International Journal of Civil Engineering and Technology (IJCIET)
Volume 9, Issue 13, December 2018, pp.290–302, Article ID: IJCIET_09_13_030
Available online at http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=13
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

WEAP MODELING FOR EFFECTIVE MANAGEMENT OF WATER DEMAND AND SUPPLY IN SHATT AL-HILLABASIN –IRAQ

Ahmed Zghair Jaber
University of Al-Qadisiyah, collage of Engineering,
Civil Engineering Department

ABSTRACT

Achieving sustainable development is one of the biggest challenges facing water management because the effects of increasing water demand as well as climate change. In this context, providing the decision-makers with the best solution for water allocation requires the use of more effective ways to overcome the complexity of the water system and uncertainty. In this study, an assessment of the future and current management system of the Shatt Al-Hillahbasin was carried out under various scenarios by using the Water Evaluation and Planning (WEAP) models.

The WEAP model is concerned with studying the factors affecting water availability, especially the factors influencing the demand and supply of water in the river basin. The WEAP model is one of the integrated decision support systems and is therefore suitable for simulating the hydrological system in any watershed. To construct the model, the hydrological model was devided to sixsub-hydrological catchments and twelve sources of demand. Various quantitative statistics were used to calibrate and verify the model.

The supply and demand trend in watersheds was assessed under three scenarios. High population growth is regard as the first scenario while the effect of management of demand side (DSM)was the second scenario. In third scenario, the affect DSM and Non-Revenue Water (NRW) was evaluated. Outcomes present that mitigation of the impact of unsatisfied demand can be significantly reduced by NRW reduction and application DSM.

Key word: WEAP, DSM, High Population Growth, Unmet Demand, Shat Al-Hilla Basin.

Cite this Article: Ahmed Zghair Jaber, Weap Modeling For Effective Management of Water Demand and Supply In Shatt Al-Hillabasin –Iraq, *International Journal of Civil Engineering and Technology (IJCIET)* 9(13), 2018, pp. 290–302.
http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=13

1. INTRODUCTION

Changing of socioeconomic and climate conditions, ecological consideration, expansion of urbanization, and hydrologic and hydraulic conditions were regard as an example of many various constraints influansing on water resources systems. So Management of water resources has become more controversial and complicated than before.

Thus, prevention of conflicts is require allocation water resources among different stakeholders in efficiently and effectively manner. Decision makers are achieving this action when using reliable models (Bhave, Conway, Dessai, & Stainforth, 2018), (Al-Zubari, El-Sadek, Al-Aradi, & Al-Mahal, 2018), (Zarghami, Safari, Szidarovszky, & Islam, 2015). Therefore the simulation models are a tool to assist decision-makers and stakeholders understand the impact of their actions and decisions on outcomes, as well as better understanding water allocation problems by providing a systematic decision-making that indirectly gives a sustainable solution for disagreements. (Nandalal & Simonovic, 2003), (Simonovic, 2012). One of these models is a WEAP model, which presented by a non-profit research organization, Stockholm Environment Institute (SEI), USA, conduct research and engage with decision – makers on energy, water and climate policy (WEAP, 2016.).

The WEAP model has been used in many parts of the world to evaluate many water-related projects. Hence The WEAP model has a high global popularity in analyzing water supply requirements and scenarios. For the example, the WEAP model was used in South Africa to measure future water demands and their availability in the Olifants catchment (Arranz & McCartney, 2007). While in Ethiopia, the WEAP applied to assess the expected impact of various potential growth scenarios on Lake Tana water levels (ICID, 2010). WEAP was also used to simulate the scenario of the impact of medium-term climate change on the performance of current hydropower plans and proposed irrigation, which influenced Ethiopia's policy of building a reservoir in the Blue Nile basin (WEAP, Water Evaluation and Planning Model Tutorial, 2016).Alemayehu, et al. (2011) used the WEAP model in the Niger River basin to study the impact of various possible scenarios on future water resource management (Alemayehu, McCartney, & Kebede, 2011). While in the Yolo County watershed in California, the WEAP model was used to determine the effects of adaptive capacity and potential climate changes on irrigation water supply (McCartney & Menker, 2012). WEAP was also used in the Wadi Dara Middle, Morocco, to assess the impact of land use and land cover changes due to climate on the future demand and availability of water (Bhatti & Nasu, 2010)

In 2016 an ecosystem services was modelled for periodic socio-ecological engagements in water management decisions byJorda-Capdevila et al. 2016 (Jorda-Capdevila, Rodríguez-Labajos, & Bardina, 2016).Another model was suggested for defining the hydrological prediction water balance of an irrigation project in semi-arid zone by using a combined deterministic and stochastic protocol with WEAP model (Duque & Vázquez, 2017). While a Demand Management Strategy (DMS) was proposed to increase water sustainability by reducing water demands at a basin (Metobwa, Mourad, & Ribbe, 2018).

The aim of this study is to present a WEAP model to determine the future demand and supply of water in the Shatt Al-Hillah basin. In addition to studying the impact of different factors on them. In this model, the simulation was conducted on three different possible scenarios. These scenarios were population growth rate first, demand-side management (DSM) second and third, a mixture of Non-Revenue Water (NRW) with DSM. The model was implemented until 2050 to determine the water shortage under the influence of the above factors. Model evaluation statistics were used to evaluate model performance and future demand reliability(K.N.Kadhim,2018).

2. STUDY AREA

The Shatt Al-Hilla basin is placed in the southern of central parts of Iraq. The boundary of this region was showed in Figure (1). While climatic details were mentioned in Table 1. It do not have viable alternative water resources such as groundwater, so it depends entirely on any available flow from the Alhilla River. Water is distributed from the Hindya barrage that was built in the Saddat Al- Hindya town. Hindya Barrage is the last structure that controls the Euphrates River and provides water for non-domestic and domestic usages for approximately five million capita living surrounding and within basin.In the southern part of the city of Al-Ramatha, the Haila River is divided into several channels that provide water to villages and farms. The Shatt Al-HillahRiver under study in this research is a branch of the Euphrates River. The catchment is a very important basin in Iraq and has a key role in economic and social life. So The region is a good case study for modeling water demand and supply due to lack of water supply and increasing demand for water due to factors such as population growth

3. METHODOLOGY

3.1. INPUT PARAMETERS

The rate of population and consumed water per capita were obtained from the Ministry of Planning / Central Bureau of Statistics and the Ministry of Water, respectively. Water consumption per capita per day varies from 200 (liters per person per day) to (350 liters per person per day). Historical climatic data, such as precipitation, temperature, humidity, wind and evaporation (ET) are obtained from the Iraqi Meteorological Organization and Seismology / Ministry of Transport. Crop trends, and irrigated area of the Babil, Dewanya and Ramtha cities were obtained from the Ministry of Agriculture.

Table 1 CLIMATIC DETAILS OF SHATT AL-HILLA BASIN

Station	Av. Temp(C)	Rainfall(mm)	Irrigated Area(hectares)
Babil	34	99.5	227804
Dewanya	35	105.8	20000
Rumatha	35	89.7	14090.5

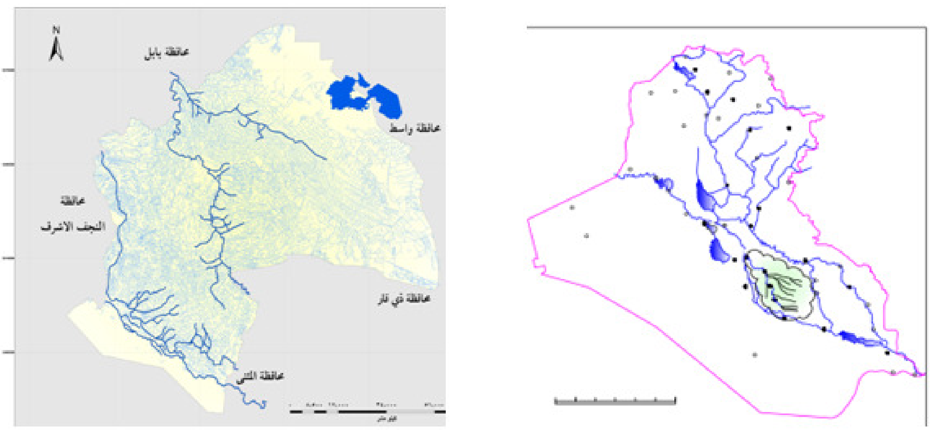


Figure 1. Shatt Al-Hilla basin

3.2. Development of Model

WEAP for executive simulations uses two basic principles during:(Arranz & McCartney, 2007)

1) Simulating runoff, infiltration, and evaporation for assessment and availability of waters within a catchment.
2) Analysis impacts of anthropogenic activities on water resources.

For the purpose of developing the model structure, the entire Shatt al-Hillahbasin is separated into six hydrological catchments (depending on availability of hydrological data) and twelve (12) subregionst that may have demand of non-domestic and domestic. Figure (2) shows the overall hydrological modeling of WEAP model (Leong & Lai, 2017). As a result, the structure of the developed model takes into account the elements involved, including the location of the request (municipal and non-municipal), transport link, river (stream), water treatment plant (waterway), gageflow and catchment Figure (3).The potential water problems and problems of water resources that may occur in the near future have been investigated through several scenarios. The scenario which has best outcomes among these scenarios, it was recognized. Figure (4) shows the WEAP sample node network.

3.3. Calibration and validation of model

In this study, the criteria that affect runoff such as climate inputs have been calibrated using historical data of the flow of rivers, these data were collected from three stations, the first north of the city of Hilla, the second north of Diwaniyah, And the third north of the city of Rumaitha (i.e. north, middle, and south of Hilla River basin respectively).Sets of data for the year (2008-2015) were selected among periods when flow data are available. The first six years (2008-2013) were used for the model calibration, while the next two years (2014-2015) were used to validate the model. This was done using the built-in calibration feature of WEAP called PEST (WEAP, 2016.).

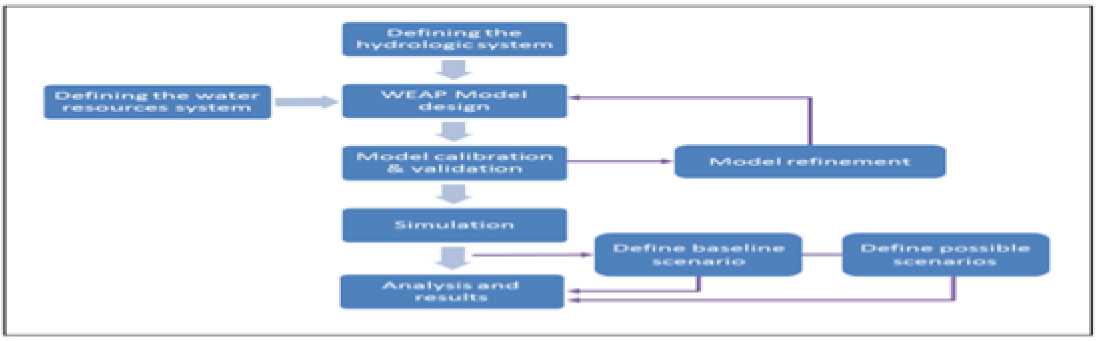


Figure 2. Framework of WEAP model (Leong & Lai, 2017)

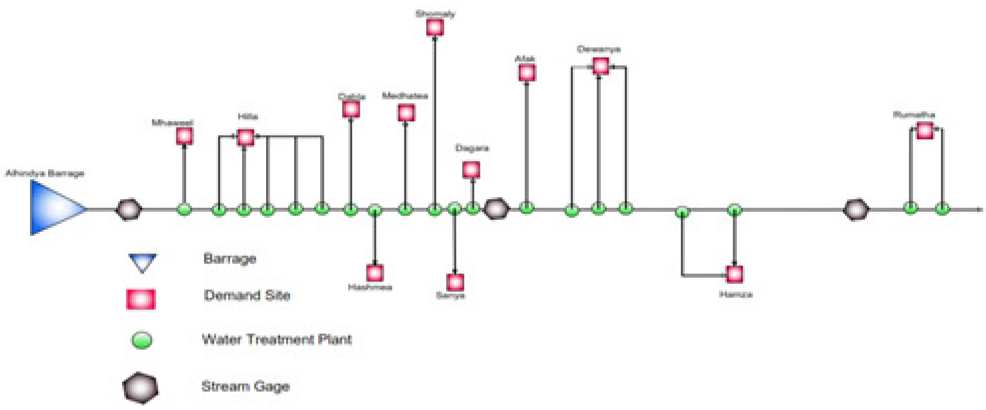


Figure 3. The essential ingredients of model

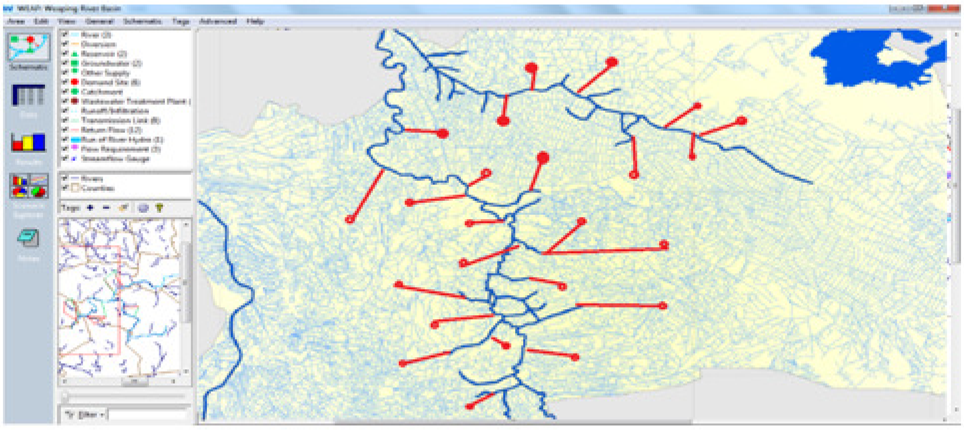


Figure 4. The Shatt Al-Hilla basin in WEAP model

3.4. Statistical Evaluation for model

Statistical quantitative coefficients were used for performance assessment of model. These were the coefficient of determination (R^2), the efficiency of the (NSE), and the percent Bias (PBIAS). These groups were calculated for each historical and simulation flow during the period 2008-2015.

3.4.1. Coefficient of determination (R^2).

R^2represent the variance proportion in observed data to the simulated by the WEAP model. R^2values was with range from (0 to 1), where high value corresponding to less error variance. In addition the values has greater than (0.5) are regarded acceptable. R^2 is computed by eq (1) (Van Liew, Arnold, & Garbrecht, 2003), (Santhi, et al., 2007)

$$R^2 = \frac{\sum_{i=1}^{n}(Y_i - \mu)\,(O_i - \delta)}{\sqrt{\sum_{i=1}^{n}(Y_i - \mu)^2 \sum_{i=1}^{n}(O_i - \delta)^2}} \quad (1)$$

Where,
Yi: the ith simulated streamflow
Oi: the ith observed stream flow.
μ: the mean of simulated stream flow.
δ: the mean of observed stream flow.

3.4.2. Coefficient of Nash-Sutcliffe for Efficiency (NSE).

(NSE) is a normalized statical coefficient for recognizing noise (relative value of residual variation) compared to information (variance of measured data) (Nash & Sutcliffe, 1970). NSE was used to measure predictive skill of the model corresponding to observation data. NSE values range from (-∞to 1.0), where the positive value indicates acceptable levels of performance, while negative values indicate unacceptable performance. The value of NSE equals (1, 0.65, and 0.5) refer to the optimum, good, and satisfactory performance, respectively.NES is computed by eq. (2) (Nash & Sutcliffe, 1970):

$$NSE = 1 - \frac{\sum_{i=1}^{N_v}(y_i - o_i)^2}{\sum_{i=1}^{N_v}(o_i - \delta)^2} \quad (2)$$

Where,
Yi: the ith simulated stream flow
Oi: the ith observed stream flow

δ: the mean of observed stream flow

3.4.3. Percent Bias (PBIAS)

Percent Bias (PBIAS) represents the error in predicting corresponding to observation. PBIAS value indicates the optimal state when it is equal zero, while low magnitude for PBIAS value indicates that simulation of model acceptable. In the other side positive value indicates that model was under estimations bias, so the model considering over estimation bias when takes negative value. Therefore PBIAS represent tendency of observed data relative to simulated data. PBIAS was computed in eq (3) (Gupta, Sorooshian, & Yapo, 1999):

$$\mathrm{PBIAS} = 100 \times \frac{\sum_{i=1}^{n}(Y_i - O_i)}{\sum_{i=1}^{n} O_i} \qquad (3)$$

Where.

Yi: the ith simulated streamflow

Oi: the ith observed streamflow

3.5. Future Possible Scenarios

Water supply capacity was assessed to satisfying water demand in the Shatt Al-Hilla basin through three scenarios. These were management of demand side, high rate of population growth, and mixture of management of demand side with Non-Revenue water.

3.5.1. Reference scenario

Under this scenario, the population growth was assumed to be same the current situation as well as the corresponding use and supply of water. In addition, the capacity of production for water treatment plants was at current design capacity with growth rate of 2.7% (Ministry of Planning / Central Bureau of Statistics).

3.5.2. Scenario 1: High population growth rate.

This scenario assumes that the production capacity of the treated water was at a design capacity and the rat of population growth was high, about (4%). The aim of this scenario was assess the future influence of rising of growth rat of population on the water demand and supply for middle Ephraties basin.

3.5.3. Scenario 2: Demand Side Management (DSM).

This scenario assesses the impact of applying the demand-side management strategy at the reference and first scenarios (i.e. “reference” and "high population growth"). The model calculation assumes the provision of water by reducing the amount of water consumption per capita (250 liters/day) to (225 liters/day), and reducing irrigation water (35% and 25% by using spray and drip irrigation system respectively).

3.5.4. Scenario 3: Mixture of DSM with Reduction of Non-Revenue Water (NRW).

This scenario evaluates applied strategy of demand side management conjugate with applied strategy of supply side management on reference and first scenarios (i.e. “reference” and “high population growth”). The model calculation assumed water savings by decrease the amount of water consumption per capita and irrigation water as previous scenario in addition to decrease the losses of NRW from (32%) to (16%)

4. RESULTS AND DISCUSSION

4.1. Performance of model

The hydrological calibration of the simulation model included comparing the monthly flow of rivers in the Shatt Al-Hillah basin recorded from (2008-2013) with the values of the simulation model, while the verification of the reference model included a comparison of the monthly flow recorded for these rivers from (2014-2015) with the values of the simulation model. Figure (5) shows calibration and validation of simulation model. Monthly simulated flows are well suited to observed flows based on quantitative statistical coefficients. Table (2) shows the quantitative statistics to calibrate and verify the simulation model.

Table (2). The statistical coeficients for performance evaluation of model.

	Coefficient of calibration model			Coefficient of validation model		
River	NSE	R^2	Pbias	NSE	R^2	Pbias
Babil	0.90	0.92	1.23 %	0.91	0.93	4.16 %
Dewanya	0.94	0.93	3.31 %	0.87	0.95	6.65 %
Rumatha	0.93	0.96	0.94 %	0.92	0.98	5.72 %

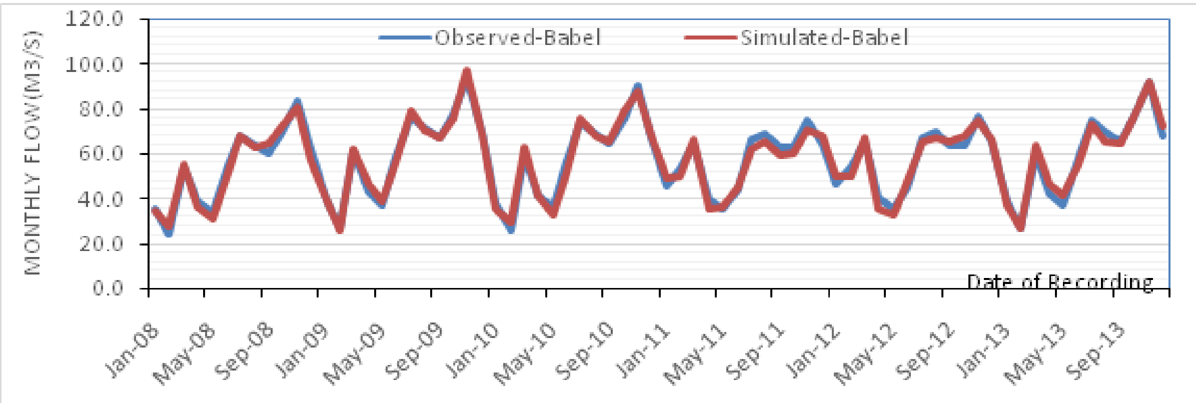


Figure 5-a. Calibration of Babil River

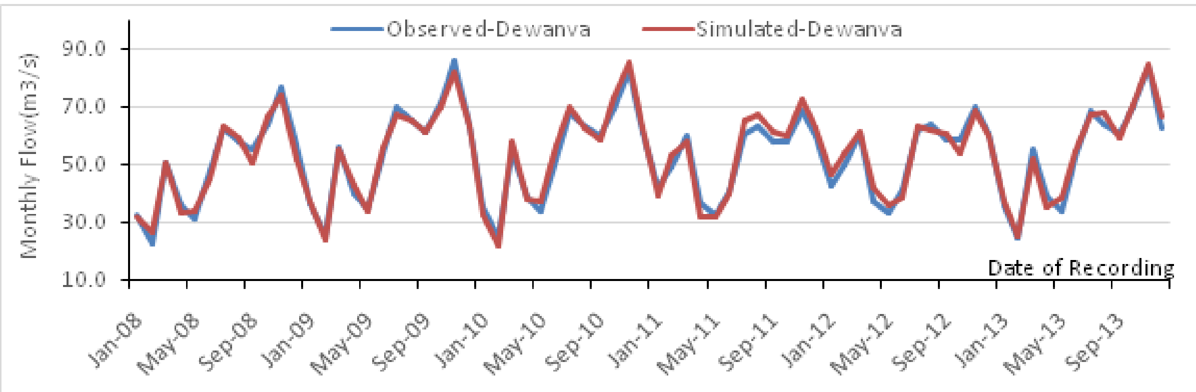


Figure 5-b. Calibration of Dewanya Rive

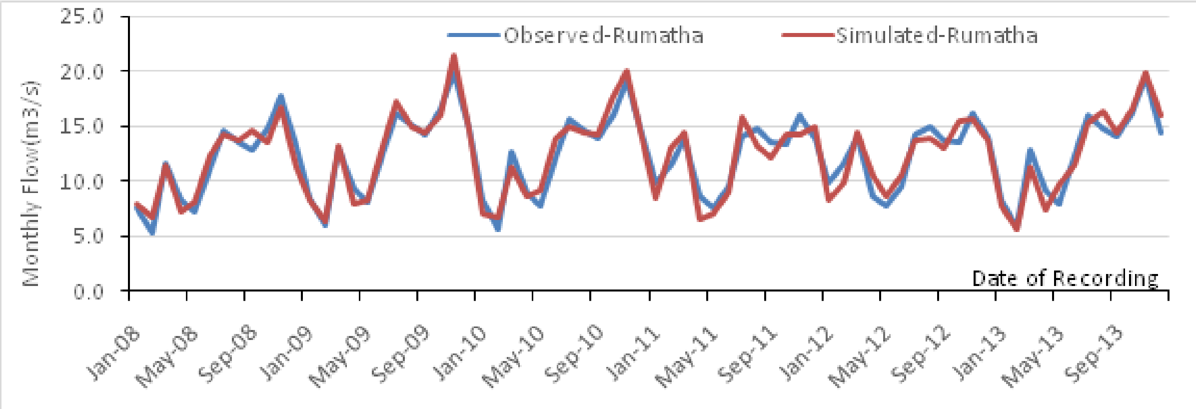


Figure 5-c. Calibration of Rmatha River

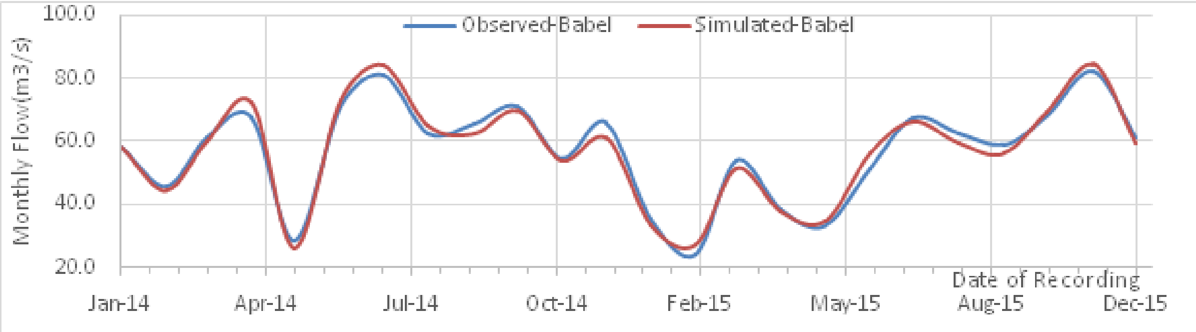


Figure 5-d. Validation of Babil River

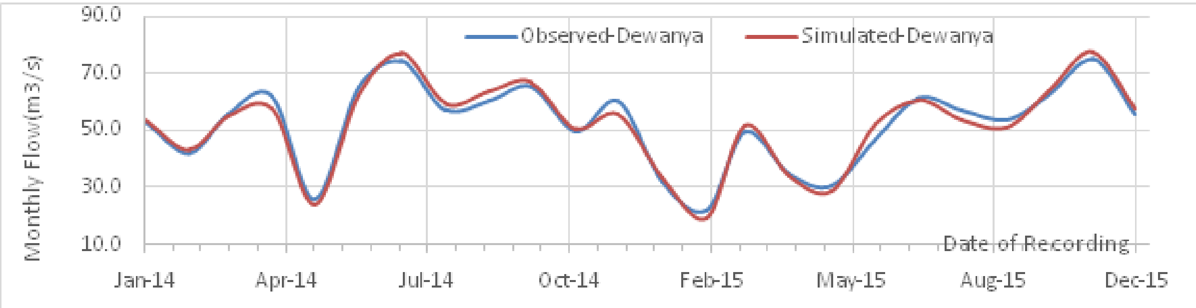


Figure 5-e. Validation of Dewanya Rive

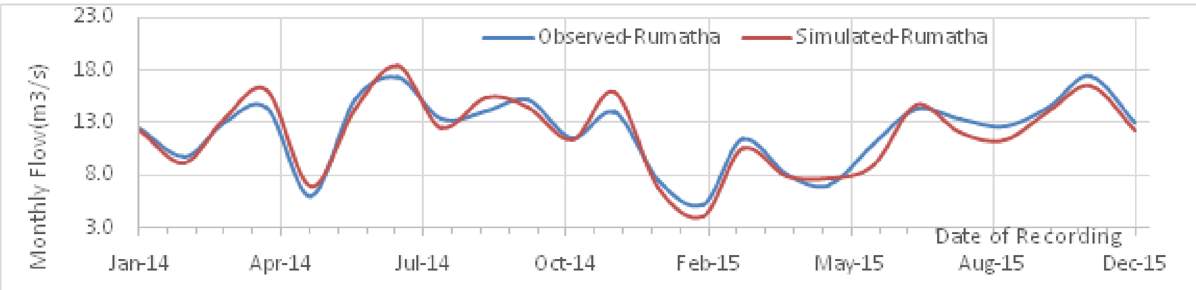


Figure 5-f. Validation of Rmatha River

Figure5. Calibration and Validation of Simulation Model

4.2. Reference Scenario

The demand of water was reflactes to population growth, so the demand of water will continue in growth with population growth at same rat 2.7%. The population are increasing from (5,265,420) in 2008 to (16,494,874) capta by 2050. Therefore, the current water demand (4200 cubic meters) and the future water demand (10200 million cubic meters) Figure (6), which is about three times the demand at 2008. The WEAP model showed that the region of Shatt Al-Hilla basin will face shotages for both non-domestic and domestic demand concerns at 2019 when the system of water use and supply remains stable.

4.3. First scenario: high rate of population growth

In this scenario, the impact of increasing population growth to 7% on water demand and supply in the region of Shatt Al-Hilla basin was assessed within (2015-2050). In the current situation, water usage and supply were maintained, the demand was (10500 million cubic meters) while demand for water rises to a maximum (15600 million cubic meters) as shown in figure (6). The projected annual unsatisfied demand for water based on the two scenarios (reference and high rate of population growth) shows in figure (7). The simulation results indicate that the high rate of population growth will make the region of Shatt Al-Hilla basin face water shortages in 2017, only two years before expectations of reference scenario. In anther word, the annual unsatisfying demand touched a maximum of 10,800 million cubic meters in 2050 for high rate of population growth scenario, double the annual demand at the reference scenario (5100 m^3). This indicates that the population growth has a significant impact on water demand with respect to long term and shows the development a wide cooperation, a novel technologies, and a good water management plans is an essential measurements to addressthis expected shotfall.

4.4. Second scenario: Management of demand side (DSM)

The both (refrence and high population growth rate) scenarios were employed in evaluation of the model in this scenario. Where the influence of application DSM and conservation of water measures (mentioned above) were assessed. The implementation of DSM via high rate of population growth and reference scenarios was produce saving in water as illustrated in Figures (8 and 9). Figure (8) shows that the application of DSM at reference scenario makes the water supply of the Shatt Al-Hilla basin capable to keep pace with demand until 2023, as low water consumption due to DSM will overcome the deficit resulting from demand growth. The maximum annual aggregate demand that was not met in 2050 could also be reduced to 9000 million cubic meters in relation to the demand in the reference case (11,100 m^3). In total, the total unsatisfied demand for the period 2005-2050 decreased from 5670 million cubic meters to 3786 million cubic meters. On the other hand, WEAP model showed the DSM procedure reduce only 10% of per capita water consumption, a total of 1760 cubic meters of water could be provided to reduce water demand until 2050. While Figure (9) shows at scenario of high rate of population growth, supply was able to keep up with demand until 2022, then after this demand will be greater than supply. The model also expected a decline in entire unmet demand from 11120 MCM for 9050 MCM. This means the water savings can reach a total of 2035 MCM for expected water demand until 2050 and shows that more water can be saved relative to the reference scenario (1680 m^3).

This finding shows that savings are demand-driven and therefore have a greater impact on scenario of higher population growth, a level at which water demand is high.

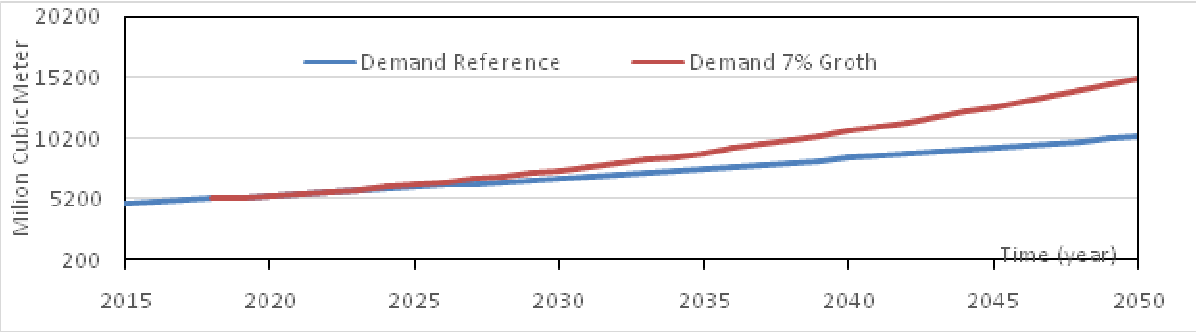


Figure 6. Annual total water demand for both scenarios (reference and population growth)

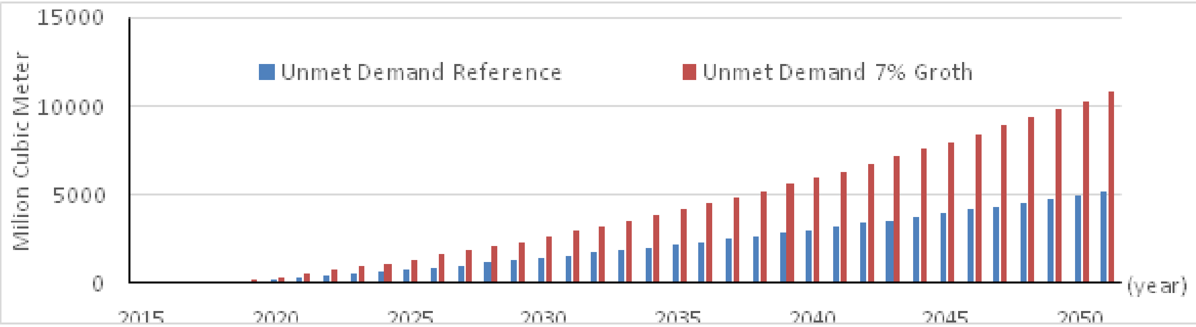


Figure 7. Anuual total water unmet demand for both scenarios (reference and population growth)

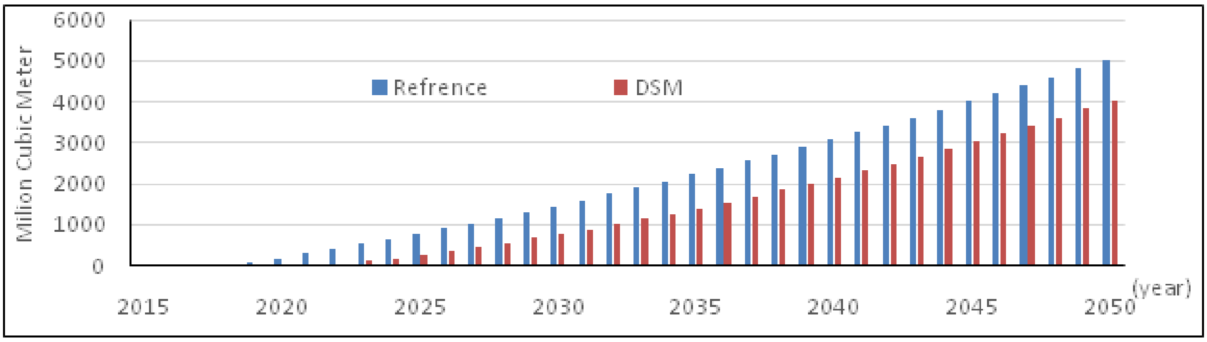


Figure 8. Annual total water unmet demand for reference scenario and implementation of DSM

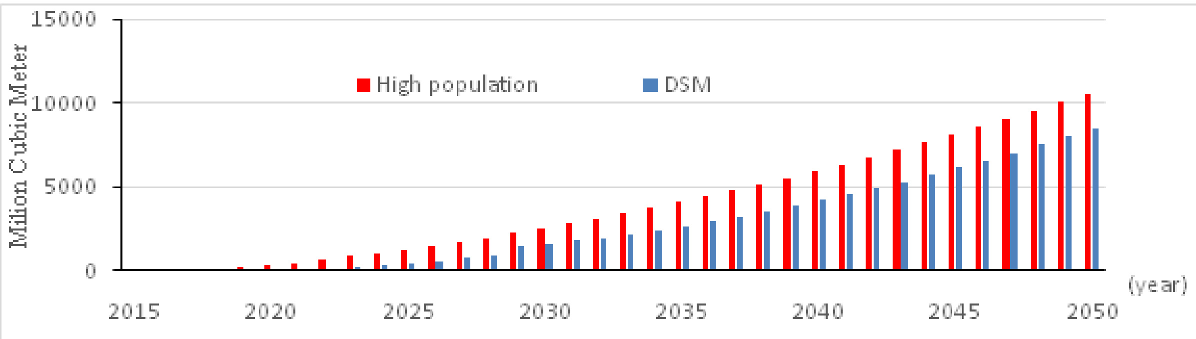
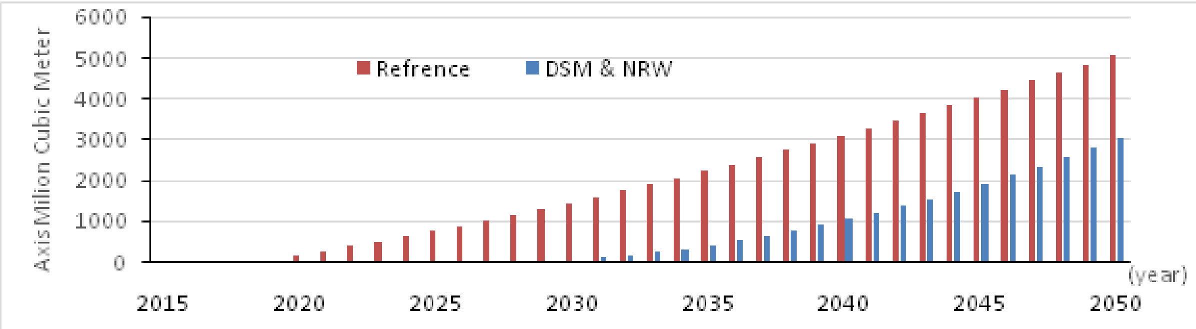


Figure 9. Total annual unsatisfied demand for high rate of population growth and implementation of DSM

4.5. Third scenario: mixture of DSM with reduction of non- revenue water (NRW)

This scenario includes implementation of management strateges of supply side (reduction in NRW from the current statuse of 33.4% to 16.7%) and demand side management (reduce water consumption per capta), which were evaluated against scenarios of reference and high rate of population growth. Figure (10) shows the implementation of the DSM strategy and the reduction of NRW makes water supply has capability to met water demand until 2023, this means shortage delay in a 13-years compared with reference scenario when DSM and NRW are non applied. In addition, when the implementation of the DSM strategy and the reduction of NRW, the deficit can be reduced by 62.85%, from 4,491.53 million cubic meters to 1,688.70 million cubic meters.

When evaluating the impact of implementing the DSM strategy and reducing NRW under the scenario of high population growth, the results showed that all demand could be satisfy until 2025, which means that the water shortage is delayed for a period of 9- years compared with the scenario when DSM and reduction NRW are non applied.



Figur 10. Annual total unmet demand for the reference scenario and implementation of DSM and reduced NRW

The model also predicted a decrease of 42.11% in unmet demand, ie, the decrease is from 8878.16 million cubic meters to 5139.85 million cubic meters. as illustright in Figure (11).

5. CONCLUSION

In the present research, WEAP model was used for evaluating the water conflict and present an integrated model of hydrologic. The model developed by WEAP is showed great performance and highly capable to manage water demand vs available water resources.

The quantitative statistics (R^2, NSE, and PBIAS) were used to evaluation of validation and calibration of model produce certain the model outputs defensible, robust, and scientifically sound.

This model provides a tool for decision makers to develop appropriate integrated water management plans. Thus enabling them to address potential conflicts arising from water policies and water distribution among stakeholders. Since the model can predict the results of the application of different possible management scenarios and compare with the results of the current management systems.

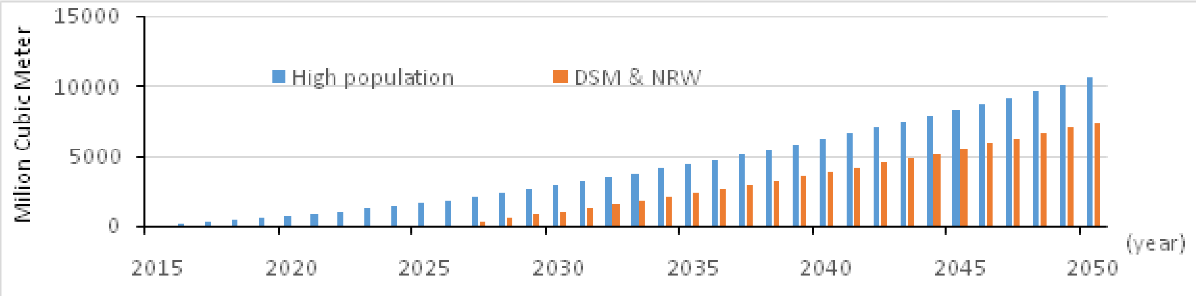


Figure 11. Annual total unmet demand for the population growth rate scenario and implementation of DSM and reduced NRW

ACKNOWLEDGEMENT

The author expresses his deep thanks and gratitude to the Stockholm Environmental Institute (SEI), USA for his support and also thanks the University of Qadisiyah, especially the Faculty of Engineering for its unlimited support.

REFERENCE

[1] Alemayehu, T., McCartney, M., & Kebede, S. (2011). The water resource implications of planned development in the Lake Tana catchment, Ethiopia. Eco hydrology and Hydrobiology, 10(2), pp.211–222.

[2] Al-Zubari, W. K., El-Sadek, A. A., Al-Aradi, M. J., & Al-Mahal, H. A. (2018). Impacts of climate change on the municipal water management system in the Kingdom of Bahrain: Vulnerability assessment and adaptation options. Climate Risk Management 20 , 95-110.

[3] Arranz, R., & McCartney, M. (2007). Application of the Water Evaluation And Planning (WEAP) model to assess future water demands and resources in the Olifants catchment, South Africa. Colombo, Sri Lanka: International Water Management Institute. .

[4] Bhatti, M., & Nasu, S. (2010). Domestic Water Demand Forecasting and Management Under Changing Socio-Economic Scenario. Society for Social Management Systems (SSMS-2010).

[5] Bhave, A. G., Conway, D., Dessai, S., & Stainforth, D. A. (2018). Water resource planning under future climate and socioeconomic uncertainty in the Cauvery River Basin in Karnataka, India. Water Resources Research, 54,, 708-728.

[6] Duque, L. F., & Vázquez, R. F. (2017). WEAP21 based modelling under climate change considerations for a semiarid region in southern-central Chile. , MASKANA, Vol. 8, No. 2, P.P. (125-146).

[7] Gupta, H. V., Sorooshian, S., & Yapo, P. O. (1999). Status of Automatic Calibration for Hydrologic Models: Comparison with Multilevel Expert Calibration. Journal of Hydrologic Engineering, 4, 135-143.

[8] ICID. (2010). International Commission on Irrigation and Drainage . Murcia, Spain.

[9] Jorda-Capdevila, D., Rodríguez-Labajos, B., & Bardina, M. (2016). An integrative modelling approach for linking environmental flow management, ecosystem service provision and inter-stakeholder conflict. Environmental Modelling & Software, vol. 79, p. 22-34.

[10] Kadhim Naief Kadhim (Estimating of Consumptive Use of Water in Babylon GovernorateIraq by Using Different Methods). (IJCIET), Volume 9, Issue 2, (Feb 2018)

[11] Leong, W. K., & Lai, S. H. (2017). Application of Water Evaluation and Planning Model for Integrated Water Resources Management: Case Study of Langat River Basin,

Malaysia, IOP Conf. Series: Materials Science and Engineering 210. IOP Conf. Series: Materials Science and Engineering 210.

[12] McCartney, M. P., & Menker, G. M. (2012). McCartney,Evaluating the downstream implications of planned water resource development in the Ethiopian portion of the Blue Nile River. Water International, 37(4), pp. 362-379.

[13] Metobwa, O. G., Mourad, K. A., & Ribbe, L. (2018). Water Demand Simulation Using WEAP 21: A Case Study of the Mara River Basin, Kenya. International Journal of Natural Resource Ecology and Management. Vol. 3, No. 1, pp. 9-18.

[14] Nandalal, K. D., & Simonovic, S. p. (2003). Resolving conflicts in water sharing: A systemic approach. Water Resour. Res., 39(12), 1362.

[15] Nash, J., & Sutcliffe, J. (1970). River flow forecasting through conceptual models part I — A discussion of principles. Journal of hydrology 10(3), 282-290.

[16] Santhi, C., Arnold, J. G., Williams, J., Dugas, W. A., Srinivasan, R., & Hauck, L. M. (2007). Validation of The Swat Model On A Large Rwer Basin With Point And Nonpoint Sources. Journal of the American Water Resources Association 37(5), pp. 1169-1188.

[17] Simonovic, S. P. (2012). Managing water resources: methods and tools for a systems approach. London, UK.: UNESCO,.

[18] Van Liew, M. W., Arnold, J. G., & Garbrecht, J. D. (2003). Hydrologic Simulation On Agricultural Watersheds : Choosing Between Two Models. ,Transactions of the ASAE 46, pp. 1539-1551.

[19] WEAP. (2016). Water Evaluation and Planning Model Tutorial.

[20] Zarghami, M., Safari, N., Szidarovszky, F., & Islam, S. (2015). Nonlinear Interval Parameter Programming Combined with Cooperative Games: a Tool for Addressing Uncertainty in Water Allocation Using Water Diplomacy Framework, . Water Resources Management 29 (12), 4285-4303.