of demand coverage and unmet demand.

Regression analysis is done and equations are developed to predict the water demand and the unmet demand requirements from the year 2017 till the year 2050, as shown in Figures 10 and 11.

TABLE 2. Demand Coverage (%)

Demand	Years				
	2017	2020	2030	2040	2050
Agriculture demand	73.29	73.54	60.03	48.96	39.06
Municipal demand	74.95	74.9	61.57	49.82	39.76
Industrial demand	73.59	73.77	60.26	49.08	39.19

TABLE 3. Unmet Demand (Billion Cubic Meter)

Unmet Demand	Years				
	2017	2020	2030	2040	2050
Agriculture unmet demand	0.918	0.928	1.548	2.184	2.880
Municipal unmet demand	0.078	0.083	0.150	0.230	0.348
Industrial unmet demand	0.001	0.001	0.002	0.003	0.003
The total unmet demand	0.997	1.012	1.7	2.417	3.231

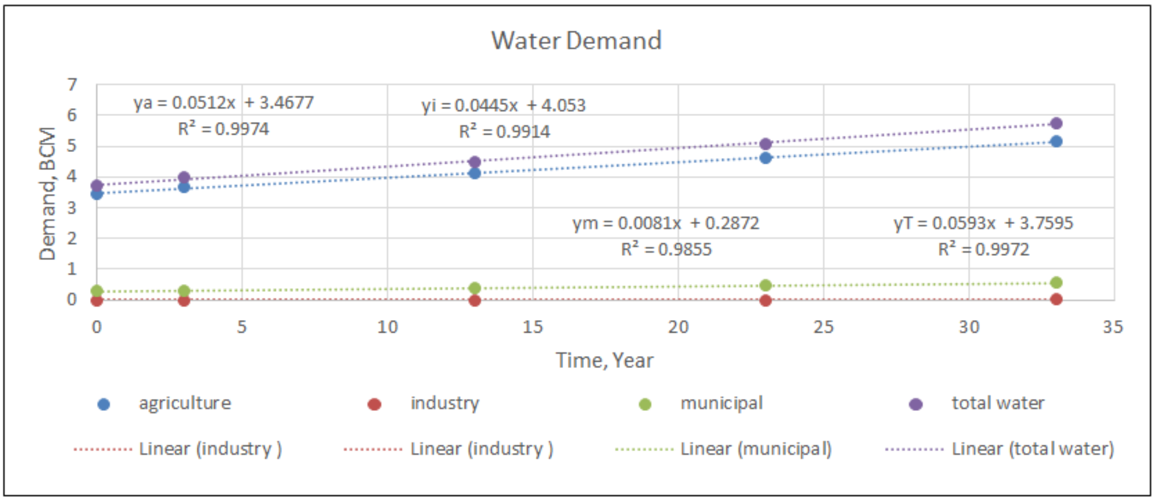


FIGURE 10. Regression Water Demand (Billion Cubic Meter)

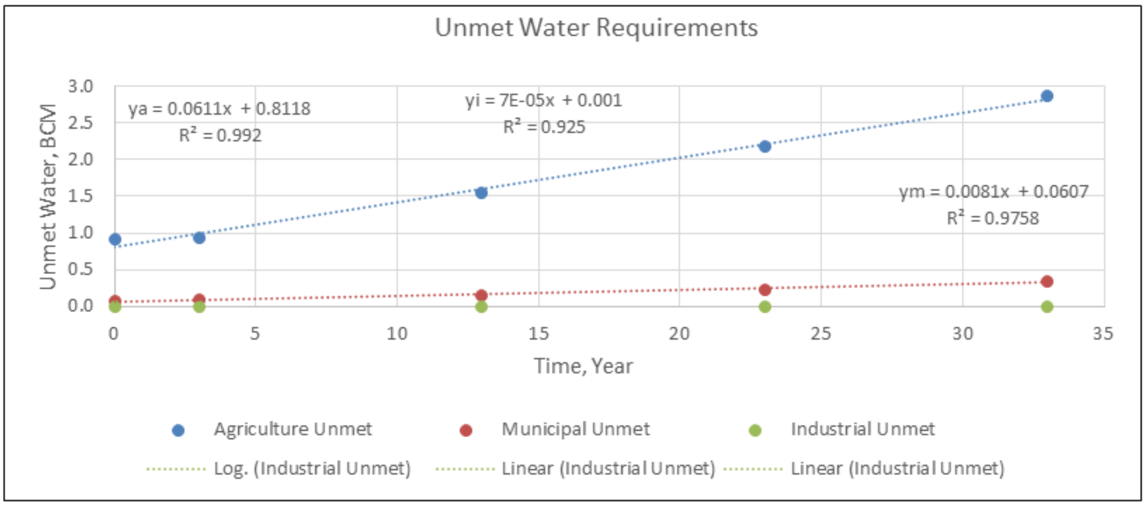


FIGURE 11. Regression Unmet Demand Requirements (Billion Cubic Meter)

4. CONCLUSION

The WEAP model was used in the current study to estimate the state of water resources from 2017 to 2050. The unmet water demand in 2017 was 0.997 BCM and is expected to rise to 3.231 BCM by 2050, with agricultural water reuse and shallow groundwater compensating. Water scarcity means that demand is more than supply, so there will be unmet demand. The current study suggests reducing the total unmet demand in the study area. Recommendations are listed below:

- covering irrigation canals' effective reaches.
- leveling the ground, watering it at night.
- getting rid of aquatic weeds, and maintaining irrigation canal lining.
- converting sugarcane lands to sugar beet fields and preserving the rice area in the former fields of agriculture.
- Implementing regular maintenance.
- Creating an acoustic leak detection system that includes automatic scanning for distribution leaks.
- Propose alternate methods to optimize the water resources system in the future.

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REFERENCES

[1] Pallavi, S.; Yashas, S.R.; Anilkumar, K.M.; Shahmoradi, B.; Shivaraju, H.P. "Comprehensive understanding of urban water supply management: Towards sustainable water-socio-economic-health-environment nexus". Water Resour. Manag. 2021, 35, 315–336.

[2] Abd Ellah, R.G. "Water resources in Egypt and their challenges, Lake Nasser case study. Egypt". J. Aquat. Res. 2020, 46, 1–12.

[3] Amer, S.E.-D.; Arsano, Y.; El-Battahani, A.; Hamad, O.E.-T.; Hefny, M.A.E.-M.; Tamrat, I.; Mason, S.A. "Sustainable development and international cooperation in the Eastern Nile Basin". Aquat. Sci. 2005, 67, 3–14.

[4] Ayyad, S.; Al Zayed, I.S.; Ha, V.T.T.; Ribbe, L. "The performance of satellite-based actual evapotranspiration products and the assessment of irrigation efficiency in Egypt". Water 2019, 11, 1913.

[5] Falkenmark, M.; Widstrand, C. "Population and water resources: A delicate balance". Popul. Bull. 1992, 47, 16.

[6] Hefny, M.; Amer, S.E.-D. "Egypt and the Nile basin. Aquat". Sci. 2005, 67, 42–50. –36.

[7] Karajeh, F.; Oweis, T.; Swelam, A. "Water and Agriculture inEgypt". ICARDA: Beirut, Lebanon, 2013; pp. 1–81.

[8] Luo, P.; Sun, Y.; Wang, S.; Wang, S.; Lyu, J.; Zhou, M.; Nakagami, K.; Takara, K.; Nover, D. "Historical assessment and future sustainability challenges of Egyptian water resources management". J. Clean. Prod. 2020, 263, 121154.

[9] Bhave, A.G.; Bulcock, L.; Dessai, S.; Conway, D.; Jewitt, G.; Dougill, A.J.; Kolusu, S.R.; Mkwambisi, D. "Lake Malawi's threshold behavior: A stakeholder-informed model to simulate sensitivity to climate change". J. Hydrol. 2020, 584, 124671.

[10] Yates, D.; Sieber, J.; Purkey, D.; Huber-Lee, A. "WEAP21—A demand-, priority-, and preference-driven water planning model: Part 1: Model characteristics". Water Int. 2005, 30, 487–500.

[11] Sieber, J.; Purkey, D. "WEAP Water Evaluation and Planning System User Guide". Stockholm Environment Institute, US Center; EU: Somerville, MA, USA, 2015.

[12] Hughes, D.; Mantel, S.; Farinosi, F. "Assessing development and climate variability impacts on water resources in the Zambezi River basin: Initial model calibration, uncertainty issues, and performance". J. Hydrol. Reg. Stud. 2020, 32, 100765.

[13] Tran, H.Q.; Fehér, Z.Z. "Water balance calculation capability of hydrological models". Acta Agrar. Kaposváriensis 2022, 26, 37–53.

[14] Mounir, Z.M.; Ma, C.M.; Amadou, I. "Application of water evaluation and planning (WEAP): A model to assess future water demands in the Niger River". Mod. Appl. Sci. 2011, 5, 38.

[15] Sieber, J.; Purkey, D. "Weap: Water Evaluation and Planning System". User Guide; Stockholm Environment Institute: Somerville, MA, USA, 2011. Available online: http://weap21.org/downloads/WEAP_User_Guide.pdf (accessed on 15 March 2023).

[16] Kahlerras, M.; Meddi, M.; Benabdelmalek, M.; Toumi, S.; Kahlerras, D.; Nouiri, I. "Modeling water supply and demand for effective water management allocation in Mazafran basin (north of Algeria)". Arab. J. Geosci. 2018, 11, 547.

[17] Psomas, A.; Panagopoulos, Y.; Konsta, D.; Mimikou, M. Designing water efficiency measures in a catchment in Greece using WEAP and SWAT models. Procedia Eng. 2016, 162, 269–276.

[18] Alamanos, A.; Latinopoulos, D.; Xenarios, S.; Tziatzios, G.; Mylopoulos, N.; Loukas, A. "Combining hydro-economic and water quality modeling for optimal management of a degraded watershed". J. Hydroinform. 2019, 21, 1118–1129.

[19] Maliehe, M.; Mulungu, D.M. "Assessment of water availability for competing uses using SWAT and WEAP in South Phuthiatsana catchment, Lesotho". Phys. Chem. Earth 2017, 100, 305–316.

[20] Nasrollahi, H.; Shirazizadeh, R.; Shirmohammadi, R.; Pourali, O.; Amidpour, M. "Unraveling the water-energy-food-environment nexus for climate change adaptation in Iran: Urmia Lake Basin case-study". Water 2021, 13, 1282.

[21] Opere, A.; Waswa, R.; Mutua, F. "Assessing the Impacts of Climate Change on Surface Water Resources Using WEAP Model in Narok County, Kenya". Front. Water 2022, 3, 789340.

[22] Najm ABA, Abdulhameed IM, Sulaiman SO. "Water requirements of crops under various kc coefficient approaches by using water evaluation and planning (WEAP)". Int J Des Na Ecodynamics. 2020 Nov;15(5):739–748. doi: 10.18280/ijdne.150516.

[23] Sattler S, Macknick J, Yates D, et al. "Linking electricity and water models to assess electricity choices at water-relevant scales". Environ Res Lett. 2012 Dec;7 (4):045804. doi: 10.1088/1748-9326/7/4/045804.

[24] Simons, G.; Droogers, P.; Contreras, S.; Sieber, J.; Bastiaanssen, W. Virtual "Tracers to Detect Sources of Water and Track Water Reuse across a River Basin". Water 2020, 12, 2315.

[25] Jaramillo, M.F.; Galvis, A.; Escobar, M.; Forni, L.; Purkey, D.; Siebel, J.; Lozano, G.; Rodríguez, C.; Castaño, J.; Sabas, C. "Integración de los modelos WEAP y QUAL2K para la simulación de la calidad agua de fuentes superficiale". Caso de estudio: Cuenca del río La Vieja, Colombia. Aqua-Lac 2016, 8, 14–24.

[26] Ramadan, E.M.; Shalash, O.S.; Fahmy, M.R.; Abdel-Aal, G.M. "Integrated water resource management in Sharkia Governorate, East Nile Delta using numerical evaluation of water management strategies". Alex. Eng. J. 2019, 58, 757–771.

[27] Arab Republic of Egypt, Fayoum Governorate, and National Water Resources Plan Project, Egypt. Fayoum Water Resources Plan; 2012.

[28] Arab Republic of Egypt, Ministry of Water Resources and Irrigation/Planning Sector. Country Strategy: National Water Resources Plan Egypt; 2013

[29] The Second National Water Resources Plan 2017 - 2030 - 2037. Cairo, Egypt: Ministry of Water Resources and Irrigation Arab Republic of Egypt; 2021.

[30] El-Sadek A. "Water use optimisation based on the concept of partial rootzone drying". Ain Shams Eng J. 2014 Mar;5(1):55–62. doi: 10.1016/j.asej. 2013. 09. 004.

[31] Anderson MP, Woessner WW, Hunt RJ. "Applied groundwater modeling". Amsterdam, Netherlands: Elsevier; 2015.