Engineering and Technology Journal
Journal homepage: engtechjournal.org

Modelling of Future Water Use Scenarios Using WEAP Model: A Case Study in Baghdad City, Iraq

Mustafa M. Al-Mukhtar [a] **, Ghasaq S. Mutar** [b*],

[a] Civil Engineering Department, University of Technology, Baghdad, Iraq.42369@student.uotechnology.edu.iq

[b] Ministry of Water Resources, General commission for maintaining irrigation and drainage projects, Baghdad, Iraq. 40156@uotechnology.edu.iq

*Corresponding author.

Submitted: 26/10/2020 Accepted: 14/12/2020 Published: 25/03/2021

K E Y W O R D S

WEAP model, calibration and validation, if-scenarios, Baghdad

A B S T R A C T

Iraq is one of the Middle East countries that suffer from water scarcity. In addition to the water policy of the upstream riparian countries; rapid population increase, economic growth, and climate changes are the major stressors of water resources available for domestic and agricultural sectors in this country. Therefore, it is of importance to determine the optimal water management methodology. This study aims to identify the optimal water allocation among the domestic, agricultural, and industrial sectors of Baghdad city under present and potential future scenarios. As such, the WEAP model was used to assess and analyze the current and projected balance of water resource management. The model was firstly calibrated and validated using the monthly streamflow data at Sarai station on the Tigris River. Subsequently, the calibrated model was fed with different future scenarios over the period 2020-2040. The employed future scenarios included normal growth population rate (I), high growth population rate (II), halved river discharges (III), combined scenario of the high population with halved water flow (IV) and the simulated future water year type scenario (V). Results proved that the WEAP model satisfactorily modeled the water supply/demand in Baghdad with R^2 *and Pbias of 0.73 and 2.43%, respectively during the validation period. Also, it was found that the water demand and supply were unmet under all proposed future scenarios which implies that there is a swift need for sustainable water management in Iraq and in Baghdad.*

How to cite this article: M. M. Al-Mukhtara, G. S., Mutar, "Modelling of Future Water Use Scenarios Using WEAP model: ACase Study in Baghdad City, Iraq", Engineering and Technology Journal, Vol. 39, Part A, No. 03, pp. 488-503, 2021.

DOI: https://doi.org/10.30684/etj.v39i3A.1890

1. INTRODUCTION

In arid areas, water resource scarcity has become one of the determinants which restrict social and economic sustainable development [1]. Improving water use efficiency through optimizing water resources allocation currently has been considered as the essential method for solving water scarcity in a river basin. Meanwhile, the main aim of water resources allocation is to find a balance for allocation methods among different water use sectors, such as domestic, agricultural, and industrial uses to ensure the sustainable development of society and economy. However, the problem of insufficient or excessive water allocation within each sector may occur in the traditional water allocation pattern, which distributes water resources based on the current situation and trend of water use [1].Recently, Iraq has faced concerning water management challenges due to the rapid urbanization, industrialization, or population growth which led to the increasing of natural resources demand. For example, in Baghdad, the rapid urbanization and population growth affected the water consumption for each person which reaches up to 250 L/capita/day and 300 L/capita/day in Baghdad sub-district and districts, respectively. The number of populations increased from 3985,382 in 2000 to about 8048900 capita in 2020 [2]. That is to say, that the water demand is increasingly stressed despite the diminished water resources. Iraq mainly depends on Tigris and Euphrates water rather than on its rainfall (MOWR, 2020), hence, utilizing these resources by the wrong method leads to great damage in the future. The rainfall occurs from October to May [3] with a maximum of about 170.7 mm. While, the maximum evaporation mainly occurs in the summer season (from May to September), which is about 599 mm [3]. The lack of rainfall and the prolonged hot seasons are additional problematic issues towards efficient management. It is obvious that the water resources in the Tigris river basin in Baghdad have been exposed to severe pressure due to the climate conditions and the increased demand for the water resources. The climate conditions are of significant fluctuation over the Tigris River basin that led to changes in the amounts of runoff and irrigated agriculture area. The lack of rainfall typically leads to irrigate the crops directly from the Tigris River, which means crowding out the population's consumption of water and taking a share of the river's water for irrigation purposes. Therefore, water allocation measures in the Iraqi river basins that consider equity, efficiency, and sustainability in every water sector should be treated as the main goal for the stockholders and decision-makers. The water evaluation and planning system (WEAP) is a widely used decision support system in integrated water resources management. The WEAP model has attained a global reputation to evaluate many waters related projects and was applied across different regions. For example, Adgolign et al. [4] used the WEAP model in Didessa sub-basin in west Ethiopia to assess the impacts of water resources development on water availability in the upstream and downstream and identify the sub-basin locations that facing decreasing in the water surface. Their results showed that there will be a decrease of about 10.3% in the annual streamflow for Didessa River and will be unmet demand in the last year of the evaluated period for all scenarios. Kerim et al. [5] studied the availability of current and future water under the influence of climate changes scenarios until 2031 in the Upper Awash sub-basin in Ethiopia. Results showed that there would be an increasing water demand but, however, the quantities of water are sufficient to meet the demand in the future. They suggested giving priority to the irrigation sector as it represents the forefront followed by livestock and finally the industrial projects. Mourad & Alshihabi,.[6] used the WEAP model to assess the current and potential water demand and supply in Syria until 2050. They investigated the impacts of six scenarios considering the actual statues, climate change, best available technology, advanced technology, regional collaboration, and regional contention. Results showed there will be unmet demand and to balance this demand, new water resources are needed to be invested. They showed that there will be effects on the water resources from the climate changes in addition to the regional conflict. However, they suggested that by using the best available technology, the gap between supply and demand can be reduced. Amin et al [7] studied the current and future water demands in the Upper Indus Basin in Pakistan under IPCC climate changes scenarios and made some scenarios (population growth, urbanization, and living standards) using the WEAP model. The results showed that the water demand will increase in 2050 and there will be unmet demand according to the user scenarios. Jaber, A.Z., [8]. Used WEAP model to manage the supply in Shatt Al-Hilla basin which is in the south of Iraq central parts. The paper showed that the water demand can be satisfied until 2025 when a decrease in the consumption for each capita to 225-250 L/capita/day is applied that meaning without this scenario the basin will face a shortage in water demand.Kahlerras et al., [9] studied Mazafran basin (north of Algeria) using the WEAP model to assess and analyze the current and projected balance of water resource management which is taking into account the different policies and operational factors that can affect the demand up to the year 2050. The results of the simulation showed that a deficit of 18.936 Million m^3 will be registered in the year 2042. And found the demand will be the same as the supply in the years 2043, 2044. Also, the deficit from 2045 to 2050 will be 3.44 Million m^3 to 85.48 Million m3. On the other hand, in the case of the other scenario, they found that the deficit will start from the year 2025 and will continue until the year 2050 with 130.95 Million m^3. Sithiengtham [10] applied the WEAP model in the Nam Ngum downstream area, Laos to evaluate the water resources availability until 2050. It was concluded that there will be more quantity of water resources greater than the demand from the Nam Ngum river streamflow and rainfall and groundwater. Kishiwa et al., [11] studied the dynamics of the available current and future streamflow for different users in the upper Pangani River Basin under climate changes. They combined the Soil and Water Assessment Tool (SWAT) and Water Evaluation and Planning (WEAP) models to simulate streamflow under climate change scenarios to assess the future availability of water under different socio-economic activities up to 2060s. They reported that the water unmet demand would be increasing by 2060s to 51.5% where this shortage would be more severe in irrigation among the others. Mena et al. [12] studied the potential impacts of climate changes on unsatisfied demand for water in the Guila river basin in Colombia over the period 2011-2100 using the Hydro-BID modeling tool along with the WEAP. They found that the studied climate change affecting the hydrological services in Andean basins, so the reduction in the water supply can lead to unmeet water for different users. They reported that there a possible decrease in streamflow compared to the current stateand an increase in precipitation and temperature. Agarwal et al., [13] evaluated the agricultural water demand in Ur river watershed in India for 2015-2030. Their research was about the drought season and its relation to the demand and supply analysis by using the WEAP MABIA method. They found that there will be unmet demand in the agriculture sector and recommended to narrow down the gap between existing demands and water supply by employing water-efficient crops in addition to efficient agricultural practices and rainwater harvesting, lastly, Al-Chalabi et al 2019.,[14] studied the effect of climate changes on stream flow and sediment yield in Darbandikhan Watershed, which is a major challenge faced by five Global Circulation Models (GCM) and the Soil and Water Assessment Method (SWAT) used to measure the temporal and spatial distribution of streamflow and sediment distribution in Diyala River, Iraq. By using five Global Circulation Models (GCM) and the Soil &Water Assessment Tool (SWAT) which was used to measure the temporal and spatial distribution of the study area's streamflow and sediment yield for the period 1984 to 2050 and SWAT results, the results showed that the average future forecast for the five climate models that the average annual flow and sediment yield in the water yield will be decrease about 49% and 44%, respectively, until the year 2050 compared with these in the previous period 1984-2013.The goal of this study is to assess the water supply/demand in Baghdad over the future period (2020-2040) and manage the water resources allocation under climate changes which is the carrier of social and economic development and human activities. Each type of climate, such as (cold or hot, wet, or dry) climate, directly influences the scale of each industry and the population supporting capacity. To that ends, the WEAP model was calibrated and validated using the monthly streamflow at Sarai station in Baghdad. Thence, the calibrated model was employed to assess five different future scenarios;normal population growth, high population growth, halved Tigris River inflows, combined scenario of the high population growth rate with the halved Tigris river inflow, and water year type scenario.

2. METHODS AND MATERIALS

I. study area description

The study area covers the basin of Tigris River in Baghdad (Karkh & Rusafa) on both sides of the river. The area of Baghdad Governorate is about 4555 Km^2 [10] and it constitutes approximately 1% of Iraq's area (438060 Km^2). The coordinates of Baghdad are 44.43º E eastern of the Grinch line and

33.34º N in the northof the equatorial [15]. Most areas of Baghdad depend on the Tigris River, except some areas that depend on the Euphrates River (i.e., Youssoufia, Mahmudiyah, Radwaniyah and Latifiyah). Therefore, they were not included in this study. The study area is discretized into nine districts extend from north to south of Baghdad which are Al-Khadhimiya, Adamiyah, Karkh, Abu Ghraib, Tarmiyah, Madain, Rusafa, Al-Sadr city. Also, the study area includes one wastewater treatment plant (WWTP), three industrial units and two agriculture areas as shown in Figure1. Table I list the population of the study area districts and sub-districts obtained from the Central Statistical Organization/Iraq for the period of 2000-2020. The population is estimated as 8048900 capita in 2020 and it is expected to be 13396471 capita in 2040 by using a growth rate of 2.58%, which represents the normal growth rate in Iraq.

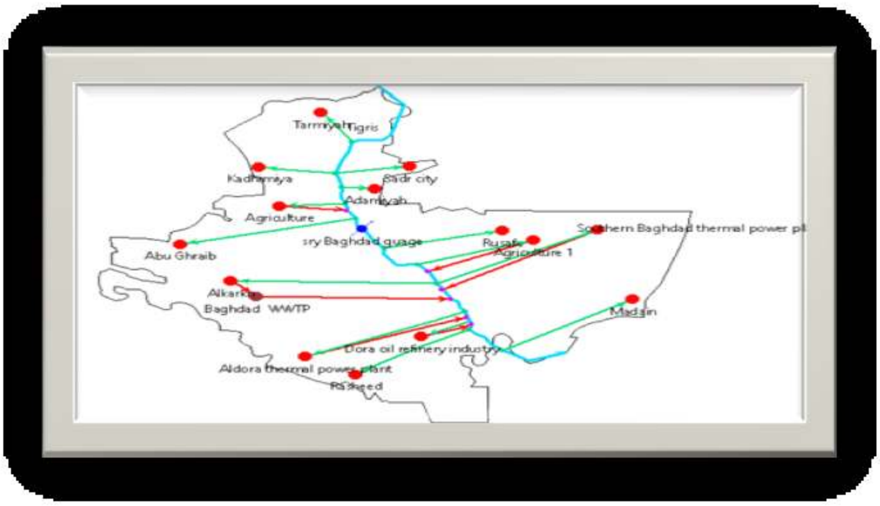

Figure 1: Consumption water Nodes from Tigris river in Baghdad

TABLE I: Population of Baghdad districts & sub-districts in 2020

District and sub-district	Population
Rusafa	1905628
Karkh	1678368
Sadr city	1276249
Adamiyah	1266395
Kadhimiya	945085
Tarmiyah	152841
Madain	484098
Abu – Ghraib	340236

The length of the Tigris River between Al-Muthana Bridge (north Baghdad) to Diyala river (south of Baghdad) is about 55 Km. This area is mainly dependable on the surface water without groundwater. Thus, it represents a bounded area for water supply and demand from only Tigris River and can be well simulated with the least interactions from other water resources. It is noteworthy to mention that there is rapid development in this study area, especially in the urbanization sector. The urbanization (population growth rate) is increasing by 2.58%every year [2], the average water consumption per capita per day varies from 250 liters per person per day to 300 liter per person per day (MOB, 2020). According to the ministry of agriculture data, almost all the agricultural area is located on the Rusafa side (62 %) and the other area (38%) is on the Karkh side. The developments in the industrial sectors are also imposed additional stress on water demand in the study area. Water demand substantially increased in this sector recently owing to the increase in oil production capacity in Baghdad oil refinery.

II. Input data

In this study, various data were used as inputs to the WEAP model to model the water supply/ demand in Baghdad city. These data are categorized into the followings:

A. Weather data (Rainfall, temperature, wind speed, evaporation)

Observed weather data, such as precipitation, temperature, humidity, wind, and evaporation were obtained from the Iraqi Meteorological Organization and Seismology / Ministry of Transport throughout 2000-2018 and all this data was either monthly or annually. Table II lists the statistical characteristics of the weather data in Baghdad.

TABLE II: Statistical characteristics of the average annual weather data in Baghdad from 2000 to 2018

Weather data	Maximum	Minimum	Mean
Precipitation (mm)	172.7	0.001	10.7
Temperature (C°)	47.7	1.3	23.9
Evaporation (mm)	599	48.1	262.63
Humidity %	82	16	41.41
Wind speed (m/sec)	5.40	1.60	3.17

Baghdad receives most of its annual precipitation from October to May. The distribution of rainfall around Baghdad is not uniform either but there is one station working in Baghdad which is in Baghdad Airport. The 18 years of monthly data available from 2000 to 2018 for Baghdad station show that 50 % of rainfall occurs during the winter season, with 25% in the spring season and 25% in the autumn season [3]. This means that the dry seasons in the summer days may require a substitute source to be met the demand. That is to say that Baghdad relies heavily on river water more than rainfall to meet its water demand.

B. Agriculture Area

Data on agricultural areas of Baghdad were obtained from the Ministry of Agriculture as listed in Table III**.** As it can be noticed from the table, there are thirteen areas of agricultural lands within the boundary of Baghdad. These areas are typically cultivated with wheat, barley, yellow and white corn, tomato, eggplant, leafy pomegranate, okra, beans, trees, onions, green beans, alfalfa, cotton, watermelon, pepper, sunflower, mash, sesame, lahan, chunther, sulcum, garlic, potato, lettuce, corolla, leek, raspberry, radish, and caffeine. The different types of previous crops consume a different quantity of water. Therefore, this paper divided the agriculture area into two nodes; one of these nodes consumes an average water quantity by about (22000m^3 /ha.year) and the other node (53040 m^3 /ha.year).

TABLE III: Cultivated areas in Baghdad

Agriculture region	Area (ha)	Agriculture region	Area (ha)
Centre of Karkh	8692	Tarmiyah	13844.00
Mishahda	14097.50	Aabychy	7940.00
Abu-Ghraib	15431.00	Kadhimiya	12069.50
Al-Rasheed	18221.50	Madain	500

Al-Taji	13686.50	Al-jsr	750
Alnsr & Alsalam	34493.25	Nahrwan	90973.25
Rusafa	16250		

C. Tigris river flow

The monthly Tigris River discharges at Sarai station, for the period from 2000 -2018 were obtained from the Ministry of Water Resources. The maximum, minimum, and mean flows for that period were recorded as 711, 392, and 508 cumecs, respectively. These monthly data were used to calibrate and validate the WEAP model, Figure 2. Shows the location of the Saria station in Baghdad.

Figure 2: Saria Baghdad location in Baghdad

D. Wastewater treatment plant (WWTP) discharge

Data on the wastewater treatment plant (WWTP) of Baghdad was obtained from the Mayoralty of Baghdad for the year 2019. Al-Doura Project and Al-Rustumia Project are the main WWTPs in Baghdad that discharge their disposals into the river. The amounts of daily wasted water received to the plant from each one of these projects are approximately 550×10^3 m^3/day.

E. Types of future water years (2021-2040)

The future water years types represent the drought/wet severity. These data were classified according to the types of water year in WEAP (dry, very dry, normal, wet, and very wet). These categories are obtained by dividing the streamflow of the Sarai station of 2021-2040 by the mean value. The source of these collected data (future discharges) was from the MOWR/ strategic study department. The future data were modeled using several models (Stochastic model, HEC-HMS model, and POWER SIM model) considering the present and future climatic characteristics of the riparian countries (Iran and Turkey). However, the future modeled Tigris river discharges were varied as wet in some years to very dry in other years as shown in Figure 3. The future discharges of Tigris River reaching Baghdad were interpreted as follows:

Dry year (0.8), very dry year (0.7), normal year (1), wet year (1.3), and very wet year (1.45). Subsequently, these types were fed into the calibrated WEAP model to be considered as a baseline scenario for the future period (2021-2040).

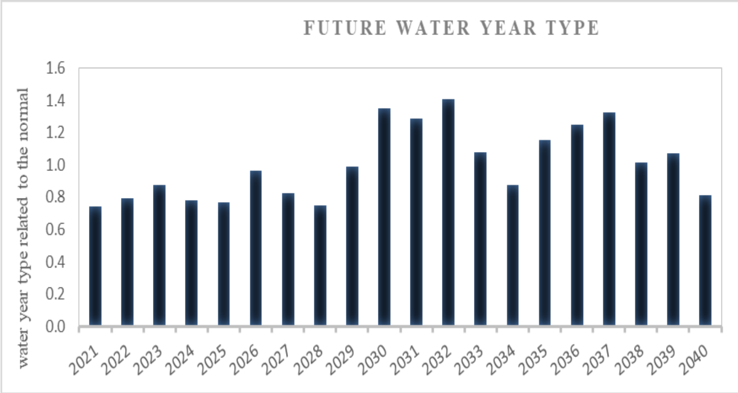

Figure 3: Future water year method

F. Industrial units' discharges

The industrial units available in Baghdad are represented by two major parts: electrical station and oil refinery. There are two electrical power stations in Baghdad the first station called Al-Doura thermal electrical power station which contains two cycles, opened and closed cycles. The open cycle consumed 40×10^3 to 50×10^3 m^3/hr. and worked 24 hours (the total water consumption 96 X 10 ^{4} m^3/day to 12 X 10 ^{5} m^3/day). While the closed cycle consumed approximately 3.5×10^3 m3/day of which a quantity of 1×10^3 m^3/ day used to clean the filters in the stations then it is thrown into the river. The second station is called the southern Baghdad thermal electrical station which consumes halved the water demand in Al-Doura station and released approximately 1×10^3 m^3/day to the river. The second industrial unit in Baghdad is Oil refinery which is in the south of Baghdad, this refinery is consuming water by about 10.3685×10^6 m^3/year from the Tigris River and releases wastewater treatment into the river with about 6.23858×10^6 m^3/ year.

3. WEAP MODEL

WEAP is a microcomputer tool for integrated water resources planning. It provides a comprehensive, flexible, and user-friendly framework for policy analysis. It aims to incorporate the values of the input data into a practical tool for water resources planning. WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP places the demand side of the equation - water use patterns, equipment efficiencies, re-use, and allocation - on an equal footing with the supply side - streamflow, groundwater, reservoirs, and water transfers. WEAP is a laboratory for examining alternative water development and management strategies. WEAP is comprehensive, straightforward, and easy-to-use, and attempts to assist rather than a substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, and storage, treatment, and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options and takes account of multiple and competing uses of water systems [16].Operating on the basic principle of a water balance, WEAP applies to municipal and agricultural systems, single catchments, or complex transboundary river systems. Moreover, WEAP can address a wide range of issues, e.g., sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and streamflow simulations, reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, vulnerability assessments, and project benefit-cost analyses. The Stockholm Environment Institute [16] provided primary support for the development of WEAP. The Hydrologic Engineering Center of the US Army Corps of Engineers funded significant enhancements. Some agencies, including the World Bank, USAID and the Global Infrastructure Fund of Japan have provided project support. WEAP has been applied in water assessments in more than one hundred countries. The WEAP model uses some equations to calculate the water demand in the study area, below equation (1) which was used to calculate the water demand:

$$\boldsymbol{Waterdemand = A.W \times A.L} \tag{1}$$

A.W = annual level of activity driving demand (such as agriculture area, population using water for domestic purposes or industrial units)

A.L = annual water use rate per unit activity

4. Future scenario development

The year 2020 data on total water demand for various sectors agricultural, industrial, and domestic demand were selected as a reference year since that year data were completed and represents the starting point for the future scenario. Water supply/demand capacity was assessed to satisfying water demand in the Baghdad basin through five scenarios during 2021-2040 and as follows:

1) Reference scenario (I): which represents the real status of the water resources with 2.58% population growth keeping all other driving factors constant (climatological, water uses etc.).
2) High-rate population growth scenario (II): which represents the scenario when the population growth rate increases from 2.58 % to 5% until 2040.
3) Halved flow scenario (III): this scenario is considering a 50% reduction of the Tigris river discharges from 2000-2018 to represent the future discharges.
4) Halved flow with high-rate population growth scenario (IV): which is a combination of the two above scenarios (II and III).
5) Water year method (dry scenario) (V): This scenario is represented by taking future data as dry water years to represent the worst behavior in future water years (dry years). In other words, there would be a small amount of water in the Tigris that might depict the worst effects of climate change (high temperature, less rainfall, and limited amounts of flow from the river.

5. Model Assessment

In this study, two statistical criteria were employed to assess the WEAP model performance. The first one was the determination coefficient Equation (2) and the second was the percentage bias Equation (3).

$$\boldsymbol{R^2} = \frac{\sum_{i=1}^{N}(\boldsymbol{Yi}-\boldsymbol{\mu})(\boldsymbol{Oi}-\boldsymbol{\delta})}{\sqrt[2]{\sum_{i=1}^{N}(\boldsymbol{Yi}-\boldsymbol{\mu})\text{^}2\sum_{i=1}^{N}(\boldsymbol{Oi}-\boldsymbol{\delta})\text{^}2}} \tag{2}$$

$$\textbf{PBIAS} = 100 \times \frac{\sum_{i=1}^{N}(Yi-Oi)}{\sum_{i=1}^{N}Oi} \tag{3}$$

Where Yi= simulated streamflow, Oi= observed streamflow, $\mu =$ The mean of the simulated streamflow

δ = The mean of the observed streamflow

6. Results and Discussion

I. WEAP model calibration and validation

In this study, the domestic, agricultural, and industrial water uses were simulated based on the available data for the period of 2000-2018. The WEAP model was calibrated for the period 2008-2013 and validated for the period 2014-2016 against monthly streamflow from Tigris River at Sarai station in Baghdad. Thereafter, future scenarios considering socioeconomic and climatic variations were postulated and fed into the model.

The water loss was the only sensitive parameters to improve the model efficiency in the calibration process. Surface runoff was optimized until the difference between measured and simulated surface runoff was within 15 percent and a value of R^2> 0.6 (Santhi et al. [17] and Moriasi et al, [18]). The same parameters were applied to base flow, and the surface runoff was regularly rechecked as the variables of base flow calibration often affect surface runoff. Figure 4. a and b show the monthly streamflow at Sarai station during the calibration and validation periods, respectively. It is noticeable that the observed and simulated streamflow were consistent and in good agreement along the two periods though some discrepancies between the peak flow from the observed and modeled data were noticed during the calibration period. However, the results of R^2 and Pbias values during calibration were 0.70 and 2.52% and for validation were 0.73 and 2.43%, respectively. Suggesting that the model was capable to capture the real water uses status and thence could be used in further analysis i.e., scenarios managements.

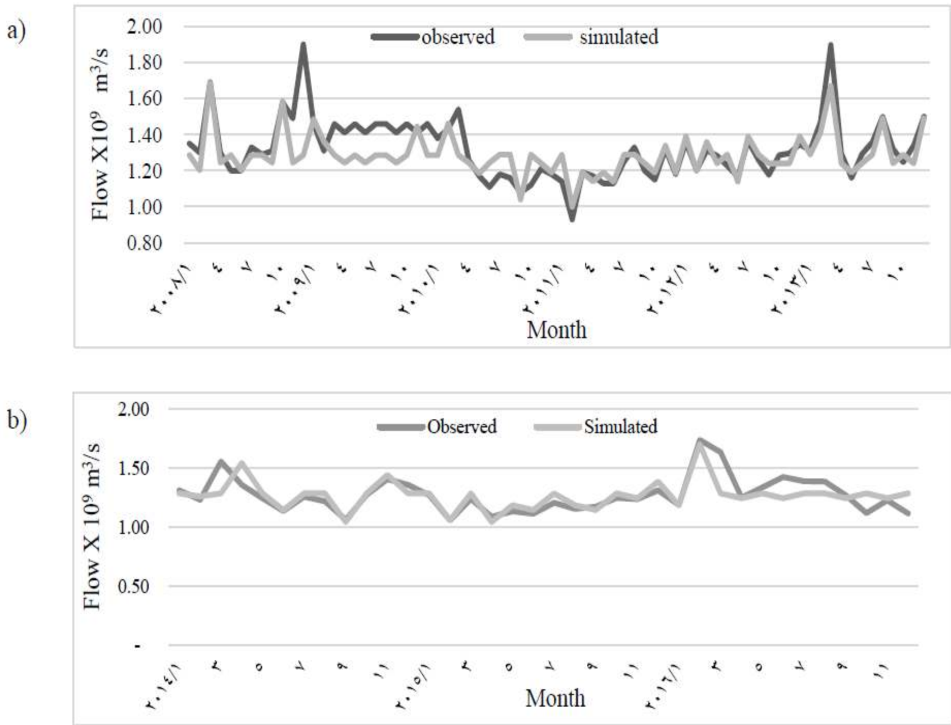

Figure 4: Monthly streamflow during the a) calibration (2008 to 2013) and b) validation (2014 to 2016)

7. Future Possible Scenarios

I. Reference scenario (I)

The calibrated WEAP model was run with the reference scenario to investigate the future behavior of the water system in Baghdad. According to this scenario, the amounts of water in Tigris River along the future period (2021-2040) were taken as modeled by the strategies studying department in (MOWR). While the capacity of the water treatment plant was the same as in base years. So that this scenario takes into consideration only the population growth rate which is 2.58 %. The demand for water was reflecting in population growth, so the demand for water will continue in growth with population growth at the same rate (2.58%). Accordingly, the population is expected to increase from 8048900 capita in 2020 to 13396471 capita by 2040. Figure 5a. shows the future water demand including all sectors in this study (domestic, agriculture and industrial) which are all represented as a bar plot for every year. According to the scenario, it shows that the current water demand is 10.40 Billion $m^3$and the future water demand in 2040 will be 10.68 Billion m^3. In other words, the increase in demand will be about 2.69 % from 2020 to 2040. Subsequently, the result shows that the greatest demand will be for the agriculture sector which will be about 82% then the domestic sector which will be 12% and lastly the industry sector which will be about 6% as shown in figure 6.based on this result, it was concluded that the unmet demand will be fluctuating in the future as shown in Figure 5b. As the lowest unmet demand is expected to occur in 2024, 2026 and from

2028 to 2033 and 2035. While the greatest unmet demand is expected from 2036 to 2040 (~ 1.4 to 4.0 Billion m^3).

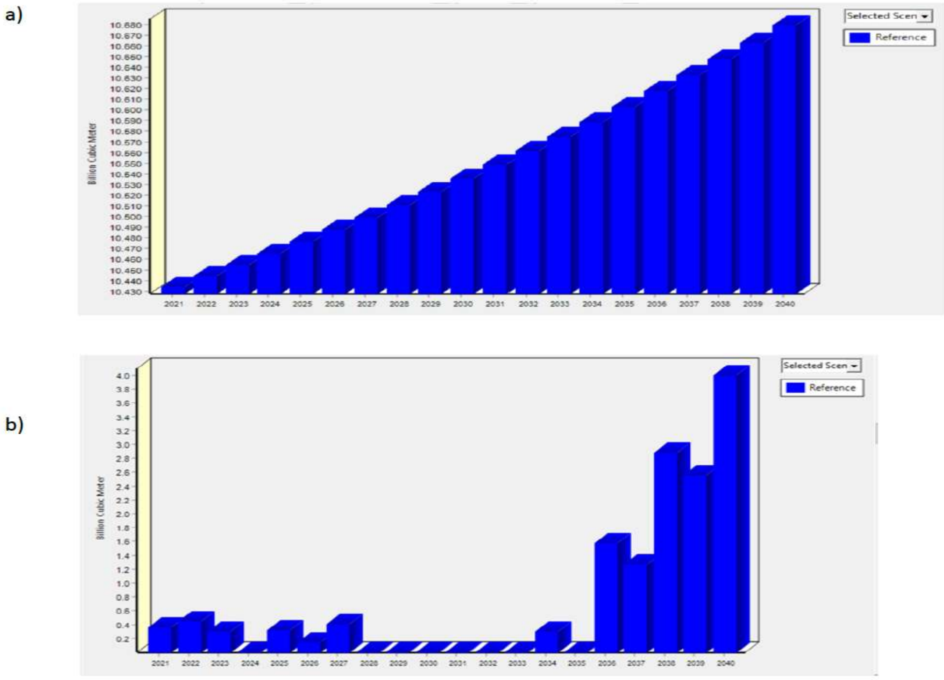

Figure 5: Bar plots of the reference scenario along the period 2021-2040 a) demand and b) unmet demand

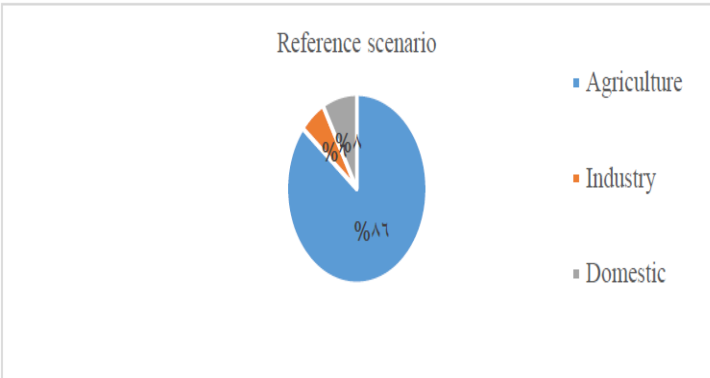

Figure 6: Percentage of water demand for all sectors

II. High population growth rate scenario (II)

In this scenario, the rate of population growth was assumed to be 5% for the period (2021-2040) and Tigris river streamflow was taken as in the reference scenario. Figure 7a. shows the bar plot of the demand of this scenario along with that from the reference scenario. In this scenario, the demand for water arises to a maximum of 11.05 Billion m^3 in 2040. The simulation results indicate that the high rate of population growth will expose the Baghdad basin to facing a water shortage in 2040. This implies that the population growth has a major long-term impact on water demand and to address this shortage, new technologies and successful water management strategies must be used. Also, the water demand will be increased by about 6.25 % from 2040 to the year 2020 in the reference scenario (which is 10.40 Billion m^3). Also, the results show that the greatest demand will be for the agriculture sector about 67% then the domestic sector 28%, and lastly the industrial sector 5% as shown in figure 8. While Figure 7b. Shows the unmet water demand from 2021 to 2040 of this scenarios to the reference scenario. It was found that the streamflow will not be able to satisfy the water demand in 12 years and satisfying the demand in the remaining 8 years. The greatest unmet demand will be 4.3 Billion m^3 in 2040.

a)

b)

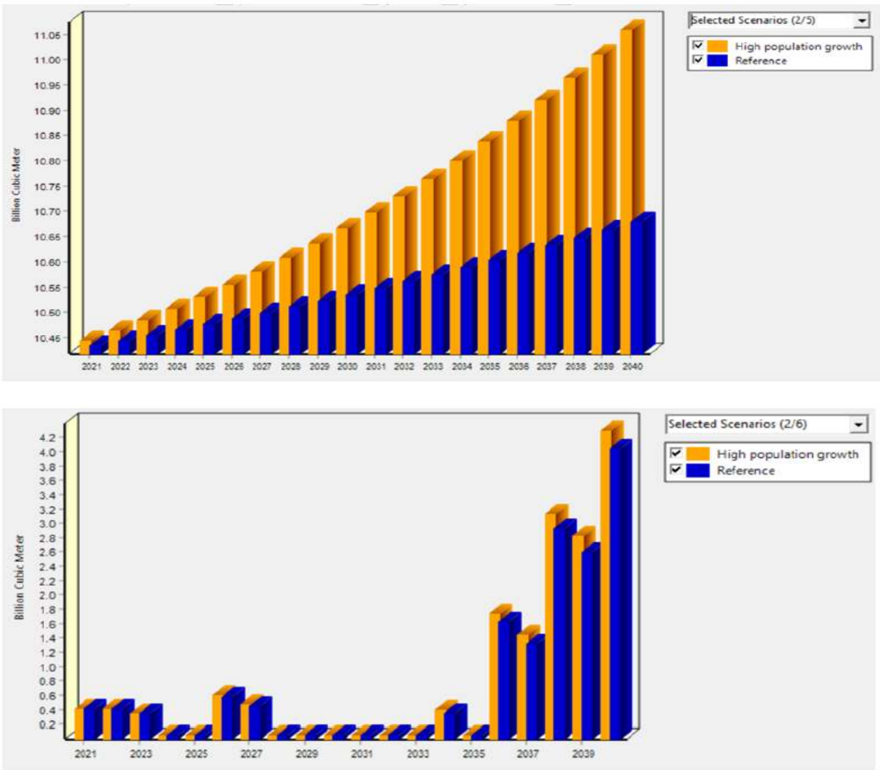

Figure 7: Bar plots of the high population scenario along with the reference scenario a) demand and b) unmet demand

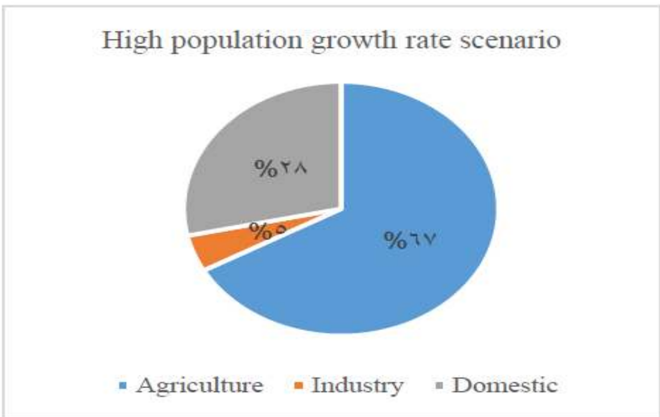

Figure 8: Percentage of water demand for all sectors

III. Halved water inflow scenario (III***)***

The halved inflow scenario was modeled to investigate what might happen if the inflow from the upstream Tigris River in the north of Baghdad decreases by 50% of those in the reference period. This means that the amount of water released from downstream Samaraa barrage with Tigris arm and AL- Adhim river inflow reduced by a half. Figure 9a. shows the bar plot of the halved inflow scenario demand along with the reference scenario. It is worth noting that even when the inflow to the area is halved, water demand in the 2040s is 10.7 Billion m3 which implies that water streamflow is unable to satisfy water needs for all users. The results show that the agriculture sector will be the biggest demand sector 81% the second bigger sector will be the domestic 13% then the industrial sector 6% as shown in figure 10 while the figure 9b. shows the unmet demand for the future. It can be raised from the figure that the unmet water demand will be about 4 Billion m3 in 2021 to 8 Billion m3 in 2040, in other words, the unmet demand will be higher than that of the reference scenario

a)

b)

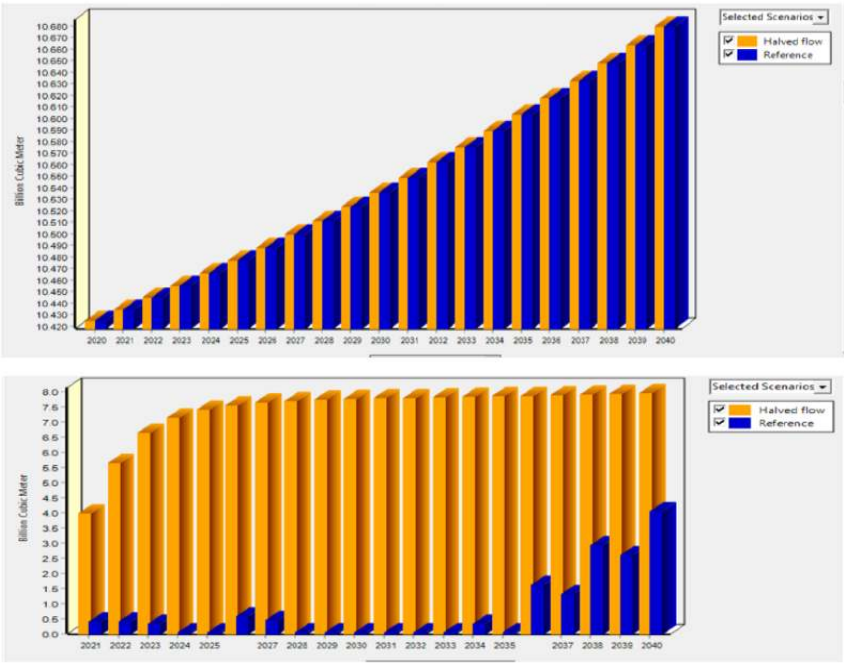

Figure 9: Bar plots of the halved inflow scenario along with the reference scenario a) demand and b) unmet demand

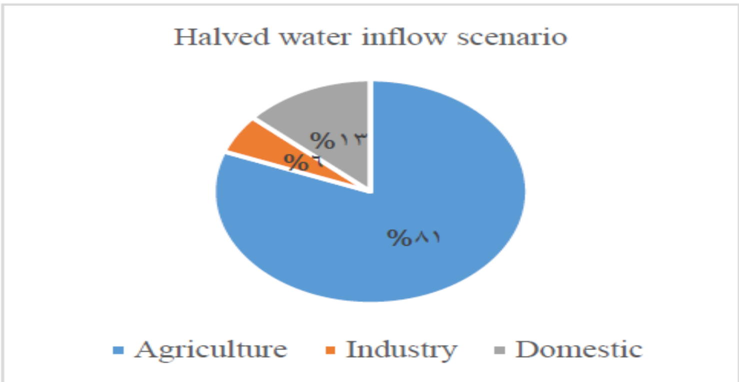

Figure 10: percentage of water demand for all sectors

IV. Halved water inflow with a high population growth rate scenario (IV)

According to this scenario, the streamflow of the Tigris river was considered as in scenario IV andthe population growth rate was taken as in scenario III. Figure 11a. shows the bar plot of this scenario demand along with the reference scenario. The water demand will be ranged from 10.44 Billion m^3 in 2021 to 11.06 Billion m^3 in 2040. While the unmet water demand will be high (Figure 11b.) and ranged from 1.6 Billion m^3 in 2021 to 14.3 Billion m^3 in 2040 because of increasing the population growth rate. The streamflow discharges in this scenario are identical to the halved flow scenario therefore the deficit in meeting the water demand is expected to be high. In other words, this scenario will be as the population growth rate scenario in demand water and the demand percentage for each sector while it will be similar to the halved flow scenario in the quantity of the streamflow in the Tigris River to Baghdad.

a) b)

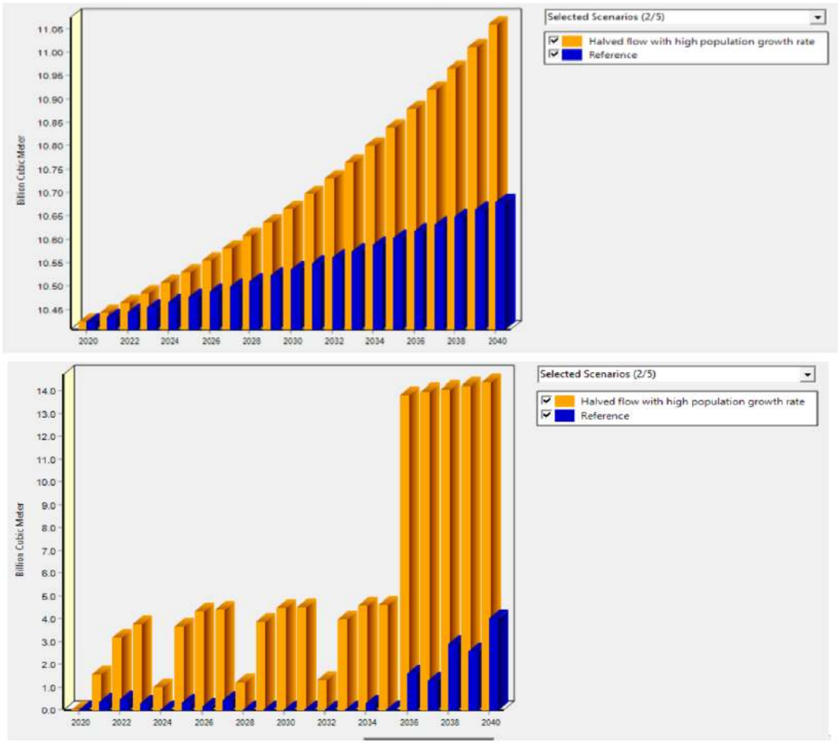

Figure 11: Bar plots of Halve water inflow with a high population growth rate scenario along with the reference scenario a) demand and b) unmet demand

V. Water year method scenario (Dry scenario) (V)

This scenario aimed to investigate how the natural variation in streamflow data can be considered in WEAP through scenario analyses by using the "Water Year Method". The Water Year Method is a simple means to represent variation in hydrological data such as streamflow. The method first involves defining how different climate regimes for the river flow (e.g., very dry, dry, very wet) in comparison to a normal year, which is given a value of 1. Therefore, dry, and very dry years were identified based on a value of less than 1 which is about 0.8 and 0.7, respectively. On the other side, wet and very wet years were identified based on a value larger than 1 which is about 1.3 and 1.45, respectively. This scenario assumes that the future years will be dry (streamflow quantity is less than normal). In other words, this scenario will take the river discharges less than their value in the reference scenario. Figure 12. depicts the demand of this scenario along with that of the reference one. According to this scenario, it was shown that the unmet demand from 2020 to 2040 will be about 0.28 Billion m^3 in every year and the total unmet demand from 2021 to 2040 will be 5.55 Billion m^3. While the water demand will be 10.6 Billion m^3, and 10.68 Billion m^3 in 2035, and 2040, respectively. From the previous scenarios appears that the worst unmet demand was stimulated by scenario IV "halved water inflow with high population growth rate" in 2036 to 2040 which is about 13.8 Billion m^3 to 14.3 Billion m^3 respectively. On the other side, the greatest unmet demand related to the other scenarios is expected to be from scenario III (halved water inflow scenario) for the years 2021 to 2035 which is about 3.9 Billion m^3 to 7.8 Billion m^3, respectively.

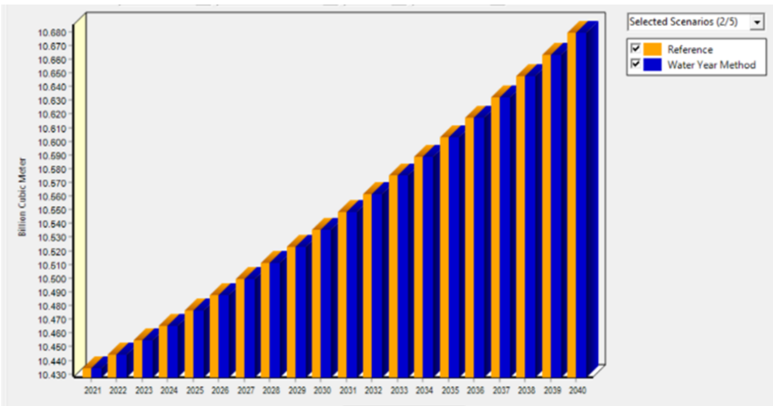

Figure 12: Bar plot of dry scenario demand along with the reference scenario

Lastly, Figure 13 below shows the unmet demand in the Dry scenario and comparison it with the unmet demand in all the previous scenarios which explains that the maximum unmet demand will be in scenario (IV) followed by scenario (III). While the unmet demand in the last scenario (V) (Dry scenario) will be continuous from 2021 to 2040 by about 0.28 Billion m^3/year which drawing in a straight dark blue line.

Figure 13: The Unmet demand in all scenarios

8. Conclusions

In this study, the WEAP model was used to model the water demand/supply in Baghdad city. The model was fed with data from 2000 to 2018 but was calibrated and validated against monthly streamflow data at Baghdad station (Sarai) from 2008 to 2016. The model performance was assessed with two different statistical metrics i.e., determination coefficient and percent bias. It was concluded that the water losses are the most sensitive parameter on the modeling results. The model performed well in simulating the water uses across the three different sectors (Domestic, Industrial, and Agricultural). The future scenarios show that the water demand and supply is unmet under five scenarios, reference scenario (normal population growth), high population growth rate scenario (5%), halved flow scenario (reduction in the streamflow of Tigris river to the half values, the combined (high population growth rate scenario with halved water flow scenario), and lastly dry water year method scenario. The unmet demand in the future will be varied but in different percentages and different years. For example, the unmet demand will be encountered over the entire future years according to the reference and high population growth rate scenarios, however, the greatest unmet demand quantity will be in the last five years from 2036 to 2040 and less unmet demand from 2021 to 2027 except 2024, which will not suffer from unmet demand. Also, from 2028 to 2033 and 2035 will be met with all water demands for all sectors. Also, the other three scenarios show that there would be unmet demand along the study period (2020-2040). The greatest unmet demand will be in the halved flow scenario and the combined scenario, while the other scenarios will have less unmet quantities.

Acknowledgment

The authors are greatly gratitude for the generous support of the Ministry of Water Resources for their financial support. Also special thanks to the Ministry of Oil, and Ministry of Agriculture in Iraq for providing the required data.

References

[1] Z. Wang, J. Yang, X. Deng and X. Lan." Optimal water resources allocation under the constraint of land use in the Heihe River Basin of China". China., *Sustainability*, *7*(2), pp.1558-1575.2015, DOI:10.3390/su7021558.2015, [Online]. Available: https://www.mdpi.com/2071-1050/7/2/1558.

[2] MOP/CSO, 2020, Ministry of Planning / Central Statistical Organization, Annual Report. Baghdad

[3] MOT/IMOAS, 2020, Ministry of Transport /Iraqi Metrological Organization and seismology. Annual Report. Baghdad

[4] T.B. Adgolign, G.S. Rao, and Y.Abbulu, "WEAP modeling of surface water resources allocation in Didessa Sub-Basin" West Ethiopia, Sustainable Water Resources Management, 2(1),pp.55-70.2016,DOI:10.1007/s40899-015-0041-4,[Online].Available: Adgolign2016_Article_WEAPModelingOfSurfaceWaterReso (3).pdf

[5] T. Kerim, A.Abebe, & B.Hussen. "Study of Water Allocation for Existing and Future Demands under Changing Climate Condition: Case of Upper Awash Sub River Basin" .J. Environ. Earth Sci, 6, 14.2016.

[6] K.A. Mourad, and O.Alshihabi, 2016. Assessment of future Syrian water resources supply and demand by the WEAP model. *Hydrological Sciences Journal*, *61*(2), pp.393-401.2016, DOI: 10.1080/02626667.2014.999779. [Online]. Available:https://sci hub.se/10.1080/02626667.2014.999779

[7] A. Amin, J.Iqbal, A. Asghar, and L. Ribbe, "Analysis of current and future water demands in the Upper Indus Basin under IPCC climate and socio-economic scenarios using hydro economic WEAP model". Water, 10(5),p,537.2018,DOI:10.3390/w10050537,[Online].Available:https://sci hub.se/https://link.springer.com/article/10.1007/s40030-018-0329-0

[8] A.Z.Jaber, "WEAP MODELING F MANAGEMENT SUPPLY IN SHATT AL." International Journal of Civil Engineering 9.13 (2018), Civil engineering Dep.,Univ of Al-Qadisiyah, Al-Qadisiyah city, Iraq.

[9] M. Kahlerras, M. Meddi, M. Benabdelmalek, S. Toumi, D. Kahlerras, and I.Nouiri."Modeling water supply and demand for effective water management allocation in Mazafran basin (north of Algeria)". Algeria. Arabian Journal of Geosciences, 11(18), 547.2018, DOI:10.1007/s12517-018-3869-8, [Online]. Available: https://sci-hub.se/10.1007/s12517-018-3869-8.

[10] P. Sithiengtham. "Projecting water demand and availability under climate change through the application of WEAP in the Nam Ngum downstream area, Laos", M.Sc. thesis, College of Science and Engineering.,Univ ofFlinders., Adelaide., SouthAustralia,2019.,[Online].Available:https://www.weap21.org/Downloads/ThesisSithiengtham2019.pdf

[11] P. Kishiwa, J.Nobert, V. Kongo and P. Ndomba. "Assessment of impacts of climate change on surface water availability using coupled SWAT and WEAP models: case of upper Pangani River Basin, Tanzania" ,Proceedings of the International Association of Hydrological Sciences, 378, p.23.2018,DOI: 10.5194/piahs-378-23-2018. [Online]. Available: https://d-nb.info/1161423133/34.

[12] D. Mena, A. Solera, L. Restrepo, M. Pimiento, M. Cañón and F. Duarte. "An analysis of unmet water demand under climate change scenarios in the Gualí River Basin, Colombia, through the implementation of Hydro-BID and WEAP hydrological modeling tools". Colombia .2019. Journal of Water and Climate Change.2019, DOI:10.2166/wcc.2019.118, [Online]. Available: https://sci-hub.se/10.2166/wcc.2019.118

[13] S. Agarwal, J.P. Patil, V.C. Goyal and A. Singh, "Assessment of water supply–demand using water evaluation and planning (WEAP) model for Ur river watershed, Madhya Pradesh". Journal of The Institution of Engineers (India): Series A, 100(1), pp.21-32, India, 2019, DOI:10.1007/s40030-018-0329-0, [Online]. Available: https://sci-hub.se/10.1007/s40030-018-0329-0.

[14] R. Al- Chalabi, M. Al-Khafaji, “Impact of climate change on the spatiotemporal distribution of stream flow and sediment yield of Darbandikhan watershed, Iraq,” Engineering and Technology Journal, Vol. 38, Part A, No. 02, pp. 265-276, 2020.available: https://doi.org/10.30684/etj.v38i2A.156

[15] F. M. Abdulla, "Calculating the variations of sunrise, sunset and day length times for Baghdad city". With comparison to different regions of the world in year 2019. Iraqi Journal of Science, 2732-2741. (2019),[Online].Available: 1279-Article Text-18994-1-10-20191229.pdf.

[16] Stockholm Environment Institute, 2016. Water Evaluation and Planning System Tutorial (Stockholm, Sweden). [Online]. Available: https://www.weap21.org/

[17] C. Santhi, J.G. Arnold, J. Williams, W.A. Dugas, R. Srinivasan & L.M. Hauck. "Validation of The Swat Model on A Large Rawer Basin with Point and Nonpoint Sources". , 2007. Journal of the American Water Resources Association.37(5), p. 1174. 2007, DOI: 10.1111/j.1752-1688. 2001.tb03630.x, [Online]. Available: https://sci-hub.se/10.1111/j.1752-1688.2001.tb03630.x.

[18] DN. Moriasi, JG. Arnold, M V. Van Liew, RL. Binger, RD. Harmel, TL.Veith." Model evaluation guidelines for systematic quantification of accuracy in watershed simulations .“Transactions of the American Society of Agricultural and Biological Engineers, 50(3), 885–900.2007, DOI: 10.13031/2013.23153[Online]. Available: https://sci-hub.se/10.13031/2013.23153.