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ORIGINAL ARTICLE

Water Environment in the Coastal Basins of Syria - Assessing the Impacts of the War

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Abstract The water environment in the Syrian coastal basins was already under pressure over the past decade (2000–2010) due to recurring drought and increased water demand. The armed-conflict, which started in 2011, had resulted in the displacement of more than 1.45 million people from the inland regions towards the coastal area. This study investigates the impact of war and conflict on the water environment in the coastal river basins of Syria. An evaluation of existing water sources, water uses, and pollution sources is made to highlight the major driving forces and stresses using a pre-war, during the war, and a post-war scenario. A reference time frame between 2000 and 2010 is used as a reference for these scenarios. The impact of war on the water environment is discussed next. Different actions and adaptation measures in a post-conflict scenario are presented and discussed. At present 4.45 million persons are living in the coastal area (compared to 3 million before 2011). The governmental management capacity had reduced to 30 % compared to that before war. An evaluation of major water scarcity indicators revealed a decline in renewable water resources (including groundwater reserves). It is estimated that the water scarcity index reduced from ~760 m^3/capita/year during pre-war dry years to less than 500 m^3/capita/year during the war. The impact of war also revealed an increase in pollution risks due to the uncontrolled water abstraction, lack of management and decreased water accessibility. Proposed measures in a post conflict scenario suggest that water demand and water quality can be restored to the status quo using suitable economic development options.

Keywords Water vulnerability · Water resources indicators · Water and conflict · Syria

1 Introduction

Water resources availability is driven by the changes and alteration of the climate, social, economic and management systems (IPCC 2013). Mediterranean coastal zones are among the

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most vulnerable areas to climate variability and water scarcity (Bates et al. 2008). In fact, water availability is highly sensitive to the variability of the climate system which has a direct impact on the water, the agricultural sectors and the sustainability of the environmental system (IPCC 2013). According to Guardiola-Claramonte et al. (2011), the Mediterranean region, with 7 % of the global population, has only ~2 % of the world's freshwater resources. The southern and eastern Mediterranean regions are constantly more exposed to the decrease in water availability to meet their ever increasing domestic and agricultural water demands. Based on IPCC (2013) climate change scenarios, these areas are expected to have increased temperature and a decrease in precipitation. It is most certain that the combined changes of temperature and precipitation will impact the water balance by altering the partitioning between rain, evapotranspiration, surface runoff and groundwater recharge. These changes are expected to impact the sustainability, quality, quantity and management of water resources, and eventually increase the water stress (Cardona 2011; Brauch 2007, 2011, 2013; Bates et al. 2008; Shahin 2009; IPCC 2013)

Various studies carried over the time period between 2000 and 2010 in Syria suggested that the major drivers for water scarcity are mainly the recurring drought (Haktanir et al. 2004), increased water demand from urban and agricultural sectors, poor management (Zimmo and Imseih 2011; AbuZeid 2012), increasing water pollution (El-Kholy et al. 2012), poor sanitation from wastewater discharges (Zawahriet al. 2011), and increasing sea water intrusion (Kaisi et al. 2005). The average renewable water resources in Syria were estimated at around 16± 2.2 km^3/year. The over-exploitation of water resources was considered a major problem in Syria as a whole, though less common in the coastal area when compared to inland areas. At the national scale, the water scarcity index was estimated at 800 m^3/capita/year, which is less that the global threshold of 1,000 m^3/capita/year. The average water stress index in 2010 over the coastal area ranged between 760 m^3/capita/year (dry year conditions) and 1,000 m^3/capita/year (wet year conditions). According to UNEP (2008), the water stress indicator of a country or region is classified as "water stress" when the annual water supplies drop below 1,700 m^3/capita/year, and as "water scarcity" when they drop below 1,000 m^3/capita/year.

The armed-conflict, which escalated in 2011, exacerbated the situation. As a result, the water sector had been hindered by the decrease in the water management and operational capacities of the governmental bodies, which declined to around 30 % of their normal operation capacity, the internal population displacement, the damage to the water systems, and the decrease of the quality of the water environment system due to numerous pollution sources.

Few studies had assessed both surface and groundwater resources, the interaction between groundwater and surface water (i.e., springs), water quality, and use for drinking and agricultural practices. The impact of armed-conflict on these resources, and the potential increased risk on population health, remain unassessed. The purpose of the current research is to review the state of water resources in the Syrian coastal area over the time period between 2000 and 2010. A review of the climate and water resources use are presented first, followed by the assessment of the war impact on the water resources sector. In this context, simulations based on changes regarding population displacement, system performance and water quantity and quality indicators are used. Potential impacts are outlined using indices, and potential adaptation measures in a post-war scenario are also presented.

2 Study Area

Located on the eastern part of the Mediterranean Sea, the coastal basins of Syria extend from the Turkish border to the north to the Lebanese borders to the south. The coastal basins have a total area of 5,070 km^2, distributed between the administrative units of Lattakia and Tartous (occupying 80 % of the total area). The Syrian coast lies mainly on a flat plain, where topography varies from 0 m at the coastal region and flat areas to around 1,500 m above mean sea level (amsl). The geomorphology of the coastal region can be divided into the following 5 main distinctive areas: (i) the shoreline, which comprises the shallow water and the area between the seawater edge and the beach; (ii) the lower coastal plain, which comprises the flat, fertile and water rich land, and is associated with concentration of human activities; (iii) the coastal plateau, which is dominated by the adjacent hills of elevation ranging between 100 and 400 m amsl, which are usually less fertile and less rich in water; (iv) the steep hills, where elevation ranges between 400 and 600 m amsl which are dominated by intermittent river valleys; and (v) the upper plateau with elevation of 600 up to 1,000 m amsl. Among the most vulnerable areas are river valleys, which cross the coastal plain to reach the sea and are mainly subject to small impoundments collecting water during winter runoff.

The climate is typically Mediterranean humid or subtropical climate, with a gradual decrease in rainfall and temperature patterns from north to south, and increase in precipitation with elevation as one moves from the coastal area to the more elevated mountainous areas located eastward of the coastal zones (PAP/RAC 1990). Based on the observed climatology, rain occurs between November and May, and varies between 800 mm/year (coastal plains) and 1,500 mm/year (mountainous area) with an average annual rainfall of ~1,100 mm/year. The average annual temperature is 20 °C.

2.1 Hydrology and Water Resources

The hydrology of the coastal area in Syria consists of a single hydrologic unit from north to south. Twenty eight coastal rivers discharge into the sea (Fig. 1). Most of these rivers are seasonal and usually less than 50 km in length. Twenty one dams are located on major rivers to store water for irrigation (DOWR 2008). In addition to the existing rivers, numerous springs and streams exist in the coastal areas. Many springs and streams end to small seasonal rivers penetrating the lower coastal plain to reach the sea. The hydrogeology of the coastal zone has major locations for groundwater reserves (Carlo and Ammar 1998). Despite the importance of groundwater in the coastal basin, little emphasis has been given on fully assessing these resources at the local scale. The most complete study on soils and hydrogeology remains at the national scale and dates back to the late 1960s and 70s (FAO 1965; Grozgiprovodkhoz 1979a, b).

The coastal area receives around 5.6 km^3 per year of precipitation (average 2000–2100 mm). Between 45 and 60 % is lost via evapotranspiration. Surface and groundwater resources are estimated to range between 2.2 km^3/year (dry years) and around 2.9 km^3/year (in wet years). Before the civil war, dam operation and management allowed for an annual storage of around 0.850 km^3 of water per year. Total usable water resources are estimated at around 2.3 km^3/year. This includes surface storage in the 21 dams. Water requirement for irrigation was estimated at ~0.650 km^3/year in 2010 (~0.550 km^3/year in 2002) (Kaisi et al. 2005). Water sources included well abstraction (0.150 km^3/year) accounting for around 45 % of the usable groundwater resources in the basin; meanwhile, surface water supply from dams, lakes and reservoirs amounted to around 0.500 km^3/year (~25 % of usable surface water resources). Water management was achieved via governmental organizations (~70 % of total supplies) and from private wells and other surface water sources (~30 %).

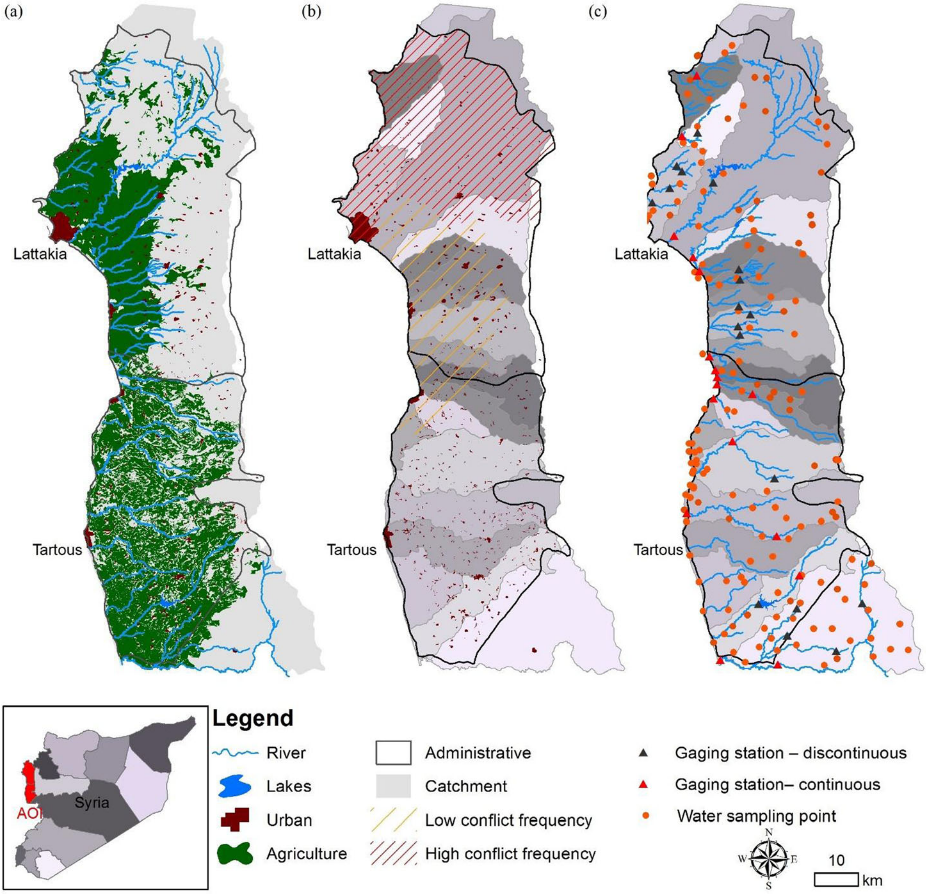

Fig. 1 Study area, with detailed presentation of (**a**) urban and agricultural areas, **b** conflict zones, and (**c**) the water system with its major components

2.2 Water Quality

Water pollution remains a threat for both surface and groundwater resources, especially from the uncontrolled discharge of untreated sewage, industrial wastewater, and agricultural practices. The downstream areas of most river basins in the coastal area are the most vulnerable, due to the increased population concentration and environmental transport of pollutants from upstream areas. In the pre-armed conflict period, direct wastewater discharges from various water polluters (e.g., olive mill wastes and solid wastes) into sensitive surface waters, such as lakes and reservoirs, were the major drivers of the decrease in water quality. Over the time period between 2000 and 2010, most of the wastewater was discharged into the environment and reused directly for agricultural purposes. Additionally, the same collection network-systems were used for both surface rainfall-runoff and wastewater. Pollution generated from large industries had little impact before the war. The impact of the war had increased the risk as the reasonable compliance of these industries to the water pollution control had decreased. The civil war had further deteriorated the system and posed increased pollution and leakages.

During the time period between 2000 and 2010 there was evidence of degradation of groundwater resources in the coastal area, which were under pressure from over-exploitation and seawater intrusion. According to recent studies (SPC 2006; Zakhem and Hafez 2003, 2007), the over-exploitation of groundwater resources from intensive pumping in the coastal area had contributed to the increased saline intrusion, especially in shallow aquifers. Mixing percent of saline water to freshwater were estimated at around 8.5 % in the Northern parts of the coastal zone near Lattakia and to no more than 3 % in the southern parts (near Tartous). The percent saline content is sensitive to the annual recharge and water abstraction. Groundwater vulnerability is high, with an average restoration factor of 10 years if all abstractions are stopped (Zakhem and Hafez 2007).

2.3 Socio-Economic Considerations

Several population censuses, at the level of Provinces, are available from different sources and date back to 1970, while the newest was completed in 2009. In 1970, the coastal population was estimated at around 720 thousands, equaling about 5 % of the total population; at that time the country's total population was estimated at 6.3 million. In 2004, the coastal population was estimated at 1,640 million, in 2006 at 1,850 million, and in 2009, it increased to 2.9 million, representing around 15 % of the country's total population (CBS 2010b). The population density was estimated at ~550 capita/km^2 in 2009. The war has resulted in the increase of the coastal population by an additional 1 million people due to internal displacement.

The major agricultural practices are vegetables and orchards. Orchards are mainly olive trees where no irrigation is available and citrus where irrigation is present. Arable lands were estimated at around 250,000 ha. Out of the total arable lands an estimated 65,000 to 75,000 thousands hectares are irrigated annually (average 2,005–2,010 mm); the remainder 154,000 ha are non-irrigated and depend on rainfall, with only 18,000 ha left without exploitation (CBS 2004, 2010a). The dominant agricultural practices are vegetables (~24,000 ha), and citrus, olives and other trees (~47,000 ha). Greenhouse farming is heavily practiced in the area, where more than 150,000 plastic greenhouses are used for growing tomatoes and cucumber (DOWR 2008).

2.4 Impact of Armed Conflict

The conflict in Syria began in March 2011, and had soon escalated into an armed conflict between rebels and government forces. The current syntheses are based on recent reports from UN affiliated organizations, e.g., Relief and Works Agency (UNRWA), the High Commissioner for Refugees Office (UNHCR), the Office for the Coordination of Humanitarian Affairs (OCHA), the Food and Agriculture Organization (FAO), and the World Health Organization (WHO), humanitarian groups such as the Syrian Humanitarian Assistance Response Plan (SHARP), the Assessment Capacities Project (ACAPS), Reliefweb, and MapAction.

By the end of the first quarter of 2014, the armed-conflict had resulted in more than 12.75 million displaced persons in Syria. The internally displaced people are estimated at around 8 million, while more than 4.75 million are currently refugees in neighboring countries, including ~1,300,000 in Lebanon, ~1,300,000 in Jordan, and another 1,000,000 in Turkey. According to the UN OCHA, an estimated 1.4 million people, accounting for 30 % of the coastal population, have been currently displaced from the internal regions and are living in the coastal area (~900,000 in Lattakia and ~500,000 in Tartous). In the coastal region, most armed-conflict occurs in the mountain areas (i.e., upper stream regions) and this causes people to displace downstream to major coastal cities such as Lattakia.

The combined impacts from changes in climate and war are expected to result in decreased food production and an increase in the prices of food and water, and contribute to the increased health concerns and occurrence of waterborne diseases. Water vulnerability is expected to increase during the summer period due to the decrease in water quantity and the impairment of quality. Rainfall deficiency between 2010 and 2013 was estimated between 55 and 85 %. The prevailing drought conditions over the past few years also continued through 2014, with precipitation estimated at 50 % below the normal average year.

3 Methodology

A conceptual framework (Fig. 2) was developed in order to assess the water resources system, and investigate the major drivers and their potential impacts using indicators. The assessment covered the evaluation of surface and groundwater resources, the investigation of environmental and man-made impact factors, as well as the potential impacts of the armed conflict. The investigation of water resources focused on: (i) mapping climate variables; (ii) mapping the location and boundaries of surface water resources (i.e., watersheds, rivers, streams, etc.) and groundwater resources (i.e., geologic, and hydrogeological, springs, wells, etc.); (iii) determining the baseline conditions for the surface water (i.e., hydrologic cycle) and groundwater (water table/levels); (iv) determining the baseline conditions for water resources use (domestic and agricultural water requirements and consumption) and their impact on the status of surface water and groundwater; (v) defining water quality indices and assessing water vulnerability; (vi) assessing demography, and social and water economics; and (vii) assessing the increased risk on the water system due to the civil war.

Synthesis of baseline information covered both the acquisition and pre-processing of historical spatial data, namely soil, geology and land use/land cover maps, and the compilation

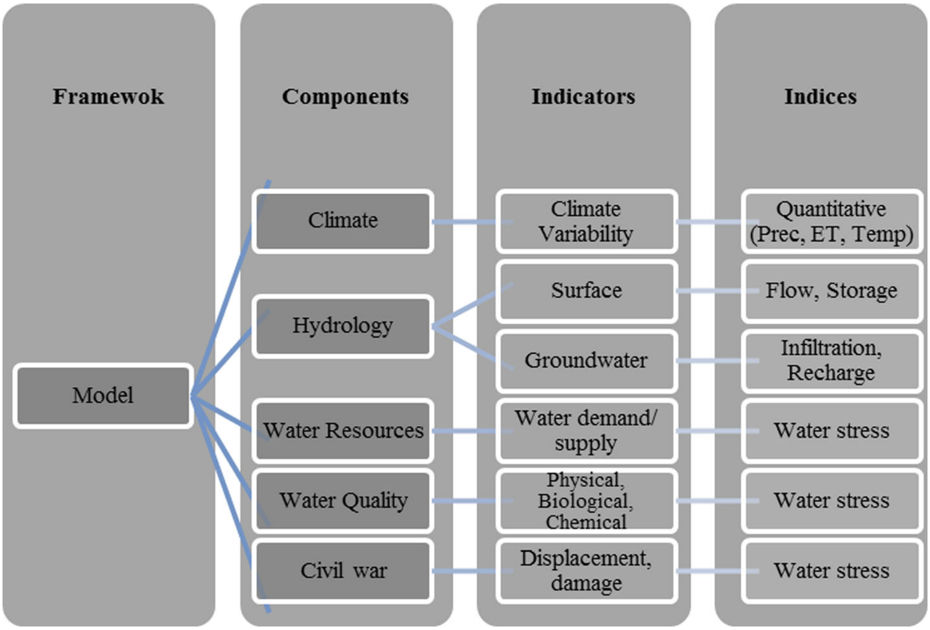

Fig. 2 Research methodology

of time series data of hydrology, meteorology and water quality collected over the time period between 2000 and 2010. Table 1 summarizes data used along with their biophysical scale and significance on hydrologic and water systems. Climate data were used as model inputs and the surface runoff for model calibration. Both the hydrologic and aquifer system depict model outputs. Water quality is another variable that controls the amount of water usability. The socio-economic system defines water net demand per sector, whereas the management system controls water supply and system efficiency. Water impact was defined as additional forcing variables, such as increased demand for satisfying the increased urban demand due to internal displacement, the degradation of the water supply network due to water damage, and the degraded governmental management services.

3.1 Model Formulation

Since the hydrologic, climatologic, hydrogeologic, and water use and demand parameters are integrated in a single modeling framework, it was essential to define data requirement as well as the scale for each parameter. Vulnerability of the water system and its sensitivity to the different drivers of climate, water use, and war pressure are usually associated with uncertainties. It was essential to define both qualitative and quantitative measures in order to assess the significance of the water pressures.

A Hydrologic model was implemented at the watershed scale using the Water Evaluation and Planning System (WEAP) software (Sieber and Purkey 2013). The representation of the hydrologic system in WEAP is based on a one-dimensional, two-bucket, quasi-physical water balance model (Yates et al. 2005a). The hydrologic model is overlaid with the water resources system, allowing for integrated hydrologic and water resources modeling in a single framework (Yates et al. 2005b). The expanded representation of hydrologic processes under WEAP allows for the run of alternative climate sequences without having to externally translate the implications of these changes into a hydrologic response, and the subsequent impacts of the supply–demand balance on the overall water resource system. In this context, the water allocation algorithm computes, at each time step, the hydrologic fluxes from the hydrology modules, and then solves the water allocation problems using linear programming. Water resources assessment is then evaluated based on demand priorities, supply preferences, and constraints (Sieber and Purkey 2013). Water allocation is solved by maximizing the water demand satisfaction, while accounting for pre-defined operational rules and restrictions on water supply. A detailed description of the theory behind the WEAP model is found in Yates et al. (2005a, 2009). This approach proved useful for assessing the different drivers and their impacts by explicitly weighing the advantages and disadvantages of various responses based on a set of inputs such as water supply defined using population estimates and crop patterns, reused wastewater, conjunctively managed surface and groundwater supplies, and water use efficiency. The WEAP model has been used in many research areas (e.g., Yates et al. 2009; Ruth et al. 2007; Droubi et al. 2008). The model was then calibrated using existing information related to surface flow over the time period between 2000 and 2010. The overall model performance was assessed using objective functions against observed flow.

3.2 Water Risk Assessment

To investigate the state of the water system of the Syrian coastal area, the definition of pre-war (reference scenario), war, and post-war scenarios was required. Each scenario was defined in terms of population estimates (including population displacement), agricultural practices, and changes in water demand and supply efficiency

Table 1 Major hydrological, meteorological, and water resources drivers and impacts

Parameter	Biophysical scale	Significance	Indicator	Risk
Basin	Watershed area	High	–	–
	River flow	High	Droughts or floods	Reduced surface water availability
	Lakes/Dams	Moderate	Storage/release	Reduced surface water availability
	Land cover	Moderate	Evapotranspiration	Surface runoff
	Topography	Moderate	Slope	Surface runoff
	Soil water capacity/ conductivity	High	Soil moisture changes	Surface runoff
Climate system	Precipitation	High	Wet and dry	Reduced freshwater availability
	Temperature	Moderate	Cold and warm	Increased evapotranspiration
	Wind	Low	–	–
	Humidity	Low	–	–
	Snow cover	Low	Control water release	–
Hydrologic system	Runoff	High	Water shortages or surpluses	Reduced surface water supply
	Evapotranspiration	Moderate	Water shortages or surpluses	Reduced groundwater recharge
	Recharge	High	Water shortages or surpluses	Reduced groundwater
Aquifer system	Aquifer capacity/ conductivity	High	Storage	Decreased water availability
	Wells	High	Water levels in aquifers	Decreased water supply
Water quality	Water/wastewater treatment	High	Water supply	System reliability and increased health risks
	Water quality indicators	High	Changes in chemical and biological quality	Decreased water supply and increased health risks
Socio-economic system	Population	High	Water demand	Water demand increase
	Water demand per capita	High	Water demand	Increased water demand
	Agricultural and crop lands	High	Agricultural water demand	Increased water demand and decreased water supply
	Crop types	High	Agricultural water demand	Increased water demand
	Irrigation practices	High	Agricultural water demand	Increased water demand
Water management system	Supply networks	High	Water supply	Decreased water supply
	Water Sources	High	Water supply	Decreased water availability and or accessibility
	Supply preferences	Moderate	Water supply	Decreased water supply
War impact	Population	Moderate-High	Displacement	Increased water demand
	Supply	High	Change in supply preferences	Decreased water accessibility and supply
	Management	High	Lack of Management	Decreased water supply
	Water quality	High	Decreased water quality	Increased health risks

(including estimated damaged system and lack of proper governmental management practices). The reference scenario is defined over the time period between 2000 and 2010, and portrays the pre-war scenario conditions. The war scenario describes the ongoing time period and accounts for increased population based on internal displacement, the degradation of the water supply system, and the degradation of the environment. The post-war scenario is based on stabilizing post-war conditions with low to moderate return to status quo. Table 2 illustrates in detail key inputs and constraints under each scenario.

3.3 Assessment of the Hydrologic System Performance

The hydrologic model performance was assessed using performance metrics which are defined as a function of the goodness of fit between the observed and modeled streamflow (Fleming and Neary 2004; Moriasi et al. 2007). The coastal area is subdivided into 21 major river basins. Among the 21 river basins there are two with an average annual discharge greater than 75,000 m^3/year, five with an average annual discharge between 25,000 and 75,000 m^3/year. The remainder 14 are basins with an average annual flow between 10,000 and 25,000 m^3/year. The Alkabir Alshimali (with an area of 1,100 km^2) located northern to Latakkia and the Alkabir Aljanobi (~620 km^2) located southern to Tartous along the Lebanese borders are the two most important river basins in the coastal area (Fig. 1c). Sixteen major basins were continuously monitored with gaging stations over the time period between 2000 and 2010 (Fig. 1c). Three metrics were used: the percent bias (PBIAS), the Nash-Sutcliffe efficiency criterion (NSE), and the RMSE-observations standard deviation ratio (RSR). The PBIAS is the percent model tendency to produce outputs larger or smaller than the field observations. The objective functions along with their relative performance ratings for a model running on a monthly time step, adopted after Moriasi et al. (2007), are presented in Table 3.

3.4 Assessment of the Water Resources System

The reliability (R) and vulnerability (V) indices (Fowler et al. 2003) were used to assess the impacts of war on the water resources system. These indices are used in studies covering the assessment of water availability, water supply, demand sustainability, water quality socio-economic changes (Jubeh and Mimi 2012; Norman et al. 2013; Martin-Carrasco et al. 2013; Gunasekara et al. 2014). The reliability (R) represents the system reliability in meeting demands at each time step and the vulnerability (V) represents the total unmet volumetric water in the time of system deficit. R and V are defined as follows:

$$R = \frac{\sum_{t=1}^{T} Z_t}{T} \tag{1}$$

$$\mathrm{V} = \max\left\{ \sum\nolimits_{\mathrm{t}\in\mathrm{U_i}} \left(\mathrm{D_{(t)}} - \mathrm{S_{D(t)}}\right), \quad \mathrm{i} = 1, \ldots, \mathrm{N} \right\} \tag{2}$$

where: Z_t is a generic indicator variable that indicates if the system performance is considered satisfactory or not; D is the minimum monthly water volume required to meet all demands (i.e., agricultural, domestic, and industrial); S_D is the monthly delivered water supply

Table 2 Summary of key drivers and variables

Scenario	Drivers	Key variables
Reference (2000–2010)	• Population • Economy/ industry • Agriculture/ irrigated surface area • Crop water consumption • Water supply network • Water management • Lake storage and management • Water quality	• Population estimates ~3 million • Stable economic and industrial development, estimated between 15 and 20 % of total urban demand • Water consumption per capita 58.4 m^3/capita/year • Agricultural area (~700 ha irrigated, of total 2,500 ha arable lands) • System losses 52.5 % • Irrigation efficiency 68 % • Crop type distribution (240 ha mixed vegetables, 470 ha citrus and olives). • Water sources: 65–70 % surface, 30–35 % groundwater • 21 dams with total lake storage estimated at 0.850 km^3/year and a management efficiency of 80 % • Governmental contribution to total supply ~70 %
War (2011- ongoing)	• Population (highly increasing due to internal displacement) • Economy/ industry (moderately decreasing) • Agriculture and irrigated surface areas (moderately decreasing) • Crop water consumption (increasing due to the decrease in irrigation schemes) • Water supply network • Water management • Lake storage and management • Water quality (degraded)	• Population in basin ~4.45 million • Degraded economic and industrial development ~10 % • Water consumption per capita 30–50 m^3/capita/year • Decreasing agricultural area by 10–20 % • System losses 65 % • Irrigation efficiency 50–55 % • Crop type distribution: (180–200 ha mixed vegetables, 450 ha citrus and olives). • Water sources: ~45–60 % surface, 40–55 % groundwater • 21 dams with total lake storage estimated at 0.700 km^3/year due to dry years and a management efficiency of 30 %
Post-war	• Population (moderately decreasing and stabilizing) • Economy/ industry (stabilizing) • Agriculture area (stabilizing) • Crop water consumption (slightly decreasing due to incorporation of schemed irrigation) • Water supply network • Water management • Lake storage and management • Water quality (slightly improving)	• Population estimates ~3.5 million • Stable economic and industrial development, estimated between 15 and 20 % of total urban demand • Water consumption per capita 58.4 m^3/capita/year • Agricultural area (~700 ha irrigated) • System losses 55 % • Irrigation efficiency 61 % • Water sources: ~65 % surface, ~35 % groundwater • 21 dams with total lake storage estimated at 0.850 km^3/year and a management efficiency of 70 % • Governmental contribution to total supply ~70 %

from all surface and groundwater sources. At each time t and in relation to D, S_D is classified as satisfactory (S) or unsatisfactory (U), and Z_t is given the values of 1 or 0, respectively, as in

Table 3 Performance rating statistics for a monthly time step model (Moriasi et al. 2007)

Objective function		RSR	NSE	PBIAS
Description		Observations standard deviation ratio	Nash-Sutcliffe efficiency criterion	Percent bias
Formula		$\sqrt{\frac{\sum_{i=1}^{N}(Qo_i - Qs_i)^2}{\sum_{i=1}^{N}(Qo_i - \overline{Q}o_i)^2}}$	$1 - \frac{\sum_{i=1}^{N}(Qo_i - Qs_i)^2}{\sum_{i=1}^{N}(Qo_i - \overline{Q}o_i)^2}$	$\frac{\sum_{i=1}^{N}(Qo_i - Qs_i) * 100}{\sum_{i=1}^{N}(Qo_i)}$
Performance ratings	Very good	$0 \leq RSR \leq 0.5$	$0.75 < NSE \leq 1$	$PBIAS < \pm 10$
	Good	$0.5 \leq RSR \leq 0.6$	$0.65 < NSE \leq 0.75$	$\pm 10 \leq PBIAS \leq \pm 15$
	Satisfactory	$0.6 \leq RSR \leq 0.7$	$0.5 < NSE \leq 0.65$	$\pm 15 \leq PBIAS \leq \pm 25$
	Unsatisfactory	$RSR > 0.7$	$NSE \leq 0.5$	$PBIAS \geq \pm 25$

Q_{oi} is the observed discharge, $\overline{Q}o$ is the mean of the observed flows, Q_{si} is the simulated discharge, and N is the number of observations

following Eq. (3). N is the total number of unsatisfactory (U) periods reported over the entire time series of length T.

$$\left\{ \begin{array}{c} If\, S_{D(t)} \geq D_{(t)}\, then\, S_{D(t)} \in S\, and\, Z_t = 1 \\ else\, S_{D(t)} \in \; U\, and\, Z_t = 0 \end{array} \right\} \tag{3}$$

3.5 Water Quality Indicators

Water quality indicators are used preliminarily to assess water contamination in order to protect the public health (WHO 2011). In this context, different guidelines are proposed and recommended by the United States Environmental Protection Agency (USEPA 2002, 2009, 2014) and WHO (2011) for managing the risk from the use of contaminated drinking-water, due to the lack of national standard for water quality in Syria. Table 4 synthesizes the main source of contamination, recommended ranges and potential health risks for the available water quality observations that were carried prior to 2010 in the coastal area.

4 Results and Discussion

4.1 Identification of Major Drivers

Figure 3 illustrates the calibrated (2001–2005) and validated (2006–2010) results over the two major basins in Lattakia (Alkabir Alshimali River Basin) and Tartous (Alkabir Aljanobi) (Fig. 1c). The overall hydrologic performance was acceptable for all modeled coastal basins (not shown), according to the hydrological statistical tests ($\pm 10 < PBIAS < \pm 25$; $0.65 < NSE < 0.80$; $0.4 < RSR < 0.5$; and $0.75 < R < 0.90$). The average water budget and water resources use over the entire coastal area were assessed for the time period between 2000 and 2010 serving as the baseline scenario. Figure 4 represents the average monthly precipitation and flow over the entire coastal area over the same time period where it is clear that water availability from rivers is minimal between May and November. The hydrologic budget over the coastal area is summarized in Table 5 for the average, dry and wet year conditions. Figure 5 is the box plot of the yearly overall coastal hydrologic budget over the same time period. It is evident that the renewable yearly water resources per capita in the coastal area were between

Table 4 Water quality indicators after USEPA (2002, 2009, 2014) and WHO (2011)

Indicator (Type*)	Unit	Source/origin	Reg. (M/R†)	Health symptoms
Temperature (P)	°C	Climatologically influenced	N/a	None
Hardness (P)	mg/L	Rock formations (e.g. limestone)	N/a	N/a
pH (C)	Unitless	Physical characteristic of water	6.5–8.5	None - except that extreme acidity or alkalinity are generally associated with organoleptic consequences (e.g. taste and odor).
TDS (P)	mg/L	Natural or added solutes to water	500	Organoleptic consequences (e.g. taste and odor)
Chloride (C)	mg/L	Soil and rock formations, sea water intrusion, and waste discharges	250	None, Organoleptic (e.g. taste)
Sulphate (C)	mg/L	Rocks, geological formations, and discharges	250	Excess sulphate has a laxative effect, especially in combination higher concentration of magnesium and/or sodium.
Calcium (C)	mg/L	Occurs in rocks		Indirect (associated with hardness)
Magnesium (C)	mg/L	Geological formations		Indirect (in conjunction with Sulphate)
Nitrate (C)	mg/L	Runoff from fertilizer and leaking sewage	10	Shortness of breath and blue-baby syndrome
Nitrite (C)	mg/L	Runoff from fertilizer and leaking sewage	1	Shortness of breath and blue-baby syndrome
Ammonia (C)	mg/L	Naturally present; excess quantities are related to sewage or industrial contamination	0.1–0.3	Indirect (sewage pollution and potential presence of pathogenic)
Phosphate (C)	mg/L	plants, micro-organisms, animal wastes, run-off and sewage discharges	0.03	None
DO (C)	mg/L		8.5–11.5	Slight organoleptic significance
BOD (C)	mg/L		3	No direct health implications
Turbidity (P)	NTU	Soil runoff	N/a	Nausea, cramps, diarrhea and headaches
Total coliforms (B)	mg/L	Human and animal fecal waste	Zero	Nausea, cramps, diarrhea and headaches and other symptoms from the availability of microbes (pathogens)

* *P* Physical, *C* Chemical, *B* Biological

† Reg. is the regulative recommended limits according to USEPA. M indicates that the recommended limits are a mandatory standard while R portray suitable recommended, non-mandatory, limits

750 and 1,000 m^3/capita/year (average dry and wet years, respectively, over the time period between 2000 and 2010) and are expected to have decreased to around ~550 m^3/capita/year during the time of war. Net water demand for population was estimated to range between 0.085

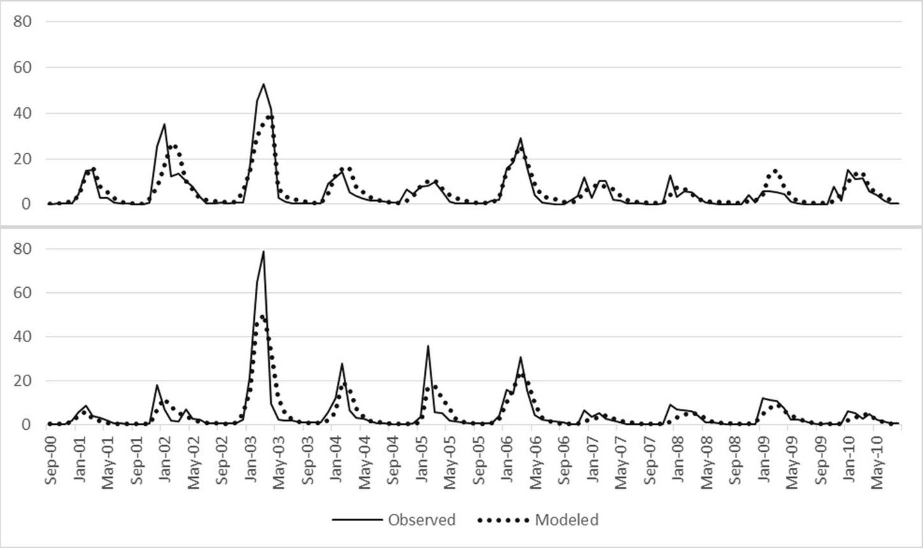

Fig. 3 Observed (solid line) and modeled (dotted line) flow over the major basins in (**a**) Lattakia – Alkabir Alshimali and (**b**) Tartous – Alkabir Aljanobi. Performance metrics for calibration (2000–2005) were for (**a**)/(**b**): Bias =10.4/−12.6; NSE =0.76/0.75; RSR =0.49/0.50; R=0.87/0.88. Validation (2006–2010) values were for (**a**)/(**b**): Bias =13.6/−15.8; NSE =0.72/0.79; RSR =0.51/0.45; R=0.86/0.90

and 0.100 km^3/year, with an estimated loss in the system between 25 and 40 % (average 2000–2010). The net water demand for agricultural use was estimated to range between 0.350 and 0.600 km^3/year (average 2000–2010) with an estimated loss in the system of around 22.5 %. Water availability had decreased significantly due to the increased demand needed to meet population and the degradation of the water management capacity. The agricultural sector, which was affected by the war and drought, had resulted in the degradation of crop quality, while water abstraction remained the same. Table 6 summarizes the water indicators under the reference scenario, war and the post-war scenarios.

More than 600 water samples were collected over different time periods in 2006 and 2010 at different sampling sites (Fig. 1c) by the directorate of water resources in Syria. Water sampling revealed higher water contamination for agricultural purposes, exceeding the maximum allowed standard of 1,000 coliforms per 100 mL in more than 20 % of the areas. The percent of exceedance of water standard for recreational areas was found to be between 45 and 50 % for recreational water use (400–500 coliform per 100 mL). The plots for the different chemical, biological concentrations and physical indicators are

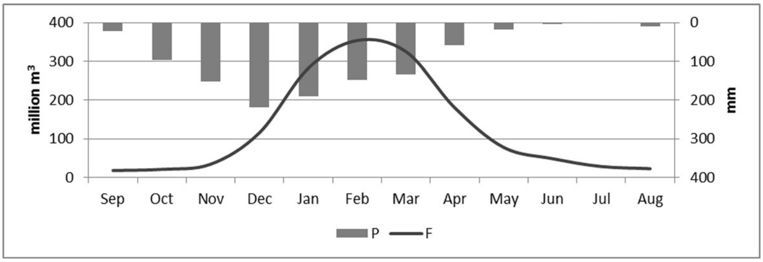

Fig. 4 Average monthly precipitation (P) and flow (F) over the coastal area between 2000 and 2010

Table 5 Water balance under different climate scenarios (average 2000–2010)

Watershed area =5070 km^2		Year		
		Average (STD)	Dry (STD)	Wet (STD)
Precipitation (mm/year)		1,030 (72)	875 (64)	1,365 (261)
Inflows (million m^3)	Precipitation	5,225 (366)	4,430 (326)	6,925 (1,325)
Outflows (million m^3)	Surface flow	1,510 (258)	1,065 (91)	2,445 (733)
	Groundwater recharge	1,290 (119)	960 (112)	1,910 (413)
	Actual evapotranspiration	2,485 (221)	2,030 (169)	3,385 (551)

presented in Fig. 6. The boxplots represent median, quartile, and minimum and maximum values. It was evident that most indicators exceeded the recommended standards for potable water set by the USEPA (2002, 2009). Hardness, measured as $CaCO_3$ concentration, was estimated at 5.9±3.8 mg/L (Soft water <50 mg/L $CaCO_3$). Turbidity had an average of 0.4 NTU (recommended standard <0.5 NTU). pH average value was estimated at 8±0.5 which is at the upper extreme of the recommended range (recommended values 6.5<pH <8.5). The same applies to alkalinity estimated at an average value of 13.6±8.2 mg/L. Chloride and sulfate concentrations were below the maximum allowable limits of 250 mg/L (Fig. 6). Nitrate concentration exceeded the maximum allowable 1 mg/L (average nitrate concentration was 8.4 mg/L). Values for DO and BOD were also close to the allowable limits for potable water scoring 8.1±0.6 and 2.3±1.3 mg/L, respectively (recommended standard for DO between 8.5 and 11.5 with an average of >6.5 mg/L for DO and <3 mg/L for BOD). Average nitrite concentration was estimated at 0.19±0.17 mg/L (recommended standard for potable water <1 mg/L). Ammonia was between 0.25 and 0.47 mg/L (recommended standard <0.3 mg/L), and phosphate average concentration was estimated at 0.35±0.24 mg/L (recommended standard <0.03 mg/L). In summary, despite working under full capacity of the governmental bodies, it was clear that water quality was at the extreme of the recommended values for potable water under the reference time frame (2000–2010). The decline in the working capacity of the governmental bodies to less than 30 % during the time of war, in addition to the increased conflict, people displacement and lack of control, is believed to have contributed to the degradation of the water quality in the coastal area and to have increased the population health hazards.

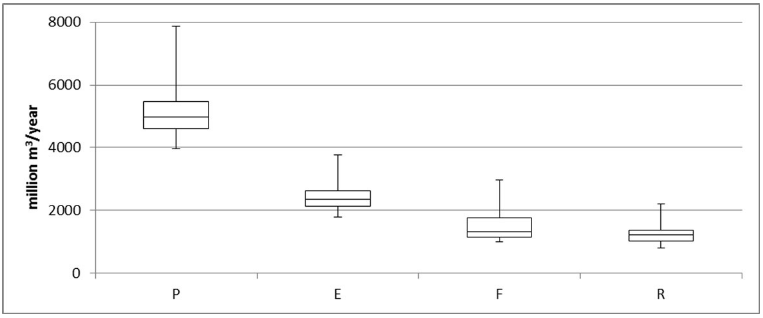

Fig. 5 Boxplot for the total hydrologic budget over the coastal area covering the time period between 2000 and 2010 where P is precipitation, E is actual evapotranspiration, F is flow, and R is groundwater recharge

Table 6 Water indicators under the reference scenario and the implications of war impacts

	Reference (2000–2010)	Current (2011-Ongoing)	Post-war (Scenario)
System reliability (%)	75–90	45–55	65–80
System efficiency (%)	70–80	40–60	55–75
Vulnerability	Low	High	Low-moderate
Increased urban water demand	Moderate	High	Moderate
Increased agricultural demand	High	Moderate	Moderate-high
Water resources distribution	High	Unstable	Moderate-high
Surface runoff reused	Moderate	Low	Low-moderate
Pollution control in urban areas	High	Low-moderate	Moderate-high
Pollution control in rural areas	High-Moderate	Low	Moderate
Pollution control of olive mills	Moderate	Low	Moderate
Modern irrigation techniques	Moderate-high	Low	Moderate
Water supply network efficiency (%)	60–70	50–55	55–65
Water optimization	Low	High	Low-Moderate
Water contamination	Low	High	Low-Moderate
Water protected areas (% area)	50–60	0–10	30
Water pollution	Low-Medium	High	Medium
Water pollution (% area) (potable standard (<1/100 mL)	50	70–80	50–60
Seawater Intrusion	Low-moderate	High	Moderate

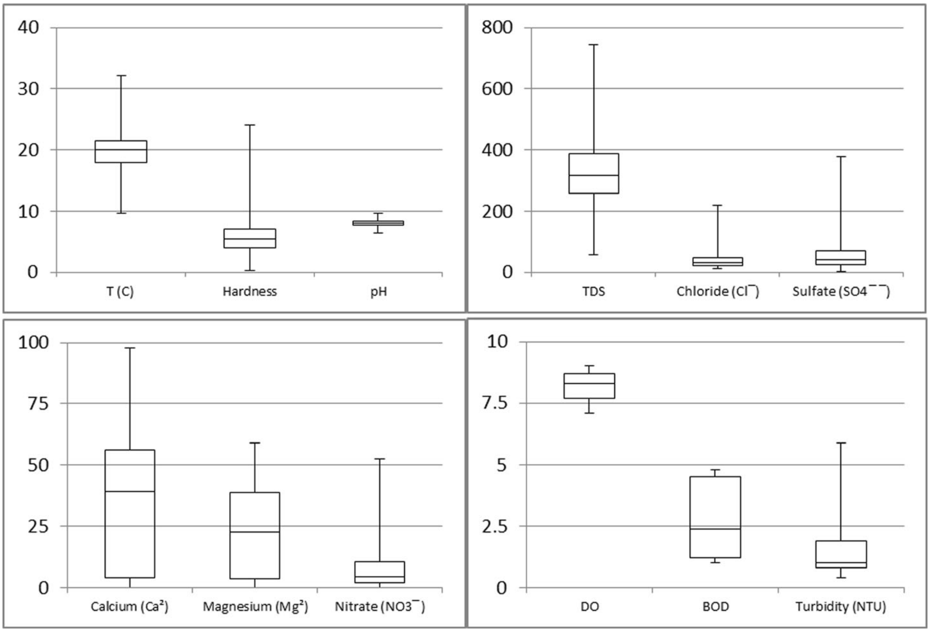

Fig. 6 *Boxplots* indicating values of major physical, chemical and biological indicators. All units are in mg/L, except for T in °C, pH unitless, and Turbidity in NTU

Brackish and saline water intrusion is a main threat in the coastal zones. Prior to the war, the over-abstraction of groundwater in the coastal area increased the risk of saltwater intrusion, especially in the lowland coastal areas located to the north of Lattakia, and the Littoral plain zones, especially between Lattakia and Northern Tartous. Saltwater intrusion was more visible during the late spring and early summer periods, especially in the coastal cities where over abstraction of groundwater resources from wells is common. During the war, the increased abstraction in the southern part of the coastal area put increasing pressures on the groundwater and elevated the risk of saline water intrusion. Figure 7 presents the scatter plots of well depth, static water level, altitude and water use from wells. The well depth is defined as the total depth measured from the ground surface to the bottom of the well. Meanwhile the static water level depicts the depth to groundwater and is represented by the distance between the ground surface and water under normal, no-pumping, conditions. According to these figures, it is clear that intensive groundwater abstraction is more common in the downstream areas located at the coastal zones, and results in the increased saltwater intrusion into the aquifer due to the increase in population and uncontrolled abstraction. It is obvious from these figures that most wells are found at lowland areas (below 250 m amsl) near the coastal cities (Fig. 7). Also evident is the static groundwater which is found at depths of less than 100 m in lowland area (Fig. 7). The concentration of population in lowland areas (Fig. 7) is putting increased pressure on the groundwater levels in the coastal zone. It is believed that groundwater is currently stressed by the pollution from untreated urban water as

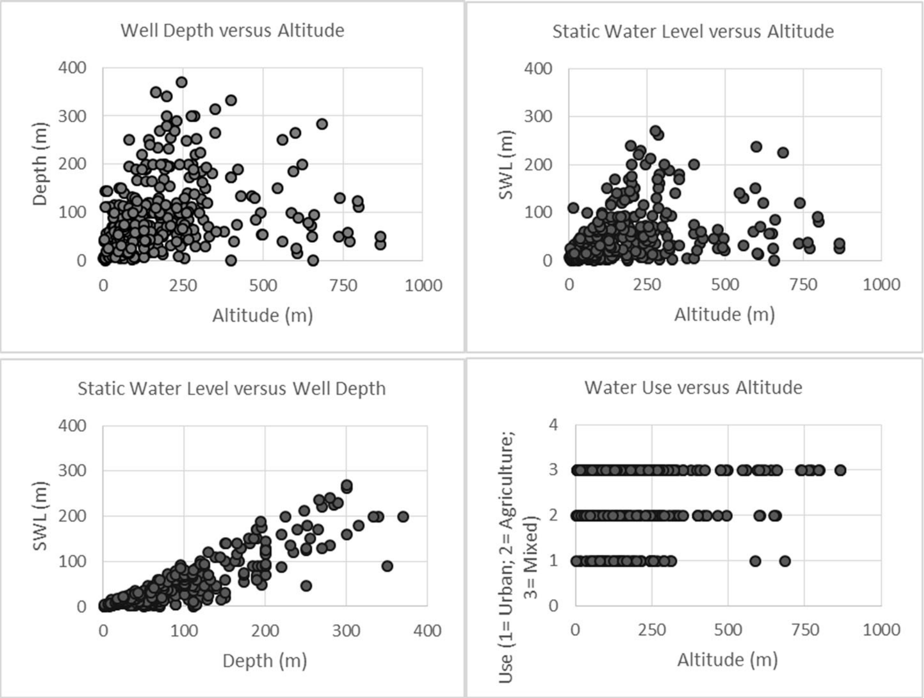

Fig. 7 Scatter plots of well depths, altitude, static water level, and water use from wells

well as the increased risk to seawater intrusion which was already evident during the same time period (2000–2010) (Zakhem and Hafez 2007).

4.2 Mitigation Measures

4.2.1 Water Supply

Water saving measures are a priority. Despite of water scarcity resulting from dry years or conflict, or a combination of both, public awareness should be sought and guidelines on how to save water should be provided to minimize water consumption. Water saving measures in a post-war scenario should prioritize fixing the leakages from the damaged system; this should go alongside with separating the water supply and sewage systems in order to minimize water contamination, especially in downstream areas. In the past years, little emphasis was given on investigating the potential use of rainfall-runoff water, especially when using combined sewer systems for the collection of rainwater and wastewater in urban areas. In the post-war scenario, there is a need to separate both these systems, especially in areas where precipitation and runoff coefficients are high (e.g., residential areas).

4.2.2 Optimization and Water Management Practices

Best management practices and optimization measures were not prioritized in the coastal area. This has resulted in an increase in the consumption of water resources by all users, namely the agricultural and industrial sectors. The war had increased the cost of water due to the increased population and lack of the resources. Water pricing for potable use had increased and is tight with the water risk situation which varies depending on time and location. In the northern part of the coastal area, military conflict had resulted in increased population displacement and increased risk. In the southern coastal area, the situation is more stable, but the increase in population had increased the demand for water, eventually increasing the cost. The same pressures are threatening the groundwater resources by seawater intrusion due to the increasing and uncontrolled abstraction. In a post-war scenario, there is urgent need to involve more policy measures to prioritize water use and use optimization measures for water management, especially in industries and agriculture. Reducing agricultural water demand by the adaptation of enhanced irrigation techniques is expected to reduce water demand by this sector between 40 and 50 % and at the same time reduce groundwater pollution from fertilizer and herbicide use. Water reuse from treated wastewater is advised, especially in upper stream areas. Under this context, less sophisticated and complex technologies for treating wastewater in rural areas can be implemented. An option is the application of constructed wetlands.

4.2.3 Water Quality

In a post-war scenario there is critical need to control major pollution sources and start by the rehabilitation of damaged water systems. Regional approaches are needed to minimize the rehabilitation cost (investment in large scale networks is not feasible). Pollution control of municipal wastewater and rehabilitation of wastewater networks in urban area is a priority. Different options are available from centralized wastewater treatment plants (WWTP) based on activated sludge and anaerobic sludge treatment. However, high investment is needed for such type of mitigation options. In the short-term, a less expensive measure is advised and consists of simply use the constructed wetlands technology to minimize contamination in most vulnerable zones. Contamination by olive mills should be considered as a priority. The use of wetland technology had proven to be a feasible low-cost alternative solution to treat municipal wastewater in Mediterranean like regions (Tsihrintzis and Gikas 2010; Liolios et al. 2014). The same applies to the contamination from agricultural pesticides and herbicides. Among the available options is the less expensive use of lagoons where all wastes are collected. Such approach is expected to reduce the total volume of wastes while taking into consideration that the area is protected to minimize potential leakage hazards. A comprehensive review on the use of different methods for environmental flow assessment can be found in Godinho et al. (2014).

5 Conclusions

The potential impacts of war on the water resources in the coastal basins of Syria were presented. An integrated hydrologic water resources model was used to evaluate the impacts of the combined climate variability under average, wet and dry conditions. It was evident that the consequence of war and conflict is high even in the most impacted regions of the country. The impact of war has resulted in the damage to the existing system and little investment being made in the water supply and treatment utilities. Population displacement and increasing demands and water pollution are among the driving forces in the area. The most critical drivers were the decrease in the management options, decrease in the system reliability due to damage and the increased pollution. Adaptation measures are necessary during and in a post-war scenario to increase water supply and decrease the adverse pollution impacts. Most of the proposed options take into consideration the economic and social aspect as a priority. It was evident that system stabilization is achieved and the status quo could be reached.

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