

Article

Strategic Decision-Making in Sustainable Water Management Using Demand Analysis and the Water Evaluation and Planning Model

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Abstract: Water infrastructure management relies on information, communication strategies, and affordable technologies. This paper used demand analysis and modeling to guide strategic decision-making in sustainable water management for the urban cluster in Tlemcen, Algeria. To achieve this, the water supply and demand of the study area were assessed over the past three decades. The Water Evaluation and Planning (WEAP) system was employed considering different future scenarios to help decision-makers consider the best choices for sustainable urban water resources management. The results showed that the average water production and distribution efficiency was only 46% due to the high network loss. Therefore, urgent action should be considered to increase the efficiency of the distribution network. Moreover, the outcome showed severe unmet demand in 2050, which can be managed by improving the water networks, increasing conventional water production, and reducing personal water consumption. In cooperation with key stakeholders, new scenarios can be analyzed to develop efficient water management policies and to implement sustainable water allocation approaches.

Keywords: non-revenue water; loss index; water supply; decision support system; Tlemcen; Algeria



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1. Introduction

1.1. Background

Smart city is an innovative concept for managing urban centers with the aim of enhancing sustainability and increasing the quality of life for its citizens. Although urban water infrastructure (UWI) performs important functions in any city, information and communication technologies and system-wide management of the network need more development. Oberascher et al. [1] summarized a wide range of applications in the field of UWI networks for a comprehensive analysis of the spatial and temporal resolutions of measurement data. For example, inflow measurements of drinking water at the district scale were utilized for real-time operations considering service pressure, leakage detection, and energy consumption. Furthermore, global population growth, urbanization, industrialization, and climate change have contributed significantly to water scarcity [1,2], which has also placed additional pressure on the effective municipal water management and energy usage [3].

Accurate water runoff forecasting and appropriate prediction models based on the actual characteristics of the reservoirs play a critical role in the sustainable utilization and management of water resources [4]. In a related investigation, Chandran et al. [5] developed an integrated urban water resources management strategy for a smart city in India, which showed that there was a huge potential for rainwater storage at the surface level and subsequent recharge through artificial techniques to sustain urban water supply. Moreover, due to the complexity of several interacting issues in water supply management, including sustainability, socio-economic aspects, and health-environmental concerns, there is a need for a comprehensive understanding of urban water supply management [6].

Pallavi et al. [6] involved social-economic and environmental parameters in simulating water demand and supply. The outcomes showed that sustainable utilization of recycled sewage has great potential in sustainable water supply systems to meet anticipated demands. Likewise, Ren and Khayatnezhad [7] simulated the behavior of subsurface water flow based on a stormwater management model to improve urban water allocation under drought conditions. The results showed that the model could improve water productivity in urban areas and protect the environment.

Rahbar and Riasi [8] proposed novel configurations of conventional solar chimney power plants integrated with transparent photovoltaic solar cells and a saline water desalination method to improve the utilization of solar energy and land resources. Mathematical models were developed for each configuration and validation was performed with experimental results to enhance the performance of the plant considering four indicators, namely: efficiency, capacity, cost, and pollution.

To improve the understanding of the potential contribution of planning urban land change, Bacău et al. [9] developed and simulated scenarios for future demands considering future land uses, current policies, and management decisions. In a related report, Jabari et al. [10] proposed an innovative multi-generation system for hospital buildings based on a biogas-driven gas turbine cycle for electricity production and an air-to-water source heat pump. Results were presented for simultaneous extraction of cooling and potable water. Likewise, robustness and effectiveness were evaluated under different climatic conditions and variable demands.

1.2. Modeling Approach

Accessing water supply and demand for various uses is one of the crucial socio-economic issues, especially in arid regions [11]. Modeling approaches are widely used to develop decision support systems (DSSs) to assist strategic decision-making on sustainable water resources management [6,7,12–14]. The analysis and forecasting of urban water demand are complex operations but essential to meet the needs of users [6,7,15].

The WEAP model has been used widely to assess water demand and supply. Amisigo et al. [16] applied WEAP to simulate the impact of climate change on water resources and agriculture demand in Ghana. Mourad and Alshihabi [17] developed five future scenarios, namely best available technology, high technology, temperature increase, regional cooperation, and conflict. Sandoval-Solis et al. [18] utilized a regional water planning model for evaluating the water supply and demand interaction as well as current and alternative water management strategies for the Aragvi River Basin. Rajosoa et al. [19] used the WEAP system to assess future water supply and demands at the Medjerda River Basin (MRB), shared by Tunisia and Algeria. Rajosoa et al. [20] evaluated the impact of climate change on the water resources of the (MRB) using the WEAP system under two climatic scenarios of representative concentration pathways: RCP 2.6 and RCP 6.0. Gao et al. [21] utilized a development plan for a typical arid/semi-arid area in China and tested the effectiveness of the WEAP approach in assessing the impact of proposed activities on local water resources. Sun et al. [22] reviewed the effects of climate change on hydropower generation in China.

Urban water resource management must be an integrated process that allows for your prediction of alternative future situations based on an analysis of past regional water supply and demand. This can be based on population growth, infrastructure, development, climate change, socio-economic activities, and other related factors [5]. To assess the sustainability of the available water resources in any area, models can be used to predict the future, considering the current conditions, or possible changes in the current conditions, for example, changing traditional irrigation methods can reduce water scarcity.

1.3. Problem Statement

Drinking water supply strategies of many cities in arid and semi-arid regions, such as North Africa, should be improved. Water systems in Algeria face many challenges [23], including water losses, intermittent distribution, water quality, failure of the wastewater collection networks, and the low percentage of treated wastewater [24], due to the inefficiency of infrastructure investments, the inadequacy of management models, and the difficulties in integrating the management of water, sanitation, and water resources services [25].

This study deals with a prospective analysis of water supply and demand in the urban cluster in Tlemcen (UCT). With a connection rate to the water supply network estimated at over 94% [12], the question of how to reconcile water supply and demand in the UCT has been the subject of several research or technical studies. However, they often propose solutions based on a logic that gives primacy to demand, making consumption a constraint to which supply must always be adapted. This *modus operandi* is based on false logic, pretending that water potential is inexhaustible, especially in a region characterized by water stress.

This must necessarily lead to a difference in consumption patterns, especially domestic consumption, and therefore a difference in technological and economic choices. As a result, water scarcity needs to be integrated into the representation of the future. Achieving this means developing mechanisms for water demand management [26]. This approach reduces the total demand for water and gives priority to higher-value uses, given the increasing pressure on available conventional water resources.

1.4. Objectives

This paper employed a combination of demand analysis and modeling tools to guide strategic decision-making in sustainable water resources management taking the urban cluster in Tlemcen, Algeria as a case study. An examination of the water supply and demand of the study area over the past three decades was performed. Then, the WEAP system was used to examine 64 future scenarios to help decision-makers in making better choices for sustainable urban water resources management.

2. Methodology

2.1. Study Area

Located in the northwest of Algeria, the urban grouping of the communes of Tlemcen, Chetouane, and Mansourah (Figure 1) occupies approximately 112.2 Km² [24]. Tlemcen constitutes a single inseparable territory where problems, in particular those related to water issues, can only be solved within an inter-municipal framework. Before 1980, the Meffrouch dam and two springs were able to meet all water demands. However, drought and population growth affected water availability. Figure 2 shows an annual decrease, of about 3.5 mm in rainfall between 1943 and 2017. According to the National Statistics Office (ONS), from 1987 to 1998, the region experienced high annual rates of population growth that reached 3.7% [27].

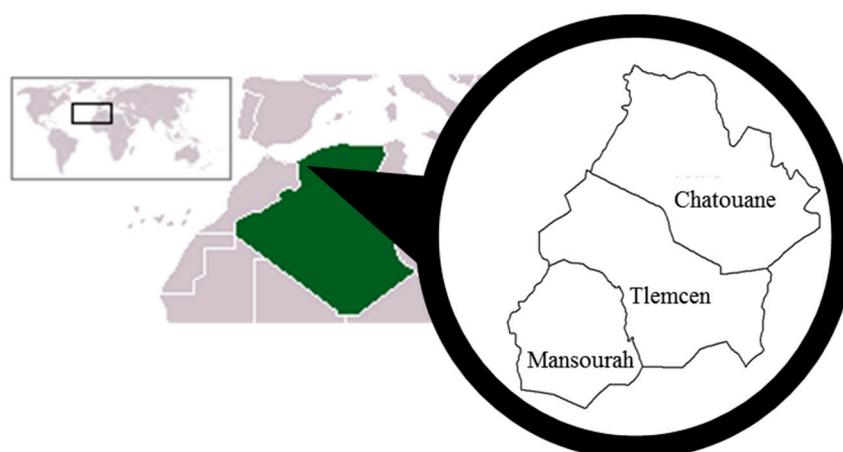


Figure 1. Geographic location of the study area (Latitude: 34°52'41" North–Longitude: 1°18'53" West).

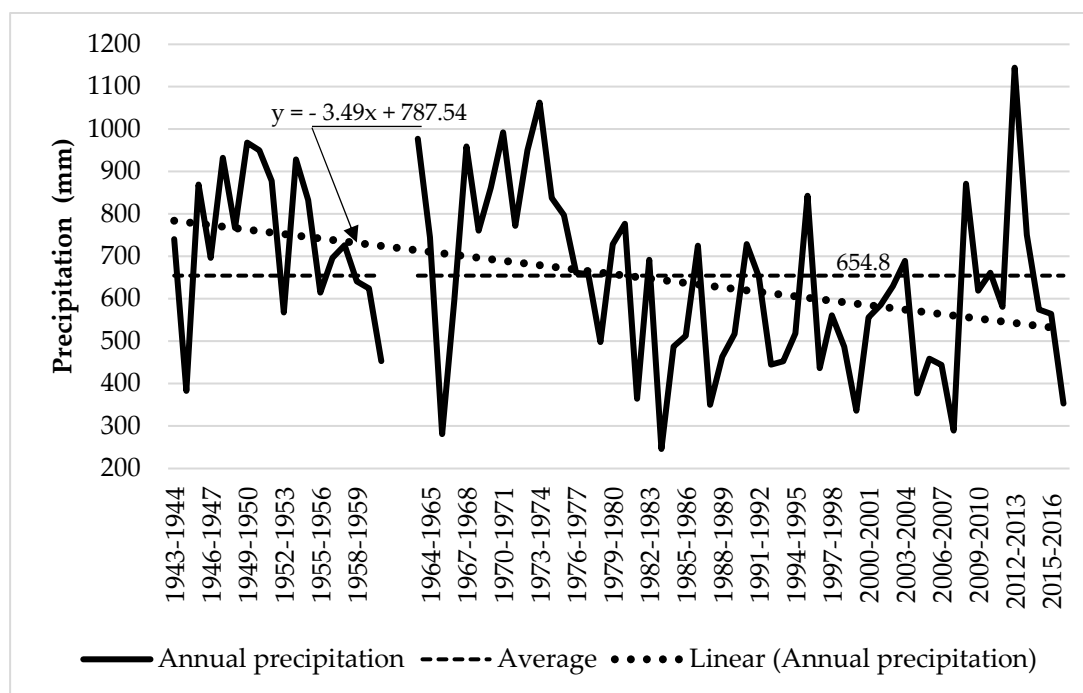


Figure 2. Annual precipitation recorded at the Meffrouch station (1943–2017). Source: Directorate of Water Resources—Tlemcen.

Exploitable water resources were estimated at 6300 Mm³ with renewable reserves estimated at 200 Mm³/year [28]. By 2017, the area had 37 boreholes, but only 8 were in service due to the collapse of the walls of the boreholes or the deterioration of pumps. Surface water was regulated by the Meffrouch dam (storage capacity of 15 Mm³). To secure the drinking water supply, the Wilaya (i.e., department) of Tlemcen set up two seawater desalination plants, the Souk El Tleta station (commissioned on 13 April 2011) and the Honaine station (commissioned on 18 July 2012), for a daily production of 200,000 m³ each [28]. Data were lacking on actual water consumption by users of the Tlemcen urban area. The assessment of needs was thus based solely on demography. Urban water demand per capita per day (UWDC) (L/c/d) was considered as consumption by households, public establishments (e.g., schools, hospitals), and professional and commercial activities.

For the current study, based on the literature [29–33], four values of urban water demand per capita (UWDC) were adopted to estimate the water needs of the case study (Table 1). At a very low water demand of 120 L/d/c, water savings were excellent. However, user satisfaction was very weak. In contrast, at 200 L/c/d, user satisfaction increased but water savings were reduced.

Table 1. Scenarios of different urban water demands per capita (UWDC) and its effects on water saving and user satisfaction. Effects ranged from very positive (++++ to very weak (+).

UWDC (L/c/d)	Water Saving	User Satisfaction
120	++++	+
150	+++	++
200	++	+++
250	+	++++

Assessment of the water supply was established in two stages. Initially, water production was analyzed without considering water leaks, which was calculated by dividing the daily volume produced by the number of inhabitants in a specific year. Then, the estimation of daily consumption per capita was carried out by inserting the rate of overall leaks, including at the same time production leaks and network leaks. The annual rainfall was recorded at the Meffrouch station with a rain gauge, or pluviometer (Figure 2).

2.2. Modeling Future Urban Water Demand

To develop different scenarios of future urban water demand and balance in the study area, the WEAP system was employed considering demand priorities and supply preferences (Figure 3) [21,34,35].

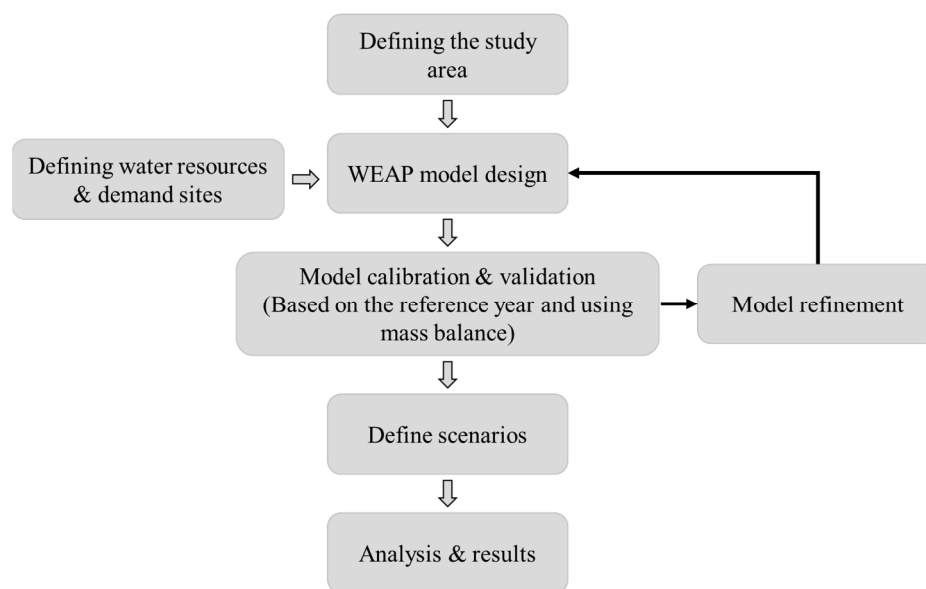


Figure 3. WEAP model flowchart [35].

As a first step, the reference scenario, water supply, demand, and balance were calculated for the period of 2017–2050, with intermediate dates (2025, 2030, and 2040). The year 2017 was considered the reference year due to data availability, Table 2, while 2050 represented the horizon of long-term urban water management. Furthermore, the average annual population growth rate of 1.8% was adopted. Likewise, to meet the future water needs of the region, without seeking new water resources [35], it was essential to apply internationally recognized standards for the regulatory performance threshold or efficiency of water supply systems. This efficiency value varied from 52% to 85% [36]. In

the current investigation, three network efficiencies (i.e., 65%, 70%, and 75%) were utilized. However, the network efficiency of the urban cluster of Tlemcen in 2017 was 52%.

Table 2. Supply and demand balance for the case study region from 2017 to 2050. UWDC refers to urban water demand per capita.

Water Resources (m ³ /d)		Population	Annual Growth Rate (%)	Network Efficiency (%)	UWDC (L/c/d)
Groundwater	13,827	298,488	1.8	52	120
Surface water	22,206			65	150
Desalination	51,377			70	200
Total	87,410			75	250

In the second stage, a few scenarios to meet urban water demands up to 2050 were developed to consider water production, unconventional water, water production costs, leakages, and water prices. The volume of conventional water resources (i.e., ground and surface water) was determined based on statistical data of the annual conventional water supplies recorded during the period from 1984 to 2012. During this period, conventional water resources could meet all needs in the study area.

The average annual volume of conventional water was estimated by Student's law and was found to be between 11.83 and 14.87 Mm³, with a confidence level of 95%. In other words, the daily intake was estimated at 36,575 m³ with a margin of error of 4164 m³/d, at the tolerated confidence level. For calculation reasons, this value was rounded to 36,000 m³/d. The volume was equivalent to data from the year 2017. From this same series, a minimum value was identified by considering the smallest value of each of the two separate series, namely groundwater and surface water. Furthermore, the sum of these two values was about 17,000 m³/d. The same operation was carried out for the maximum value, which gave a daily volume of 65,000 m³/d.

The water potential of the Tlemcen Mountains aquifer system was large enough for the daily volume of conventional water to reach 100,000 m³, which used to be used for irrigation [28]. It can be argued that there was a reason to encourage and assist farmers, both technically and financially, to practice efficient and sustainable agriculture practices. This would save substantial volumes of water, which could be injected into the region's water supply. Table 3 summarizes the used data in the simulation process of the WEAP system. For each conventional water volume, scenarios were developed by changing the values of network efficiencies and urban water demand per capita (UWDC). For example, the first scenario was designed with a conventional water volume of 17,000 m³/d, a network efficiency of 52% (i.e., 48% water loss), and a UWDC of 120 L/c/d.

Table 3. Basic data for developing the scenarios in the WEAP system up to 2050.

Conventional Water Volume (m ³ /d)	17,000	36,000	65,000	100,000
Network efficiency (%)	52	65	70	75
Urban water demand per capita (UWDC) (L/c/d)	120	150	200	250
Population in 2050	537,779			

3. Results and Discussion

3.1. Analysis of Water Supply and Consumption

The water supply over the past 30 years in the case study region came from conventional and unconventional sources including rainfall (i.e., Pluviometry) (Figure 4). Water consumption, with the support of seawater desalination, increased from 10 million m³ in 1984 to 30 million m³ in 2017.

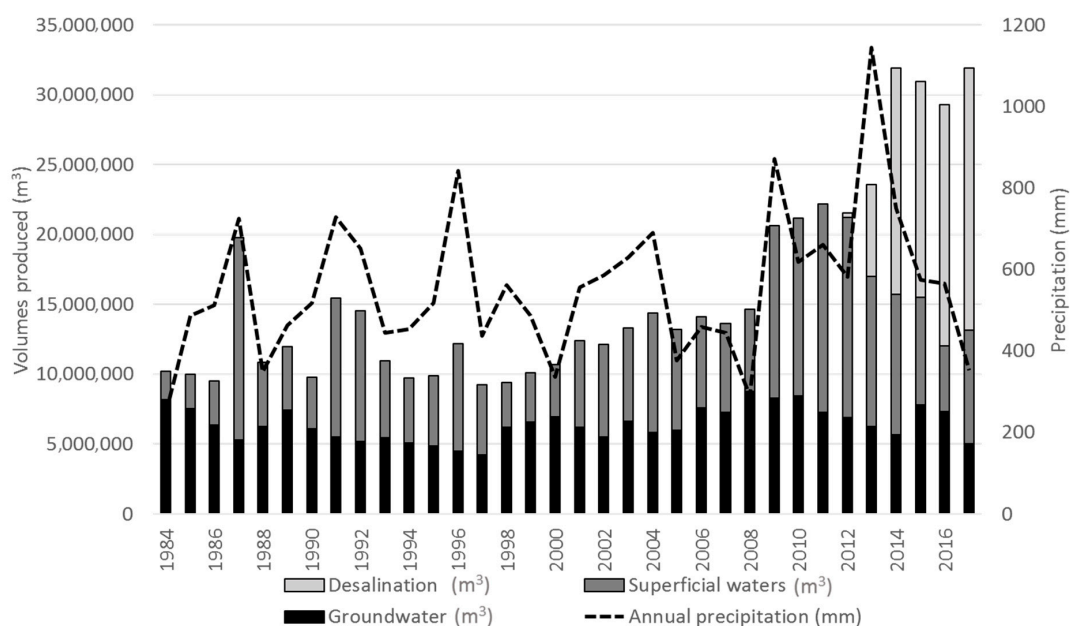


Figure 4. Total water resources in the case study region over three decades. There were four water sources: ground, superficial or surface, desalinated, and rain or pluviometry.

Based on the produced water during the period of 1984–2016 (Figure 5) for the average water consumption of 120 L/c/d, the produced water satisfied the water requirements of the community since the water volumes were all above the solid line. For the demand of 150 L/c/d, the volumes produced volumes satisfied the water requirements of the community in 23 out of 34 years. However, there were 11 dry years when the demand exceeded the supply. On the other hand, for UWDCs of 200 and 250 L/c/d, the per capita water demand was only met some years before 2013. After this year, all urban water demands were met as shown by all the solid bars being above the dotted line in Figure 5. The utilization of desalination technology has thus made it possible to produce sufficient water to meet all the needs of the community. The average urban water allocation increased from 175 to 279 L/c/d after the commissioning of two seawater desalination plants.

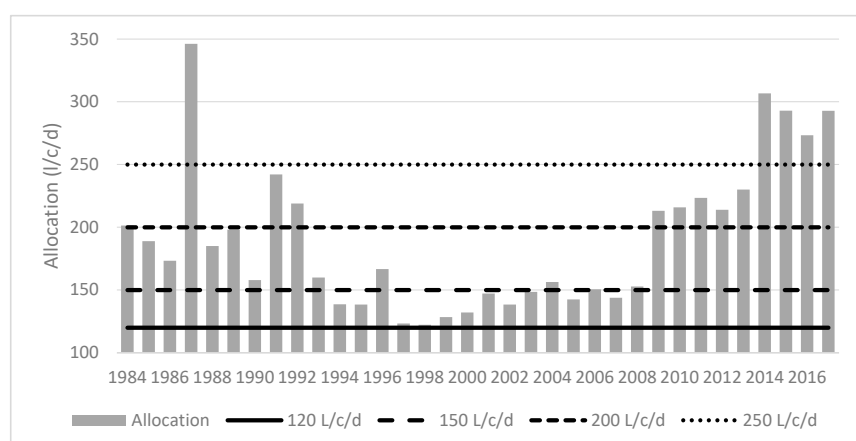


Figure 5. Comparison of four levels of urban water demand per capita (UWDC) (i.e., allocation shown by lines) and total water produced from all sources on an annual basis in the case study region.

Non-revenue water (NRW), which is the lost water in the distribution systems, was a serious problem, as shown in Figure 6. For example, in 2010, the gross allocation was 216 L/c/d, while the real consumption was only 87 L/c/d, which means the NRW was about 60% of the produced water. It was only after the desalination plants were put into

operation in the case study area in 2013 that the daily per capita real consumption was able to cross the threshold of 120 L/c/d and even just reach that of 150 L/c/d during the last two years (i.e., 2016 and 2017). Before 2011, daily real consumption was well below 80 L/c/d and even reached as low as 50 L/c/d in 1999. Consequently, the water services in Algeria had to employ rationing to establish equality in distribution. For example, water supply was provided twice a week, averaging 6 to 12 h per distribution [25].

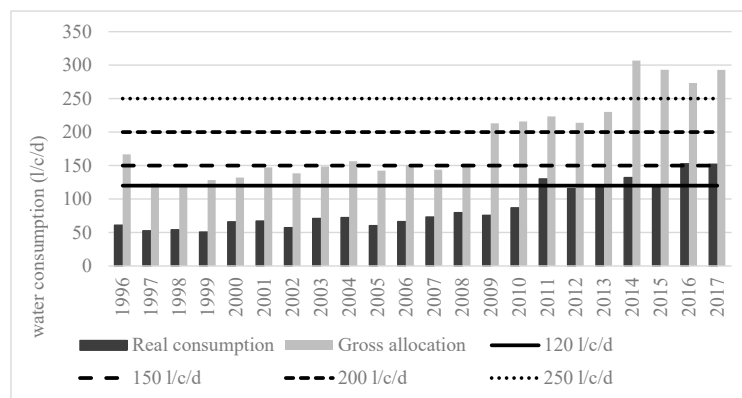


Figure 6. Increase in real water consumption and gross allocation (i.e., water production/availability from different sources) over two decades in the case study of an urban cluster in Tlemcen Algeria in northwest Africa. Water loss due to, for example, pipe leakage was the difference between gross allocation and real consumption.

During the period from 1996 to 2017, for which data were available, the cumulative volume lost 209 Mm^3 was greater than that of the volume consumed at 184 Mm^3 . On average, the cost of producing a cubic meter of conventional water was estimated at around USD 0.70 and that of unconventional water was around USD 1.2. This cost included investment, operating, and maintenance [23,37,38], resulting in more than a USD 168 million loss during the period. These expenses were applied for the whole study when it came to determining the costs of production, leaks, and consumption. Any inflation rates or variations in the currency's quotation were not considered.

Water losses or the NRW were the result of frequent breaks in the supply lines and pipes of the distribution network. This was due to the instability, obsolescence, and absence of protection systems for the supply and delivery. There was inadequate sealing at subscriber connections, poor calibration of water meters, water diversion by some subscribers, and illegal connections.

From 1996 to 2017, the average overall efficiency of the case study area water production and distribution system was 46% (i.e., 54% of the water was lost). This translated into a very high linear network loss index ranging from 0.95 to $1.92 \text{ m}^3/\text{h}/\text{km}$ [24] and indicated that the distribution network was unreliable and required urgent restoration. At the consumer level, daily per capita consumption was clearly below the gross allocation, including water losses across the entire water production and distribution system (Figure 6). Despite the apparent repairs and renovations to the network, the volume of water lost through leaks was still very large, as indicated by the differences recorded between the volumes produced (gross allocation) and the volumes invoiced (real consumption by subscribers). Data was obtained from the services of Algerienne des Eaux for water supplied to subscribers.

The rationing of water in the study area appears to be a thing of the past [25]. While water cuts have not disappeared completely, the overall situation has improved significantly. However, consumers still only receive half of what is produced (i.e., the difference between the black and grey bars in Figure 6). The high NRW was an indication of the deterioration of the network distribution system [39]. It can be argued that in economic terms, the cost price per cubic meter of water consumed was more than double [40]. Thus, there is a

direct relationship between reduced utility revenues and the water that never reaches the user [41].

3.2. Future Scenarios

Figure 7 presents the results of the first step, which indicate water demand satisfaction rates of the urban cluster of Tlemcen, based on network efficiencies and UWDC for the years 2030 and 2040. If no measures are taken to improve the 52% efficiency of the water distribution system, water supply will cover only 84% of the demands from 2040 for a community requiring 120 L/c/d (Figure 7A), and this percentage will reduce to 70% by 2050. For a UWDC of 150 L/c/d, the decline will begin in 2025, satisfying only 88% of water needs (Figure 7B). Supply satisfaction will continue to decline to 56% by 2050. Obviously, the higher the UWDC, the more difficult it is to meet water needs. For a demand of 250 L/c/d, only 34% of the water needs of the subscribers will be satisfied by 2050 (Figure 7D).

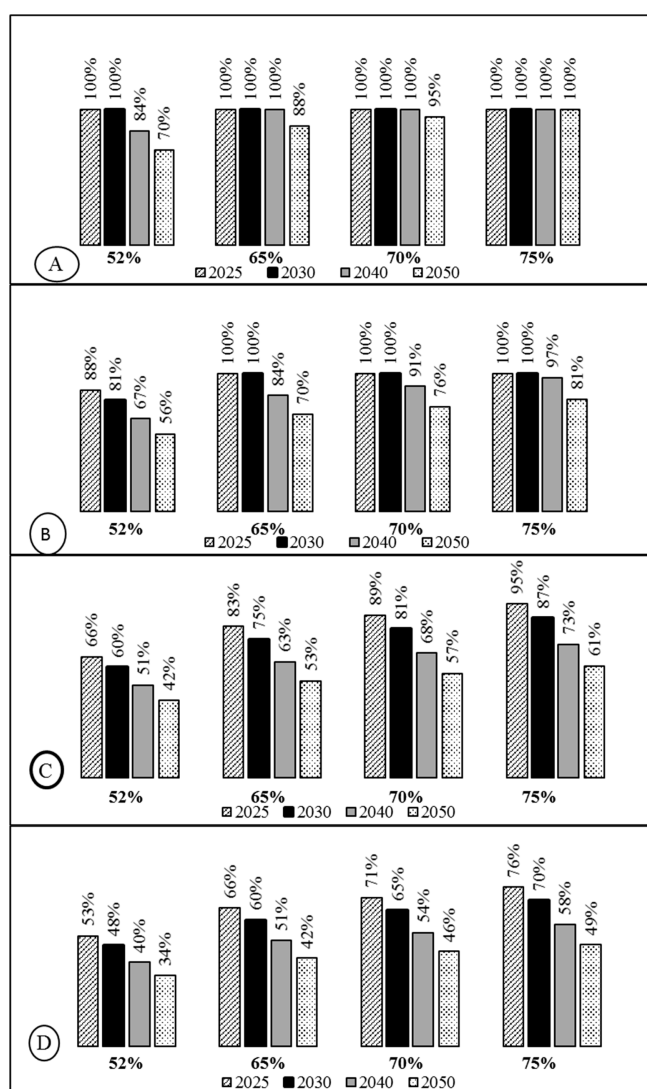


Figure 7. Water demand satisfaction rates for the case study region. (A) UWDC 120 L/d/c; (B) UWDC 150 L/d/c; (C) UWDC 200 L/d/c; (D) UWDC 250 L/d/c.

If managers decide to work to reduce the NRW to less than 35% (i.e., network efficiencies at 65%), then the recovery of the water demand will be ensured with an urban water demand equivalent to 150 L/d/c until 2030 (Figure 7B). If the population could reduce their

		Conventional Water 10 ³ m ³ /d				Network Efficiency (%)				UWDC (L/c/d)			
		17	36	65	100	52	65	70	75	120	150	200	250
Number of scenarios		1	3	5	7	0	3	5	8	9	6	1	0
Scenarios 1 to 16	Minimum value					Maximum value							
	Volume produced m ³ /d					86,045143,408							
	Vol. unconventional m ³ /d					071,556							
	Production cost M\$/year					22.645.3							
	Cost of leaks M\$/year					6.612.9							
	Price 1 m ³ product \$/m ³					0.721.11							
	Price 1 m ³ consume. \$/m ³					0.961.47							
			Conventional water 10 ³ m ³ /d				Network efficiency (%)				UWDC (L/c/d)		
		17	36	65	100	52	65	70	75	120	150	200	250
Number of scenarios		1	3	5	7	2	4	5	5	5	4	5	2
Scenarios 17 to 32	Minimum value					Maximum value							
	Volume produced m ³ /d					92,191179,260							
	Vol. unconventional m ³ /d					24,103114,260							
	Production cost M\$/year					36.867.1							
	Cost of leaks M\$/year					11.020.6							
	Price 1 m ³ product \$/m ³					0.811.13							
	Price 1 m ³ consume. \$/m ³					1.241.82							

Table 4. Cont.

	Conventional water 10 ³ m ³ /d				Network efficiency (%)				UWDC (L/c/d)			
	17	36	65	100	52	65	70	75	120	150	200	250
Number of scenarios	5	5	3	3	4	5	4	3	2	4	5	5
Scenarios 33 to 48	Minimum value				Maximum value							
	Volume produced m ³ /d				124,103							
	Vol. unconventional m ³ /d				55,128							
	Production cost M\$/year				48.0							
	Cost of leaks M\$/year				15.0							
	Price 1 m ³ product \$/m ³				0.89							
	Price 1 m ³ consume. \$/m ³				1.36							
Scenarios 49 to 64	Conventional water 10 ³ m ³ /d				Network efficiency (%)				UWDC (L/c/d)			
	17	36	65	100	52	65	70	75	120	150	200	250
	6	5	3	2	10	4	2	0	6	5	3	2
	Minimum value				Maximum value							
	Volume produced m ³ /d				155,128							
	Vol. unconventional m ³ /d				106,838							
	Production cost M\$/year				61.6							
	Cost of leaks M\$/year				23.3							
	Price 1 m ³ product \$/m ³				0.97							
	Price 1 m ³ consume. \$/m ³				1.59							

The most pessimistic scenarios were those constructed with high leakage rates and high water demands and favoring a significant desalinated supply of water. For example, in scenario number 64, as shown in the last column of Table 4, a total of 10 out of 16 scenarios were constructed with a network efficiency of 52%. More than half of the scenarios designed with a UWDC of 250 L/c/d were in this category. The same was true for the other criteria. These scenarios were characterized by large volumes of water being produced (ranging from 155,128 to 258,547 m³/d), overall costs of the annual water production (ranging from USD 61.6 million to USD 110.3 million), and the 1 m³ consumed price (ranging from USD 1.59 to USD 2.25).

With two of the categories, namely the least favorable (17 to 32) and the least pessimistic (33 to 48) in Table 5, the results were not sufficiently distinct to be interpreted separately. For example, scenario number 17 and scenario number 34 (Table 4). Indeed, almost half of the 32 scenarios were constructed with UWDCs of 200 L/c/d and above and a network efficiency of 65% or more. The same was observed for the other criteria; the difference between the values of the two categories was around 10%, as was the difference between the production cost of scenario 17 and scenario 34, 3.6% (Table 4).

Hydro-economic simulation models are considered valuable tools for understanding water allocation systems and improving decision-making in water resources management. As shown by the current investigation, both water economy and consumer awareness should be considered in water pricing. A related study by Arasteh and Farjami [42] presented a hydro-economic model based on system dynamics and agent-based simulation to enhance the sustainability of urban groundwater. Their results showed that several scenarios can achieve the goal, but, in drought conditions, only a combination of all the strategies will work. They concluded that changing the focus of water management approaches from supply to demand can enhance water conservation and sustainability. The authors recommended that specific adaptive management policies are needed for a

transition towards groundwater sustainability. This was like the observations found in the present work.

Table 5. Scenarios of water demand of the urban cluster of Tlemcen in 2050. Note that UWDC refers to urban water demand per capita.

Scenario Number	1	9	17	34	51	63	64
Network efficiency (%)	75	75	70	65	65	52	52
UWDC (L/c/d)	120	120	200	150	250	250	250
Volume of water produced (m ³ /d)	86,045	86,045	153,651	124,103	206,838	258,547	258,547
Conventional water volume (m ³ /d)	100,000	36,000	100,000	36,000	65,000	36,000	17,000
Unconventional water volume (m ³ /d)	0	50,045	53,651	88,103	141,838	222,547	241,547
Production cost (M\$/year)	22.6	31.4	49.8	48.0	79.2	106.9	110.3
Cost of leaks (M\$/year)	6.6	7.8	14.9	16.8	27.7	51.3	52.9
Price 1 m ³ produced (\$/m ³)	0.72	1.00	0.89	1.06	1.05	1.13	1.17
Price 1 m ³ consumed (\$/m ³)	0.96	1.33	1.27	1.63	1.61	2.18	2.25

The most favorable scenarios in the current investigation were those that recommended economical solutions in terms of water volumes (i.e., products, leaks, unconventional water) and/or costs (i.e., water production, leaks, 1 m³ produced or consumed), as indicated by scenario number 1 in Table 5. In 13 out of 16 cases, scenarios were constructed with a network efficiency of 70% and above. All scenarios in this category were designed with a water demand of either 120 L/d/c (i.e., 9 scenarios) or 150 L/d/c (i.e., 6 scenarios). More than half of the situations in this category were constructed with less than a third of the water volume produced from desalination. Furthermore, it can be argued that if mechanisms for efficient management will be put in place by 2050, to significantly lower the demand to 120 L/d/c, the stress on the case study area water supply would be reduced [43]. The need could be met by conventional water with an input of less than 100,000 m³/d, even with a leakage rate of 35%. If these efforts were accompanied by technical and social measures to improve the efficiency of the distribution system to 75% the price of 1 m³ consumed water would be reduced from USD 1.11 to USD 0.96. Thus, local authorities would save, annually, USD 2.6 million. This would represent 10% of the overall cost of water production in 2050 with a network efficiency of 65%.

If the conventional water supply remains unchanged from that of 2017, namely 36,000 m³/d, the overall cost of the leaks in the scenario constructed with a network efficiency of 52% and a demand of 250 L/d/h would be USD 51.3 million in 2050. This value is more than 163% of the overall water production cost compared to the scenario with a network efficiency of 75% and a demand of 120 L/d/c. Under these circumstances, the price per cubic meter of water consumed decreased from USD 2.18 to USD 1.33 (Table 4), resulting in an annual production cost saving of almost USD 75 million. It can be debated that this sum may largely cover the costs of rehabilitation of the area's water distribution system. Furthermore, it was important to produce reliable results, in terms of water production and distribution, while saving money. Achieving these required developing mechanisms of efficient water management based on, for example, the soft water path (SWP) model [43–45]. This would reduce the total demand by improving water use productivity rather than trying to find new sources. It was claimed that the model promoted sustainable use of water resources and produced economic benefits by increasing efficiency as well as greater equity, reduced environmental damage, and allowing for greater citizen participation in decision-making.

If the situation remains unchanged, in terms of the reduction of leaks on the water distribution network, the misuse of unconventional water, and a high UWDC, the costs of production and leaks would be very significant. This would have an impact on the price per cubic meter consumed. However, if measures were taken to improve network efficiency, prioritizing conventional resources and raising user awareness to reduce water demand, substantial savings could be achieved (Figure 8). The bottom of Figure 8 shows

the preferred conditions which are high overall performance (i.e., low water leakage), high conventional water availability, and low urban water demand per capita. It is of great significance to carefully choose the appropriate models based on the actual characteristics of a case study site. This was the purpose behind performing an analysis of the supply and demand of the urban cluster in Tlemcen in Algeria over the past 30 years. A related study was performed by Niu and Feng [46] from two huge hydropower reservoirs in China, where the authors showed that artificial intelligence methods could achieve adequate forecasting results. They also concluded that it is of great importance to carefully choose the appropriate prediction models based on the actual characteristics of the case study site.

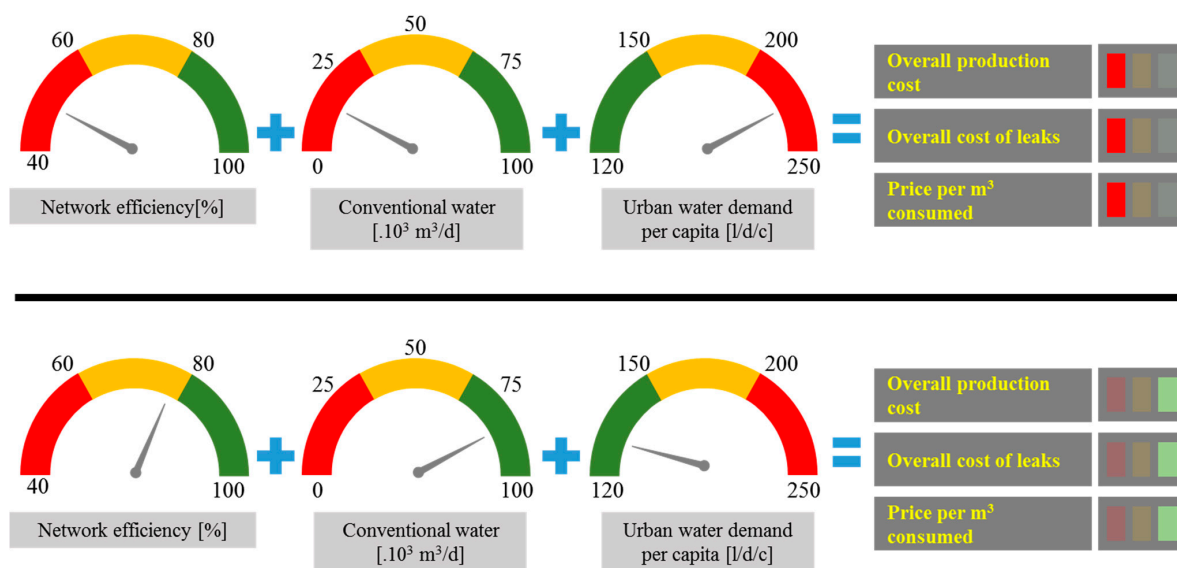


Figure 8. Dashboard summarizing the efficient and rational management of water resources in 2050 (bottom Figure). Preferred conditions are high overall performance (i.e., low water leakage), high conventional water availability, and low urban water demand per capita.

Finally, based on the analysis, it appears that for the efficient and sustainable management of the water resources in the study area by 2050, a combination of efforts and coordinated simultaneous actions are required. A reduction in water loss (i.e., improved performance) can be achieved through rehabilitation and renovation of the defective sections of the water distribution network, the renewal or installation of subscribers' water meters, and fixing illegal connections. A reduction in individual water consumption may be realized by an incentive approach adapted to local conditions and values. Optimal and rational use of local conventional water resources should go in coordination with employing water-conserving irrigation techniques such as micro-irrigation as well as electrical energy conservation.

Smart electricity control, which is often referred to as demand side management (DSM), has raised interest as a core enabler of future sustainable cities. A study by Janhunen et al. [47] examined the economics and environmental implications of DSM by analyzing an energy model using hourly-level energy consumption data in Finland. The results of this study, similar to the current investigation, highlighted the importance of an in-depth analysis of the value-creation logic of smart control. The authors recommended that more financial incentives and other motives for property owners are required to fully deploy smart electricity control in future heating and cooling systems. Likewise, multi-energy systems can enhance the flexibility and efficiency of conventional energy distribution systems. Liu et al. [48] presented work on providing an efficient energy management scheduling model for a retailer of a multi-energy system. In their model, the retailer was in touch with multi-energy markets, including electricity, heat, and gas, to meet the multi-energy demand of the end-users. An associated study by Pluchinotta et al. [49]

also emphasized the importance of a participatory process. The authors concluded that while dynamic models can be developed by experts alone, building them collaboratively allows the process to benefit from local knowledge, resulting in a collective learning process and increased potential for adoption. All these reports support the findings of the current investigations, which indicated the need for models based on real historical data, the use of multiple scenarios for predicting future demand, and the importance of collaborating with stakeholders who have local knowledge.

4. Conclusions

The simulation studies showed that for a sustainable society, the available water resources can secure the case study region's supply beyond 2050. However, this requires a combination of simultaneous efforts and coordinated actions on three fronts, namely improving the overall performance of the distribution system (i.e., reducing leakage), increasing conventional water production, and lowering urban water demand per capita. To achieve this, a water policy that promotes efficient water management must be implemented. These changes include the improvement of the technical performance of the distribution network, new approaches to modify the behavior of users to save water and promoting the rational exploitation of conventional water resources to increase overall conventional water supplies. The cost of cubic meter of the consumed water can be reduced from USD 2.25 to USD 0.96, which will allow taxpayers in the case study region to save almost USD 88 million annually by 2050. On the other hand, the lack of data on daily personal consumption and the real amount of water produced made it difficult to establish credible estimates of the volumes of water consumed by different users according to their needs. The availability of such detailed data would have allowed for a more comprehensive analysis. There is still an urgent need to fundamentally rethink the issue of sustainable water management in cities in arid regions such as in Algeria. Reducing total water demand and improving water use productivity need efficient water management mechanisms that ensure economic and sustainable water production and distribution.

Finally, promoting sustainable use of water resources is based on economic benefits, equitable distribution, reducing negative environmental impacts, and engaging stakeholders. The current study is a starting point in the development of a sustainable city in the case study region. The results will help to guide local policies and water managers to adopt approaches to ensure long-term sustainable water resources management.

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