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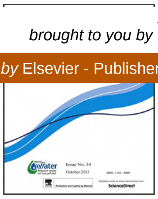

Evaluation of actions for better water supply and demand management in Fayoum, Egypt using RIBASIM

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Abstract

Fayoum Governorate faces many water-related challenges being; compensating the water shortage and controlling the volumes of drainage water effluents into Quarun Lake. There are many actions, based on water resources management approach, which can help overcome these water-related challenges. These actions are classified to developing additional water resources (supply management), and properly using the existing water resources (demand management). This study investigates using the RIBASIM (RIver BAsin SIMulation) model, the most suitable actions for the future. RIBASIM was used to simulate the current condition and evaluate various scenarios in 2017 based on different actions. Three scenarios were formulated being optimistic, moderate, and pessimistic which represent different implementation rates of the tested actions. RIBASIM results indicated a water shortage of 0.59, 1, and 1.85 Billion Cubic Meter (BCM)/year, for the simulated scenarios, respectively. Since Fayoum is a miniature of Egypt with respect to both, the natural and water resources systems, the results of this study can be used as guidelines for optimization of the water resources system in Egypt.

Keywords: RIBASIM; Water supply; Water demand; Water shortage

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1. Introduction

Fayoum Governorate as shown in Figs. 1 and 2, is a large depression in the Egyptian western desert, located 90 km south-west of Cairo. Bahr Youssef Canal is the only water resource for Fayoum, and it is one of the main branches of Ibrahimia Canal. Ibrahimia Canal takes off the water from the Nile River at a distance of 539 km from Aswan High Dam. The length of Bahr Youssef Canal is 313 km and it provides water to four districts: West Menia, Bani-Swif, Fayoum and Giza. Fayoum is the largest district served by Bahr Youssef Canal with 454,700 Feddans (1 Feddan = 4200 m^2) (NWRP/MWRI, 2013). Fayoum Governorate has been selected in this study, because it has similar characteristics of Egypt with respect to both, the natural and water resources systems. Fayoum water shortage is compensated by drainage reuse, which negatively affects the soil and plants. The remaining drainage water flows into Quarun Lake and Rayan

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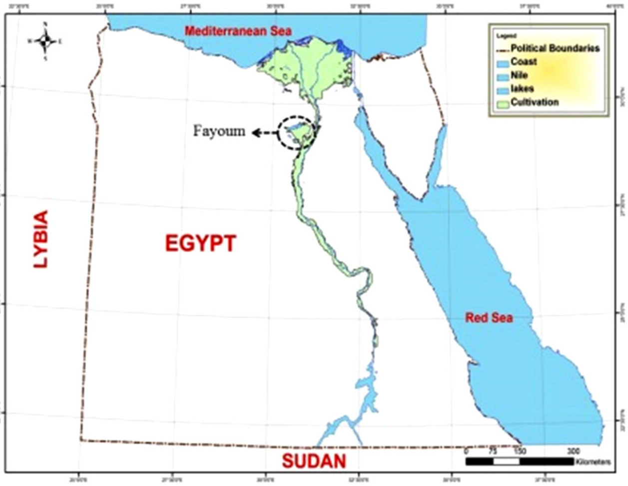

Fig. 1. Location of Fayoum in Egypt (National Water Research, Egypt).

Channel. The excess of drainage water beyond the capacity of Quarun Lake and Rayan Channel floods the surrounding villages, lands, and resorts. This limits horizontal expansion projects, since Fayoum is a closed depression.

This primary goal of this study is to evaluate the influences of different management actions on the quantitative water system performance of Fayoum Governorate in the future. This evaluation enables the interested stakeholders to identify and implement actions for minimizing water shortages and controlling volumes of drainage water effluents into Quarun Lake.

It was found that many researchers locally and worldwide investigated the water resources management actions using numerical models. The Agro-hydrological modeling system (ACRU) has been developed and applied in South Africa for simulation of land use/management influences on water resources demand and supply (Schulze and Smithers, 2004). Water evolution and planning (WEAP) model has been developed by Stockholm environment Institute to evaluate planning issues related to water resources for both municipal and agricultural systems including: sector demand analyses, water conservation, water rights and allocation priorities, stream flow simulation, reservoir operation, ecosystem requirements and project cost–benefit analyses. The model has been applied to assess scenarios of water resource development in the Pangani Catchment in Tanzania (Arranz and McCartney, 2007).

The Nile Decision support Tool (Nile DST) has been developed as part of the FAO Nile Basin Water Resources project to objectively assess the benefits and tradeoffs associated with various water development strategies. The Nile

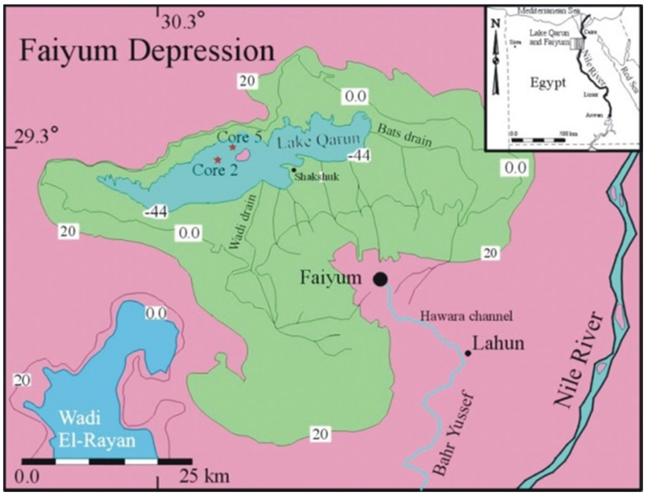

Fig. 2. Fayoum depression, Lake Quarun and the surrounding deserts in 2012.

DST comprises six main components: databases, river simulation and management agricultural planning, hydrologic modeling, remote sensing and user-model interface (Georgakakos, 2006).

RIBASIM was applied in more than 20 countries to support the process of water resources planning. Van der Krogt and Verhaeghe (2001) used the RIBASIM Model to describe the effects of changes in the farming system on the regional water balance for three river basins via the Jratunseluna, Serayu and Cidurian Basins, Indonesia. Van der Krogt (2010) applied the RIBASIM model to clarify the importance of the natural system for the socioeconomic situation, and also to develop the Sistan Basin, Iran. Through the Hydrology Project at Water Resources Department Government of Maharashtra, India, RIBASIM model was used to predict the water shortages in the Godavari river basin, India for years 2015 and 2020, and to develop decisions for minimizing deficit.

The National Water Resources Plan in Egypt (NWRP) developed a Decision Support System (DSS) based on the RIBASIM7 model. The author was involved in developing the NWRP-DSS. RIBASIM7 of NWRP-DSS provided a full picture of the current water balance in Egypt at Aswan High Dam. But, it did not show the future situations according to expected developments and different management measures.

2. Methodology

2.1. The study area

Several visits were carried out to Fayoum in order to perceive a complete data picture of the study area. The visits included two site locations being; Quarun lake, and one of the new agricultural projects in the surrounding desert eastern of Fayoum depression. The visits also included the Water Resources Unit, Fayoum irrigation directorate, Fayoum agricultural directorate, the holding company for water and wastewater treatment at Fayoum. The collected data were the population number and population growth, total agricultural area and cropping patterns, total agricultural area of new lands in the surrounding deserts and the applied irrigation systems, capacities of all drinking water plants, capacities of primary and secondary wastewater treatment plants, number of factories and total industrial demand, and the total irrigation volumes discharged into agricultural lands.

Based on the site visits and the assembled data, Fayoum water balance was developed for water resources analysis (Fig. 3). The water balance is an accounting of the inputs and outputs. It also represents the water consumptions for all sectors, and the volumes which return back to the system. Fayoum water balance could be described, as follows:

- The major inputs are the discharge from Bahr Youssef Canal via Lahon Dam, rainfall, and shallow groundwater;
- The outputs are evaporation, water uses for different sectors and drainage to Quarun Lake and Rayan Valley;

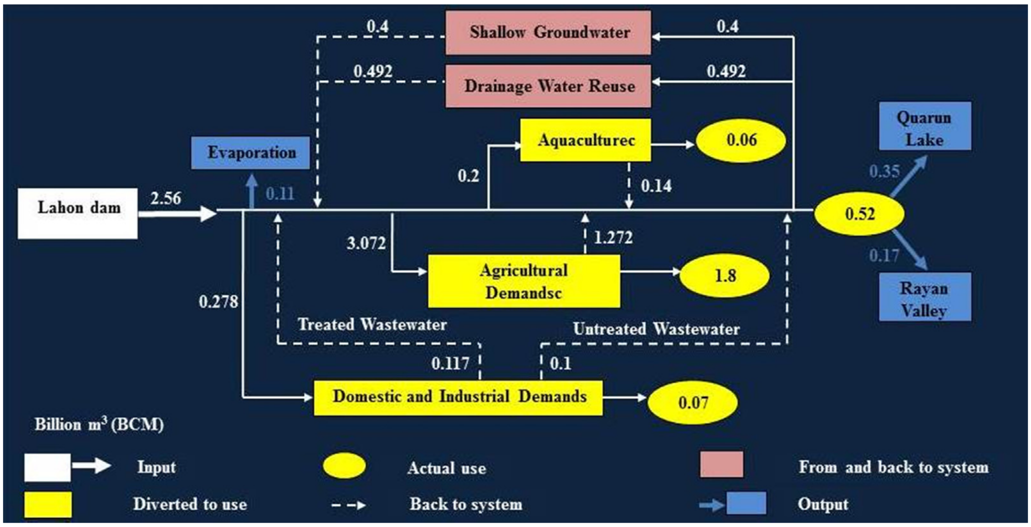

Fig. 3. Water balance in Fayoum in 2011.

- The total domestic and industrial demand is 0.287 BCM, which is obtained as the total capacity of all drinking water plants and factories. The actual use is only 0.07 BCM, which is calculated as population number multiplied by consumption rate. The remaining volume returns back to the system as treated wastewater (0.117 BCM) and untreated wastewater (0.1 BCM).

The agricultural demand is 3.072 BCM, which is obtained as the total irrigation volumes discharged from canals to agricultural lands via weirs. The actual consumption is 1.8 BCM, which is calculated as the sum of each crop multiplied by its consumption rate. The remaining volume of 1.272 BCM returns back to the system.

The geomorphologic features of Fayoum depression are Ecocene limestone and marls, surrounded on all sides by high rocky walls. These formations generally contain no groundwater aquifers. There is also the Nubian sandstone aquifer whose depth is too great to allow exploitation. Thus, groundwater is unreliable source in Fayoum. The annual rainfall averages 14 mm, and is rather irregular in time and place. Thus, rainfall is very scanty and cannot be a reliable source of water. The soil analyses of Fayoum Governorate show that the soil texture is clay in Fayoum depression, and sandy loam in the desert surrounding the depression (Shendi et al., 2006).

- Based on the site visits, assembled data and water balance analyses, the challenges facing the study area could be described, as follows:
- The water availability is limited, since Fayoum is a closed water depression with only one limited source of water from Bahr Youssef Canal with very scanty rainfall, and no reliable groundwater.
- The drainage water is the limiting factor in the water balance which controls the irrigation water requirements. This is attributed to the fact that Quarun Lake is of limited capacity that receives about 67% of the total drainage water (i.e. 0.35 BCM/year). Above this amount, the lake floods over the surrounding villages, lands, and resorts which limits the expansion of irrigated agriculture.
- The soils of the new agricultural lands in the desert areas surrounding Fayoum depression have a low water storage capacity and a high infiltration rate due to its sandy loam texture. In addition, old irrigation methods are applied in these lands. This means that the field application loss is high in these new agricultural lands.

From the above, the main problem facing Fayoum is the excess of drainage water beyond the capacity of Quarun Lake. This deteriorates the soil and plants' productivity. If the drainage water into Quarun Lake exceeds 0.35 BCM/year, the water level rises in the lake and floods the surrounding villages, lands, and resorts. The last accident recorded was in November 2012, when the lake flooded over the agricultural lands and houses of two villages being Shakshook and Shamata located on the western coast of the lake.

2.2. *RIBASIM description and model capability*

It was decided to rely on RIBASIM model in order to evaluate different management actions that can contribute in minimizing the water shortage and reducing the drainage water effluent to Quarun Lake. RIBASIM is a generic model package for simulating the behavior of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool which links the hydrological water inputs at various locations with the specific water-users in the basin.

The structure of RIBASIM model is based on an integrated framework with a user-friendly, graphically oriented interface. The main RIBASIM user interface is a flow diagram representing the tasks involved in carrying out a simulation analysis is used to assist the user through the analysis from data entry to the evaluation of the results. As for the capabilities of RIBASIM, it can model various future and potential situations and system configurations by setting various scenarios and management actions (Van der Krogt, 2010).

2.3. *Schematization of RIBASIM*

The schematization of RIBASIM reproduces all necessary features of a basin by nodes connected by links. Van der Krogt (2010) defined the model schematization as a translation and a simplification of the real world into a format which allows the actual simulation. The result of the schematization is a network of nodes and links which reflects the spatial relationships between the elements of the basin, and the data characterizing those nodes and links. The nodes represent reservoirs, dams, weirs, pumps, hydro-power stations, water users, inflows, man-made and natural bifurcations, intake structures, and natural lakes. The links transport water between the different nodes.

2.4. Schematization of water system of Fayoum Governorate

For Fayoum Governorate, groundwater was not modeled in the schematization. This is because deep ground water is rarely available and irrigates only 0.15% of the total agricultural area due to the geologic nature of the place. Shallow groundwater is directly used by the local water users for irrigation, so it is considered as a reuse of drainage water. All the necessary features of Fayoum water system were reproduced by 11 nodes and 13 links.

The "Advanced IRrigation (AIR) node" reflected the water demand for irrigation. Only one "Advanced irrigation node" was located for Fayoum. The water demand was computed based on crop characteristics and crop plans. The crop characteristics were stored in the fixed data base of RIBASIM. However, the crop plan was generated by the Agricultural Sector Model for Egypt (ASME). The ASME model can be used to estimate the annual crop plan for a specific area (MWRI, 2001). Therefore, the ASME model was also used in this study to compute the annual crop plan (list of cultivations), which was developed as direct inputs to RIBASIM. Both RIBASIM and ASME used the same 31 crops. The crop characteristics in the fixed data base of RIBASIM7 were described as crop plan and crop characteristics, hydrological input, soil characteristics, topography and lay-out of the irrigation area, operation and irrigation management, and potential crop yield and production costs, and actual field water balance.

The "Public Water Supply (PWS) node" represented the domestic, municipal and industrial demands. For domestic demand, the population and consumption rates were input values to RIBASIM7. The domestic demand in Fayoum was divided into two PWS nodes. One node represented the demand from Bahr Youssef Canal and its branches while the second node represented the demand from Bahr Hassan Wasef Canal and its branches. Bahr Hassan-Wasef is a main canal taking its water from Bahr Youssef Canal. Table 2 presents the population number and the consumption rate for both PWS nodes. The industrial demand was also represented by one PWS node with an explicit demand of 0.63 m^3/s.

There was one main diversion node which reflected the Lahon Dam, where the water entered Fayoum Governorate from Bahr Youssef Canal. There were other three diversion nodes representing the water diverting into one irrigation node (AIR) and two domestic (PWS) nodes.

There was only one recording node to represent the flow gauging station for Fayoum network. The recording node followed Lahon Dam diversion node was used for comparison between simulated demand and monitored flow (supply) at Lahon Dam. One terminal node was available in the schematization representing the downstream boundary of the system where water leaves the network. One confluence node was allocated in the schematization to represent the location where various outflows of different nodes join the system.

There were four diversion links in the schematization being; one diverted flow from Lahon Dam, one diverted irrigation flow, and two diverted flows for domestic demands. In addition, there were eight surface water flow links used to link between any different nodes, except those links following diversion nodes.

2.5. Simulated scenarios

The strategy of Fayoum Water Resources Plan-2017 is a coherent combination of actions with respect to water quantity and quality. The current study only focused on actions dealing with water quantity including developing new water resources (supply management), and properly using existing water resources (demand management). It is to be noted that the sensitivity analysis of actions in future scenarios requires modifications of some input data in RIBASIM. Table 3 shows the input values for the current scenario and the future scenarios being optimistic, moderate, and pessimistic. The descriptions of all scenarios are given in the following sections.

2.5.1. Current scenario

Nile River is the only source of water from Bahr Youssef canal with 2.56 BCM/year. Due to the geomorphologic and climatic features of Fayoum depression as explained in Section 2.1, the groundwater and rainfall are is unreliable sources.

Concerning agricultural demands, agriculture is the largest consumer of water which irrigates 407,544 Feddan (169,810 ha) in Fayoum. The irrigation efficiency for the whole agricultural network is 56%, calculated as the ratio of the amount reaching the root zone of the plants (estimated consumption) to the amount diverted to the system (actual

Table 1
Water balance in Fayoum in the year 2011.

Water supply				Water demand		
Conventional resources		Unconventional resources		Sector	Estimated consumption (BCM/year)	Actual use with losses (BCM/year)
Water Resources	Volume (BCM/year)	Water Resources	Volume (BCM/year)	Municipal and industry	0.07	0.287
		Shallow Groundwater	0.4	Irrigation	1.8	3.072
Lahon Dam	2.56	Drainage Water Reuse	0.492	Aquaculture	0.06	0.2
		Wastewater	0.217	Evaporation	0.11	0.11
Total	2.56	Total	1.109	Drainage to Quarun lake	0.35	
				Drainage to Rayan Valley	0.17	
Total	3.669	Total	3.669	Total	2.56	

Table 2
PWS nodes for domestic demand in Fayoum.

Node name	Description	Population (–)	Unit demand (l/capita/day)
Dom_FAY_FAY_Fayoum1	From Bahr Youssef canal and its branches serving the middle and the northern east parts of Fayoum	2,086,350	175
Dom_FAY_FAY_Fayoum2	From Bahr HassanWasef canal and its branches serving the southern and western parts	460,532	175

use with losses). The irrigation efficiency is subdivided into field application, distribution, and conveyance efficiencies. Therefore, the values of field application, distribution, and conveyance efficiencies for the current scenario in RIBASIM were assumed to be 56%.

Concerning domestic and industrial demands, inputs in RIBASIM7 are the total population number (2.781 million capita), population growth rate (2.42%), average consumption use of water for rural and urban population (195 l/capita/day) and distribution water loss (30%).

2.5.2. *Future scenarios*

Three scenarios were formulated optimistic, moderate, and pessimistic to represent different rates of implementation of the tested actions in the year 2017. The tested actions were classified under two main pillars which are: (i) developing additional water resources (supply management), and (ii) properly using existing water resources (demand management).

2.5.2.1. Optimistic scenario. Regarding the supply management, three main projects are expected to be fully implemented which will provide additional water quantities from the Nile river to Fayoum Governorate. The three projects are as following:

(i) New Bahr Kouta Project which takes off an amount of 0.36 BCM/year from Ibrahimia canal from a distance of 25 km before Lahon dam to feed Bahr Kouta canal;
(ii) Bahr Gerza Project which intakes an amount of 0.019 BCM/year directly from the Nile river via pipes that enter Fayoum Governorate at Gerza village and then to Tamia district;
(iii) Bahr Wahby Project which supplies an amount of 0.18 BCM/year from Ibrahimia canal to Bahr Wahby canal.

Therefore, the water amount of the Nile River to Fayoum Governorate was 3.12 BCM/year in this scenario.

For agricultural demand management, more efforts are expected toward decreasing the areas of crops having high consumption rates of water such as rice. It is also expected to accelerate the implementation rates of irrigation improvement projects (IIP). The projects include actions for increasing the irrigation network efficiency such as installing automatic downstream water level control gates, and maintenance of branch and distributary Canals. The irrigation methods in most of new agricultural lands in Fayoum desert areas with sandy and loam sandy soils are old methods. This is not in agreement with Brouwer et al. (1988), which recommended that the sandy and loam sandy soils need frequent but modern small irrigation applications such as sprinkler or drip irrigation. Therefore, a wide application of such irrigation techniques is expected in this scenario, which improves the field application efficiency.

As a result, the water use efficiency for the whole agricultural network is expected to increase up to 70%. Therefore, the values of field application, distribution, and conveyance efficiencies in RIBASIM were modified to 70% in the optimistic scenario instead of 56% in the current situation. It is also assumed that growth rate of agricultural lands will increase by 11,000 Feddan/year due to horizontal expansion plans and will decrease by 0.5 Feddan/year due to urbanization. As a result, the total agricultural area is to 575,000 Feddan (239,400 ha) as an input in this scenario.

For domestic and industrial demand management, a successful public awareness campaign could reduce population growth rate to 2.1%. This makes the population number 3.26 million capita in this scenario. The campaign could also reduce the water consumption rate to 185 l/capita/day. It is also expected to achieve a progress in application of water saving technologies in municipal and industrial sectors. This could make a water distribution loss reduction by 20%.

Table 3
Tested actions and their corresponding inputs in RIBASIM7.

Tested actions	Modified inputs in RIBASIM7	Current scenario (actual)	Optimistic scenario (assumed)	Moderate scenario (assumed)	Pessimistic scenario (assumed)
Increase fresh water availability from Nile at Lahon Dam	Time series monitored flow (10-day step) in the TMS file[a]	10-day flow (m^3/s) in the TMS file of current situation with a sum of 2.56 BCM/year	3.119 BCM/year is distributed over 10-day values (m^3/s) with same patterns of the current TMS file	2.777 BCM/year is distributed over 10-day values (m^3/s) with same patterns of the current TMS file	2.579 BCM/year is distributed over 10-day values (m^3/s) with same patterns of the current TMS file
Continue improvement irrigation project	Distribution efficiency in advanced irrigation node	56%	70%	63%	56%
Maintenance of canals with high losses	Conveyance efficiency in advanced irrigation node	56%	70%	63%	56%
Apply modern irrigation techniques	Field application efficiency in advanced irrigation node	56%	70%	63%	56%
Make horizontal agricultural expansions	Total area in the advanced irrigation node	512,000 Feddan (215,040 ha)	570,000 Feddan (239,400 ha)	560,000 Feddan (235,200 ha)	545,000 Feddan (228,900 ha)
Make campaigns to reduce average of rural and urban consumption	Demand in the public water supply node	195 l/capita/day	185 l/capita/day	190 l/capita/day	195 l/capita/day
Promote domestic water saving technologies	Distribution loss in public water supply node	30%	20%	25%	30%

[a] TMS: time series file producing monitored (supply) flow at the recording node of Lahon dam.

2.5.2.2. Moderate scenario. For supply side, Bahr Gerza and Bahr Wahby Projects are expected to be completely implemented. However, New Bahr Kouta Project is assumed to provide only half of the targeted quantity due to the conflict with the neighboring governorates around Bahr Youssef Canal (the source of the project). Therefore, the water amount of the Nile River to Fayoum Governorate is 3.12 BCM/year in this scenario.

For agricultural demand management, areas of rice and other crops having high consumption rates of water are expected to be less than them in the optimistic scenario. It is also expected to have moderate implementation rates of irrigation improvement projects (IIP). Application of sprinkler or drip irrigation methods is also planned in the new agricultural lands but in smaller areas than those in the optimistic scenario. As a result, the water use efficiency for the whole agricultural network is expected to increase up to 63%.

Therefore, the values of field application, distribution, and conveyance efficiencies in RIBASIM are modified to 63%. It is assumed that growth rate of agricultural lands will increase only by 9000 Feddan/year due to horizontal expansions and will decrease by 1000 Feddan/year due to urbanization. Hence, the total area is 560,000 Feddan (235,200 ha) in this scenario.

For domestic and industrial demands, a successful public awareness campaign could make the population growth rate to be 2.25% which makes the population number becomes 3.3 million capita. The campaign also reduces the consumption to 190 l/day/capita. The distribution water loss is assumed to decrease to 25% as a result of a little progress in application of water saving technologies.

2.5.2.3. Pessimistic scenario. Only Bahr Gerza project is expected to be fully implemented. This project will add extra amount of Nile river water, which will raise the total amount to 2.579 BCM/year. It is assumed in this scenario that the other planned projects will stop due to conflicts with neighboring governorates or due to financial obstacles.

For agricultural demands, no success is expected in decreasing rice areas and other crops having high consumption rates of water. Very low implementation rates of irrigation improvement projects (IIP) are expected. Application of sprinkler or drip irrigation methods in the new agricultural lands will remain limited in small areas. As a result, the water use efficiency for the whole agricultural network will be equal to the current efficiency (56%).

Therefore, the values of field application, distribution, and conveyance efficiencies in RIBASIM7 are 56%. It is also assumed that growth rate of agricultural lands to increase by 7000 Feddan/year due to horizontal expansions and decrease by 1500 Feddan/year due to the urbanization. Therefore, the total agricultural area is 545,000 Feddan (228,900 ha).

For domestic and industrial demands, the absence of public awareness campaign makes the population growth rate 2.4% resulting in 3.325 million capita. The consumption use of water remained 195 l/day/capita. The distribution water loss is assumed to remain 30% as a result of expected failure in application of water saving technologies for municipal and industrial sectors.

3. Results

Data was applied to the above scenarios and results were obtained. The results are analyzed and represented. This section is devoted to present the results. For the verification of the base case 2011, Fig. 4 shows the simulated water demand for Fayoum at the recording node of Lahon dam every 10-day time step along year 2011 by RIBASIM. It also shows the actual measured demand obtained from Fayoum Water Resources Plan, in which the author participated in preparation.

The accuracy of the numerical model predictions for the current scenario was measured in terms of the Root-mean-square deviation (RMSD), which was calculated as follows:

$$\mathrm{RMSD} = \sqrt{\frac{\sum_{i=1}^{n}(\hat{Y}_l - Y_i)}{n}} \tag{1}$$

where $\hat{Y}_l$ is a vector of a number (n) of simulated values, Y_i is the vector of a number (n) of actual values.

The RMSD value was 29.5, which was statistically considered low. This value indicated that the RIBASIM model can perform well in the evaluation process of the three future scenarios (optimistic, moderate, and pessimistic).

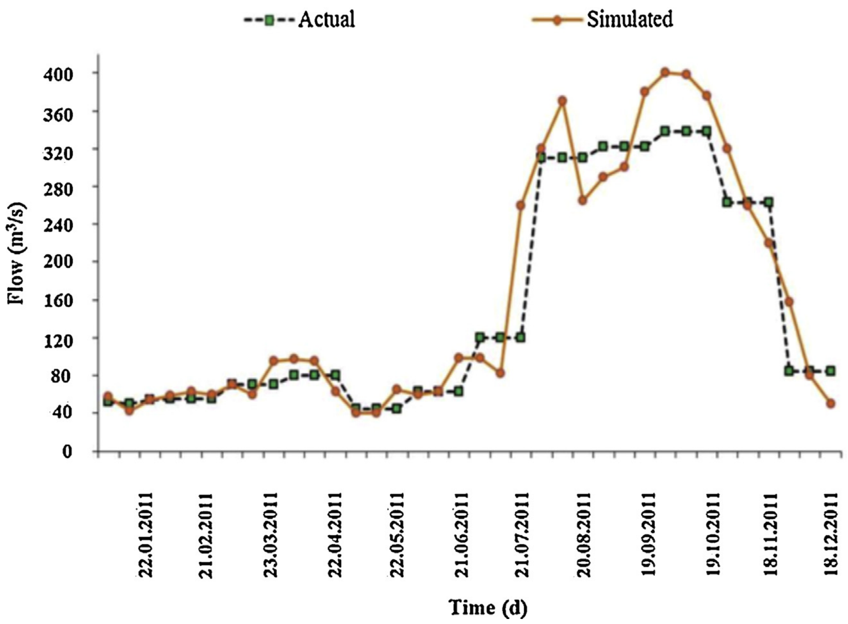

Fig. 4. Actual (measured) and simulated (RIBASIM7) demand in Fayoum during year 2011.

It was also noticed that the total simulated demand was 3.91 BCM/year which was obtained as the area under the demand curve in Fig. 4. However, the total actual demand was 3.669 BCM/year, as estimated from the collected data from Fayoum visits and the water balance in Table 1.

At the recording node of Lahon dam, the water supply values were entered as inputs in the 10-day time series (TMS) file, and the water demand values were simulated. When the yearly water supply was changed due to planned projects, a new TMS file was developed with new 10-day values distributed as same ratios as patterns of the current file. Fig. 5 shows both, the water supply and simulated demand at Lahon dam distributed over 10-day time steps. Based

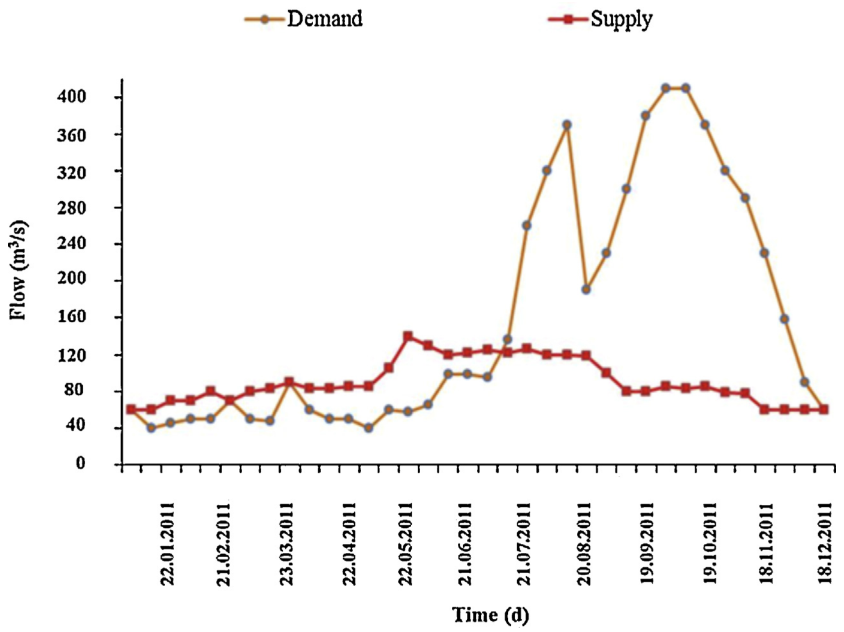

Fig. 5. Simulated demands and supply in Fayoum during the year 2011 without the reuse of drainage water or wastewater.

Table 4
Water supply and simulated demands (m^3/s) every 10-day time steps for the three scenarios during the year 2017.

Pessimistic scenario	Moderate scenario		Optimistic scenario		Time	
	Supply (m^3/s)	Demand (m^3/s)	Supply (m^3/s)	Demand (m^3/s)	Supply (m^3/s)	Demand (m^3/s)
20	20	40	30	48	20	01.01.2017
22	15	43	25	49	20	11.01.2017
25	18	63	29	60	20	22.01.2017
27	20	86	32	65	29	01.02.2017
32	22	70	37	80	30	11.02.2017
27	21	60	39	65	30	21.02.2017
33	25	72	40	83	35	02.03.2017
35	24	77	40	85	35	12.03.2017
39	38	88	69	95	45	23.03.2017
36	40	77	60	85	50	01.04.2017
38	40	80	69	89	45	11.04.2017
39	20	82	30	90	19	22.04.2017
40	15	85	22	93	20	01.05.2017
45	15	98	23	100	19	11.05.2017
62	25	130	40	155	33	22.05.2017
58	20	128	36	140	30	01.06.2017
55	23	120	40	135	30	11.06.2017
58	40	122	62	137	50	21.06.2017
59	41	125	62	140	50	01.07.2017
57	38	122	58	137	45	11.07.2017
59	130	129	200	145	145	21.07.2017
50	162	110	35	125	175	01.08.2017
52	188	112	270	127	205	11.08.2017
49	90	108	130	120	100	21.08.2017
40	112	88	165	95	125	31.08.2017
30	150	68	220	75	165	10.09.2017
30	200	67	283	73	210	19.09.2017
33	215	72	310	82	232	29.09.2017
32	215	70	310	80	232	09.10.2017
35	190	79	277	98	205	19.10.2017
30	160	77	35	75	175	29.10.2017
29	140	75	207	70	145	09.11.2017
22	109	50	160	55	115	18.11.2017
20	72	40	104	49	80	28.11.2017
19	30	39	47	45	35	08.12.2017
20	15	40	283	47	19	18.12.2017

on the difference between the supply and demand, the current water shortage was 1.6 BCM/year without the reuse of drainage water or wastewater. It was observable, that the water shortage was accumulated in the period between July and November.

As for future scenarios, the water shortages were also presented without the reuse of drainage water or wastewater (Table 4). The yearly water shortages in the optimistic scenario, moderate scenario, and pessimistic scenario will be 0.59, 1, and 1.85 BCM/year, respectively. The water shortages in the three scenarios will be clearly found in the period between July and November. The water shortages will be compensated by drainage water reuse. It is noticed that, there will be a high excess in water supply from January to June in the three future scenarios. The excessive volumes will be 1.25, 0.9, and 0.35 BCM for the optimistic, moderate, and pessimistic scenarios, respectively. The estimated water balance for future scenarios showed that, the drainage water effluent into Quarun Lake will be 0.35, 0.34, and 0.32 BCM/year in the optimistic, moderate, and pessimistic scenarios, respectively.

The comparison among different scenarios proved that, the water shortage differs due to change in the implementation rates of different actions. These actions are: control of rice areas, application of modern irrigation techniques in new agricultural lands, enhancement of irrigation network efficiency, making successful public awareness campaigns for water use, and application of water saving technologies for municipal and industrial sectors. The water shortage will increase from 1.6 currently to 1.85 BCM/year in the pessimistic scenario, if implementation rates are low. However, the shortage will decrease to 0.59 BCM/year in the optimistic scenario without exceeding the maximum allowed drainage effluent to Quarun Lake (0.35 BCM/year), if the implementation rates are high. Water supply should be reduced for the period between January and June in the optimistic scenario to save the observable water excess.

Future water shortages for the Godavari river basin, India have also been obtained by RIBASIM model through the Hydrology Project, Water Resources Department Government of Maharashtra, India. The simulation results showed that the water requirement will increase from 2155 in the year 2000 to 4219 and 4768 Mm^3 by the years 2015 and 2020, respectively. The water shortage will increase from 234 in the year 2000 to 1908 and 2375 Mm^3 by the years 2015 and 2020, respectively. Results of Godavari river basin, India are in agreement with the current study. From the simulation results of the Godavari river basin, the following recommendations have been reported to minimize the water shortages:

- Increasing irrigation efficiency from 39 to 55% by modernization and improvement of existing conveyance;
- Efficient management of public water supply schemes by using closed pipe supply system and thereby reducing transit losses from 50% to 10%.

4. Conclusions and recommendations

The current water shortage in Fayoum Governorate is 1.6 BCM/year without reuse of drainage water and wastewater. According to RIBASIM, the water shortage will range between 0.59 and 1.85 BCM/year in optimistic and pessimistic scenario for the year 2017. This water shortage reduction is a result of high implementation rates of different actions. The actions are classified under supply management, and demand management. The supply side includes implementation of new projects that increase the Nile water supply such as New Bahr Kouta, Bahr Gerza, and Bahr Wahby projects. The demand side includes control of rice area and other crops having high rates of water consumption, application of modern irrigation techniques in new lands, enhancement of irrigation network efficiency, making successful public awareness campaigns for water use, and application of water saving technologies for municipal and industrial sectors. In the optimistic scenario, the water shortage and the drainage water volume were the lowest, although the agricultural area was the largest. The optimistic scenario was achieved, when the tested packages of actions are implemented with high rates. Since Fayoum is a miniature of Egypt with regard to natural and water resources systems, the results of this study can be used as guidelines for optimization of the water resources system in Egypt. The present study recommends the followings:

Water supply release at Lahon Dam should be reduced in the period between January and June to save 0.9 BCM of the excessive water, and hence to reduce the volume of drainage effluents and to keep the safe water level in Quarun Lake. This will protect the surrounding areas from the over-flooding.

New projects should be implemented to transfer the drainage water effluent away from Quarun Lake such as Al-Katea and Al-Tagen drain stations, which are planned to be installed by the Ministry of Water Resources and Irrigation, Egypt. The two stations can lift drainage water into Bahr El-Bashawat canal to keep the safe water level in Quarun Lake and irrigate new 50,000 Feddans.

According to the soil analysis, sprinkler and drip irrigation systems should be applied in the new lands. Since these lands have high infiltration rates and water percolates from them into agricultural lands in Fayoum depression.

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