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Future Water Management under Climate Change Conditions in Fayoum, Egypt

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Abstract: Climate change and rising water demand have made the sustainable management of water resources a significant challenge. In this context, simulation models prove valuable in addressing the uncertainty and complexity of water systems by providing stakeholders with optimal solutions. This research introduces a comprehensive management planning framework developed using Water Evaluation and Planning (WEAP) alongside the Water Security Quality-based Index (WSQI) to evaluate the current and future water management systems of Fayoum Governorate under various scenarios. The WEAP model serves as a decision-support tool that assesses major stressors on demand and supply in relation to water availability at the catchment scale. It can depict intricate systems, integrating multiple sectors within a single watershed or a cross-border river system while considering water supply and related demand areas. The model development for the Fayoum base case in 2023 has been calibrated and validated using quantitative statistics. The base case in 2023 and three future scenarios in 2050 (realistic, optimistic, and pessimistic) were evaluated. According to global circulation models, the future scenarios predicted a 25% decrease in Nile flow by 2050. The WSQI is a new ranking system based on both water security and water quality. The reduction in flow aggravated water scarcity and increased reuse. Consequently, the WSQI indicated significant water insecurity. The severity of the water shortage decreased from severe to moderate. The research revealed that adaptation measures could enhance future water availability and safety in Fayoum.

Keywords: Water Evaluation and Planning (WEAP) model, Water Security Quality-based Index (WSQI), Water Resources.

1. INTRODUCTION

Water scarcity poses a major challenge for many nations due to unequal water distribution. Sustainable practices and efficient water use are vital, especially for water-short countries. Sustainable development aims for effective water management and universal access to safe, clean water [1]. Egypt serves as a quintessential example, dealing with a swiftly increasing population and numerous advancements across various sectors [2]. Egypt's national strategy now focuses on efficiently utilizing all water resources to meet sector needs. This involves a transition from local to national management, addressing the impacts of population growth and urbanization, while ensuring sustainable water resource systems align with national and regional objectives [3].

Water resources management involves overseeing both natural and man-made water systems to benefit humans and the environment [4]. The competition for water resources at global, national, and local levels escalates because of population increase, climate alterations, and economic progress [5]. It is essential to establish suitable policies and initiatives that reconcile trade-offs among various water uses while considering social limitations and conflicts [6]. In the last ten years, a cohesive approach to water development has developed, tackling issues concerning demand, water quality, and the safeguarding of ecosystems [7]**.** A necessity in today's world, arising from the swift increase in climate variability and water needs, is the sustainable management of water resources via effective water distribution [8]. Anticipated swift transformations due to urbanization and climate change raise concerns about water resource stress, prompting the development of various hydrological response models to address these concerns effectively [9].

WEAP is a water management model created by the Stockholm Environment Institute. It is a tool for data processing that allows water managers to assess various management scenarios in a region by simulating numerous alterations [10-11]. This instrument in managing water resources features a spatial geodatabase within a geographic information system (GIS). Even though it cannot compute an independent water balance [12]. A wide range of administrators and scholars across the globe have applied WEAP in water resource planning and management [13], there are extensive investigations that have employed the WEAP software [1,14–15]. It is a tool for forecasting and a database tool as well [16]. The WEAP model regulates mass flow in river systems, allowing for both inflows and withdrawals [17]. Every demand location receives a priority score ranging from 1 to 99, with 1 indicating the highest priority. In a water emergency, water distribution is progressively decreased to areas with lower-priority needs [18].

Worldwide, multiple indices for water accessibility and security have been developed to evaluate water systems and gauge levels of water scarcity. Comparable water stress indicators have been designed based on the ratio of water extractions to water resources [19]. All indices disregarded the use of reused or recycled water, a vital resource in Egypt. Alternative indices have been created that focus on consumptive water use instead of total withdrawals [20-21]. This is inappropriate for Egypt since irrigation systems experience significant losses thus, gross withdrawals need to be tackled. Water security encompasses both the amount and the purity of water. In Egypt, repurposing drainage is the fastest and most practical method to connect water supply with demand. This could be an appropriate solution solely if it is of excellent quality. Therefore, a water security index should represent Egypt's characteristics.

This study aimed to address water conflicts using WEAP and WSQI to demonstrate how well this methodology can manage the intricacies of a water system. The model simulated the behaviour of demand and supply components while optimizing the distribution of water to demand locations at each time interval throughout the timeframe in four distinct potential situations. These Scenarios were the current status of 2023 and three future scenarios till 2050 (realistic, optimistic, and pessimistic). Finally, the model performance was assessed using statistics for model assessment.

2. Description of the Study Region

Fayoum Governorate is a natural depression around 90 km southwest of Cairo. It is bordered by desert on every side except the southeast, where it links to the Beni Suef Governorate, as shown in Figure 1. The sole water source for Fayoum is the Bahr Youssef Canal (313 km), a major branch of the Ibrahimia Canal. Fayoum has an irrigated area of 420,000 Feddans (1 Feddan = 0.42008 ha).

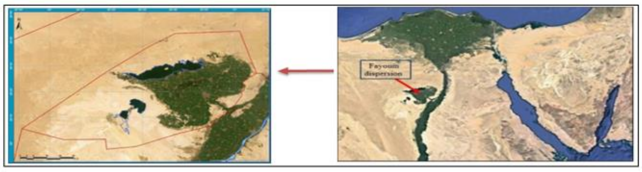

Fig 1: Location of Fayoum, Egypt

Fayoum Governorate was selected for this research because it shares similar characteristics with Egypt in terms of both natural and water resource systems.

The characteristics of the water resources system and water demand in Fayoum are shown in Table 1.

Table 1. The Water system of Fayoum Governorate, MWRI 2023

Water Supply, BCM		Water Demand, BCM		
Bahr Youssef Canal	2.641	Sector	Actual Use	Total Demand
Conventional supply	2.641	Domestic and industrial	0.081	0.339
Shallow groundwater	0.150	Agricultural	1.67	2.9
Reuse of agricultural wastewater	0.448	Agricultural drainage to lakes	0.6	-
Unconventional supply	**0.598**			-
Total water supply	**3.239**	**Total water demand**	**2.351**	**3.239**

The total water demand from households and industries is determined by the combined output of all water treatment facilities and factories. Actual consumption is calculated by multiplying the population by the per capita consumption rate. Agricultural demand is assessed based on the volume of irrigation water released from canals to farmland, while actual agricultural usage is obtained by summing the water

Component	Formula/Expression	Description
Water Demand	$D=P\times U$	Water demand D is calculated as the population P multiplied by per capita usage U.
Supply Availability	$S=Q-E-L$	Water supply $\boldsymbol{S}$ is derived by subtracting evaporation E and losses $\boldsymbol{L}$ from inflow $\boldsymbol{Q}$.
Allocation	$A=\frac{Di}{\sum Di}\times S$	Allocation $\boldsymbol{A}$ for user $\boldsymbol{i}$ is based on their demand proportion relative to total demand.
Environmental Flow	$EF=min(D,F_{required})$	Environmental flow $\boldsymbol{EF}$ ensures a minimum required flow $\boldsymbol{F_{required}}$ is met.
Return Flow	$RF=Q\times Rate$	Return flow $\boldsymbol{RF}$ is a proportion of total inflow $\boldsymbol{Q}$, governed by a defined rate.
Demand Management	$D_{reduced}=D\times(1-R)$	Reduced demand after a management intervention, with $\boldsymbol{R}$ as the reduction rate.
Groundwater Recharge	$R_g=P\times Recharge\ Rate$	Groundwater recharge $\boldsymbol{Rg}$ is derived from precipitation $\boldsymbol{P}$ and recharge efficiency.
Available Water for Irrigation	$AWI=R+GW+RF$	Available water for irrigation $\boldsymbol{AWI}$ includes river flow $\boldsymbol{R}$, groundwater $\boldsymbol{GW}$, and return flows $\boldsymbol{RF}$.
Water Deficit	$WD=ID-AWI$	Water deficit occurs when irrigation demand exceeds available water.

consumption of individual crops, each multiplied by its respective consumption rate. Any remaining water is returned to the system.

3. WEAP Model

3.1. Model Description

WEAP (https://www.weap21.org/) is an easy-to-use paradigm for integrated water resource planning. WEAP offers a comprehensive, flexible, and intuitive framework for analyzing policies. It considers water demand (water usage, recycling, costs, and distribution) as equally significant as the water supply (streamflow, groundwater, and storage). It models usage, consumption, flow, contamination, and release [22]. WEAP begins with the greatest-priority demands and progresses to lesser-priority locations until all demands or resources are satisfied [23]. WEAP has many equations, as shown in Table 2, to account for complicated water demand and supply factors.

Table 2: The Set of Formulas of the WEAP Model

The main equation is:

Storage change (S) = input (I) - output (O) (Eq. 1)

Inputs consist of precipitation, groundwater, and runoff; outputs include municipal, irrigation, industrial, losses, and evaporation; leading to a change in storage.

3.2 Global Circulation Models

This study analysed the Current status in 2023 and three future scenarios projected for 2050, which are realistic, optimistic, and pessimistic. These Future scenarios were modelled with adaptation strategies. [24] identified climate change as the worst predicted outcome for the future scenarios, affecting Nile water flows in Egypt. A rainfall-runoff model was developed to illustrate a variety of future scenarios using five distinct global circulation models (GCMs). Different scenarios were generated based on two scenarios (A2 and B2), as shown in Table 3.

Table 3: Percentage of Future Nile Inflow in the year 2050

Scenario	Baseline	CGCM2	CSIRO2	ECHAM	HadCM3	PCM
A2	100%	75%	92%	107%	97%	100%
B2	100%	81%	88%	111%	96%	114%

Where:

CSIRO2: CSIRO Atmospheric Research, Australia.

HadCM3: Hadley Center for Climate and Prediction and Research, UK.

CGCM2: Meteorological Research Institute, Japan.

ECHAM: Max Planck Institute for Meteorology, Germany.

PCM: United States National Center for Atmospheric Research.

A2: illustrates a world characterized by rapid population increase, sluggish economic progress, and gradual technological advancement.

B2: illustrates a world characterized by a moderate population, economic development, and community-based approaches to sustainability in the economy, society, and environment.

3.3 Water Security Based on Quality Index (WSQI)

The present study used the Water Scarcity Quality Index (WSQI). This index considered the drainage reuse and its impact on the status of water quality. The WSQI is computed as follows:

$$WSQI = \sum[WS \times Fq] \times 100 / WD \quad \text{(Eq. 2)}$$

Where: WS represents water supply, WD represents total water demand, and Fq is the variance factor for water quality utilizing a variety of water quality factors.

Each parameter was turned into a sub-index. The study identified and compared new sub-indices based on Law 48/1982, amended in 2013. The WSQI ranges between 0 and 1. A value of 1 indicates that the water resources are fully sufficient in both quantity and quality to meet water demand. Conversely, any value below 1 signal that there is a shortfall either in the amount of water available, its quality, or both, as shown in Table 4.

Table 4: Indices and Categories of Water Scarcity Quality Values

Index	Category
1	Complete water security
0.99 – 0.90	Low water insecurity
0.89 – 0.85	Medium water insecurity
Less than 0.85	Absolute water insecurity

3.4. Model Data and Assumptions

The Fayoum Governorate faces limited water resources and increasing seasonal water demands, notably during the summer. Quantifying water resources is crucial for developing effective management to mitigate scarcity. WEAP was used to simulate four scenarios, including the Current status in 2023 and three future scenarios till the year 2050. The future possibilities were assessed for water sufficiency. The domestic and industrial sectors prioritized surface water and shallow groundwater to meet their requirements. According to global circulation models, the future scenarios assume a 25% reduction in Nile inflow by 2050.

3.4.1 Base Case

This scenario represents the existing state of the water system in Fayoum Governorate. So, Q_{in} and Q_{base} had identical values of 2.641 BCM, assuming f1=1. Reuse involved the disparity between overall water supply and overall water demand. The water system's efficiency is the ratio between total demand and actual use. The overall water consumption in the agricultural sector (Irr_{total}) reached 6500 m3 per feddan. Agriculture consumes the most water, irrigating 420,000 feddan. The total Agriculture sector is 2.9 BCM. The consumption is 1.67 BCM, derived by summing the individual crops and multiplying them by the rate of consumption. The remaining volume, 1.23 BCM, is returned to the system. Shallow groundwater of 0.15 BCM was reused, and the drainage water reuse was 0.448 BCM. The model predicted 0.598 BCM of drainage water to be utilized to meet the water shortfall.

For both domestic and industrial needs, WEAP consisted of the overall population (4.0234 million), the growth rate of the population (2.2%), and the average water usage of 180 liter daily per person. The total demand for domestic and industrial use was 0.339 BCM, determined by the capacity of all water treatment facilities and manufacturing plants. The actual use was 0.081 BCM, while the leftover amount of 0.258 BCM was sent back to the system

3.4.2 The Realistic Future Scenario

Based on CGCM2 model findings, the accessible water flow in this scenario relies on a decrease in Egypt's customary allotment, resulting in 2 BCM/year.

For agriculture, the efficiency is anticipated to be 60%. The expansion of agricultural lands is projected to rise by 6,000 Feddan annually due to horizontal growth, while urban development is anticipated to reduce it by 1,000 Feddan per year. This scenario involves a total area of 555,000 Feddan (233,100 ha). A good public awareness campaign might result in a 2.25% population growth rate, reaching 6.97 million per capita for home and industrial demands. The initiative also seeks to lower usage to 170 liters/capita/day.

3.4.3 Optimistic Future Scenario

This scenario explored strategies to compensate for the deficit caused by the impacts of climate change. The study additionally evaluated the measures using SMART criteria, which guide the determination of the causes for measure and activity failure or success. Three major supply management projects were expected to be completed, bringing additional flow. The projects were the New Bahr Kota project, Bahr Grza project, and Bahr Wahbi project. It is also anticipated to speed up the execution of irrigation enhancement projects such as using laser-leveling, sprinkler irrigation, and canal lining projects. Consequently, the efficiency was anticipated to rise to 70% from 56% in the Current status. The anticipated agricultural land was projected to rise by 10,000 Feddan annually from plans for horizontal expansion while decreasing 1,000 Feddan annually as a result of urban development. So, the overall farming land utilized in this scenario amounts to 663,000 Feddan (278,460 ha). The Irrigation water per feddan has been reduced to 6,000 m^3/feddan in this scenario.

A public awareness campaign could effectively manage domestic and industrial demand, reducing population growth to 2.16%. The population was 6.389 million, and water consumption was reduced to 160 l/day/capita. Progress was also expected in implementing water-saving technologies in the household and industry sectors, reducing distribution losses to 22% from 30%.

3.4.4 Pessimistic Scenario

The CGCM2 model predicted a decrease in flow in this scenario, relying on a decrease in Egypt's customary allotment, resulting in 1.980 BCM/year. Improvement projects would be implemented very slowly. Sprinklers or drip irrigation would only be used in small areas of new agricultural land. Consequently, the efficiency would equal the current 56%. The expansion of agricultural land was projected to rise by 7,000 Feddan annually.

In the absence of public awareness campaigns, domestic and industrial needs cause a 2.4% population, reaching 7.130 million. The water usage per person was 190 liter daily per person. The allocated water loss was 32% because of the anticipated failure of water-saving technologies in both domestic and industrial areas.

3.5. WEAP Model Development for Fayoum Governorate

The scheme of Fayoum water resources system has been developed, red circles represent the different sectors of the demand, green circles represent indicator to take the flow to the demand, red arrows represent returning flows, green connections indicate the transport of water resources to user sites, and the blue line represents Bahr Youssef (conventional water supply) as shown in Figure 2.

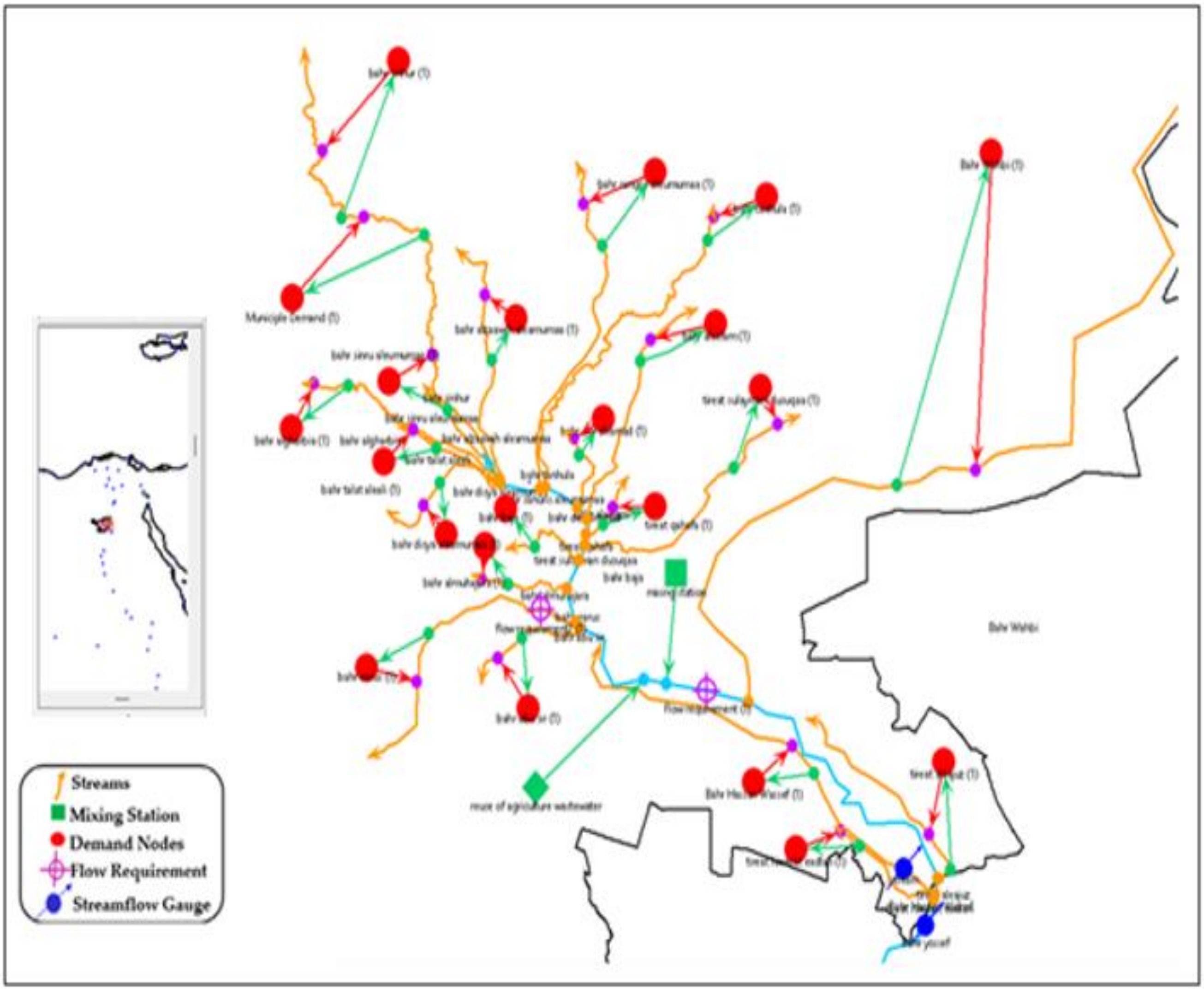

Fig 2: Schematic of the Fayoum in the WEAP

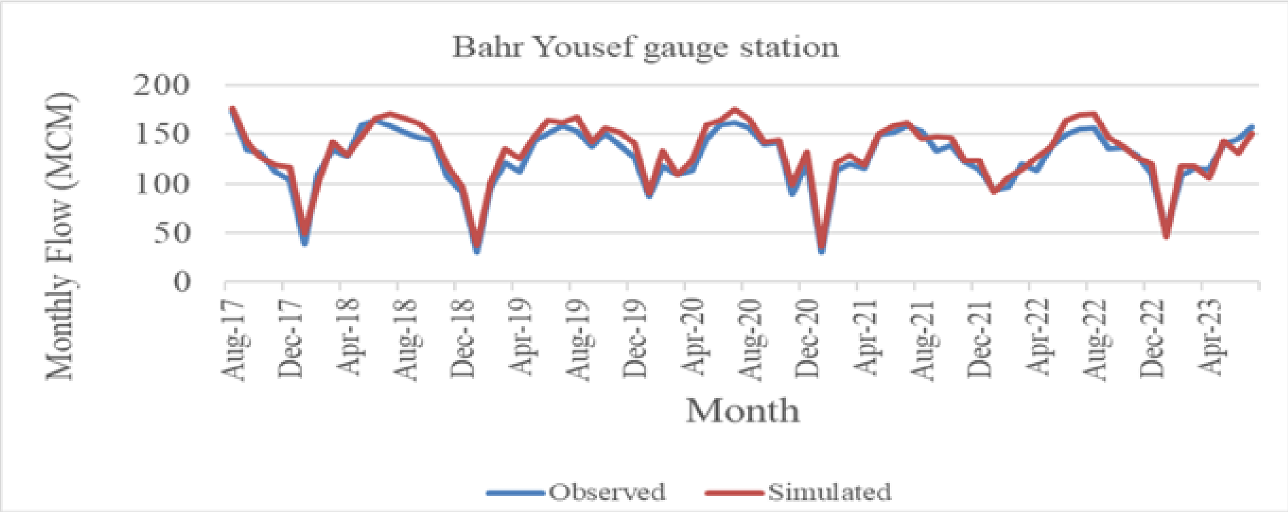

Fig 3: Bahr Yousef Gauge Station

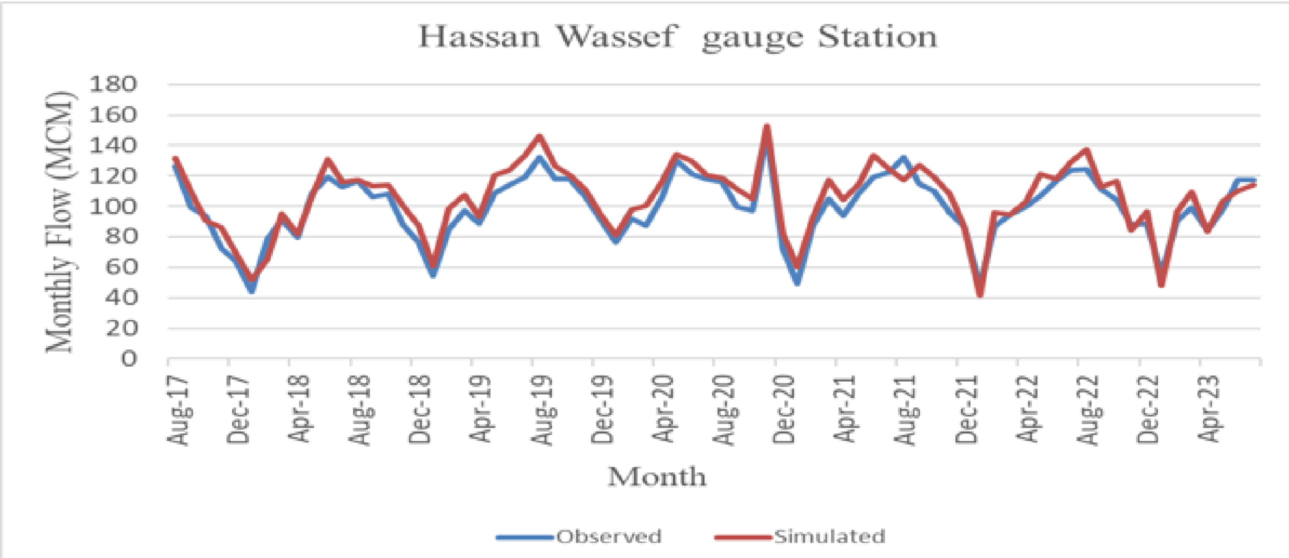

Fig 4: Hassan Wassef gauge station

Table 5: Quantitative Statistics of Simulated and Observed Streamflow

	Bahr Yousef gauge station		**Hassan Wassef gauge station**	
	Calibration	**Validation**	**Calibration**	**Validation**
$\mathbf{R^2}$	0.94	0.96	0.93	0.98
NSE	0.94	0.97	0.93	0.91
PBIAS	0.82%	3.12%	0.42%	7.95%

3.6. Model Calibration and Validation

This work used observed streamflow measurements from two gauging stations in the Fayoum Governorate to calibrate and assess runoff formation parameters from climate inputs. The streamflow stations are Bahr Yousef and Hassan Wassef gauge stations. These gauge stations have suitable streamflow records for calibration and validation. Data sets from 2017–2023 for model calibration and validation were used because of the availability of additional relevant input data. The model was calibrated from 2017 to 2021 and then validated from 2022 to 2023. The calibration of the WEAP was performed using trial and error. For every set of simulated and historical streamflow data from 2017 to 2021, the quantitative statistics (coefficient of determination, or R2; Nash-Sutcliffe efficiency, or NSE; and percent bias, or PBIAS) were computed.

4. Results and Discussion

4.1 Model Performance

For model calibration, streamflow data were collected from two gauging stations situated on the primary canals within the study regions. Figures 3 and 4 illustrate the calibration and validation of the model's hydrology. The measured monthly streamflow at each gauging station was compared with the simulated model values. The quantitative statistics were calculated, indicating good results, as shown in Table 5.

4.2 Base Case Scenario for 2023

According to Figure 5, the total domestic and industrial demand is 0.339 BCM, determined based on the output of all water treatment plants and facilities. The consumption is 0.081 BCM, determined by multiplying the population by the consumption rate. The leftover volume is sent back to the system. The demand in agriculture is 2.9 BCM, calculated as the total irrigation volume discharged from canals to agricultural lands through weirs. The consumption is 1.67 BCM, calculated by adding each crop and multiplying it by its consumption rate. The remaining volume, 1.23 BCM, returns to the system.

According to Figure 5, the overall demand for domestic and industry is 0.339 BCM, calculated based on the output from all water treatment facilities and plants. The real usage is 0.081 BCM, determined by multiplying the population by the consumption rate. The demand in agriculture is 2.9 BCM, calculated as the overall irrigation amount released from canals to farmland. The real consumption is 1.67 BCM, determined by summing each crop and multiplying that total by its consumption rate. The leftover volume of 1.23 BCM goes back to the system.

The mathematical model estimated that the volume of drainage water needed to mitigate the water deficit would be 0.598 BCM. Table 6 presents the WSQI for the baseline and the three alternative scenarios according to the estimated Fq sub-index values for different factors. Although addressing the entire water deficit, the WSQI revealed low water insecurity in the present situation.

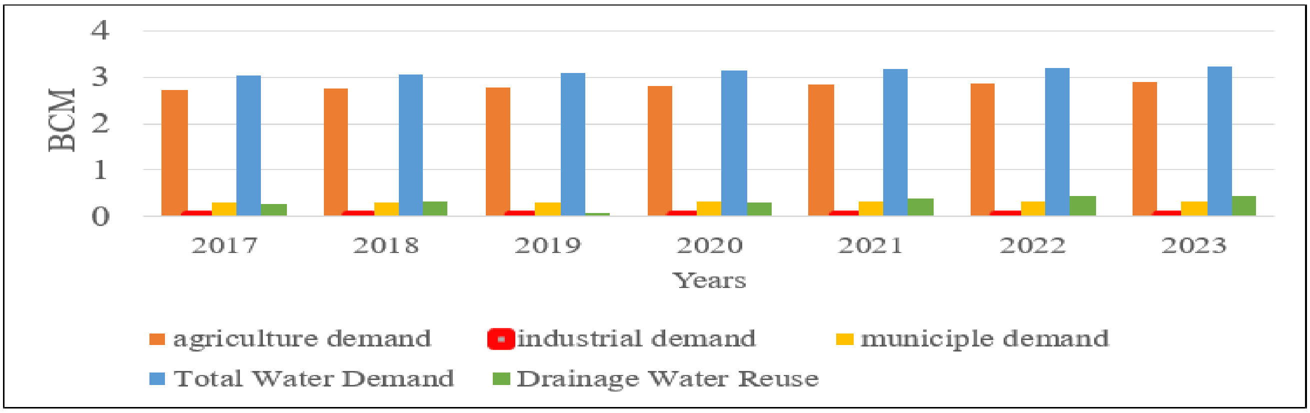

Fig 5: Water Demand and Drainage Water Reuse for Base Case Scenario till 2023

Table 6: WSQI for the Base Case

Case	WS	Fq	Amount of supply	WD	**WSQI**
Base Case	Nile Water	1	2.641	3.239	**0.94**
	Shallow groundwater	0.833	0.150		
	Drainagewater	0.666	0.448		

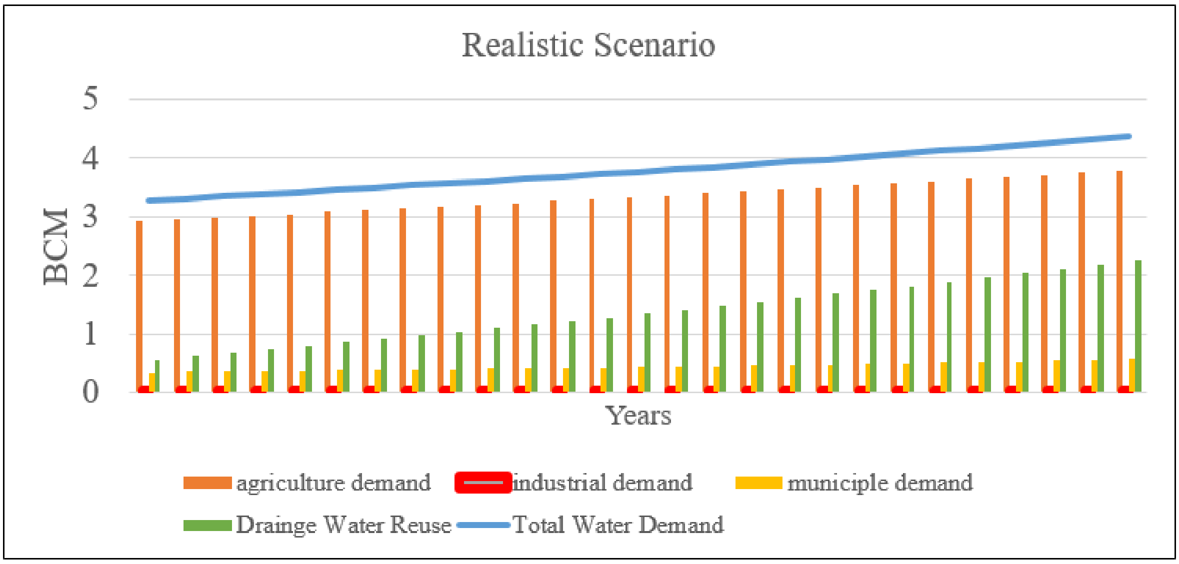

Fig 6: Water Demand and Drainage Water Reuse

Table 7: WSQI for the Realistic Scenario

Scenario	WS	Fq	Amount of supply	WD	**WSQI**
Realistic Scenario	Nile Water	1	2	4.36	**0.82**
	Shallow groundwater	0.833	0.12		
	Drainagewater	0.666	2.252		

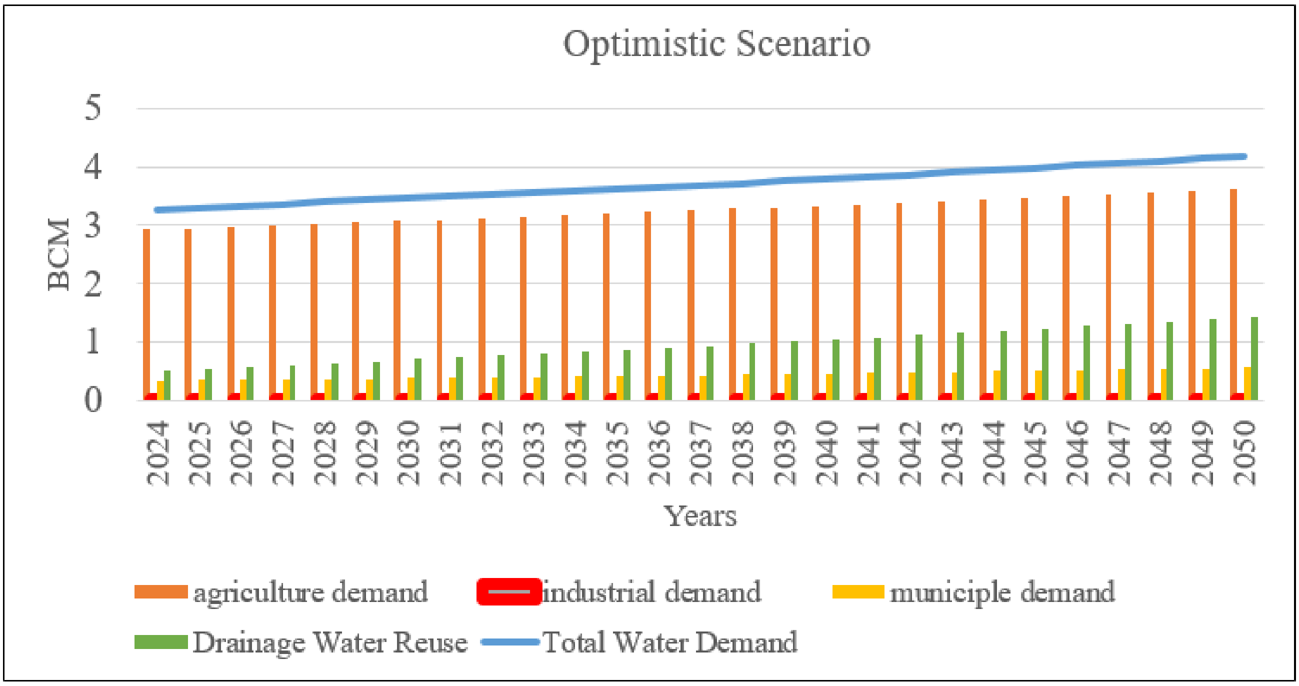

Fig 7: Water Demand and Drainage Water Reuse for the Optimistic Scenario

Table 8: WSQI for the Optimistic Scenario

Scenario	WS	Fq	Amount of supply	WD	**WSQI**
An optimistic scenario	Nile Water	1	2.6	4.18	**0.87**
	Shallow groundwater	0.833	0.13		
	Drainagewater	0.666	1.433		

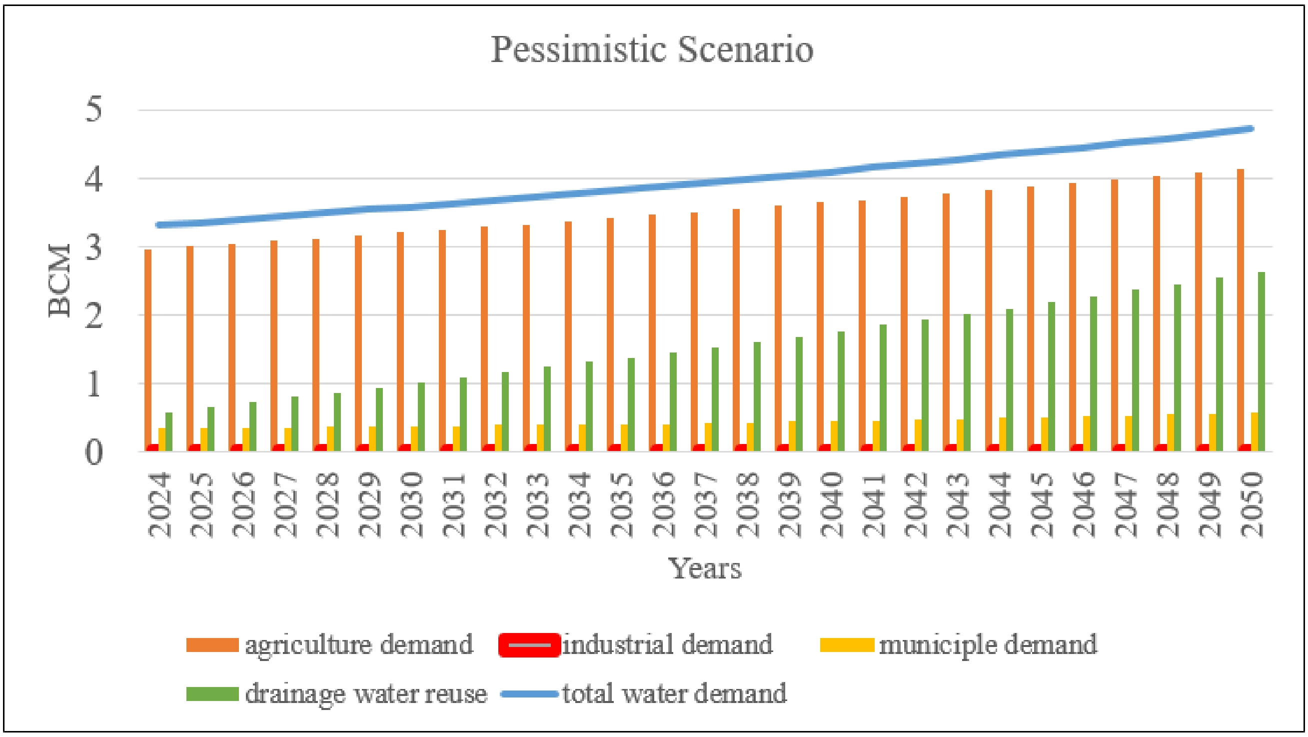

Fig 8: Water Demand and Drainage Water Reuse for the Pessimistic Scenario

Table 9: WSQI for the Pessimistic Scenario

Scenario	WS	Fq	Amount of supply	WD	**WSQI**
Pessimistic scenario	Nile Water	1	1.98	4.717	**0.80**
	Shallow groundwater	0.833	0.1		
	Drainagewater	0.666	2.63		

4.3. The Realistic Future Scenario

WEAP model's projections for the Realistic Scenario in 2050 indicate that conventional water resources would total 2 BCM, whereas total water demand would increase to 4.36 BCM. To bridge the water deficit, 2.252 BCM of drainage water was reused (Figure 6).

Despite fully covering the water shortfall, increasing drainage water reuse led to complete water insecurity in this Scenario, as indicated by the WSQI as shown in Table 7.

4.4. Optimistic Future Scenario

The optimistic scenario included the same Nile flow reduction as previous scenarios incorporates adaptation measures and supply management projects. It integrates DSM and supply-management approaches, lowering total demand sectors from 4.71 BCM to 4.18 BCM while also decreasing per capita water usage. Compared to the "pessimistic" and "optimistic" scenarios, traditional water resources were estimated at 2.6 BCM per year (Figure 7). Overall, with the execution of DSM water conservation, the shortage can be reduced from 2.633 BCM to 1.433 BCM, considering the population and industrial growth.

The water shortfall was addressed by reusing 1.433 BCM of drainage water. Under these conditions, the WSQI reflected medium-level water insecurity. This scenario demonstrated an improved status compared to the pessimistic, as shown in Table 8.

4.5. Pessimistic Scenario

The WEAP model results for the Pessimistic scenario indicate that total conventional water resources would amount to 1.980 BCM. The anticipated water demand amounts to 4.717 BCM. Figure 8 additionally illustrates the anticipated yearly unmet water demand resulting from both a swift population increase and a decline in Egypt's conventional portion of Nile water. The simulation findings indicate that due to a high population growth rate, Fayoum will experience water shortages amounting to 2.633 BCM.

This indicates that increasing population will considerably affect water demand over the long term, requiring the creation of innovative technologies, enhanced collaboration, or improved water management strategies to address the expected deficit. Due to the rise in drainage water reuse, the WSQI indicated total water insecurity in this situation, as shown in Table 9.

4.5. Comparison between Scenarios

The WEAP model results for the scenarios tested in the future encompassed all sectors' consumption, usage and the quantities returned to the system. The WEAP model's outputs and WSQI were utilized for the performance of the Current status and projected future scenarios, as presented in Table 10. Figures 9,10,11 show the water demand of each sector for the three future scenarios, and Figure 12 shows the annual water unmet for all future Scenarios. In the optimistic scenario for 2050, the overall water demand was the least among all scenarios, as shown in Figure 13. Also, the difference between total demand and actual use in this scenario is small. The optimistic scenario adaptation methods increased water efficiency in agriculture, leading to better overall water system conditions.

Table 10: Values of Parameters for the Base Case and Three Future Scenarios

Parameter		Units	Base Case	Realistic	Optimistic	Pessimistic
WS	Total water supply	BCM/year	2.64	2.00	2.60	1.98
WD	Total water demand	BCM/year	3.24	4.36	4.18	4.72
PN	Population number	Million capita	4.234	6.978	6.846	7.130
C_{person}	Per capita consumption rate	Liter/day/capita	180	170	160	190
CWW_{person}	Per capita wastewater discharge	Liter/day/capita	0.56	0.60	0.7	0.56
Irr_{feddan}	Water consumption per Feddan	m^3/Feddan	6500	6300	6000	7000
Distribution loss	Domestic & industrial	%	30	25	22	32
WSQI	Water security quality-based index	-	0.94 Low water insecurity	0.82 Absolute water insecurity	0.87 Medium-water insecurity	0.80 Absolute water insecurity

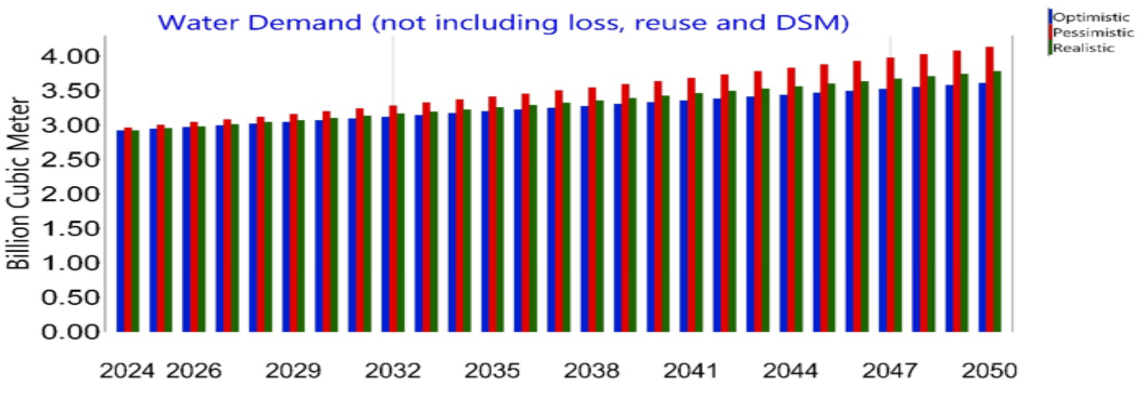

Fig 9: Annual Water Demand of the Agriculture sector for all future Scenarios

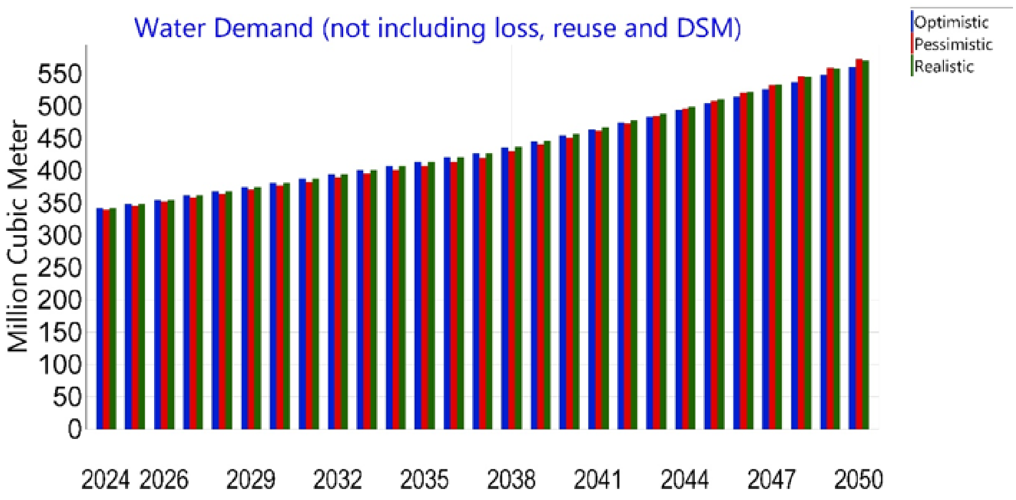

Fig 10: Annual Water Demand of the domestic sector for all future Scenarios

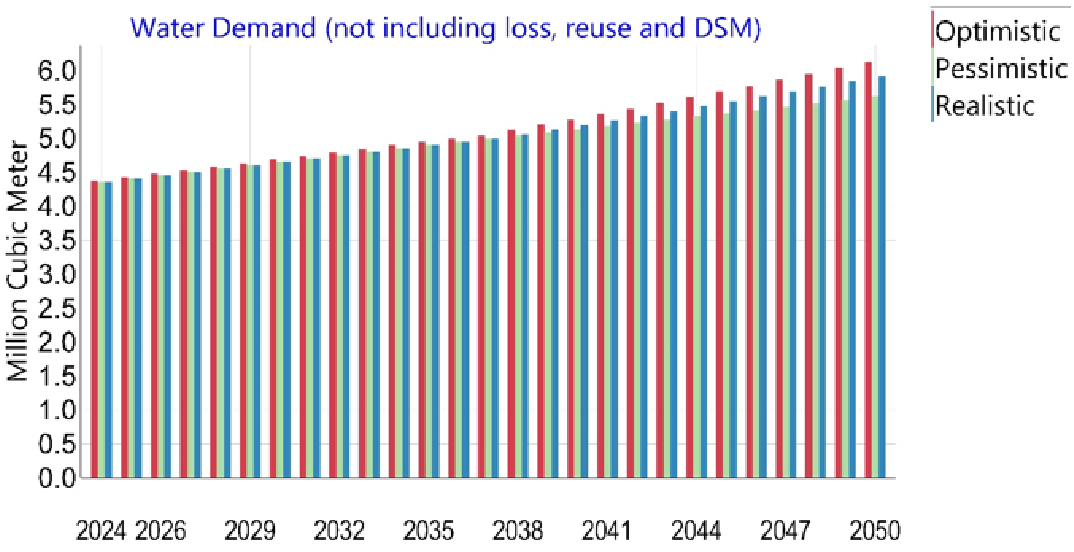

Fig 11: Annual Water Demand of the Industry sector for all future Scenarios

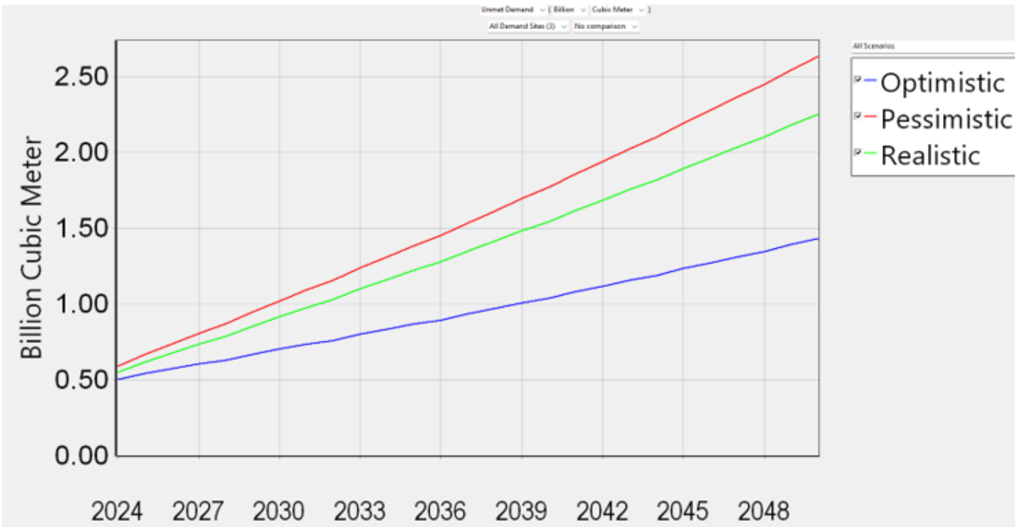

Fig 12: Annual Water unmet for all future Scenarios

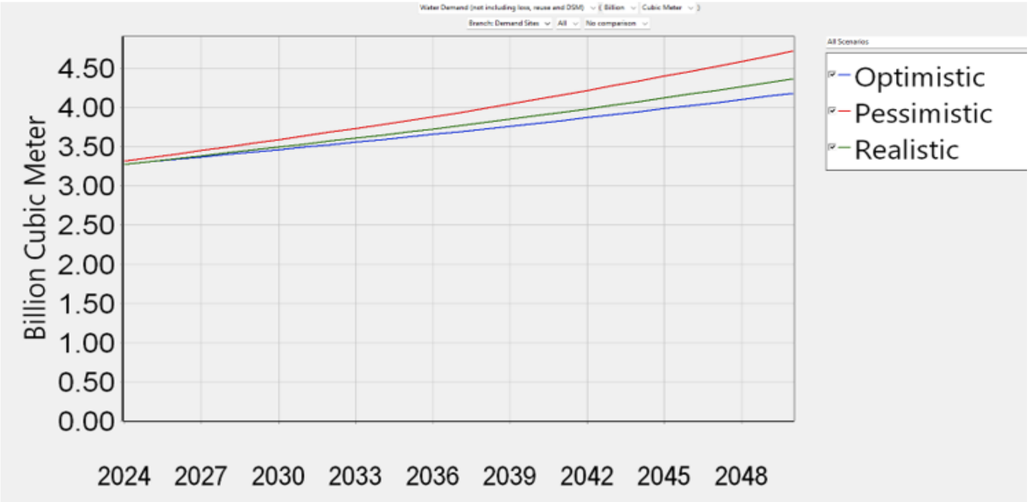

Fig 13: Comparison in water Demand of all future Scenarios

5. Conclusions

This study used WEAP and the WSQI index to assess water systems in Fayoum Governorate. The WEAP proved highly effective in managing available water resources relative to demand. The adjustment and verification of the model were done, achieving scientifically robust and justifiable results by applying quantitative statistics (R^2, NSE, and PBIAS). The model evaluated the current and three future water management systems in Fayoum and served as a unified planning system for decision-makers to address disputes regarding water distribution.

Fayoum Governorate currently faces a water shortage of 0.498 BCM in the year 2023 if drainage water is not reused. The water shortage in 2050 is expected to range between 1.43, 2.25, and 2.63 BCM/year, depending on optimistic, realistic, and pessimistic future scenarios. Medium water insecurity in the optimistic scenario was observed due to high implementation rates of supply and demand management actions, which has a superior WSQI compared to the pessimistic scenario. Projects focused on the supply side, as New Bahr Kota, Bahr Grza, and Bahr Wahbi, are underway to enhance the Nile water supply. Demand-side strategies included controlling rice areas, implementing modern irrigation techniques, improving irrigation network efficiency, conducting public awareness campaigns, and applying water-conserving technologies in public and industrial areas. The optimistic scenario shows the least amount of water deficit and drainage water volume, and the results can assist in optimizing Fayoum's water resource management system. and applying water-conserving technologies in public and industrial areas. The optimistic scenario shows the least amount of water deficit and drainage water volume, and the results can assist in optimizing Fayoum's water resource management system.

The study recommends decreasing water discharges at Lahon Dam between January and June to save 0.87 BCM of surplus water, minimize drainage outputs, and maintain Qarun Lake at secure levels, avoiding floods in neighboring regions. Proposed new projects such as the Al-Kat and Al-Tigan drainage stations, aim to redirect drainage water from Qarun Lake, as outlined by Egypt's Ministry of Water Resources and Irrigation. These systems can lift drainage water into the Bahr El-Bashawat canal, maintaining a safe water level in Qarun Lake and offering irrigation. The research also advises using sprinkler and drip irrigation techniques on new lands to improve water quality evaluations .

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