Abstract

The impacts of the growing population in Lebanon including Lebanese, Palestinian, and Syrian refugees, together with the changing climate, are putting the Bekaa Valley’s water resources in a precarious situation. The water resources are under significant stress limiting the water availability and deteriorating the water quality in the Upper Litani River Basin (ULRB) within the Bekaa Valley. Here, the impacts on water balance and water quality for a 2013 baseline and future scenarios are simulated using the Water Evaluation And Planning model, served by the Watershed Modeling System which provides flows throughout the ungauged zones of the Litani River and its tributaries. The output from a General Circulation Model is used to project the future climate up to 2100 under several emissions’ scenarios which shows a critical situation in the high emission scenario where the precipitation will be reduced by about 87 mm from 2013 to 2095. The research highlights the need 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 to maintain water supply and quality, even after 80 years. This may be achieved by removing encroachments on the river, adding wastewater treatment plants, reducing the amount of lost water in damaged water network, and avoiding the overconsumption of groundwater.

Keywords  Climate change impacts · Water resources management · Water quality assessment · Litani River Basin

1 Introduction

The fact that human activities are striking a dramatic thrust on the environment’s resources has led to increasing the attention on the sustainability of these resources. The growing population and the climate change factors affected the water resources that face
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 a high percentage of pollution (Awoke et al., 2016; USAID-LRA, 2011a, 2011b; Yan et al., 2015), resulting in huge water scarcity, particularly in the Middle East region (Bou-Zeid & El-Fadel, 2002; Khouri et al., 2014).

Population growth has reduced the availability of freshwater resources in the Arab region. It dropped from 921 m$^3$ per capita per year in 2002 to 727 m$^3$ per capita per year a decade later (UNESCO, 2015). About twenty-two Arab countries fall below the water scarcity level of 1,000 m$^3$ per capita per year. In the case of the Litani River Basin at Bekaa Valley, Lebanon, the total per capita water availability registers 800 m$^3$/capita/year in the year 2016 (UNESCO, 2015). The tremendous development in population including refugees from different countries poses direct stress on all water resources within the Bekaa valley (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 including refugees. These refugees were stationed on the river banks of the Upper Litani River Basin (ULRB) resulting in a population increase of about 413 thousand per capita in the year 2016 (Jaafar et al., 2017).

Moreover, the predicted climate changes, represented in meteorological factors changes, directly affect the hydrological fluxes (Gautam et al., 2018; Pham et al., 2017). Global warming, associated with drought (Gautam et al., 2018; Jaafar et al., 2017) and flood phenomena (Meresa & Gatchew, 2019; Zhong et al., 2018) in many countries, is affecting the water resources. The negative impacts of temperature and precipitation changes on water resources are remarkable in the Middle East North Africa (MENA) region. High CO$_2$ emissions increase the future temperature and may reduce, increase, or unchange the rainfall (Bou-Zeid & El-Fadel, 2002; Ministry of Foreign Affairs, 2018) and that will affect hydrologic fluxes (Pham et al., 2017). Previous studies showed that the predicted climate change 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 MENA region including Lebanon country which shows a decrease in its main rivers and springs (Bates et al., 2008; Bou-Zeid & El-Fadel, 2002; Shaban, 2011). Therefore, Lebanon, including the Upper Litani River Basin (ULRB), will be subjected to climate change that will negatively affect the hydrological components such as the evapotranspiration, the streamflow volume, and the groundwater recharge (Beighley et al., 2013; Jaafar et al., 2020; Ramadan et al., 2013).

Besides the increase in the water demand due to population growth, the shortage in water, and dropped groundwater levels due to climate change and overextractions, the river’s water quality is deteriorating. Human activities and unawareness harm the water quality (USAID-LRA, 2014), which in its turn reduces the availability of clean usable water leading to a water imbalance in this region. Besides the occurring population inflation, these people are discharging their wastewater directly into the river without any treatment leading to the deterioration of the Upper Litani River water quality (USAID-LRA, 2011a, 2011b).

However, water balance studies to assess deficit and surplus water are done in the MENA region, focusing on the case of the Litani River Basin which shows a deficit in water supply during the dry seasons (King-Okumu et al., 2016; USAID-LRA, 2011c). On the other hand, the bad water quality limits the abstraction from the Litani River resulting in an overextraction of the available surrounding groundwater within the Litani River Basin, leading to a drop in its storage volume by about 70 Mm$^3$/year (Assaf & Saadeh, 2008; Baydoun, 2016; USAID-LRA, 2011c).
Some studies on water-related problems are done over the world, especially across the MENA region including as a special case Lebanon country and the Litani River. Some have concentrated on the climate change impacts on the hydrologic response of the Upper Litani River (Alameddine et al., 2018). Besides, other studies focused on the effects of population growth due to the Syrian refugees on the water balance in Lebanon and within the Bekaa district as a special case (Jaafar et al., 2017, 2020). Another study added the change climate effects on this water balance mentioning briefly the water quality threats faced in this region (Darwish et al., 2021; King-Okumu et al., 2016). Moreover, Assaf and Saadeh (2008) focused on the deteriorated river water quality and found a solution that might save the river’s water from pollution.

Therefore, combining all these factors including the assessment of the impacts of the population growth and climate change on water resources together with the water pollution and resolving the negative consequences is in high demand. This study highlights the need of investigating integrated water management under the effects of climate change, population growth, and water quality deterioration at the Upper Litani River Basin in Lebanon. To reach balanced sustainable water resources, and meet the Sustainable Development Goals 6 and 13: to reach clean water and sanitation, and climate action. 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 has been used in 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 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 the Bekaa district to the South district and pours into the sea with a length of 174 km and a basin area of 2110 km². It is divided into two sub-basins, the upper and the lower sub-basins, 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 km² approximately as shown in Fig. 1 (USAID-LRA, 2013). The Upper Litani River Basin (ULRB) covers an area divided into 40% agricultural lands, 10% urban lands, and 50% natural lands that incorporates five underground aquifers (Cretaceous, Jurassic, Neogene, Eocene, and Quaternary) (Saadeh et al., 2012; USAID-LRA, 2012b, 2013). These aquifers are fed 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 groundwater supplies the diverse sectors of water demand within the Bekaa Valley area. The growing population exposes 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 and then a shortage in water supply and a 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 in informal settlements, which records 18,775 tents in the Litani River Basin in 2016, and in formal settlements in apartments (Jaafar et al., 2017). Associated with the already existing Palestinian refugees in the Bekaa valley, the domestic water demand, which requires potable water, began to increase. The Lebanese, Palestinian, and Syrian populations are shown in every district of the Bekaa valley in Table 1.

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

| 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  |
Lebanese domestic water demand per capita is assumed to vary between 100 and 150 l/capita/day (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 Syrians in the 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 varied between 30 and 70 l/capita/day (Machayekhi et al., 2017). In this study, a domestic water demand per capita of 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 them 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, since it has a higher industry to population ratio (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 41,240 ha in 2001, 55,000 ha in 2005, and 50,000 ha in 2011, respectively (USAID-LRA, 2011c, 2012a). The crop pattern shown in Table 2 is essential to identify the agricultural water demand (Nouri et al., 2019; USAID-LRA,

| Crop         | Water consumption m³/ha/year | Crop area (ha) | Crop pattern               |
|--------------|------------------------------|----------------|----------------------------|
|              | Baalbeck | Zahle | West Bekaa |                          |
| Wheat        | 6290     | 2000 | 2500 | 3000 | Nov-Oct-Jan-Feb-Mar-Apr-May-Jun |
| Corn         | 6190     | 1200 | 800  | 1800 | Jul-Aug-Sep               |
| Barley       | 6190     | 800  | 1200 | 1200 | Nov-Oct-Jan-Feb-Mar-Apr-May-Jun |
| Cucumber     | 6540     | 200  | 200  | 200  | Jul-Aug-Sep-Oct           |
| Lettuce      | 6540     | 500  | 600  | 600  | Sept-Oct-Nov              |
| Late Potato  | 5740     | 1000 | 1500 | 1300 | Jul-Aug-Sep-Oct           |
| Early Potato | 5740     | 1000 | 1300 | 1500 | Feb-Mar-Apr-May-Jun-Jul   |
| Tomato       | 6540     | 1000 | 1500 | 1500 | Jun-Jul-Aug-Sep           |
| Chickpeas    | 6190     | 800  | 1000 | 1000 | Jan-Feb-Mar-Apr-May      |
| Fava beans   | 6190     | 600  | 600  | 800  | Jun-Jul-Aug              |
| Tobacco      | 4860     | 800  | 800  | 1000 | -                        |
| Fruit trees  | 5300     | 1000 | 4000 | 2000 | -                        |
| Olives       | 6890     | 800  | 100  | 1100 | -                        |
| Vineyards    | -        | 1000 | 2000 | 2500 | -                        |
| Grape yards  | 3800     | 400  | 800  | 800  | -                        |
| Sub-total    | 13,100   | 18,900| 20,300| -       |
| Grand total  | -        | 52,300| -     | -                      |

Note: Vineyards supply its need only from rainfall water.
Besides, crop water consumption was estimated referring to the USAID and the World Bank (USAID-LRA, 2016; World Bank, 2003).

### 2.2.4 Precipitation

The precipitation data were taken throughout the time interval 2009–2019 from three different weather stations each one located in the district that it represents: Talia station at Baalbeck, Tal Al Amara station at Zahle, and Kherbet Anafar station at West Bekaa as shown in Table 3 and Fig. 3a.

### 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 percolate throughout the soil and reaches the aquifers as shown in Table 4 (USAID-LRA, 2012c).

### 2.2.6 Water quality

Water quality released in the river from different sectors has specific parameters for each pollutant. In this study, the concentration of each pollutant for each effluent released from every single sector is shown in Table 5. 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 acceptable limit of concentration for each pollutant in the supplied water for each sector are shown in Table 5.

### 2.2.7 Wastewater 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 174,243 m$^3$/day of sewage effluents shown in Table 6 (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 (WEAP) model. The first is used to get the river flow throughout the river, explained and calibrated in Sect. 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 Sect. 3.2.

Starting with the WMS model; the Digital Elevation Model (DEM) of Lebanon, the monthly precipitation of the ULRB, and the evapotranspiration represented by the curve number (CN), are used as input in order to get the hydrograph of the river as output. This step is done because of the lack and uncertainties in some measured river flows of the Upper Litani River (ULR), especially at the outlet of some tributaries. Moving to the WEAP model, a group of data shown in the flowchart shown in Fig. 2 is needed. First to get the total demand, population, agricultural area, and water network efficiencies are used.
Table 3  Historical average precipitation in mm 2009–2019 over ULRB within each district

| Station                      | Month |       |       |      |      |    |       |       |       |       |       |
|------------------------------|-------|-------|-------|------|------|----|-------|-------|-------|-------|-------|
|                              | Jan   | Feb   | Mar   | Apr  | May  | Jun | Jul   | Aug   | Sep   | Oct   | Nov   | Dec   |
| Talia at Baalback            | 127.2 | 83.95 | 39.05 | 13.6 | 5.55 | 0.15| 0     | 0     | 1.35  | 4.8   | 34.95 | 105.5 |
| Tal Al Amara at Zahle        | 136.93| 134.87| 77.58 | 33.59| 12.4 | 0.14| 1.014 | 0.5   | 2.21  | 32.83 | 63.24 | 109.92|
| Kherbet Anafar at West Bekaa | 215.92| 137.92| 52.2  | 49.64| 23.36| 7.84| 4.24  | 0     | 5.4   | 47.32 | 68.72 | 180.12|
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 is 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 Sect. 3.3.4 and evaluated to pick up the optimum one. The best scenario must include a minimum unmet demand, groundwater depletion, and river streamflow depletion associated with a minimum river water pollution.

Table 4  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 (Mm³) | Natural recharge (Mm³/year) |
|--------------|----------|----------------------------------------|-----------------------------|
|              |          | East | West | East | West |
| Baalbeck     | Cretaceous| 922.5 | 553.5 | 14 | 19 |
|              | Jurassic  | 182.5 | -    | 29 | -  |
|              | Neogene   | 280.5 | 187  | 4  | 4.1 |
|              | Quaternary| 255  | 255  | 3.5| 3.5 |
|              | Eocene    | 33.5 | -    | 0.85| -  |
| Zahle        | Cretaceous| 811.8 | 295.2 | 18.3| 15.7|
|              | Jurassic  | -    | 109.5 | - | 7.4 |
|              | Neogene   | 280.5 | 46.75 | 6.1| 1.6 |
|              | Quaternary| 367.2 | 346.8 | 7.5| 6.8 |
|              | Eocene    | 100.5 | -    | 3.6| -  |
| West Bekaa   | Cretaceous| 922.5 | 184.5 | 27.2| 12.8|
|              | Jurassic  | -    | 438  | - | 37.3 |
|              | Neogene   | -    | 140.25| - | 6.13|
|              | Quaternary| 367.2 | 448.8 | 9.5| 11.5|
|              | Eocene    | 536  | -    | 25 | -  |
| Total        | -        | 5059.4| 3005.3| 148.55| 125.83|
| Sum          | -        | 8064.7| 274.38|

Table 5  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 |
| Domestic      | 16*      | 1--   | 20*      | 10×    | 200*     | 2+     | 700*     | 500⁺    |
| Industrial    | 16*      | 1--   | 20*      | 10×    | 100*     | 2⁺     | 500*     | 500⁺    |
| Agricultural  | 10⁻      | 3⁻    | 45⁻      | 25⁻    | 40⁺      | 200⁺   | 1000⁻    |

*FAO; World Health Organization (WHO); Beirut Arab University (BAU) report; Pesticide Safety Education Program (PSEP); Environmental Protection Agency (EPA); International Water Resources Association (IWRA).

Effluent: The pollutant concentration existed in the return flow from the demand sites rejected into the river body.

Limit: Maximum allowable pollutant concentration in the supplied water. The supplied water quality is tested against those concentrations; if it is found to be greater, the demand site will not consume this polluted water.
The Watershed Modeling System (WMS) is a semi-distributed hydrological model that calculates flow routing based on Soil Conservation Service (SCS) method. The flow path is determined based on topographical DEM inputs. The flow routing is calculated according to the sub-basin unit hydrograph (Sharkh, 2009). While gathering and analyzing the watershed’s physical and hydrological data; the WMS results in a hydrograph that shows the flowing volume of the basin over an interval of time. In our study, we apply the WMS model for the Upper Litani River (ULR) to get the hydrograph of each branch as shown in Fig. 3a.

### Table 6  Wastewater treatment plants within the ULRB (Maher Salman, 2016)

| District   | Project name | Treatment stage | Status            | Capacity (m³/day) | Population served thousand (cap) |
|------------|--------------|-----------------|-------------------|-------------------|---------------------------------|
| Baalbeck   | Iaat         | Secondary       | Completed         | 12,000            | 88                              |
|            | Maarboun     | Secondary       | Completed at 2020 | 383               | 3.727                           |
|            | Chmistar     | Trickling filter| Ongoing           | 1800              | 13.2                            |
|            | Tmnine Tahta | Secondary       | Under preparation | 25,000            | 100                             |
| Zahle      | Ablah        | Secondary       | Completed         | 2000              | 14.63                           |
|            | Ferzol       | Secondary       | Completed         | 1000              | 7.4                             |
|            | Zahle         | Tertiary       | Under preparation | 35,000            | 259                             |
|            | Aanjar       | Secondary       | Planned           | 44,500            | 275                             |
|            | Zahleh       | Trickling filter| Ongoing           | 18,000            | 120                             |
| West Bekaa | Jeb Jannine  | Tertiary       | Completed         | 10,000            | 67                              |
|            | Saghbine     | Secondary       | Completed         | 560               | 3.7                             |
|            | Qaraoun       | Secondary       | Under preparation | 24,000            | 177                             |

**Fig. 2** Flowchart showing the methodology followed by this research

### 3.1 Watershed Modeling System

The Watershed Modeling System (WMS) is a semi-distributed hydrological model that calculates flow routing based on Soil Conservation Service (SCS) method. The flow path is determined based on topographical DEM inputs. The flow routing is calculated according to the sub-basin unit hydrograph (Sharkh, 2009). While gathering and analyzing the watershed’s physical and hydrological data; the WMS results in a hydrograph that shows the flowing volume of the basin over an interval of time. In our study, we apply the WMS model for the Upper Litani River (ULR) to get the hydrograph of each branch as shown in Fig. 3a.
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 in the years 1940, 1970, and 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 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); however, the year 2013 was experiencing very low precipitation comparing to other years. The WMS results represent almost the same trend of the measured flow for the year 2013, showing a shifted peak flow as shown in Fig. 3c. It represents almost a matching volume of 447 MCM/year. So, the WMS model is a reliable model to get the flow volume for the Upper Litani River.

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

This software was developed by Stockholm Environment Institute (SEI) to analyze and assess water quantity and quality based on the water balance principle and return flows respectively, to meet sustainability conditions (Metobwa et al., 2018). It consists of a group of lines and nodes that represent water resources that are connected to the demand nodes by the transmission links to supply the water demand. In return, there are the return flows that collect 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 with each demand site on the WEAP model so that each demand site is releasing its pollutant concentrations in the river as shown in Table 5. 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 6.
The estimated WEAP nitrate, TDS, and BOD levels results were 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 nitrate and TDS levels show a match to some extent, but the BOD levels were shown to be greater in the dry season (El Hassan et al., 2011;
USAID-LRA, 2011a, 2011b). However, the estimated nitrate, TDS, and phosphates levels by WEAP showed a match with the data from RCED BAU shown in Fig. 5 a, b, and d, respectively, and exhibited closed results. Concerning the estimated BOD levels by WEAP, although it is higher than the data from RCED BAU shown in Fig. 5c and it exhibits deviated results, it shows results 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 Sect. 3.3.1. Moreover, the population growth and the agricultural area growth have been detected in Sects. 3.3.2 and 3.3.3, respectively, since these factors will affect the future water demand. Finally, a group of future suggested scenarios has been set and defined to assess the future state under each scenario. Table 7.

3.3.1 Climate change

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 8 (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 Tropical Rainfall Measuring Mission (TRMM) data 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 years 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 to deal with the worst case as shown in Table 9. In this study, the predicted precipitation is decreased by 18% by reaching the year 2095. This descending precipitation will affect the groundwater recharge and the river runoff.
Table 7  Comparison of river water quality parameter reported by BAMAS 2005, USAID 2010–2011, 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 2010–2011 | RCED BAU 2013 | BAU samples Summer 2019 |
|-----------------------------|---------------|------------------------|------------|-----------------|---------------|-------------------------|
| Nitrates                    | Wet           | Min 0.81 Max 6.72      | Min <1 Max 49.7 | Min 0.2 Max 9.6 | Min 7.3 Max 11 | 47                      |
|                             | Dry           | Min 7.4 Max 12.3       | Min 3 Max 62 | Min 0.1 Max 4.9 | Min 5.7 Max 9.5 |                         |
| Total dissolved solids (TDS)| Wet           | Min 46 Max 420         | Min 114 Max 415 | Min 118 Max 533 | Min 382 Max 1114 | 1009                    |
|                             | Dry           | Min 298 Max 994        | Min 88 Max 706 | Min 187 Max 1979 | Min 556 Max 907 |                         |
| Biochemical oxygen demand (BOD) | Wet         | Min 6.7 Max 40.56     | Min 0 Max 45 | Min 2 Max 70 | Min 5.4 Max 16 | 75                      |
|                             | Dry           | Min 28.3 Max 54        | Min 2 Max 624 | Min 2.5 Max 2530 | Min 5 Max 18.1 |                         |
| Phosphates                  | Wet           | Min 0.75 Max 6.67     | NA         | NA              | 0.85 Max 12.7 | 11.6                    |
|                             | Dry           | Min 4.15 Max 12.9     | NA         | NA              | 4.7 Max 14.9 |                         |
3.3.2 Population growth

From the historical population data (1985–2019), the average growth rate is calculated 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. Noting that the immigrations to Lebanon will be controlled by the year 2030, so some immigrants will be leaving to their countries.

3.3.3 Agricultural growth

The future agricultural area was estimated to reach 60% of the total area of the Upper Litani River Basin so the agricultural area will be 800 km$^2$ by the year 2095 with a growth rate of 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 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 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

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**Table 8 Climate change models**

| Model name | Institution | Atmospheric resolution |
|------------|-------------|------------------------|
| CanESM2    | Canadian Centre for Climate Modelling and Analysis, Canada | NA |
| CSIRO-MK3.6.0 | Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Australia | $1.9^\circ \times 1.9^\circ$ |
| GISS-E2-H  | National Aeronautics and Space Administration (NASA)/Goddard Institute for Space Studies (GISS), USA | $4^\circ \times 5^\circ$ |
| MRI-CGCM3  | Meteorological Research Institute, Japan | $2.8^\circ \times 2.8^\circ$ |
| NorESM1-ME | Norwegian Earth System Model, Norway | $1.9^\circ \times 2.5^\circ$ |
### Table 9  Historical and future average precipitation of Lebanon

| Year   | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum  | Percent decrease |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------------------|
| 2006–2019 | 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 | - |
| 2030    | 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 |
| 2050    | 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 |
| 2075    | 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 |
| 2095    | 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 |
This scenario aims to decrease the losses in the available water for use. Therefore, 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: Scenarios 3 and 4: WQI and EFFI

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

Scenario 6: Scenarios 2, 3, and 4: WQI, EFFI, and 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 the future years reaching 2095 show that the river is in poor condition, especially in case no actions are taken to improve the situation. The estimated scenarios’ result by WEAP shows the benefits and the drawbacks of each scenario.

4.1 Current results

The current 2013 WEAP estimated results mentioned in Table 10 show a total water demand equal to 375.82 MCM/year, and by adding the losses throughout the water networks, a total water requirement, which represents the water demand in addition to the losses, equal to 574.34 MCM/year occurs at the ULRB. Those results match with the studies done in this area concerning this topic. Alameddine et al. computed a total water demand of 390 MCM throughout the interval of time 2001 to 2010 (Alameddine et al., 2018). Moreover, a study assesses a domestic water demand of 83.3 MCM/year, industrial water demand of 33.4 MCM/year, agricultural water demand of 250 MCM/year, and an agricultural water requirement of 415 MCM/year with 60% efficiency corresponding to 35,500 ha of irrigated crops (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/year, thus matching

| Sector      | Demand  | Requirement | Surface | Ground  | Rainfed |
|-------------|---------|-------------|---------|---------|---------|
| Domestic    |         |             |         |         |         |
| Lebanese    | 50.35   | 71.93       | 38.52   | 33.48   | -       |
| Syrian      | 21.74   | 31.06       | 8.32    | 22.68   | -       |
| Palestinian | 0.98    | 1.4         | 0.27    | 1.13    | -       |
| Total domestic | 73.07 | 104.39      | 47.11   | 57.29   | -       |
| Industrial  | 29.23   | 41.75       | 29.2    | 12.56   | -       |
| Agriculture | 273.52  | 428.2       | 144.4   | 268.02  | 15.76   |
| Total       | 375.82  | 574.34      | 220.71  | 337.87  | 15.76   |
| Total supply delivered | |            | 574.34  |        |         |
the results in Table 10. 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 of 21 MCM/year corresponding to 380,000 capita, an industrial demand of 5 MCM/year, and an agricultural demand of 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 220.71 MCM/year which approximately matches with Alameddine et al. and Jaafar et al. who computed a surface water supply of 200 MCM/year in the year 2010 and 206 MCM/year at the year 2016, respectively (Alameddine et al., 2018; Jaafar et al., 2017). Regarding groundwater supply, the WEAP estimated result shows a 337.87 MCM/year, almost matching Jaafar et al.’s results who mentioned a 320 MCM/year groundwater abstraction for agriculture only in the year 2016 (Jaafar & Ahmad, 2020). In contrast, a groundwater withdrawal was estimated at 190 MCM/year in the year 2010 and 156 MCM/year (Alameddine et al., 2018; USAID-LRA, 2012c). Moreover, a groundwater withdrawal for the 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 in the year 2017 (Molle et al., 2017). Differences in groundwater extractions estimations mainly are due to the efficiency of water networks. Some studies take into account this efficiency and others mention the need for water which is the demand of sites from the groundwater, regardless of the efficiency of water networks.

Concerning the river’s water quality, the current results estimated by WEAP are discussed in Sect. 3.2 and compared with other studies. Having a look at those results shown in Table 7 and comparing them with the limitations shown in Table 5, the problem is illustrated. All of the nitrates, the total dissolved solids, biochemical oxygen demand, and 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 in the year 2026 and reach about 150 MCM in the year 2050 as shown in Fig. 6a which approximately matches the prediction done by Alameddine et al. that is equal to 200 MCM in the year 2050 (Alameddine et al., 2018). Jaafar et al. mentioned an unmet demand of 114 MCM in the year 2016 (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 134 MCM in the year 2013 which is lower than that estimated by the Ministry of Environment (MOE) at a value of 221 MCM in the year 2011 (UNDP, Ministry Of Environment, 2011). Other studies estimated much lower groundwater volume depletion at the value of 45.7 MCM/year in the year 2013 (Nassif, 2016), 65 MCM/year in 2014 (UNDP, 2014), 87 MCM/year in 2016 (Jaafar et al., 2017), 70 MCM/year in 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 8.2 BCM in the year 2013 to reach storage of 3.7 BCM and 0.5 BCM in the years 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 676 MCM in the year 2013 to reach 651 MCM and 531 MCM in the years 2050 and 2095, respectively, as shown by Fig. 6c. This decline
is a result of a higher future water volume withdrawal that is causing a drop of about 1.5 MCM/year in the river volume. This drop is almost matching that mentioned by Jaafar et al. (2017) who estimated an average rate of decreasing volume of 1 MCM/year between the years 1966 and 2011. Moving to the WEAP estimated results concerning the river’s water quality, a huge increase is shown in pollutant concentrations in the river over time as shown in Fig. 7. The nitrates, TDS, BOD, and phosphates’ average yearly concentrations are increasing by about 36%, 6.2%, 17.2%, and 29.2% from the years 2013 to 2095, respectively, as shown in Fig. 7. These results combining the increased unmet demand with the decreased river and groundwater volumes, associated with the morbidly deteriorated water quality, make clear that solutions must be found. For this purpose, the scenarios’ results are discussed in the section below, in order to get 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 restriction (GWR) scenario shows a huge increase in the unmet demand caused by the limited supply of groundwater. The unmet demand reaches 371.35 MCM in the year 2050 and 651.84 MCM in the year 2095 as shown in Fig. 6a. Though, the groundwater storage volume witnesses a huge increase in the storage volume that reaches 13.41 BCM and 18 BCM in the years 2050 and 2095, respectively as shown in Fig. 6b. This limitation caused stress on the Litani River which in result caused a decline in its flow volume to reach 595 MCM and 506 MCM in the years 2050 and 2095, respectively, as shown by Fig. 6c. Regarding the river’s water quality results in this scenario, the nitrates, TDS, BOD, and phosphates average yearly concentrations witness a drop by about 8.6%, 43%, 21%, and −20% going from the year 2013 to
the year 2030, respectively. After this drop, these pollutants return to increase by 52.27%, 43.77%, 52.76%, and 47.48%, 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, which 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 does not improve the river’s water quality which prevents achieving the main objectives of the study.

**Scenario 3 results: WQI** The water quality improvement scenario shows a decrease in the unmet demand caused by the increase in the availability of adequate river water for use. The unmet demand remains at 0 MCM in the year 2050 and reaches 126 MCM in 2095 as shown in Fig. 6a. Although the groundwater storage maintains its volume over several years to reach 7.63 BCM in the year 2050, then it returns to decline to reach 3.62 BCM in 2095 as shown in Fig. 6b. This improvement stressed the Litani River which as a result caused a decline in its flow volume to reach 517 MCM and 386.8 MCM in the years 2050 and 2095, respectively, as shown in Fig. 6c. Moving to the river’s water quality WEAP results, the nitrates, TDS, BOD, and phosphates average yearly concentrations show a huge continued to decrease by 44.3%, 43%, 63%, and 66.7% from the year 2013 reaching 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 pollution.

**Scenario 4 results: EFFI** The efficiency improvements scenario shows a decrease in the unmet demand; besides, the supply requirement also decreases, as a result of the decline in the losses throughout the water networks. The unmet demand reaches 70 MCM and 351.4 MCM by the years 2050 and 2095, respectively, as shown in Fig. 6a. Despite the
groundwater storage volume that declines throughout the years, but still better than the one of the reference scenario, it reaches 4.44 BCM and 1.24 BCM by the years 2050 and 2095, respectively, as shown in Fig. 6b. This improvement almost shows a result like a reference scenario results. Concerning the Litani river volume, it declines to reach 648 MCM and 544.9 MCM by the years 2050 and 2095, respectively, as shown in Fig. 6c. On the other hand, the WEAP estimated water quality results show an increasing average yearly concentration of the nitrates, TDS, BOD, and phosphates by 19.8%, 0.15%, 2.6%, and 15.25% going from the year 2013 to the year 2095, respectively, as shown in Fig. 7. This scenario is rejected since it is similar to the reference one; it does not present any remarkable advantages.

Scenario 5 results: WQI and EFFI The combining improvement 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 requirements. The unmet demand remains at 0 MCM by the year 2050 and reaches 83 MCM in the year 2095, respectively, as shown in Fig. 6a. Although the groundwater storage shows a slight increase in its volume over several years, then it decreases to reach 8.3 BCM and 6.3 BCM by the years 2050 and 2095, respectively, as shown in Fig. 6b. These improvements caused huge stress on the Litani River which as a result caused a decline in its flow volume to reach 533.6 MCM and 387 MCM by the years 2050 and 2095, respectively, as shown in Fig. 6c. Besides, the WEAP estimated results concerning the water quality of the Upper Litani River were found to be better. The nitrates, TDS, BOD, and phosphates’ average yearly concentrations are decreasing by 52.9%, 42.2%, 69%, and 75.7% from the year 2013 to reach 2095, respectively, as shown in Fig. 7. This scenario is accepted since it conserves the groundwater volume, decreases the water loss and the unmet demand, and saves the river’s water from pollution.

Scenario 6 results: GWR and WQI and EFFI Combining improvements and groundwater abstraction restriction scenario shows an increase in the water unmet demand caused by the restrictions on the groundwater withdrawals. The unmet demand reaches 242 MCM and 340.6 MCM by the years 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 14.55 BCM and 21.4 BCM by the years 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 reaches 595 MCM and 506 MCM by the years 2050 and 2095, respectively, as shown in Fig. 6c. Regarding the WEAP estimated water quality results, this scenario shows an improvement in pollutant concentration. Hence, the average yearly concentration of nitrates, TDS, BOD, and phosphates decreased by 55.2%, 63.3%, 71.2%, and 82.6% from the year 2013 reaching the year 2095, respectively, as shown in Fig. 7. This scenario is rejected although it increases the groundwater volume, and saves the river’s water from pollution; it increases the unmet demand which conflicts with the research objectives.

The scenario results estimated by WEAP show that the best scenario which represents sustainability in the water resources accompanied by the lowest water unmet demand is scenario 5 which includes both improvements, the WQI and 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 for policymakers to take action to beat the upcoming severe climate conditions and growing population. Besides the efficient use of water, 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 400 MCM/year effluent volume by the year 2095. Moreover, the water and wastewater networks must be tested and renewed if necessary, focusing on the separate sewer systems instead of the combined ones.

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 gas 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 software is used and calibrated to study the interaction of the water resources to the variation in climate and population. The monthly river flow is estimated by the Watershed Modeling 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 of 2% per year, causing stress on water resources by amplifying the need for 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 in the precipitation, leading to an overextraction of the river water and groundwater. On the other hand, the growing population accompanied by harmful human activities damages 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 action 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 network efficiency improvements, and groundwater abstraction control. By going through those solutions, the optimum scenario is that of scenario 5. The reference scenario showed an increasing unmet demand, decreasing groundwater and river flow volume, and a bad river water quality that deteriorates over time. The optimistic results of the selected strategy consisting of improved water quality and efficient water networks are resumed with a reduction in the unmet demand, preservation in the groundwater volumes, and conservation of the river’s water quality.

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Author contribution Rana Abou Slaymane: model’s creation, analysis and verification, data curation, and writing the original draft.

Mohamad Reda Soliman: checking the model’s results, exploring the problems, and reviewing the paper.
Data Availability. All measured data are gathered from the Litani River Authority and The Research Center for Environment and Development of Beirut Arab University.

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.

Conflict of interest. The authors declare no competing interests.

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