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Study of the performance of the drinking water supply network: case of the new urban pole of Boujlida (City of Tlemcen, Algeria)

Racha Medjda Bouchenak Khelladi[a,b,*], Abdelghani Chiboub Fellah[b]

[a]*Pan African University, Institute for Water and Energy Sciences (including Climate Change) (PAUWES), Abou Bekr Belkaid University of Tlemcen-Algeria, email: rashamajda@hotmail.fr*
[b]*Laboratory of Valorization of Water Resources (V.R.E), Faculty of Technology, University of Tlemcen, BP 119, 13000, Tlemcen-Algeria, email: chibabghani@yahoo.fr*

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ABSTRACT

The main aim of this study is to assess the efficiency and performance of a drinking water supply network for the district of Boujlida-Tlemcen Algeria. In order to identify the strengths and weaknesses in the control of water service from an operational perspective; indicators were quantified to assess the performance status of the water supply network. The data analysis revealed that the water supply network of Boujlida is efficient at 55% meaning that about half of the volume entering into the network is lost and that the water bill covers 92% of the total cost of water. Those results confirm that the water management requires a proper and continuous monitoring by decision-makers to improve its efficiency, especially in a country with limited fresh water resources and a rising water demand.

Keywords: Indicators; District of Boujlida; Performance; Water management; Water supply network

1. Introduction

There are many variables that need to be analyzed for water resources management and water supply such as land use, climate conditions, and pollution pressures affect water quantity and quality; water pressure, leakages, asset aging, and supply standards are important for operation and maintenance of water supply, while pricing policies affect water demand [1].

Non-revenue water (NRW: water not generating revenues) is one of the primary problems water utilities are facing today, it consists of the water losses (real and apparent ones) and the unbilled authorized water use. Climate change conditions and water demand increase worsen the global water resources status. The situation becomes even worse in countries facing water scarcity conditions, such as the Mediterranean Basin countries, where NRW levels exceed 50% of the water entering the water distribution networks (WDSs). NRW does not only represent water volume lost, but also revenues lost for the water utilities and energy lost. Globally one third of the total water volume abstracted from the water resources and used as drinking water, is lost in the distribution networks due to pipe leaks and breaks. In some low-income countries the NRW value gets as high as 50%–60% of the system input volume. A conservative estimate of the NRW-related annual cost to water utilities worldwide exceeds US$14 billion [2,3].

Algeria is one of the countries in the Mediterranean Basin that suffers from water scarcity due in large part to irregular rainfall and its heterogeneous distribution. Correlatively, flows are characterized by a significant interannual and seasonal irregularity and by the violence and the rapidity of the floods. The severity of the problems is that the irrational exploitation and the pollution make the quantity of water usefully mobilized much smaller. Algeria is currently a world leader among countries affected by water stress, and

* Corresponding author.

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if there are no real and more effective approaches, it will suffer even more in the future [4].

The evaluation of the quantities of water available to users is often set by the objectives of water endowment per inhabitant. On the other hand, the quality covers two aspects, the water itself and the quality of service to convey according to the needs. In the Algerian context, the quality of service is often measured by the frequency of water supply (generally intermittent) [5]. However, other additional and crucial indicators could be more relevant, such as the water supply per capita, without incorporating the rates of physical losses in the networks, which remain high, or carrying out surveys among users, particularly households, because the quality of service can only be measured in terms of user satisfaction [6].

Algeria, which has 1,200 km of coastline, adopted seawater desalination (three quarters) or brackish water (one quarter) as alternative to supply drinking water to cities and localities in the coastline, and up to 60 km further from the coast. In 2013, Algeria had nine large desalination plants in operation capable of producing up to 1.4 million m^3 of desalinated water per day, there are also around twenty small mono-block stations (with capacity range from 2,500 to 7,000 m^3/d); some of these have been relocated to reinforce water deficiency in other localities [7].

The water supply in the city of Tlemcen is characterized by an insufficient production that cannot meet with current needs, mainly due to the reduced rainfall during last year. Most neighborhoods are supplied once to twice a week for few hours. There is also a tremendous rate of water loss that exceeds 50%. This loss is the result of pipes, poor workmanship quality, and a lack of maintenance and renewal of pipelines. The water supply system as a whole is poorly structured as a result of extensions made without basic design [8].

Some studies have been conducted to evaluate the performance of the drinking water supply in the city of Tlemcen-Algeria [8–13], however, the city of Tlemcen is a rapidly growing city where new urban poles such as "Boujlida" that have been emerged as part of emergency plans for relocation and resolve the problem of precarious housing, where there has been no studies conducted on drinking water supplies network in those poles. Since those new poles needs to resolve an emergency relocation, they are designed under minimum time, and hence we can expect that the drinking water supply network can be underestimated that may not satisfy the water needs of the current and projected citizens, and also leading to leakages due to water pipe pressure.

The aim of this study is to assess whether the drinking water supply of the new urban pole of the city of Tlemcen-Algeria "Boujlida" which represents an extension of the city has been adequately designed to meet the citizen's water needs, and also to evaluate the efficiency and performance of the drinking water supply network, in order to sensitize water utility services about the importance of a good and adequate water infrastructure design and management. Technical indicators were used to identify the weaknesses and strengths in the management of water service from an operational perspective in order to optimize and improve the distribution network performance; such as total water losses, unaccounted water index, per capita water use index, number of subscribers per length of mains, and linear distribution loss index.

2. Methodology

2.1. Study area characterization

The municipality of Tlemcen is located in the far west of Algeria, bordered by the Mediterranean Sea in the North, by the Kingdom of Morocco in the West, and in North-East and East by the municipality of Aïn Témouchent and Sidi Bel Abbès, and to the South by the municipality of Naâma. It extends over an area of 9,061 km^2. The territory of the municipality of Tlemcen is made up of a set of natural environments that follow one another roughly parallel way. We distinguish from North to South: the mountain range of Traras, the plains and plateaus limited to the South by the mountains of Tlemcen and finally the area steppe that extends to the borders with the municipality of Naâma [14].

Chetouane is located in the center of the municipality of Tlemcen about 5 km northeast of the city center, the town represents the northern part of the agglomeration of Tlemcen, it is made up of the following localities: Ouzidan - Aïn El Hout - Aïn Defla - Saf-Saf - Medigue - Sidi Aissa - Oudjlida - Boudjlida - Koudia - Domaine Hamadouche [15].

The study area is the locality of Boujlida (Fig. 1) which is located north of Koudia, South of Ain El Hadjar, and east of Oudjlida. It constitutes a new urban center established over a total area of 105 hectares and endowed with major housing projects, necessary amenities and green spaces. It is the new urban pole which is an expansion of the city of Tlemcen. The Boujlida region is a fairly rugged region with very steep slopes ranging up to 20% [15], its altitudes vary between 550 to 620 m.

2.1.1. Drinking water supply of Boujlida

The drinking water supply to Boujlida is from the reservoir of Koudia of a capacity of 5,000 m^3. The reservoir is supplied [15]:

- The Honaïne desalination plant with a ductile iron pipe 200 mm in diameter in most of the time.
- The Sekkak Dam with a ductile iron pipe with a diameter of 400 mm when the Honaïne desalination plant is shut down.

2.1.1.1. Sekkak Dam

This dam was originally intended for the agricultural development of the plains of Hennaya and El Fehoul. Upon completion of the work, the supply to ensure the transfer of water to the city of Tlemcen was installed. The volumes of pumped water are not very important 7,000,000 m^3/y. As the drinking water supply of the populations is a priority, the water has been partially or totally diverted for this purpose. The rainfall deficit and the increase in population are the main factors which have led to this reallocation. The concern of the local authorities to ensure an acceptable daily water supply to the inhabitants is a factor not to be overlooked. Indeed, there are many localities in the

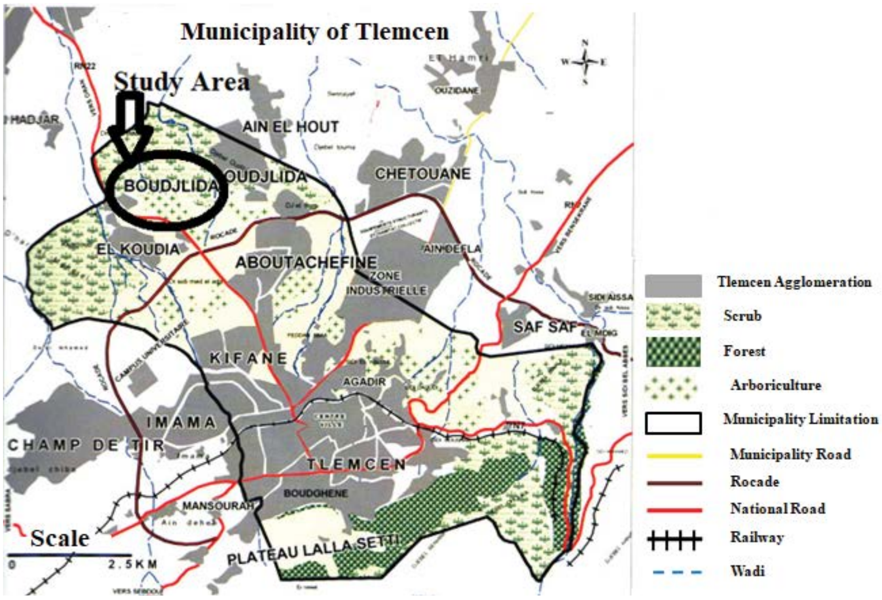

Fig. 1. Study area of Boujlida [19].

municipality of Tlemcen where the daily allowance does not exceed 0.1 m^3/d/inhabitant [16].

2.1.1.2. Honaïne desalination plant

The "Honaïne" seawater desalination plant is located in the commune of Honaïne (municipality of Tlemcen) in the western Algeria (69 km north of the town of Tlemcen, north-western Algeria), started in 2006 by the Spanish GEIDA group (Composed of companies: Cobra, Sadyt, Befesa and Codesa), it was operational in July 2012, with an investment amount of \$250 million. It is projected on an area of 80,000 m^2. It has a desalinated water production capacity of 200,000 m^3/d, ensuring the supply of potable water for a population of 555,000 inhabitants. The specific desalination energy of this unit is 43,800 kWh/d, with a daily power of 1,825 kW. The station of Honaïne is delimited to the North by the sea, to the South, to the East and the West by a farmland and some houses [17,18].

The drinking water supply network in our study area is a mixed network, with the following particularities [15]:

- Primary network already existing in high density polyethylene HDPE to which several networks are attached secondary in HDPE too (the area is expanding rapidly). Its total length is around 20 km (secondary networks included).
- All networks are built in HDPE with different standard diameters ranging from 40 mm up to 400 mm.

2.2. Indicators for assessing water demand

The alarming shortage of freshwater faced by certain countries requires urgent and immediate action, in particular, those in the arid and semi-arid areas of the globe, which do not have sufficient water and land resources to ensure the survival of the increasing population. In this regard, Algeria is among the most vulnerable areas of the world, based on the threshold of water scarcity fixed at 1,000 m^3/a/y [9]. Algeria is also one of the countries where water availability is limited while needs are growing rapidly. This growth is due to the rapid population increase, to industrial and agricultural developments as well as to drought [20]. Moreover, the rapid increase in agricultural activities and other domestic and human practices has led to the deterioration of Algerian water bodies used to cover drinking needs. This situation results in decreasing the country's per capita water availability (i.e., below 300 m^3/y). To sort out the problems of water shortage and to meet the growing water needs, most Algerian towns have undertaken a program of water rationing adopted by the Company of Production of Water "Algérienne Des Eaux" (ADE) [21].

In Algeria, the systematic inventory of water resources, in spite of many studies carried out during the last century is not completed yet, but its broad outline is known, where water consumption is not measured and if it is, data are rarely reliable due to water meter degradation. Few attempts have been made to characterize and quantify actual water consumption [10].

Growth coefficient and population statistics are the first data used in project calculation and simulation. The number of total population at time t of project was calculated using the Eq. (1) [22].

$$P_n = P_0\left(1+\frac{T}{100}\right)^n \tag{1}$$

where P_n: population at the horizon of year n; P_0: population of the reference year, T: population growth rate = 3.1% for Chetouane [23], n: difference between the actual and the projected year.

In order to estimate the water demand for the projected population, we use the Eq. (1):

$$\text{Water Needs}(\text{L/d}) = \text{Endowment}(\text{L/d/Inhab}) \times \text{Population}(\text{Inhab}) \quad (2)$$

With: Endowment = 150 L/d/inhab (for Algeria)

2.3. Indicators for assessing performance of drinking water supply network

In the field of drinking water supply, performance measurement by indicators relating to the qualitative results of the service appears to be a tool specific to improve management skills. The implementation of this methodology seeks to constitute a common panel of indicators covering all the missions of the services drinking water supply. These indicators, in a limited number and often quite simple to calculate, are ranked in order to guide the choice of the community, without withdraw the possibility of adapting the list to the particular context of its service [11]. For better management and operation of Boujlida drinking water supply network, quality indicators have been judiciously chosen to assess the state of operation network and ensure the sustainability of the service provided. These indicators allow better identification of the strengths and weaknesses in the conduct of the water service. These indicators were listed under technical and service indicators. They are calculated based on data on volumes produced, distributed consumed recorded at the level of Boujlida locality that were provided from ADE of the city of Tlemcen (July 2020–July 2021) (Appendices A and B).

2.3.1. Production yield

The production yield is an important indicator for the management technique of a drinking water supply network. It is defined as being the ratio between the stored volume and the volume produced [24]. If we deduct the production yield from 100% we get the volume lost in storage.

$$\text{Production Yield}(\%) = \frac{\text{Stored Volume}}{\text{Produced Volume}} \times 100 \quad (3)$$

2.3.2. Primary yield

This indicator represents the interannual evolution of the network's performance. It is essential to see the degradation or on the contrary the improvement in the state of the network over the years. Only the authorized consumed volumes are taken into account in the calculations of the primary yield [12].

It reflects the notion of network efficiency, since it compares the totality of the water used with that introduced into the network. It is an important element for the management of a drinking water supply network, and generally greater than 65% and may reach or even exceed 90% [24]. With the primary yield, the volumes used but not recorded are considered as losses. The primary yield "overestimates" the losses.

$$\text{Primary Yield}(\%) = \frac{\text{Volume Consumed Recorded}}{\text{Volume Supplied}} \times 100 \quad (4)$$

2.3.3. Unaccounted water index

Unaccounted water index (UW) is the most important index representing the network level-of-service. It estimates the deficit between the water supplied by the water treatment plants and the metered consumption. The UW can reach or even exceed the level of 50% in old or uncontrolled networks. A pipe network with UW less than 15% is supposed to be in good condition. If the value of UW is greater than 30% then the network needs immediate inspection [25].

$$\text{UW}(\%) = \frac{\text{Volume supplied} - \text{volume billed}}{\text{Volume Supplied}} \times 100 \quad (5)$$

2.3.4. Linear distribution loss index

The linear loss index translates the volume of water lost per unit length. This is the evolution over time of these two indicators (performance primary + linear index of loss) which will serve as the basis for any improvement plan network performance [11]. Linear distribution loss index (LDLI) is defined as the ratio between the volume distribution losses and the length of the network. This ratio varies according to the type of network and can reach 10 to 15 m^3/km d [24].

$$\text{LDLI}(\text{m}^3/\text{km.d}) = \frac{\text{Volume Supplied} - \text{Volume Billed}}{\text{Linear of the Network} \times 365} \quad (6)$$

2.3.5. Number of subscribers per length of mains

It equals the number of subscribers per network kilometer. It is expressed in service connection/km main.

$$\text{Number of Subscribers Per length of mains } D = \frac{\text{Number of Subscribers}}{\text{Linear of the Network}(\text{Km})} \quad (7)$$

Several references exist to characterize a service from this parameter [26]:

- $D < 20$: Rural type network
- $20 < D < 40$: Intermediate type network
- $D > 40$: Urban type network

2.3.6. Per capita water use index

Per capita water use index is defined as the water volume supplied daily by the water treatment plants, divided by the equivalent population served by the water utility. The value of this index follows the increase of industrial use and mean residents' income. When the index has values greater than 200 L, then water use metering and/or leakage problems probably occur [25].

$$\text{Per capita water use index} = \frac{\text{Volume Supplied}}{\text{Subscribers}} \quad (8)$$

2.3.7. Total loss and global yield of the network

Any water management body is called upon to calculate the overall yields, which constitute one of the performance indicators of the network for which it is responsible. The overall yield is expressed as the ratio of the volume consumed to the volume produced.

$$\text{Global Yield}(\%) = \frac{\text{Volume Consumed}}{\text{Volume Produced}} \times 100 \quad (9)$$

2.3.8. Water balance

The well-acknowledged methodology to assess an urban WDS, monitor the progress of the WDS performance level and check the impact of the measures taken is the International Standard Water Balance (WB) (Table 1) along with a set of 170 performance indicators. The WB determines the revenue water, the water losses and the NRW. NRW (water not bringing in revenues to the water utility) consists of physical (real) losses, commercial (apparent) losses and not billed authorized consumption (metered and unmetered) (Fig. 2) [2].

Several of the variables required for the WB assessment were either unreliable (meter's inaccuracies) or missing (unbilled authorized use, unauthorized use, and water billed but not paid) for that reason the previously cited indicators was applied.

2.4. Indicators for assessing the cost of water and economic loss

The tariff level should be determined using a cost-based approach, as well as requests consumers. In Algeria, there are few studies that specify the cost of water services. According to the SOGREAH/ICEA study [29], the real cost of water would be in a range of 100.5–117 DA/m^3 (0.72–0.84 USD/m^3); 73 and 82 DA/m^3 (0.52 and 0.59 USD/m^3) for water and 31.5 to 35 DA/m^3 (0.23 and 0.25 USD/m^3) for sanitation. Another study by Benachenhou [30] showed that the real cost of 1 m^3 of water in Algeria is around 130 DA/m^3

Table 1
The IWA water balance (WB) [27]

System input volume	Authorized consumption	Billed authorized consumption	Billed metered consumption (including water exported)	Revenue water
		Unbilled authorized consumption	Billed unmetered consumption Unbilled metered consumption Unbilled unmetered consumption	Non-revenue water
	Water losses	Apparent losses	Unauthorized consumption Metering inaccuracies	
		Real losses	Leakage on transmission, and/or distribution mains Leakage and overflows at utility's storage tanks Leakage on service connections up to point of customer metering	

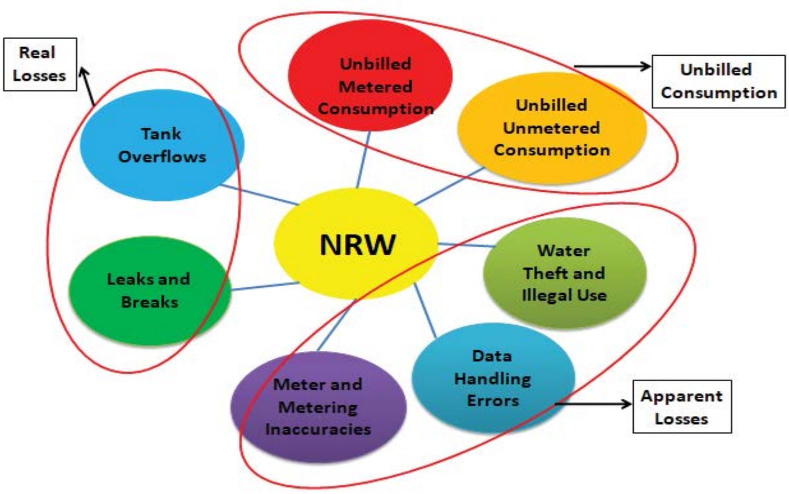

Fig. 2. Component of NRW [28].

(0.0.93 USD/m^3). The study by Boukhari et al. [31], revealed that the cost per cubic meter of water and sanitation for the city of Souk Ahras is 125 DA/m^3 (0.60 USD/m^3) including the costs of investment and operation (drinking water and sanitation) for a sale price of 18 DA/m^3 (0.13 USD/m^3). According to Benblidia [32], the selling price of 1 m^3 of drinking water is 64 DA (0.46 USD), while its production cost was estimated in 2005 at around 90 DA/m^3 (0.65 USD/m^3) and which is currently about 125 to 150 DA/m^3 (0.90 and 1.08 USD/m^3) taking into account seawater desalination. Another study carried out at ENSH by Zeroual and Meddi [33] shows that the real cost of water is equal to 170 DA/m^3 (1.22 USD/m^3) for the city of Bordj Bou Arreridj.

In order to estimate the economic loss of water production and distribution and sanitation, we have considered the following values according to literature:

- The production of desalinated water equals 120 DA/m^3 (0.86 USD/m^3).
- The distribution of water equals 50 DA/m^3 (0.36 USD/m^3), including the sanitation.

Evaluation of the cost of water production needs a special interest to calculate the cost of production of water for citizens. This may implicate all cost entered in production as energy, employees, chemical product, and hydromechanical equipment [34].

$$\text{Total cost}(\text{DA}) = \text{Water production cost}(\text{DA}) + \text{Water distribution cost}(\text{DA}) \tag{10}$$

$$\text{Economic loss}(\text{DA}) = \text{Total cost}(\text{DA}) - \text{Billed volume}(\text{DA}) \tag{11}$$

$$\text{Cover rate}(\%) = \left(\frac{\text{Economic loss}(\text{DA})}{\text{Total cost}(\text{DA})}\right) \times 100 \tag{12}$$

2.5. Data collection

The data used in this study were collected (from July 2020–July 2021) from Algérienne Des Eaux (ADE) "Algerian of Water", which is a national public institution created by Executive Decree No. 01-101 of April 2001, its role is to ensure throughout national implementation of the national policy on water through support management activities of production operations, transport, treatment, storage, supply, distribution and supply of drinking water and industrial as well as the renewal and infrastructure development related thereto. The responsibilities can be stated as; standardization and quality monitoring of the water supply; initiate any action to save water, including; improving the efficiency of network transfer and distribution; the introduction of any technical water conservation; the fight against waste in developing information campaigns, training, education and awareness towards users; design, with public educational curriculum disseminating the culture of water conservation [35].

3. Results and discussion

3.1. Network performance of Boujlida

Regarding the production and distribution of drinking water, the first savings to be made is of course the efficiency of the network since each cubic meter of water produced has consumed kilowatt-hours lost as a result of leaks in the network [36]. Network yields are seldom less than 70% in developed countries; however they can drop to less than 30% in certain urban farms in lack of support [37]. The optimization of the water distribution service for a high efficiency implies the implementation of an adapted and efficient management, which combines the aspects of rapid maintenance of the network, renewal of the network and improvement of the commercial water supply management [38]. The efficiency of the water supply network represents the ratio between the volume of water consumed by users (individuals, industrialists) and the public service (for the management of the drinking water system) and the volume of water drinking water introduced into the distribution network, the higher the efficiency (at constant consumption), the lower the losses by leaks [11].

3.1.1. Production, primary yield and unaccounted water index

The production yield (Fig. 3) of Boujlida from July 2020 to July 2021 is on average yield of 92% which is higher than standard of 90%, which is acceptable, similar results have been found by Abdelbaki et al. [13], where the production yield for the Tlemcen urban group averaged out to 93%. We have also found that the total volume lost in storage represents 8%. We have found that the total volume lost in storage is about 103,976 m^3, which corresponds to a loss in storage on average of 8%.

According to Benblidia [32] the average efficiency value of the Algerian national networks is 50% in our study, it has been found that the average primary yield of the Boujlida distribution network is 55%. This means that around 45% of the volume of drinking water introduced into the supply network is lost. For the month of April 2021 the water loss has been estimated to 49,373 m^3, the equivalent of 14 to 15 Olympic swimming pools. For the UW (Fig. 4), it varies between 40%–50%, which is greater than 30% which suggest that the network needs immediate inspection, according to Kanakoudis [25] an increase in UW might be a symptom of illegal connections to the network, water theft, inadequate or false metering and leaks.

The problem of water leakage in the drinking water distribution networks has been systematically criticized as the weak point of water management in Algeria. This indicator was and will remain a sign of water resources management. The low rate of return (i.e., efficiency ratio) of water distribution networks is due to a series of causes relatively easy to overcome (e.g., dilapidated distribution systems, weaknesses in the installation of water metering and some "free-rider" behaviors like illicit water pipe connections and water theft) [39].

The comparison between the volume distributed and the volume billed in Fig. 5; we can notice that there is a difference of almost the half, which confirms that the half of water that is distributed is lost while supplied.

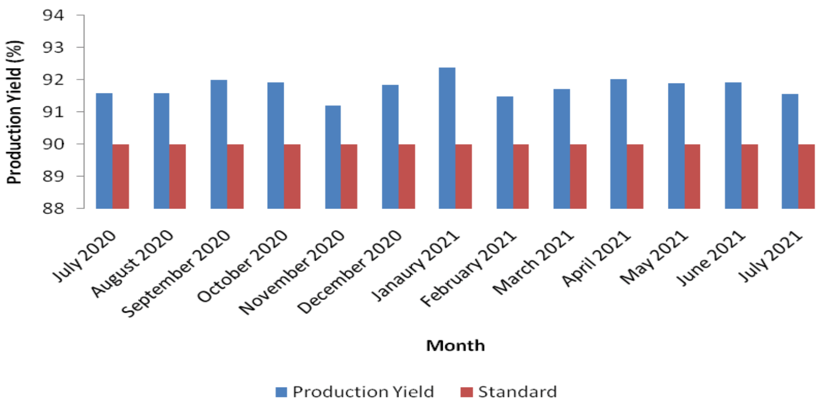

Fig. 3. Variation in production yield of the network of Boujlida.

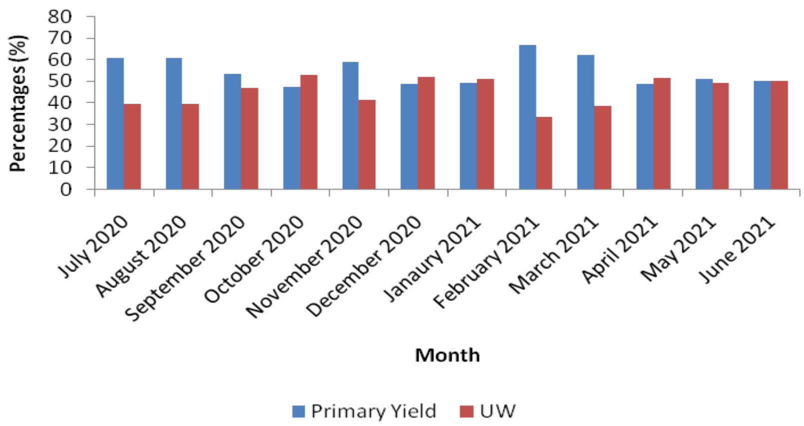

Fig. 4. Variation in primary yield and UW of the network of Boujlida.

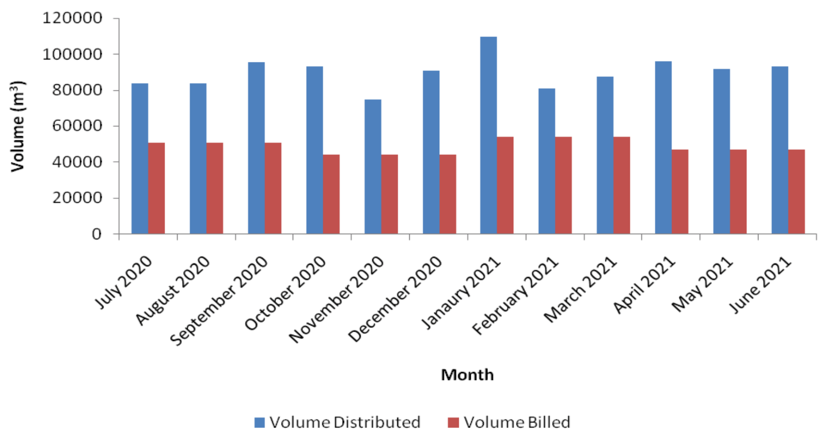

Fig. 5. Comparison between the distributed and the billed volume.

According to ADE (Tlemcen) [15], there is the loss of volumes distributed in the new locality of Boujlida that is estimated at 5 l/s, which represents a monthly volume of 13,392 m^3 due to breakage in the HDPE pipes (φ315, φ250, φ200, φ160), this allows us to be sure that 7% of the water lost comes from pipe leaks, which means from 45% of water loss found above, we have 3% coming from breakage pipes, and for the remaining 42% the losses can come from other broken pipes that have not been resent, or from illegal pecking.

Those breakages in the HDPE pipes for the water supply network of Boujlida is due to the high pressures because

Boujlida network suffers from several pressure problems due to the fact that the area is formed by several very steep slopes and therefore there is a big difference altitude between the nodes of the network. According to Kahlerras et al. [4], pressure reduction leads to reduced real loss related to background leakage, reported and unreported leaks, and that the burst frequency is also reduced, since the infrastructure operates more within its resistance limits. The reduction rate of bursts frequency depends on the pipe material, the maximum operating pressure and the rate of new breaks that are non-pressure dependent.

Renovation of water distribution net-work should be a short-term action to reduce water losses through leakages. A proactive monitoring system must be implemented to prevent future inconvenience. Losses must also be reduced in the transfer system through minimizing leakages in pipes [40].

3.1.2. Linear distribution loss index, per capita water use index and per length of mains

Reducing losses of water should always be an objective of a water utility for reasons of technical supply, environment and economics. However, it is impossible to avoid losses of water completely. The theoretical potential of a reduction of water losses specific to a system can be determined by means of the infrastructure leakage index [41]. The variation of the index of distribution water losses in Boujlida (Fig. 7) varies between 3.68 and 7.65 m^3/km d corresponding to 0.15 and 0.32 m^3/km h, respectively, according to INPE [42] those results correspond to an average water loss and that the loss can be limited by using appropriate technical means.

Per length of mains (Fig. 6) for the trimester of July-August-September 2020 reached 250 service connection/km main and increased to 263 service connection/km main on the trimester of April-May-June 2021. The subscriber density was significantly higher than 40 service connection/km main (Average 259 service connection/km main), according to Office de l'eau [26] the network is urban type (superior to 40 service connection/km main).

Fig. 4 has shown that higher per capita water use index is recorded for the trimester of April-May-June 2021 with a value of 0.30 m^3/sub/d which are greater than 0.29 m^3/sub/d corresponding to a very high level loss according to Renaud [43].

3.1.3. Total loss and global yield of the network

The variation of the global yield (Fig. 8) is on average of 50%, where the highest global yield has been recorded for the month of February 2021 with 61%.

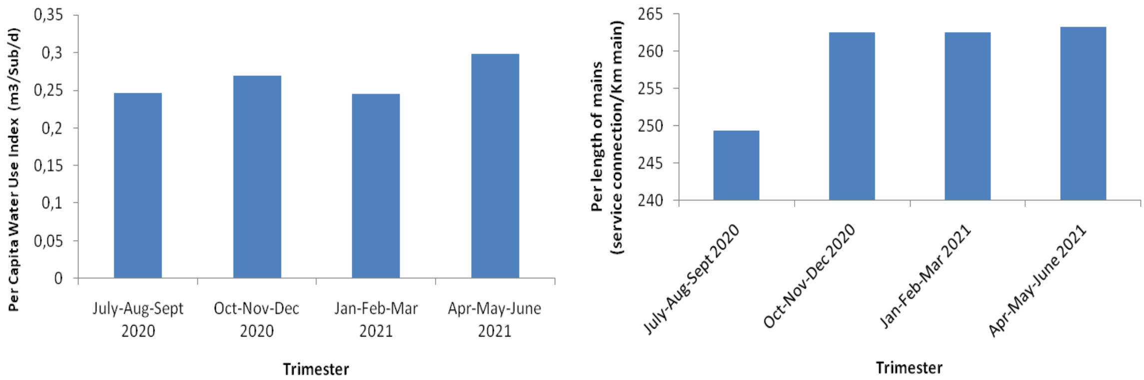

Fig. 6. Variation of the per capita water use index (a) and per length of mains (b).

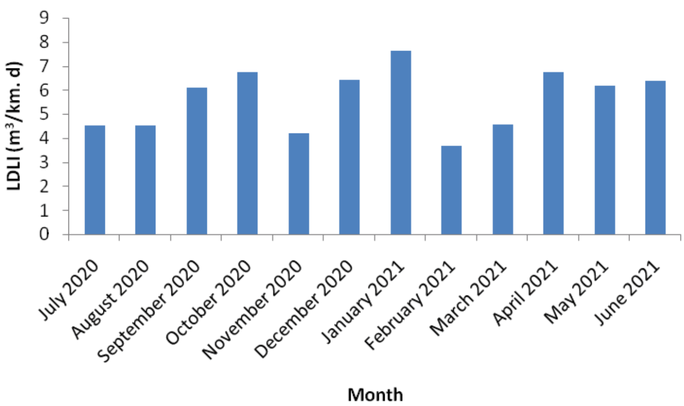

Fig. 7. Variation in linear distribution loss index.

According to Fig. 9, between July 2020 and January 2021 there was first a increase in the volume produced due to the increase in inhabitant leading to the increase on drinking water demand. Regarding volumes of water distributed and billed, they decreased due to the reduction of the volume produced.

3.2. Cost of water and economic loss

The cost of water represents the cost price of a unit of distributed water (m^3), all charges included, of a hydraulic installation. Water management activities and water and sanitation services come at a cost. This cost is made up of different elements. Failure to take into account some of these elements ultimately results in unsustainable use of water resources and services, resulting in significant welfare losses for the community. And in this case is closer to the concept of cost price which is the sum of all the costs which constitutes the consideration for a good or service [44].

Crucial parameters affecting the level of the cost of water and its components concern the necessary waterworks and the way the water utility operates. It includes parameters related to the water characteristics (surface, groundwater, brackish water, sea water), the water intake works (dams, drillings), the water aqueducts (pipes, tunnels, water-carrying distance), the water treatment plants (quality of raw water), the water storage tanks (location, size); and the water distribution network (valves, boosters, pipes) [45].

According to the Algerian Official Journal n°28 of 14th April 2021 (Executive Decree n°21-137 of 7th April 2021), the minimum wage is at 20,000 DA (143.77 USD).

The volume of water consumed per trimester for the inhabitants of Boujlida is comprised between 25 and 31 m^3/trimester, which corresponds to the 2nd tranche (Table 2), where the water tariff and sanitation equals to 28.12 DA/m^3 (0.20 USD/m^3).

The total cost of the water production and distribution from July 2020 to June 2021 in the locality of Boujlida is estimated to 195,214,245 DA (1,403,483.05 USD) a total volume produced and distributed of 1,176,651 and 1,080,323 m^3, respectively. The water loss is estimated at 178,742,983 DA (1,285,063.74 USD), the billed volume covers about 92% of the total cost of water production and distribution. According to Boukhari and de Miras [46], in some cases the consumers bills only covers 80% of the total cost, or does not barely covers the only salary charge (the first post of ADE charge is represented by salaries, which amount to 26 billion Algerian dinars (186,925,700.00 USD), almost as much as the figure business, which was 28 billion dinars in 2016 (201,304,600 USD).

In gaining an understanding of water loss from any system it is important to differentiate between real and apparent losses. Real or physical losses from a network represent a lost resource. Consequently a reduction in leakage means that a utility has additional water that can be supplied to customers, especially if there had previously been a shortage of water. If a water utility is planning to develop a new source then capital expenditure can be deferred or avoided by reducing leakage from the system. Apparent or commercial losses as they are more commonly known is water that is being taken from the system and used but not paid for and, therefore, is a loss of potential revenue

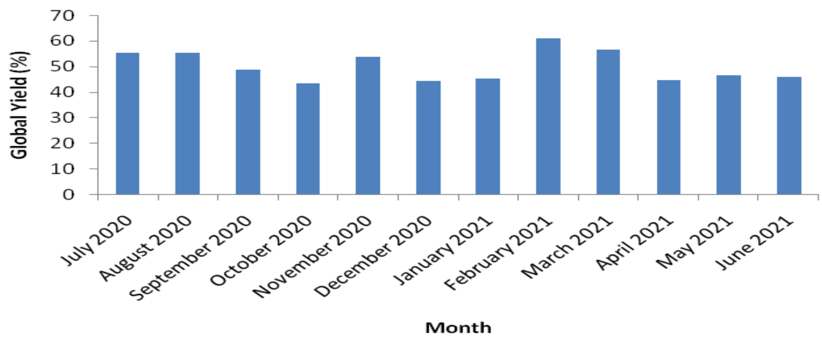

Fig. 8. Variation of the global yield.

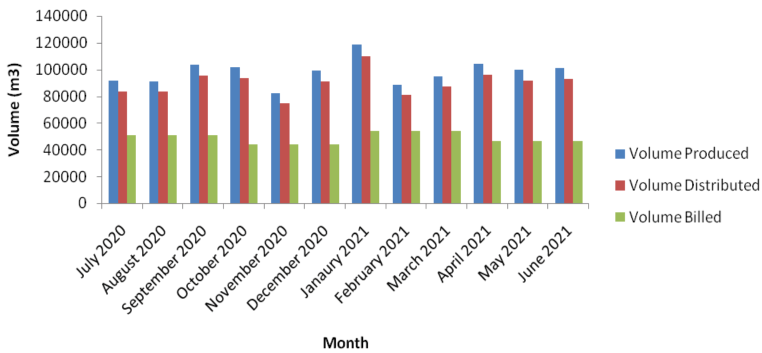

Fig. 9. Comparison between produced, distributed and billed volume.

Table 2
Water tariff for households (Executive Decree n°05-13 of 9 January 2005)

Households	Quarterly tranche consumption	Water and sanitation, DA/m^3	Water and sanitation, USD/m^3
1st tranche	<25 m^3/trimester	8.65	0.062
2nd tranche	From 26 to 55 m^3/trimester	28.12	0.20
3rd tranche	From 56 to 82 m^3/trimester	47.58	0.34
4th tranche	>82 m^3/trimester	56.23	0.40

to a water utility. Reducing commercial losses will generate more revenue but does not represent an increase in resources. Commercial losses are valued at the retail billing tariff whereas physical losses are valued at the variable cost of water production and distribution [47].

Financially, the leaks are a loss since the water treated and pumped for delivery to the consumer is never distributed or billed. In addition, the leaks, by increasing the transited flow, contribute to an increase in pressure drops and therefore in energy consumption. Leaks also contribute to increasing the withdrawal of natural resources [48]. Leaks also represent a health hazard. Bacteriological contaminations, even physicochemical, which will deteriorate the quality of the water, are then possible. Finally, leaks reduce the reliability of service in terms of continuity: pipe breaks drop the pressure and even cause service to be interrupted. Repairs often require shutting off power to a neighborhood and stopping traffic when the pipes are under the roadway [12].

Consequently a reduction in leakage means that a utility has additional water that can be supplied to customers, especially if there had previously been a shortage of water. If a water utility is planning to develop a new source then capital expenditure can be deferred or avoided by reducing leakage from the system. Reducing commercial losses will generate more revenue but does not represent an increase in resources. Commercial losses are valued at the retail billing tariff whereas physical losses are valued at the variable cost of water production and distribution [47].

The deficit is covered by the State in the form of balancing subsidies, planned to compensate for the difference between the actual charges operations and the proceeds of water sales. This results in a low turnover which, combined with the limitation of the tariff, results in difficult financial situation for managers of water and sanitation, which prevent them from ensuring proper functioning the offer of their services to users. Water tariffs are economic instruments that help conserve water resources and tackle the challenges of providing water-related services to all citizens at an affordable price. In practice, consumers pay too little for the water and sanitation services they receive, because water is seen as a social good and has been considered an abundant resource. However, with population growth and the needs of much larger communities requiring access to water, the availability of this resource is drastically decreasing in many parts of the world [49].

3.3. Water consumption in Boujlida and future water demand

The variation in water consumption in Boujlida from July 2020 to June 2021 (Fig. 10) has recorded the highest water consumption of 151,808 m^3 for the trimester

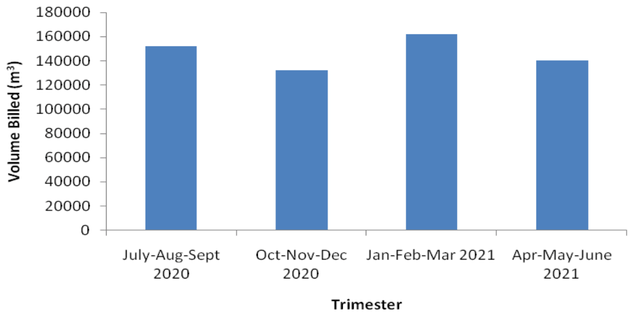

Fig. 10. Variation in water consumption in Boujlida.

July-August-September 2020 for 4,986 subscribers, this is due to the fact that this trimester refers to the summer season where the water consumption is generally the highest. There is also an increase in water consumption for the trimester January-February-March 2021 with 161,739 m^3, but this is only due to the increase of subscribers from 4,986 to 5,250, because this trimester refers to the winter season and we know that the water consumption is the lowest.

For the trimester of October-November-December 2020, which refers to the autumn season, we have the lowest water consumption of 132,088 m^3 for 5,250 subscribers, and for the trimester April-May-June 2021 referring to the spring season, we notice a slight increase in both water consumption and subscribers. It can be concluded from those results, that the highest water consumption is for the season of summer, while the lowest is for the winter season, however, for the season of spring and autumn we have almost the same water consumption.

The drinking water distributor always has the concern to cover the needs of the consumers; in sufficient quantity and quality, it is also the concern to ensure the good management and the perfection of all the infrastructures contributing to the water supply [50]. However, the endowment for the locality of Boujlida has been estimated at 52 L/d/inhab, which is far from Algerian endowment of 150 L/d/inhab.

The projected population in Boujlida at horizon 2050 is 103,882 inhabitants, which is equivalent to a water need of 15,582 m^3/d (5,687,524 m^3/y) for an endowment of 150 L/d/inhab. The water service ADE has to mobilize additional resource or to raise the produced volume to satisfy the projected population for 2050.

4. Conclusions

The IWA water balance assessment is an interesting tool to highlight the magnitude of the NRW and also allows defining its components. However, due to the unavailability of data including unauthorized use, unbilled authorized use, water billed but not paid and customer meter/metering, the water balance were not fully assessed. These water volumes need to be registered and metered by the water utilities in charge to establish in order to assess the water leaks to be as close as possible to the field study.

The drinking water supply network of the district of "Boujlida" is classified as an urban type that is struggling from water leaks due to broken pipes, and the unaccounted water index suggest that the water loss is also due to illegal connections to the network, water theft, and inadequate or false metering and leaks.

The study has shown that the drinking water supply of Boujlida service required the use of several performance indicators to identify the strengths and weaknesses in the control of water service from an operational perspective. The water services management system requires significant support public budget to ensure not only the big investments in the water sector, but identically large direct subsidies condition the balancing of the operating account of each ADE and ONA unit. The implementation of a NRW reduction strategy could be interesting for an effective water management of the available water resources especially where water scarcity is a problem and there is the decreasing possibility to develop new water sources as witnessed in Algeria, which can only be achieved when both physical and commercial water losses are reduced in a systematic way. The water audit has to address questions relating to the water infrastructure design at the stage of conception, the condition of the existent water infrastructure, the behavior of the system and how it is managed. Accurate measurement of the volume of water entering a transmission and distribution system is essential to good NRW management practice, where effort should be made to assess where leakage is occurring. By the implementation of an effective water loss reduction strategy/program significant financial savings can be achieved.

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Appendix

Appendix A: Volume produced and supplied for the district of Boujlida (ADE) from July 2020–2021

Month	Volume produced, m^3	Volume supplied, m^3
July 2020	91,371	83,678
August 2020	91,314	83,624
September 2020	103,512	95,212
October 2020	101,460	93,262
November 2020	82,023	74,797
December 2020	99,009	90,934
January 2021	118,788	109,724
February 2021	88,350	80,808
March 2021	95,076	87,198
April 2021	104,424	96,078
May 2021	99,978	91,855
June 2021	101,346	93,154
July 2021	90,459	82,811

Appendix B: Volume billed for the district of Boujlida (ADE) with the corresponding subscribers

Quarterly	Volume billed, m^3	Subscribers
July-August-September 2020	151,808	4,986
October-November-December 2020	132,088	5,250
January-February-March 2021	161,739	5,250
April-May-June 2021	140,114	5,264