

# Integrated Water Balance and Water Quality Management Under Future Climate Change and Population Growth: A Case Study of Upper Litani Basin, Lebanon

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## Research Article

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# Abstract

The impacts of the growing population at Lebanon including Lebanese, Palestinian and Syrian refugees, associated with the changing climate parameters such that the precipitation are putting the Bekaa Valley's water resources in a stymie situation. The water resources are under significant stress limiting the water availability and deteriorating the water quality at the Upper Litani River Basin (ULRB) within the Bekaa Valley region. These impacts are assessed by Water Evaluation And Planning model to assure the water balance and quality at baseline scenario in 2013, and future scenarios reaching 2095, serving by the Watershed Modeling System to get the flow throughout the Litani River's ungauged zones. Moreover, a General Circulation Model is used to predict the future climate up to 2100 under several emissions scenarios which shows a critical situation at the high emission scenario where the precipitation will be reduced about 87 mm from 2013 to 2095. The aim of this research is to reduce the water pollution that limits the availability of usable water, and to minimize the gap between the demand and supply of water within the ULRB in order to maintain water resources sustainability, and preserves its quality, even after 80 years. In particular, this may be achieved by removing encroachments on the river, by adding waste water treatment plants, by reducing the amount of lost water in damaged water network, and by avoiding the overconsumption of groundwater.

## 1. Introduction:

The fact that human's activities are striking a dramatic thrust on the environment's resources has led to increase the attention on the sustainability of these resources. The growing population and the climate change factors affected the water resources that faces many challenges. Hence, they should be protected in all ways, since all water resources are experiencing overexploitation, uncontrolled abstraction (Bou-Zeid & El-Fadel, 2002; Paul & Lakshmanan, 2018), and high percentage of pollution (Awoke et al., 2016; Yan et al., 2015), resulting in a huge water scarcity particularly in the Middle East region (Bou-Zeid & El-Fadel, 2002; Khouri et al., 2014).

Population growth have reduced the availability of freshwater resources in the Arab region. It dropped from 921 m<sup>3</sup> per capita per year in 2002 to 727 m<sup>3</sup> per capita per year a decade later. About twenty-two Arab countries fall below the water scarcity level of 1,000 m<sup>3</sup> per capita per year. As the case of the Litani River Basin at Bekaa Valley, Lebanon, where the total per capita water availability records 800 m<sup>3</sup>/capita/year at the year 2016 (UNESCO, 2015). The tremendous development in population including refugees from different countries poses a direct stress on all water resources within the Bekaa valley (H. Jaafar et al., 2017). As the whole Litani River is facing this problem, its Upper part is witnessing a worsening crisis due to the overcrowded population caused by the Syrian and Palestinian refugees. These refugees were stationed on the river banks of the Upper Litani River Basin (ULRB) resulting in a population increase about 413 thousand capita at the year 2016 (H. Jaafar et al., 2017).

Moreover, the future changes in climate, represented in meteorological factors changes, directly affect the hydrological fluxes (Gautam et al., 2018; Pham et al., 2017). The global warming, associated with drought (Gautam et al., 2018; H. Jaafar et al., 2017) and flood phenomena (Meresa & Gatachew, 2019; Zhong et al., 2018) as in many countries, is affecting the water resources. The negative impacts of temperature and precipitation changes on water resources have been shown to be remarkable. High CO<sub>2</sub> emissions increase the future temperature and may reduce, increase or unchanged the rainfall (Bou-Zeid & El-Fadel, 2002) and that will totally affect hydrologic components such as streamflow, soil moisture and evapotranspiration (Pham et al., 2017). A set of researches show that the predicted climate change for the future will present a negative alteration in the weather variables resulting in a decrease of water resources in semi-arid to arid areas such as the Middle East North Africa (MENA) region including Lebanon country (Bates et al., 2008; Bou-Zeid & El-Fadel, 2002; Ramadan et al., 2013). It is generally accepted that increased global temperatures will inevitably lead to changes in the hydrologic cycle. And since the Upper Litani River Basin (ULRB) is a global destination that is characterized by a moderate climate, it is subjected to climate change impacts, as all parts of Lebanon.

Besides the increase on the water demand due to population growth; and the water shortage and ground water level drops due to climate change, river's water quality is deteriorating. The human activities and unawareness harm the water quality (USAID-LRA, 2014), which in its turn reduce the availability of clean usable water leading to a water imbalance in this region. Besides the occurring population inflation, these people are rejecting their wastewater directly to the river without any treatment leading to deteriorate the Upper Litani River water quality (USAID-LRA, 2011a, 2011b).

However, water balance studies to assess deficit and surplus water are done on the MENA region, focusing on the case of the Litani River Basin that shows a deficit in water supply during the dry seasons (King-Okumu et al., 2016; USAID-LRA, 2011c). In the other hand, the bad water quality which limits the abstraction from the Litani River resulting to an overextraction of the available surrounding groundwater within the Litani river basin, leading to a drop in its storage volume by about 70 Mm<sup>3</sup>/year (Assaf & Saadeh, 2008; Baydoun, 2016; USAID-LRA, 2011c).

As showing lately, some water related problem's studies are done over the world, especially across the MENA region including as a special case Lebanon country and the Litani River. Every single study research focuses on a single major problem, some studies concentrates on the climate change impacts on the hydrologic response of the Upper Litani River (Alameddine et al., 2018). Besides, other studies focus on the effects of population growth due to the Syrian refugees on the water balance within the Bekaa district (H. Jaafar et al., 2017). Then a study adds the climate change effects on this water balance mentioning briefly the water quality threats faced in this region (King-Okumu et al., 2016). Moreover, Assaf & Saadeh focus on the deteriorated river water quality and find the solution that saves the river's water from pollution (Assaf & Saadeh, 2008).

Therefore, combining all these factors mentioned in those studies by assessing the impacts of the population growth and climate change on water resources accompanied by the water pollution and finding solutions to reduce the future negative consequences is extremely important. This study aimed to investigate an integrated water management under the effects of climate change, population growth, and water quality deterioration at the Upper Litani River Basin in Lebanon. In order to reach balanced sustainable water resources, first, simulations from several Global Circulation Models (GCMs) were used to predict future climate changes. Second, a water management tool, Water Evaluation And Planning (WEAP) model which have been used over many research areas (Paul & Lakshmanan, 2018), is used to evaluate the water balance within the ULRB. This model helps to predict the future state, offering a set of scenarios to reduce the negative climate change and population growth effects, to assure a future water balance and a clean water within the targeted area.

## **2. Study Area And Data:**

### **2.1. Study area:**

The Litani River is the largest river in Lebanon, which runs from Bekaa district to the South district and pours into the sea with a length of 174 Km and a basin area of 2110 Km<sup>2</sup>. It is divided into two sub-basins, the upper and the lower one separated by the lake Quaraoun as shown in Fig. 1 (Shaban & Hamze, 2018).

Our study focuses on the Upper part of the Litani River at Bekaa Valley, which runs through three districts (Baalbeck, Zahle, and West Bekaa), passing between Mount Lebanon chain and Anti-Lebanon chain to finally pour into the Quaraoun lake to record a sub-basin area of 1389 Km<sup>2</sup> approximately as shown by Fig. 1 (USAID-LRA, 2013). The upper Litani river basin (ULRB) covers an area divided to 40% agricultural lands, 10% urban lands, and 50% natural lands that hides five underground aquifers (Cretaceous, Jurassic, Neogene, Eocene, and Quaternary) (Saadeh et al., 2012; USAID-LRA, 2012b, 2013). These aquifers are feed from winter precipitation which records about 800 mm as a yearly average rainfall (FAO-IHE DELFT, 2019; Ramadan et al., 2013).

The Upper Litani river basin associated with its surrounding ground water, supply the diverse sectors of water demand within the Bekaa Valley area. The growing population expose the Upper Litani River to a dangerous loop. It is presented first by an increase in the consumption leading to an increase in the untreated effluent released in the river, and then a more polluted river water leading to an increase in the groundwater abstractions then a shortage in water supply and drop in groundwater tables.

## **2.2. Water Demand Data:**

### **2.2.1. Domestic Water Demand:**

In 2013, Syrian refugees started flowing to Lebanon in huge numbers and settle as informal settlements, which records 18,775 tents at the Litani river basin in 2016, and as formal settlements in apartments (H. Jaafar et al., 2017). Associated with the already existed Palestinian refugees in the Bekaa valley, the domestic water demand, which requires potable water, began to increase. The Lebanese, Palestinian, and Syrian population are showed in every district of the Bekaa valley in Table 1.

Lebanese domestic water demand per capita is assumed to vary between 100 to 150 l/capita/day (H. Jaafar et al., 2017), and reach 180 l/capita/day, as estimated by the Bekaa Water Establishment (BWE), (Machayekhi et al., 2017). As for the Syrian in informal settlement, the domestic water demand per capita was estimated by the UNHCR to be 120 l/day/capita (King-Okumu et al., 2016), and vary between 30 to 70 l/capita/day (Machayekhi et al., 2017). In this study, a domestic water demand per capita 150 l/day/capita is used for all domestic demands.

### **2.2.2. Industrial Water Demand:**

As reported by the Industrial Guide of Lebanon, there are 988 industries in the Bekaa with two-thirds of it located within the Upper Litani River Basin. While the ratio of the industrial to domestic water demand in Lebanon is estimated to be from 30 to 35%, industrial water demand is estimated to be 40% of the domestic water demand in the Bekaa valley region, since it has a higher industry to population ratio. (H. Jaafar et al., 2017)

### **2.2.3. Agricultural Water Demand:**

The Bekaa valley in Lebanon is characterized by agriculture, it has the largest agricultural area among Lebanon's cities. It was estimated by the ministry of agriculture, Atlas Agricole, and some satellite pictures to be 41240 ha in 2001, 55000 ha in 2005, and 50000 ha in 2011, respectively (USAID-LRA, 2011c, 2012a). Crop pattern shown in table 2 is important to identify agriculture water demand (Nouri et al., 2019; USAID-LRA, 2012a).

### **2.2.4. Precipitation:**

The average of a Tropical Rainfall Measuring Mission (TRMM) daily precipitation for Lebanon country during the interval time period 2006-2019 are used to represent the average precipitation of the year 2013 as shown in Table 3.

### **2.2.5. Groundwater:**

Groundwater storage has been estimated referring to the United State Agency for International Development (USAID). The natural recharge is calculated by getting the precipitation for each year over each aquifer's area and then multiplying it by the infiltration rate for each year, in addition to 50% of the losses from water and irrigation networks which percolates throughout the soil and reaches the aquifers as shown in Table 4 and 5 (USAID-LRA, 2012c).

### **2.2.6. Water Quality:**

Water quality released in the river from the different sectors has specific parameters for each pollutant. In this study, concentration of each pollutant for each effluent are shown below in Table 6. Besides, every sector has limitations on the water quality; deteriorated water quality is not suitable for many uses. For that reason, data about the effluent water released from all sectors coupled with the maximum accepted limit of concentration for each pollutant in the supplied water for each sector are shown in Table 6.

### **2.2.7. Waste Water Treatment Plant:**

Bekaa valley includes many wastewater treatment plants spread all over the region and serves approximately a total population of 1.128 million capita with 174243 m<sup>3</sup>/day sewage effluents shown in table 7 (Maher Salman, 2016).

## **3. Methodology:**

Two platforms are used to reach this study's goals: The Watershed Modeling System (WMS) and The Water Evaluation And Planning Model (WEAP). The first is used to get the river flow throughout the river; explained and calibrated in the section (3.1.). The second is used to get the water demand, supply, surplus or deficit in water, in addition to the flowing water quality; explained and calibrated in the section (3.2.).

Starting by the WMS model that needs as input the Digital Elevation Model (DEM), the monthly precipitation and the evapotranspiration represented by the curve number (CN) in order to get as output, the hydrograph of the river. This step is done because of the lack and uncertainties in measured river flows of the Upper Litani River (ULR). Moving to the WEAP model, it needs a group of data showed in the flowchart shown in Fig. 2. First to get the total demand; population, agricultural area, and water network efficiencies are used as input. Secondly, the aquifers and the estimated flow volume of the river from the WMS model are used as input of the available water resources. Thirdly, the inflow water quality represented by the concentration of pollutants in the released effluent from the demand sites directly to the river, and those passing throughout a group of wastewater treatment plants. Finally, the solution is represented by a set of future suggested scenarios. These six suggested scenarios are defined in section (3.3.4.) and evaluated to pick up the optimum one. The best scenario must include a minimum unmet demand, groundwater depletion and river stream flow depletion associated with a minimum river water pollution.

### 3.1. Watershed Modeling System:

The Watershed Modeling System (WMS) is a platform used to delineate all types of watersheds and sub-basins based on a Digital Elevation Model (DEM) map in order to get the flow of ungauged rivers (Sharkh, 2009). While gathering and analysing watershed's physical and hydrological data, it results with a hydrograph that shows the flowing volume of the basin among an interval of time. In our study, we apply WMS model for the Upper Litani River (ULR) to get the hydrograph of each branch as shown in Fig. 3a.

In order to calibrate the model, data from Litani River Authority (LRA) on the monthly river flow are used to compare the resulting hydrograph from the WMS river and the measured one. The average flow volume of the whole Litani river basin (with its two sub-basins) is estimated at 793 MCM/year (Machayekhi et al., 2017). The average flow volume of its upper sub-basin is estimated by the USAID at 410, 370, and 300 MCM/year at the years 1940, 1970, 2011, respectively (USAID-LRA, 2011c). As measured by the Litani River authority, the average flow volume of the ULRB is detected at 378 MCM based on the average of the flow volume during the years 1938-1962 (USAID-LRA, 2012b), and a flow volume of 234.6 MCM/year for the year 2013 (H. Jaafar et al., 2017). The WMS results represent almost the same trend of the measured flow for both 2009 and 2013 years, showing a shifted peak flow at the year 2013 as shown in the Fig. 3b and Fig. 3c (Nouri et al., 2019). It represents almost a matching volume at the year 2009 and 2013, 446 and 480 MCM/year, respectively. So, the WMS model is a reliable model to get the flow volume for the Upper Litani River.

### 3.2. Water Evaluation And Planning Model (WEAP):

This software was developed by Stockholm Environment Institute (SEI) to analyse and assess water quantity and quality based on water balance principle and return flows respectively, in order to meet sustainability conditions (Metobwa et al., 2018). It consists of a group of lines and nodes that represents water resources like that are connected to the demand nodes by the transmission links to supply the water demand. In return there are the return flows that collects the wastewater effluent coming from the demand nodes and going to the wastewater treatment plants node and then to the river as shown in Fig. 4.

The outflow concentrations of each pollutant are associated for each demand site on WEAP model, so that each demand site is releasing its pollutants concentrations in the river as shown in table 6. The water quality WEAP results are compared with the data from samples measured by the research centre for environment & development (RCED) of the Beirut Arab University (BAU) at Jeb Janine shown in Fig. 5 and Table 8.

The estimated WEAP nitrates, TDS, and BOD levels results was found to be almost in range, with respect to the values mentioned by the Basin Management Advisory Services (BAMAS 2005) (El Hassan et al., 2011; USAID-LRA, 2011b). Whereas, referring to a study done by the USAID, the nitrates and TDS levels show a match to some extent, but the BOD levels was shown to be greater in the dry season (El Hassan et al., 2011; USAID-LRA, 2011a, 2011b). However, the estimated nitrates, TDS, and phosphates levels by WEAP shows a match with the data from RCED BAU shown in the Fig. 5a-5b-5c, respectively, and exhibit closed results. Concerning the estimated BOD levels by WEAP, although it is higher than the data from RCED BAU shown in the Fig. 5d and it exhibiting deviated results, it shows results in between BAMAS and USAID studies. The WEAP model is then acceptable and reliable to be used in this study.

### 3.3. Future Conditions:

The future state will be reached by a set of adjustments in some parameters. For this purpose, the future climate parameters will change, especially the precipitation that has been predicted by the Intergovernmental Panel on Climate Change (IPCC) in section (3.3.1.). Moreover, the population growth and the agricultural area growth have been detected in sections (3.3.2.) and (3.3.3.), respectively, since these factors will affect the future water demand. Finally, a group of future suggested scenarios have been set and defined in order to assess the future state under each scenario.

#### 3.3.1. Climate Change:

In order to get the historical and future predicted precipitation, the Climate Model Intercomparison Project (CMIP5) of the Intergovernmental Panel on Climate Change (IPCC) is selected for this study (Intergovernmental Panel on Climate Change, 2014). A total of five models were selected: CanESM2, CSIRO-MK3.6.0, GISS-E2-H, MRI-CGCM3, and NorESM1-ME listed in table 9 (Bou-Zeid & El-Fadel, 2002; Karandish et al., 2017).

Each model had three emission scenarios, which are the Representative Concentration Pathways (RCPs): the high emission scenario (RCP 8.5) which is the pessimistic one named as “business as usual scenario”, the medium emission scenario (RCP 4.5) named as “stabilization scenario”, and the low emission scenario (RCP 2.6) which is the optimistic one named as “mitigation scenario”. For each scenario in each model, the period (2006-2019) was representing the average historical precipitation and compared with the TRMM data in section (2.2.4.) in order to get the bias error. The future period was divided into several intervals, 2025-2035, 2045-2055, 2070-2080, and 2089-2099, representing the average precipitation of the year 2030, 2050, 2075, and 2095, respectively. All models for each interval of years are gathered, averaged and then corrected by the bias error due to the uncertainty accompanying the IPCC models. After getting the average precipitation of all models for each emission scenario, and then correcting them, the bias corrected precipitation of all targeted years is then imported all into one sheet, and a percentage change is calculated. The climate change model’s results show that the high emission scenario is the worst one, so it was chosen to go through it in order to deal with the worst case as shown in Table 10. In this study, the predicted precipitation is decreased by 18% by reaching the year 2095. This descending precipitation will definitely affect the groundwater recharge and the river runoff.

### 3.3.2. Population Growth:

From the historical population data (1985-2019), the average growth rate is calculated in order to get the future population and compare it with the future population estimated by the World Bank (United Nations, 2019). The growth rate is taken 2% for Lebanese, Palestinian and Syrian. Assuming that, the Syrian will begin to leave Lebanon by the year 2030.

### 3.3.3. Agricultural Growth:

Future agricultural area was estimated to reach 60% of the total area of the Upper Litani River Basin so that the agricultural area will be 800 Km<sup>2</sup> by the year 2095 with a growth rate 0.52% per year (Byiringiro, 2013).

### 3.3.4. Suggested Scenarios:

Scenario 1: Reference Scenario or “Business as usual” Scenario: (REF)

This scenario represents the real current state and extends the predictions of the future state on the basis that there is no action taken to ameliorate the state.

Scenario 2: Groundwater Abstraction Restrictions Scenario: (GWR)

This scenario aims to maintain the groundwater sustainability. Wherefore, a groundwater maximal withdrawal, less than the recharge, is set for each aquifer.

Scenario 3: Water Quality improvements scenario: (WQI)

This scenario aims to protect the river water quality against the sewage water. Wherefore, the elimination of encroachments on the river to get an available suitable water quality meeting almost all uses is a must, by implementing the necessary wastewater treatment plants to treat almost all the wastewater effluent.

Scenario 4: Efficiency improvements scenario: (EffI)

This scenario aims to decrease the losses in the available water for use. Wherefore, losses in water networks are reduced by replacing the pipes whose age has already expired and by replacing the primitive methods of irrigation with modern ways.

Scenario 5: Scenario 3, and 4: (WQI & EFFI)

This scenario aims to assess both improvements combined. Therefore, both water quality improvements and efficiency improvements associated together are assessed.

Scenario 6: Scenario 2, 3, and 4: (WQI&EFFI&GWR)

This scenario is created to assess both water quality improvements and efficiency improvements, associated with the groundwater abstraction restriction scenario.

## 4. Results And Discussion:

The WEAP estimated results for the current base year 2013 and for the future years reaching 2095 show the river in poor conditions, especially in case no actions are taken to improve the situation. The estimated scenarios result by WEAP show the benefits and the drawbacks of each scenario.

### 4.1. Current Results:

The current 2013 WEAP estimated results mentioned in Table 11, show a total water demand equal to 381.9 MCM/yr, and a total water requirement equal to 597.91 MCM/year at the ULRB which matches with the studies done on this area concerning this topic. Alameddine et al. compute a total water demand 390 MCM by the year 2010 (Alameddine et al., 2018). Moreover, a study assesses a domestic water demand 83.3 MCM/yr, an industrial water demand 33.4 MCM/yr, an agricultural water demand 250 MCM/yr and an agricultural water requirement 415 MCM/yr with 60% efficiency corresponding for 35,500 ha of irrigated crops (H. Jaafar et al., 2017). These estimated values give a total water demand of 367.7 MCM and a total water requirement of 531.7 MCM/yr, thus matches the results in the Table 11. Whereas in a study done by the USAID, and before the Syrian crisis, total water demand was less, especially the domestic one. USAID researchers compute a total domestic demand 21 MCM/year corresponding to 380,000 capita, an industrial demand 5 MCM/year and an agricultural demand 249 MCM/year corresponding to a 45,700 ha of irrigated area (USAID-LRA, 2012c).

Concerning the water supply, the current WEAP estimated results show a surface water withdrawal equal to 266.6 MCM/year which approximately matches with Alameddine et al. and Jaafar et al. who computed a surface water supply 200 MCM/year at the year 2010 and 206 MCM/year at the year 2016, respectively (Alameddine et al., 2018; H. Jaafar et al., 2017). Regarding groundwater supply, the WEAP estimated result show a 329.2 MCM/year, in match with Jaafar et al. who mentioned a 320 MCM/year groundwater abstraction for agriculture only at the year 2016 (H. H. Jaafar & Ahmad, 2020). In contrast, a groundwater withdrawal was estimated at 190 MCM/year at the year 2010 and 156 MCM/year (Alameddine et al., 2018; USAID-LRA, 2012c). Moreover, a groundwater withdrawal for irrigation sector only was found to vary between 130 MCM/year and 200 MCM/year (Nassif, 2016). Besides, Molle et al. mentioned a 415 MCM/year groundwater withdrawal considering the irrigation efficiency at the year 2017 (Molle et al., 2017). Differences in groundwater extractions estimations mainly are due to the efficiency in water networks. Some studies take in account this efficiency and others mention the need of water which is the demand of sites from the groundwater, regardless the efficiency of water networks.

Concerning the river's water quality, the current results estimated by WEAP are discussed in the section (3.2.) and compared with other studies. Having a look on those results shown in table 8 and comparing them with the limitations shown in table 6, illustrates the problem. All of the nitrates, the total dissolved solids, biochemical oxygen demand and the phosphates represent concentrations higher than permissible.

### 4.2.Future Results:

#### 4.2.1. Scenario 1 results: Reference scenario:

The WEAP estimated results show that the unmet demand begins at the year 2023 and reach about 225 MCM at the year 2050 as shown in Fig. 6a which approximately matches the prediction done by Alameddine et al. that is equal to 200 MCM at the year 2050 (Alameddine et al., 2018). Jaafar et al. mentioned an unmet demand of 114 MCM at the year 2016 (H. Jaafar et al., 2017), however, in this study, this unmet is covered by the groundwater. The WEAP estimated groundwater result shows a decline in its volume estimated to be 103.76 MCM at the year 2013 which is lower than that estimated by Ministry Of Environment (MOE) at a value of 221 MCM at the year 2011 (UNDP, Ministry Of Environment, 2011). Other studies estimated much lower groundwater volume depletion at the values 45.7 MCM/year at the year 2013 (Nassif, 2016), 65 at 2014 (UNDP, 2014), 87 MCM/year at , 2016 (H. Jaafar et al., 2017), 70 MCM/year at 2017 (Stokvis, 2017), and 57.5 MCM/year between 2010 and 2016 (FAO-IHE DELFT, 2019). The WEAP groundwater volume results continue by declining its initial storage which is 8.19 BCM at the year 2013 to reach a storage of 4.43 BCM and 3.57 BCM at the year 2050 and 2095, respectively, as shown in Fig. 6b. Concerning the WEAP results related to the river flow, it represents a decline in its volume from 529 MCM at the year 2013 to reach 460 MCM and 367 MCM at the year 2050 and 2095, respectively, as shown by Fig. 6c. This decline is a result of a higher future water volume's withdrawal that is causing a drop of about 1.8 MCM/year in the river volume. This drop is almost matching that mentioned by Jaafar et al. who estimated an average rate decreasing volume 1 MCM/year between the years 1966 and 2011 (H. Jaafar et al., 2017). Moving to the WEAP estimated results concerning the river's water quality, it shows a huge increase in pollutant's concentrations in the river by time as shown by Fig. 7. The nitrates, TDS, BOD, and phosphates average yearly concentrations are increasing from 6.25

mg/L, 494.44 mg/L, 48 mg/L, and 6.3 mg/L at the year 2013 to 8.48 mg/L, 574.6 mg/L, 56.26 mg/L, and 8.14 mg/L at the year 2095, respectively, as shown in Fig. 7. These results combining the increased unmet demand with the decreased river and groundwater volumes, associating with the morbidly deteriorated water quality makes clear that solutions must be found. For this purpose, the scenarios results are discussed in the section below, in order to get to an optimum solution that saves the water resources of the Bekaa valley.

## 4.2.2. Suggested Scenarios results:

### Scenario 2 results: (GWR)

The groundwater abstraction restrictions (GWR) scenario shows a huge increase in the unmet demand caused by the limited supply from groundwater. The unmet demand reaches 427.46 MCM at the year 2050 and 791.12 MCM at the year 2095 as shown by the Fig. 6a. Although the groundwater storage volume witnesses a huge increase in its storage volume that reaches 12.82 BCM and 17.33 BCM by the year 2050 and 2095, respectively as shown by the Fig. 6b. This limitation caused a stress on the Litani river which in result cause a decline in its flow volume to reach 438.65 MCM and 356 MCM by the year 2050 and 2095, respectively as shown by the Fig. 6c. Regarding the river's water quality results in this scenario, the nitrates, TDS, BOD, and phosphates average yearly concentrations witness a drop from 6.25 mg/L, 494.44 mg/L, 48 mg/L, 6.3 mg/L going from the year 2013 to the year 2030 to reach 5.71 mg/L, 279.15 mg/L, 37.7 mg/L, 5.04 mg/L, respectively. After this drop these pollutants return to increase to reach 8.7 mg/L, 358.8 mg/L, 57.6 mg/L, 7.43 mg/L, respectively, by reaching the year 2095 as shown in Fig. 7. This drop in the pollutant's concentrations is due to the limited available water for use, that in its turn limits the quantity of polluted water released into the river. Besides, it increases again as a result of the accumulation of pollutants by time in the river. This scenario is rejected although it maintains the groundwater volume; it magnifies the unmet demand and doesn't improve the river's water quality which prevents achieving the main objectives of the study.

### Scenario 3 results: (WQI)

The water quality improvements scenario shows a decrease in the unmet demand caused by the increase in the availability of adequate river water for use. The unmet demand reaches 3.35 MCM and 253.31 MCM by the year 2050 and 2095, respectively as shown by the Fig. 6a. Although the groundwater storage maintains its volume over several years to reach 8.21 BCM at the year 2050 then it returns to decline to reach 5.83 BCM at 2095 as shown by the Fig. 6b. This improvement stressed the Litani river which in result cause a decline in its flow volume to reach 324.97 MCM and 197.2 MCM at the year 2050 and 2095, respectively as shown by the Fig. 6c. Moving on to the river's water quality WEAP results; the nitrates, TDS, BOD, and phosphates average yearly concentrations show a huge continued decrease from 6.25 mg/L, 494.44 mg/L, 48 mg/L, 6.3 mg/L, at the year 2013 to 3.48 mg/L, 284.08 mg/L, 17.73 mg/L, 2.1 mg/L at the year 2095, respectively, as shown in Fig. 7. This scenario can be accepted since it achieves almost all the goals of this research; it maintains the groundwater volume over several years, decreases the unmet demand and saves river water from the pollution.

### Scenario 4 results: (EFFI)

The efficiency improvements scenario shows a decrease in the unmet demand, besides the supply requirement also decreases, a result of the decline in the losses throughout the water networks. The unmet demand reaches 166 MCM and 469 MCM by the year 2050 and 2095, respectively as shown by the Fig. 6a. Despite the groundwater storage volume that declines throughout the years, but still better than the one of the reference scenario, it reaches 5.17 BCM and 4.65 BCM by the year 2050 and 2095, respectively as shown in Fig. 6b. This improvement almost shows a result like the reference scenario results. Concerning the Litani river volume, it declines to reach 466 MCM and 377 MCM by the year 2050 and 2095, respectively as shown by the Fig. 6c. In the other hand, the WEAP estimated water quality results show an increasing average yearly concentration of the nitrates, TDS, BOD and phosphates going from the year 2013 that records 6.25 mg/L, 494.44 mg/L, 48 mg/L, 6.3 mg/L, to the year 2095 that records 7.5 mg/L, 517.8 mg/L, 49.26 mg/L, 7.26 mg/L, respectively as shown in Fig. 7. This scenario is rejected since it is similar to the reference one, it doesn't present any remarkable advantages.

### Scenario 5 results: (WQI & EFFI)

The combining improvements scenario shows a huge decrease in the unmet demand caused by the increase in the availability of adequate river water for use and by the decline in supply requirement. The unmet demand reaches 2 MCM and 114 MCM by the year 2050 and 2095, respectively as shown by the Fig. 6a. Although the groundwater storage shows an increase in its volume over several years then it decreases to reach 9.1 BCM and 5.81 BCM by the year 2050 and 2095, respectively as shown by the Fig. 6b. These improvements caused a huge stress on the Litani river which in result cause a decline in its flow volume to reach 340.9 MCM and 235 MCM by the year 2050 and 2095, respectively as shown by the Fig. 6c. Besides, the WEAP estimated results concerning the water quality of the Upper Litani River was found to be better. The nitrates, TDS, BOD and phosphates average yearly concentrations are decreasing from 6.25 mg/L, 494.44 mg/L, 48



mg/L, 6.3 mg/L at the year 2013 to reach 2.94 mg/L, 207.58 mg/L, 14.87 mg/L, 1.53 mg/L, respectively, at the year 2095 as shown by Fig. 7. This scenario is accepted since it conserves the groundwater volume, decreases the water loss and the unmet demand and saves river's water from pollution.

#### Scenario 6 results: (GWR & WQI & EFFI)

The combining improvements and groundwater abstraction restrictions scenario shows an increase in the water unmet demand caused by the restrictions on the groundwater withdrawals. The unmet demand reaches 253 MCM and 389 MCM by the year 2050 and 2095, respectively as shown in Fig. 6a. This scenario is almost like the groundwater abstraction scenario. Although the groundwater storage witnesses a huge increase in its volume to reach 15.33 BCM and 23.32 BCM by the year 2050 and 2095, respectively as shown in Fig. 6b. The Litani river is under a stress caused by the availability of adequate water for supply and the limitations on groundwater supply. The Litani river volume reach 340 MCM and 232 MCM by the year 2050 and 2095, respectively as shown in Fig. 6c. Regarding the WEAP estimated water quality results, this scenario shows an improvement in pollutants concentration. Hence, the average yearly concentration of the nitrates, TDS, BOD and phosphates is decreasing from 6.25 mg/L, 494.44 mg/L, 48 mg/L, 6.3 mg/L at the year 2013, to reach 2.8 mg/L, 144.24 mg/L, 13.8 mg/L, 1.1 mg/L, respectively, at the year 2095 as shown by Fig. 7. This scenario is rejected although it increases the groundwater volume, saves the river's water from pollution; it increases the unmet demand which conflicts with the research objectives.

The scenarios results estimated by WEAP shows that the best scenario which represents sustainability in the water resources accompanied by the lowest water unmet demand is the scenario 5 which includes both improvements WQI&EffI scenario. This sustainability is assessed by the maintenance of the groundwater volume and the good river's water quality. Those results show the need of policy-makers to really take an action to beat the upcoming severe climate conditions and growing population. The necessary actions will be represented by some technical and political improvements, which transform the wastewater from burden to benefit, and will create a smart water management plan. To reach this end, a set of wastewater treatment plants must be planted and designed to treat an additional 200 MCM/year effluent volume by the year 2095, equivalent to a total capacity of 265 MCM/year. Moreover, the water and wastewater networks must be tested and renewed if necessary; focusing on the separate sewer systems instead of the combined one.

## 5. Conclusion:

The objective of this study is to assess the negative effects of climate change and population growth on the water resources of the Upper Litani River Basin in terms of quantity and quality. Five Global Circulation Models are used under three greenhouse gases emissions to predict the future precipitation changes. The future precipitation data shows an average decrease of about 0.23% per year under the impact of climate change. So obviously, the ULRB will face a drier climate in the future causing failure to meet water needs and deterioration of water reserves. A couple of water related softwares are used and calibrated in order to study the interaction of the water resources to the variation in climate and population. The monthly river flow is estimated by the Watershed Modelling System (WMS) software, and then used to get the water balance within the ULRB by the Water Evaluation And Planning (WEAP) model. The population is increasing by an average growth rate 2% per year, causing a stress on water resources by the aggravation on water demand. The unmet demand of all water demand sectors is exacerbating over time as a result of the increasing population accompanied by the decrease of the precipitation, leading to an overextraction from the river water and groundwater. In the other hand, the growing population accompanied by harmful human activities damage the river water quality. The effluent released from different sectors is directed to the river without any treatment causing the water to be unsuitable for use. A reference scenario is created on the WEAP software to evaluate the water balance situation without doing any additional act to improve it. Besides the reference scenario, five proposed scenarios are created to assess the effects of some valuable upgrades and compared with the reference scenario. Those scenarios carry a group of different improvements like water quality improvements, water networks efficiency improvements, and groundwater abstraction control. By going through those solutions, an optimum scenario presents an acceptable result. The Reference scenario shows an increasing unmet demand, a decreasing groundwater volume and river flow volume, and a bad river water quality that deteriorates over time. The optimistic results of the selected strategy are resumed with a reduction in the unmet demand, a preservation in the groundwater volumes and a conservation in the river's water quality.

## Declarations

### Ethics approval

This is an original paper for master study which has neither previously nor simultaneously been submitted anywhere else

### Consent to participate

The authors have seen and approved the final manuscript.

### Consent for publication

The authors have agreed to publish the study in the water resource management journal.

### Author's contributions

Rana Abou Slaymane: Models creation, analysis and verification, data curation, and writing original draft.

Mohamad Reda Soliman: Checking the model's results, exploring the problems, and reviewing the paper.

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### Conflicts of interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

### Availability of data and materials

All measured data are gathered from the Litani River Authority and The Research Center for Environment and Development of Beirut Arab University.

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## Tables

**Table 1** Upper Litani River Basin Population (Thousand capita) (H. Jaafar et al., 2017)

Governorate/District	Lebanese	Palestinian	Syrian	Total
Baalbeck	416.48	5.12	132.00	553.60
Zahle	364.15	7.67	193.00	564.82
West Bekaa	134.80	4.97	70.28	210.05
Total	915.43	17.76	395.28	1328.47

**Table 2** Agricultural water demand over ULRB by crop

Crop	Water consumption m <sup>3</sup> /ha/year	Crop area (ha)			Crop pattern
		Baalbeck	Zahle	West Bekaa	
Wheat	7000	2000	2500	3000	Nov-Oct-Jan-Feb-Mar-Apr-May-Jun
Corn	7000	1200	800	1800	Jul-Aug-Sep
Barley	7000	800	1200	1200	Nov-Oct-Jan-Feb-Mar-Apr-May-Jun
Cucumber	7000	200	200	200	Jul-Aug-Sep-Oct
Lettuce	7000	500	600	600	Sept-Oct-Nov
Late Potato	7000	1000	1500	1300	Jul-Aug-Sep-Oct
Early Potato	7000	1000	1300	1500	Feb-Mar-Apr-May-Jun-Jul
Tomato	7000	1000	1500	1500	Jun-Jul-Aug-Sep
Chickpeas	7000	800	1000	1000	Jan-Feb-Mar-Apr-May
Fava beans	7000	600	600	800	Jun-Jul-Aug
Tobacco	7000	800	800	1000	-
Fruit Trees	3000	1000	4000	2000	-
Olives	1000	800	100	1100	-
Vineyards	0	1000	2000	2500	-
Grape yards	3000	400	800	800	-
Sub-Total	-	13100	18900	20300	-
Grand Total	-		52300		-

**Table 3** Historical average Precipitation in mm 2006-2019 over ULRB

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)	96.81	96.32	49.32	23.97	15.82	2.86	0.005	0.61	7.51	48.16	41.38	86.93

**Table 4** Ground Water natural recharge MCM/year (Molle et al., 2017; USAID-LRA, 2012c)

Year	Aquifer	Precipitation mm/year	Area Km <sup>2</sup>	Average Precipitation (MCM/year)	Percent Infiltration	Groundwater Recharge (MCM/year)	Seepage to groundwater (MCM/year)	Total Recharge (MCM/year)
2006-2019	West							
	Carbonate	470	435	204.45	20%	40.89	35.14	76
	Quaternary/Neogene	470	304	142.88	10%	14.29	12.28	26.57
	East							
	Carbonate	470	604	283.88	20%	56.78	48.8	105.57
	Quaternary/Neogene	470	292	137.24	10%	13.72	11.8	25.52
Sum			1635	768.45		125.68	108	233.66

**Table 5** Groundwater Initial storage MCM and natural recharge MCM/year per district (Molle et al., 2017; USAID-LRA, 2012c)

District	Age	Initial storage at the year 2012 (Mm <sup>3</sup> )		Natural recharge (Mm <sup>3</sup> /year)	
		East	West	East	West
<b>Baalbeck</b>	Cretaceous	922.5	553.5	17	24.4
	Jurassic	182.5	-	35.9	-
	Neogene	280.5	187	4.75	5.1
	Quaternary	255	255	4.1	4
	Eocene	33.5	-	1	-
<b>Zahle</b>	Cretaceous	811.8	295.2	15	13
	Jurassic	-	109.5	-	6.1
	Neogene	280.5	46.75	4.75	1.3
	Quaternary	367.2	346.8	5.9	5.4
	Eocene	100.5	-	3	-
<b>West Bekaa</b>	Cretaceous	922.5	184.5	17.2	8.1
	Jurassic	-	438	-	24.3
	Neogene	-	140.25	-	3.7
	Quaternary	367.2	448.8	5.9	7
	Eocene	536	-	16.1	-
<b>Total</b>	-	5059.4	3005.3	131.1	102.6
<b>Sum</b>	-	8064.7		233.7	

**Table 6** Concentration of chemicals in the return flows from each sector to the river and the maximum accepted limits in the supplied water for each sector

Concentration	Phosphate mg/l		Nitrate mg/l		BOD mg/l		TDS mg/l	
	Effluent	Limit	Effluent	Limit	Effluent	Limit	Effluent	Limit
<b>Domestic</b>	16*	1-	20*	10*	200*	2+	700*	500 <sup>a</sup>
<b>Industrial</b>	16*	1-	20*	10*	100*	2+	500*	500 <sup>a</sup>
<b>Agricultural</b>	10*	1-	3*	45 <sup>-</sup>	25 <sup>-</sup>	40*	2000*	1000 <sup>-</sup>

\*: FAO; +: World Health Organization WHO; -: Beirut Arab University BAU report;  
 ×: Pesticide safety education program PSEP; α: Environmental Protection Agency EPA;  
 -: International water resources association IWRA

**Table 7** Wastewater Treatment Plants within the ULRB (MAHER SALMAN, 2016)

District	Project Name	Treatment stage	Status	Capacity (m <sup>3</sup> /day)	Population served thousand (cap)
<b>Baalbeck</b>	laat	Secondary	Completed	12000	88
	Maarboun	Secondary	2020	383	3.727
	Chmistar	Trickling filter	Ongoing	1800	13.2
	Tmnine Tahta	Secondary	Under preparation	25000	100
<b>Zahle</b>	Ablah	Secondary	Completed	2000	14.63
	Ferzol	Secondary	Completed	1000	7.4
	Zahle	Tertiary	Under preparation	35000	259
	Aanjar	Secondary	planned	44500	275
	Zahleh	Trickling filter	Ongoing	18000	120
<b>West Bekaa</b>	Jeb Jannine	Tertiary	Completed	10000	67
	Saghbine	Secondary	Completed	560	3.7
	Qaraoun	Secondary	Under preparation	24000	177

**Table 8** Comparison of river water quality parameters reported by BAMAS 2005, USAID 2010-11, RCED BAU 2013, and BAU tested samples at summer 2019 versus the WEAP estimated results. (USAID-LRA, 2011a, 2011b)

Indicator	Survey season	WEAP Estimated Results		BAMAS 2005		USAID 2010-11		RCED BAU 2013		BAU Samples Summer 2019
		Min	Max	Min	Max	Min	Max	Min	Max	
<b>Nitrates</b>	Wet	1.1	14.1	<1	49.7	0.2	9.6	7.3	11	47
	Dry	5.3	11.7	3	62	0.1	4.9	5.7	9.5	
<b>Total Dissolved Solids (TDS)</b>	Wet	64.7	781	114	415	118	533	382	1114	1009
	Dry	403	1051	88	706	187	1979	556	907	
<b>Biochemical Oxygen Demand (BOD)</b>	Wet	9.5	112	0	45	2	70	5.4	16	75
	Dry	39.9	90.6	2	624	2.5	2530	5	18.1	
<b>Phosphates</b>	Wet	1	12.7	NA	NA	NA	NA	0.85	12.7	11.6
	Dry	5.3	11.7	NA	NA	NA	NA	4.7	14.9	

**Table 9** Climate change models

Model Name	Institution	Atmospheric resolution
<b>CanESM2</b>	Canadian centre for climate modelling and analysis, Canada	NA
<b>CSIRO-MK3.6.0</b>	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Australia	1.9°x1.9°
<b>GISS-E2-H</b>	National Aeronautics and Space Administration (NASA)/Goddard Institute for Space Studies (GISS), USA	4°x5°
<b>MRI-CGCM3</b>	Meteorological Research Institute, Japan	2.8°x2.8°
<b>NorESM1-ME</b>	Norwegian Earth System Model, Norway	1.9°x2.5°

**Table 10** Historical and future average precipitation of Lebanon

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum	Percent Decrease
<b>2006-2019</b>	96.82	96.33	49.32	23.97	15.82	2.86	0.00	0.61	7.51	48.17	41.39	86.94	469.74	-
<b>2030</b>	102.93	97.69	57.72	27.62	13.58	2.79	0.00	0.64	4.99	41.33	40.43	71.58	461.30	1.796
<b>2050</b>	80.76	93.38	41.90	21.05	11.24	3.01	0.00	0.45	11.80	50.45	36.94	90.01	440.98	6.123
<b>2075</b>	81.73	96.03	48.55	20.78	9.89	2.58	0.00	0.62	12.31	44.23	36.40	72.10	425.22	9.478
<b>2095</b>	80.92	69.50	44.84	20.29	10.13	2.63	0.00	0.43	8.90	37.43	34.04	73.47	382.59	18.553

**Table 11** Current demand and supply for each sector from each source in MCM

Sector		Demand	Requirement	Surface	Ground	Rainfed
Lebanese		50.35	71.93	25.5	46.4	-
<b>Domestic</b>	Syrian	21.74	31.06	7	24	-
Palestinian		0.98	1.4	0.23	1.17	-
<b>Total Domestic</b>		73.07	104.39	32.7	71.6	-
<b>Industrial</b>		29.23	41.75	35	6.7	-
<b>Agriculture</b>		279.6	451.78	198.9	250.8	2.12
<b>Total</b>		381.9	597.91	266.6	329.2	2.12
<b>Total Supply Delivered</b>		-	-	597.91		

## Figures

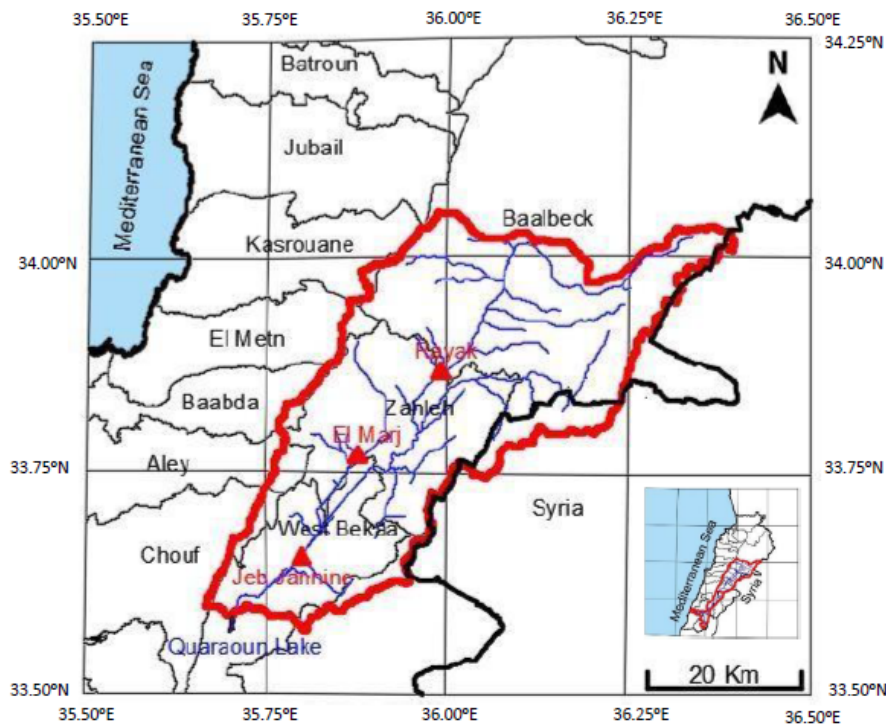




Figure 1

Study Area: Upper Litani River Basin ULRB

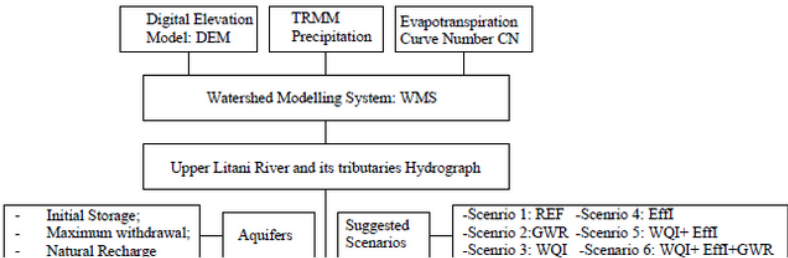


Figure 2

Flowchart showing the methodology followed by this research

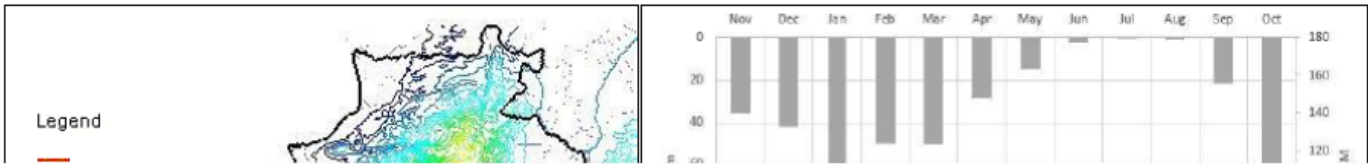


Figure 3

3a WMS model for the ULRB. 3b Correspondent observed and estimated flow volume MCM of the Upper Litani river resulted by the precipitation in mm for the year 2009. 3c Correspondent observed and estimated flow volume Mm3 of the Upper Litani river resulted by the precipitation in mm for the year 2013.



Figure 4

WEAP model for the ULRB

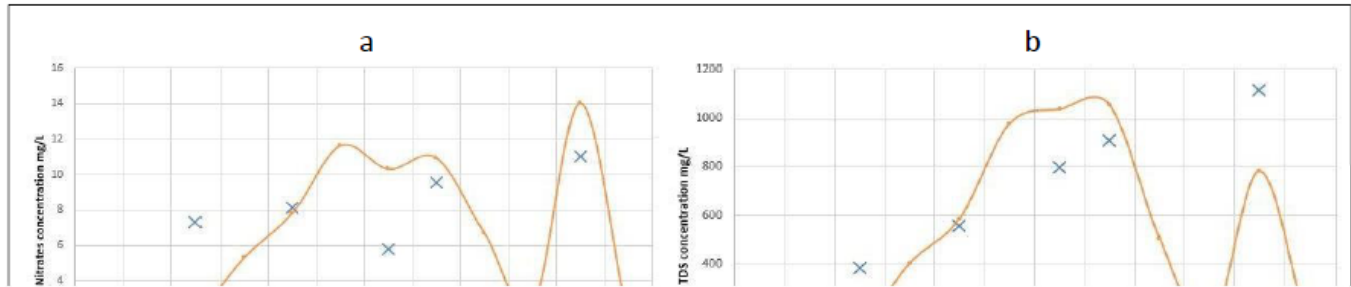


Figure 5

Measured versus WEAP estimated Water Quality concentration mg/l at Jeb Janine 2013:

5a Nitrates, 5b TDS, 5c BOD, 5d Phosphates

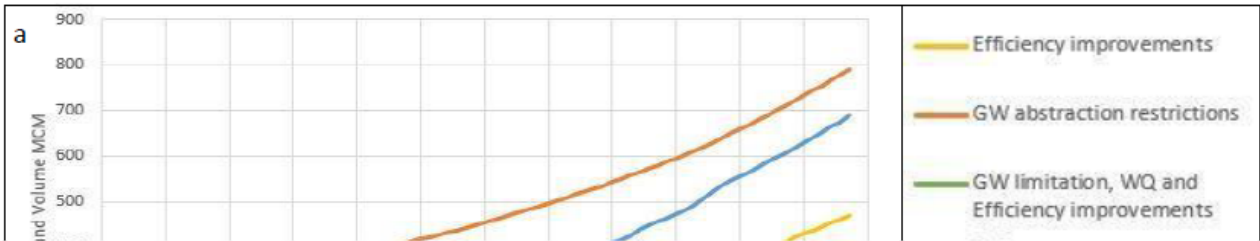
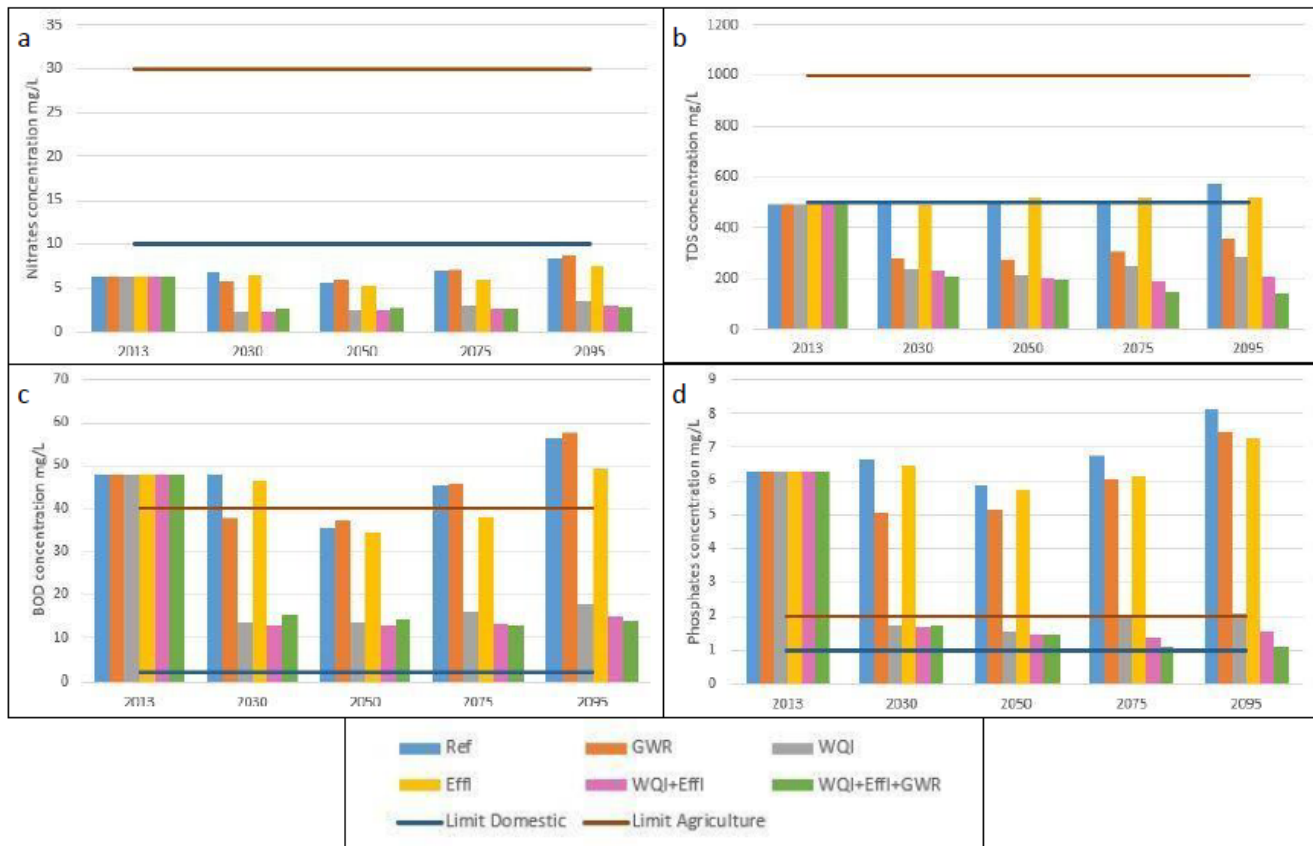


Figure 6

6a Unmet Demand Volume; 6b Groundwater Storage Volume; 6c Streamflow Volume



**Figure 7**

Pollutant's concentrations in the ULR: 7a Nitrates; 7b TDS; 7c BOD; 7d Phosphates