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Efficiency and performance of a drinking water supply network for an urban cluster at Tlemcen Algeria

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ABSTRACT

The main aim of this study was to assess the efficiency and performance of a drinking water supply (DWS) network for an urban cluster at Tlemcen Algeria. A three-stage quality management approach was employed to identify the strengths and weaknesses in the control of water service from an operational perspective. Specifically, quality indicators were measured and differences were quantified in assessing the state of the water supply network; managers in the organization as well as subscribers were surveyed; and finally corrective and preventive measures were then taken to ensure continuous operation and sustainability of the service. The results showed that the DWS in the urban group of Tlemcen was characterized by an insufficient production which could not cover the actual needs. Water was provided to the districts twice per week only for a few hours. Adding to this, there was a 50% water loss during transport as a consequence of steel pipeline corrosion, poor quality workmanship, and a lack of proper maintenance and renewal of the conduits.

Keywords: Quality indicators; Yield; Performance; Urban group of Tlemcen; Drinking water supply; Management

1. Introduction

There is an increasing global trend towards sustainable economic development which includes protection of the environment [1,2]. The role of government in managing sustainable development is also critical with one side believing that companies should manage such development while on the other side the belief is in major government intervention in order to drive the process [3]. Both technical and

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financial aspects of sustainable development have received growing attention chiefly in water purification and treatment with efficiency and performance being key indicators [1,2]. Sustainable water resources are a key component in any economic development. The shortage of potable water, particularly in arid areas, and the problem of water losses from water supply systems are of specific concern [1].

Voyer [4] reported on the measurement of the performance of public agencies by identifying management indicators in order to improve the quality of their services. Performance indicators are often used to assess and improve the quality of a product or a service [5]. This approach has been used by Kenneth et al. [6] in, for example, the study of water loss management related to urban water systems. Seifollahi-Aghmiuni et al. [7] in a related study evaluated network performance during an operational period, taking into account pipe roughness uncertainty. Results showed that an increase in pipe roughness uncertainty caused a decrease in network performance during the operational period.

Saegrov et al. [8] assessed the rehabilitation of water networks. They noted that water utilities can experience and expect greater future challenges due to shortages of water, economical constraints, and ageing water supply networks. In particular, the number and volume of pipe bursts and leaks were found to be important indicators of network condition. The measurement of performance indicators for a drinking water supply (DWS) is thus noteworthy for improving the overall management of such systems [9]. It can be argued that a common set of indicators covering the whole of the DWS services is needed. These indicators can guide a community in making choices in the managements of its water supplies [10]. Furthermore, Abdelbaki et al. [11] reasoned that from an operational point of view, the important thing is to have consensual indicators of total quality management that everyone agrees with. Their indicators were divided into technical and service indicators. They reported on the level of satisfaction of the users/consumers as well as the quality of the service. Abdelbaki et al. [11] aimed their study at water supply network managers for an urban cluster or group located at Tlemcen in Algeria. This approach allowed for continuous improvement to which all personnel contributed.

The urban group or cluster of Tlemcen Algeria (Fig. 1) contains the communities of: Tlemcen, Chetouane, and Mansourah. It is located in the west of Algeria and occupies approximately 112 Km^2 constituting the inner basin of Tlemcen. This basin is bounded on the south by Lalla Setti cliff, on the north by the Ain El Houtz hills, from the east by Oum El Allou, and the west by small mountains (i.e. volcanic cone) of Beni Mester [12].

Drinking water is provided for the population in the Tlemcen urban group from three sources; underground water through 17 drills at three sites, surface water from two dams (i.e. Mefrouche and Sikkak), and a desalination station at Souk Thelatha [13]. The distribution network of this urban group was based on space-division switching with a distribution grid with various pressure stages. Applying a systemic approach to the Tlemcen urban group water supply network, Abdelbaki et al. [12] reported that the grid consisted of 650 km length pipes with the diameter of the conduits varying from 20 to 27 mm galvanized steel to 600 mm of covered steel for the main distribution lines and from 50 to 60 mm of galvanized steel to 1,100 mm of pre-stressed concrete for the secondary lines. Furthermore, the DWS network which was managed by the Algerian Ministry of Water was composed of 24 distribution zones fed from various storage tanks. The zones were connected to the network 94% of the time [13].

It is well recognized that water distribution should be both equitable and efficient [14]. To obtain optimum levels in technical performance, network managers have a number of technology-based management techniques and methods at their disposal [15]. The objective of these various technologies is not only to optimize the performance of the water distribution network (WDN) but also to take into account the water quality and the yield of its distribution system [16]. In the urban group of Tlemcen, the water losses in the networks of DWS were estimated at approximately 50% of the produced water volume [17]. It is thus imperative to more accurately calculate this deficit. Therefore, measurements are needed for better management quality of distribution networks in order to preserve water resources, to increase the lifespan of WDN and to reduce the investments in terms of rehabilitation and restoration of these networks [13].

The aim of the current study involved assessing the efficiency and performance of the DWS network for the urban cluster at Tlemcen Algeria. Specifically, a quality management approach was employed to identify the strengths and weaknesses in the control of water service from an operational perspective in order to improve and optimize the distribution network performance. A customer and manager survey was performed to assess quality of service provided to subscribers including quality of the repair work and customer complaints. This was followed by an assessment of the technical indicators such as network yield, linear losses index (LLI) and linear index of

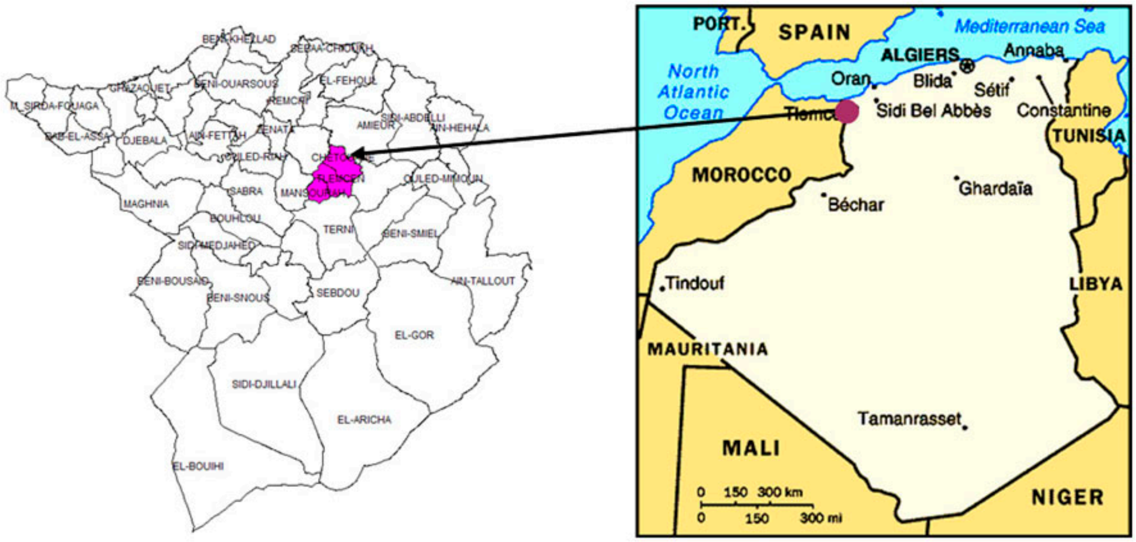

Fig. 1. The urban group or cluster of Tlemcen Algeria containing the communities of: Tlemcen, Chetouane and Mansourah.

repair, annual average rate of network renewal, operating pressure, water quality, and ability to meet work completion deadlines.

2. Materials and methods

2.1. Assessing quality of service indicators for DWS network

Quality indicators were assessed and the efficiency of the WDN operating conditions was quantified for the Tlemcen urban group. The indicators that were calculated or determined were based on the data of production volumes, as well as the quality of service provided to subscribers, water quality, quality of the repair work, and operating pressure of the network feeding the urban group of Tlemcen.

For the quality of the service, a survey was made of the subscribers of the urban group based on the methods of Abdelbaki et al. [11] and Allal et al. [13]. The issues investigated dealt primarily with the services, the reception, listening to customer, and calls for implementation. Questioning was addressed in parallel, to the executives and agents of the water administrative organization (i.e. Algerian Water Unit of Tlemcen). The topics covered primarily dealt with the organization, the culture and working atmosphere, the human resources, and the quality and management of the WDN [11,13]. The survey of the technical indicators (i.e. primary yield, LLI, and linear index of repair) was determined for the 10-year period corresponding to 2000–2010.

Specifically, questions related the following indicators were assessed: network yield (i.e. production yield and primary yield); LLI; linear index of repair; annual average rate of network renewal; rate of subscribers complaints; pperating pressure; water quality; quality of repair work; and ability to meet work completion deadlines. These indicators were then used in the following sections to show the degree of responsibility assumed by the management of the DWS network.

2.2. Network yield, LLI, and linear index of repair

As an index of performance, the production yield which is an important indicator for the technical management of a network of DWS as shown by Valiron [18] was calculated using Eq. (1):

$$\text{Production yield}(\%) = \frac{\text{Stored Volume}}{\text{Produced Volume}} \times 100 \qquad (1)$$

This yield, sometimes called technical yield, gives the percentage of the produced water that is successfully stored and is thus a measure of the technical efficiency of the network [19–21]. Another yield that was determined was the primary yield (Eq. (2)) which compares the total amount of water used with that introduced into the network:

$$\text{Primary yield}(\%) = \frac{\text{Counted consumed volume}}{\text{Volume in distribution}} \times 100 \qquad (2)$$

The LLI which refers to the volume of lost water per unit of length was also calculated [21]. This ratio, which given by Eq. (3), varies according to the network type [19] and can reach 10–15 $m^3/d/km$ [18].

$$\mathrm{LLI}(\mathrm{m}^3/\mathrm{day}/\mathrm{km}) = \frac{\text{Volume in distribution} - \text{Counted volume}}{\text{Network lenght} \times 365} \quad (3)$$

It is the evolution in the time of the primary yield and the LLI which was used as a basis for an improvement plan for network performance [16].

The linear index of repair, which is an indicator of the state of degradation of the equipment and the drains of the DWS network, was determined using Eq. (4) [22]:

$$\mathrm{LIR}(\mathrm{rep}/\mathrm{yr}/\mathrm{km}) = \frac{\text{Annual total number of repairs}}{\text{Network lenght}} \quad (4)$$

2.3. Annual average rate of network renewal

The annual average rate of network renewal of drinking water systems is the average annual pipeline renewal length carried out over a five-year period/total length of the network. This indicator gives a percentage of the renewal of the network which reflects the annual network restoration responsibility [23]. The annual average rate of return was determined for the Tlemcen urban group WDN for a 10-year period of 2000–2010.

2.4. Service pressure and quality of repair work

The water pressure and water quality of the network were measured over the 10year period of the study. It was based on the previous work reported by Abdelbaki et al. [24], who modeled drinking water network operations. Diagnoses were made of several deficiencies resulting from network discontinuity of supply, high leakage rates (60%), and outdated pipes. Modeling was developed using software Epanet 2.0 with GIS data [24].

The quality of implementation of repair work related to, for example, water leaks, restoration of conduits, and electric pumps was assessed based on a water supply distribution study reported by Godart [21]. The following factors were taken into account:

- Quality of materials and equipment used.
- Execution of work by qualified personnel.
- Laying of pipes accordance with international standards.
- Installation of signal and security devices for building sites during roadway repair work.
- Compliance with the program for intervention, repair of water leaks, and renovation of water supply.
- Updating the network drawing in case of change in the characteristics of driving to restore (e.g. steel pipe renewed by a cast iron pipe).

2.5. Ability to meet work completion deadlines

The actual time required to complete the repair work was evaluated and compared to the completion deadlines given in the original contracts. Intervention and repair work at the potable water system needed to be performed within the required time. Reducing the turnaround time would allow the organization manager to minimize water losses and save costs.

3. Results and discussion

3.1. Quality of service indicators for DWS network

Analysis of questionnaires completed by employees of the administrator service indicated that this government department did not have all the pipeline locations plans. Furthermore, updating of the plans that they did have had not been done. This lack of accurate updated information will hinder the smooth management of the service provider and will also delay the repair of any water leaks in the system. Furthermore, when asked about the quality of the welcome offered to subscribers, the employees of the Algerian of water estimate that more than 50% of its staff is mobilizing for this purpose, when subscribers estimates it at only 27%. Administrators need to improve staff training so that they provide a more professional service to their customers when answering complaints. The majority of the subscribers considered that their grievances were not being adequately addressed. Additionally, the company has to take care of subscriber complaints more rapidly to improve its quality of management.

In the context of the WDNs management, big part of the questioned staff grants an importance for the delivered service quality in spite of the network's. The later constitutes the essential element of the service quality. Several factors influence the good management of the WDN (i.e. corrosion, age of the pipe, and nature of the soil). These parameters favor the appearance of water leakages frequently and hinder the water distribution program.

A total of 69% of the subscribers were unsatisfied by the water troubleshoots repair. This was mainly due to limited human and material resources mobilized to handle the water leaks. This shortage resulted in a rather chaotic repair work and thus the poor subscriber rating. On the other hand, only 27% of the Algerian Water Company employees thought that the repair work quality was inadequate. This significant difference (i.e. 69% customer dissatisfaction versus 27% provider dissatisfaction) suggests a lack of awareness of the provider about consumers concerns.

It was recommended that the Algerian Water Authority need to review the main factors which can influence disruption in any pipeline repair, namely a lack of generators to provide electrical energy in case of a breakdown or power cut, a lack of water pumps, and the existence of massive water leaks.

According to the inquiries made, the employees of the Algerian Water Authority believed that 87% of the subscribers' complaints had been taken care of by the repair service. The subscribers or customers on the other hand thought that 76% of the complaints had not been addressed properly. Given these contradictory results, it is recommended that the Algerian Water Authority or company needs to better communicate with its subscribers and particularly to follow up on their complaints to see if outstanding issues have been resolved.

To bring to a successful conclusion its mission of quality management of the WDN, the company has to use all means of communication and information (e.g. media, display, press, and toll-free numbers) to ensure that subscribers complaints are taken care of. In particular, the managers were regarded as having influential input in the decision-making process in the programming of renovation works and improvements in quality of service provided to customers. In addition, the company should also have a better monitoring system for assessing a change in the quality of the water (i.e. color, smell, and taste); being able to monitor an insufficient pressure at the level of the faucet; being able to quickly make corrections if the actual volume does not coinciding with the volume posted in meters; and improving the method of payment by customers through facilitating the terms of payment or giving more choices (e.g. by check, at home, and online).

3.2. Network yield, LLI, and linear index of repair

The production yield for the Tlemcen urban group averaged out to 93% (Fig. 2).

This means that 93% of the produced water is successfully stored and indicates a high degree of technical efficiency of the network. This was acceptable and within the framework of this study since the standard is 90% as shown by Gomella [25]. Production yield is an important component for the management

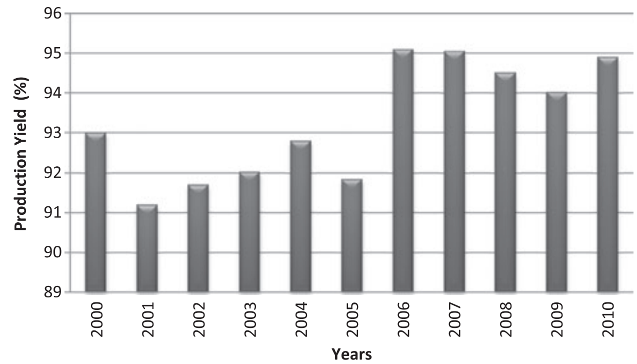

Fig. 2. Variation of production yield in the urban group of Tlemcen.

of a DWS network and generally is higher than 65%. It can reach and even exceed 90% as shown by Gomella [25] and the current study. Furthermore, the primary water yields for the urban group during the period 2000–2010 ranged from 38% to 55% with an average of 48% (Fig. 3).

This means that less than half of the water introduced into the network was actually used. As example in 2006, the primary yield was 45% which means that 55% of the water was lost due to leaks and illegal water removal. Consequently, the actual volume of water lost, 7,204,476 m^3, was equivalent to half of the capacity of the Mefrouche dam (14 Mm^3) [13]. It is thus difficult to evaluate the performance of a water supply network with only this index as noted by Guérin-Schneider in two related studies [9,10].

For the production and the distribution of drinking water, the first of the economic indicator is of course the network yield (i.e. production and primary yields) since each cubic meter of produced water consumes kilowatt-hours of energy that also caused pollution in the form of smoke [26–28]. Pipe leaks means greater

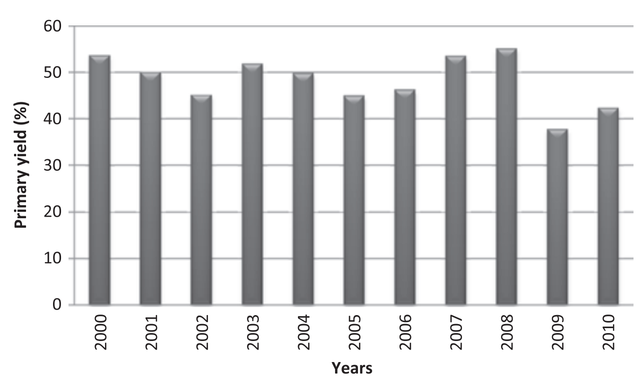

Fig. 3. Variation of primary yield in the urban group of Tlemcen.

water loss and thus the need for more electrical energy. This issue was discussed in detail by Carravetta et al. [27] who reported on better design schemes for energy recovery in WDNs by electrical regulation. Energy recovery is one area, for example, where further work is needed by the Tlemcen urban group in the control of water service from an operational perspective.

Network yields (i.e. primary yields) are rarely lower than 70% in developed countries [28]. However, they can go down to less than 30% in urban environments. We can argue that this low primary yield value is presumably due to the age of the pipes in older parts of a city, combined with poor maintenance and possibly heavy roadwork. Therefore, there is a need to optimize the water supply services to give higher yields by setting up an adaptable and effective water management structure, which combines the aspects of fast maintenance of the network, renewal of the network, and improvement of commercial management [29].

The LLI, which refers to the volume of lost water per unit of length, varied between 23 and 46 m^3/day/km (Fig. 4).

This represents very high water losses in comparison to a related report [30] and probably resulted from poor maintenance as noted by Allal et al. [13]. The quantity of lost water is an important indicator of the positive or negative evolution of water distribution efficiency, both in individual years and as a trend over a period of years. High and increasing annual volumes of water losses are an indicator of ineffective planning and construction, and low operational maintenance activities. This should be the trigger for initiating an active leakage control program as recommended by IWA (International Water Association [1]).

In the case where the LLI is high, it is desirable to determine the linear index of repair (i.e. (annual total number of repairs)/(network length) [31]. The linear index of repair calculated using Eq. (4) varied from 2 to 45 repairs/yr/km (Fig. 5).

This is higher and suggests that the network is decayed and requires restoration. Winarni [31] who reported on the infrastructure leakage index as a water losses indicator indicated that networks with more than 1 repair/yr/km require extensive renewal.

3.3. Annual average rate of network renewal and rate of users complaints

The annual average rate of network renewal for the considered period was determined to be approximately 22%; or 150 km of conduits renewed out of total of 680 km [13,32]. This average rate of renewal represents 32 years equivalent of work to renovate the WDN in the urban group of Tlemcen. The problem here is that this exceeds the average lifetime of the network which is 25 years. To better deal with this situation, it is necessary that the programming of complete DWS conduits restoration has to be modified so that it is less than the average pipeline lifetime.

When leaks occur and network pipes are being repaired, the customer complaints can be expected. These complaints can consist of water leaks, water cut-off, and problems associated with billing. The rate of user's complaints, which is the relationship between the numbers of daily water-related complaints that are answered and the total number of complaints received by the Algerian Ministry of Water, allows for evaluating the effective management of the complaints. The latter is of paramount importance for maintaining the credibility of the Government Ministry in the eyes of the customer.

According to a survey reported by Allal et al. [13], the rate of water-related complaints that were answered for the Tlemcen urban group was 76%. This

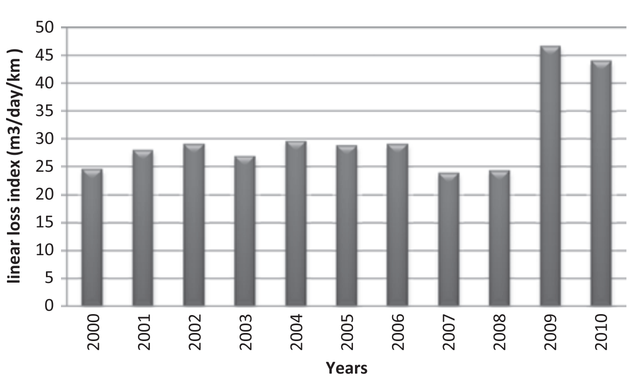

Fig. 4. LLI for the urban group of Tlemcen.

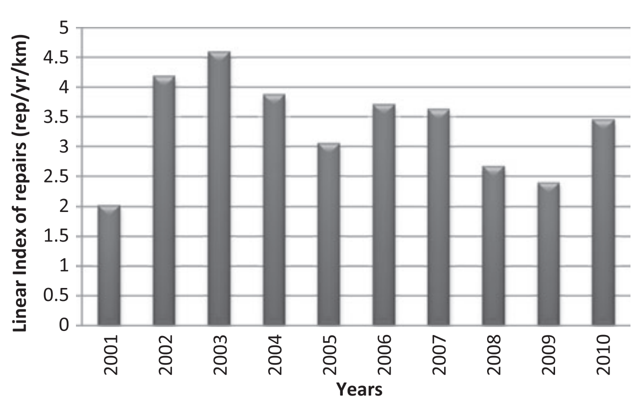

Fig. 5. Variation of the linear index of repair for the urban group of Tlemcen (2001–2010).

reflects an appreciable success rate by the Algerian Ministry in terms of taking responsibility for this commercial section. The authors argued that the 24% of the untreated complaints were due primarily to delays due to lack of personnel and exceeding the repair deadlines. This suggested a need to set up more reliable and faster response time procedures, particularly in cases of technical problems.

3.4. Service pressure, water quality, and quality of repair work

For the continuity of a water service, not only flow and water quality but also the water pressure in the pipe are important technical indicators [31]. For the urban group of Tlemcen, the pressure varied between 0, 8, and 10 bars according to the sectors of distribution in the DWS network as noted also by Abdelbaki and Touaibia [24]. However, it is generally recognized that the water pressure for the user should not exceed 4 bars [18,33]. Beyond this value, there is a risk of water leaks.

Distributed water must also be of necessary quality according to the drinking standards [34]. It was noted by Bouziane [34] that cases of hydrous transmitted diseases significantly increased from 1991 until 1999 with a peak occurring in 1998. This was explained as being mainly due to the development of unconventional DWS networks and poor cleanliness associated with establishment of illegal hazardous habitations. However, since 2000 cases of diseases have tended to decrease as a result of the efforts made by various sectors of the local governments [13,32]. Furthermore, it would be more expedient, for eradicating water network-related diseases, by avoiding contamination due to mixing as a result of illegal interconnected wastewater and drinking water systems by following the standards of installation control [34,35]. We can argue that this is a major responsibility of managers in the control of water service from an operational perspective.

The implementation of repair work related to the water supply distribution study reported by Godart [21] as well as the results of the current study suggest that the quality of repair work is one area that requires significant improvement by the government water administrative service [32].

3.5. Meeting work completion deadlines

Intervention and water leak repair work for the WDN of the Tlemcen urban group required 2–3 days according to studies led by Allal et al. [13] and Bessedik [32]. This was much longer than intervention for repair of water leaks from an urban network which required an average time of 2–3 h as reported by the International Office for Water [23].

Intervention work and repairs of DWS network must be done within a reasonable time. A reduction in the repair work completion time will allow an administrative organization to minimize water losses and to save financial resources which can then be redirected to the renewal and repair of the DWS conduits. Furthermore, the reduction in repair time would help to solve the frequent cuts in domestic water supply and consequently reduce the number of customer complaints.

3.6. Assessment of efficiency and performance of DWS network from an operational perspective

The current study found that a major reduction in water losses in the Tlemcen urban group was a result of renewal of corroded water pipes, addition of new piping, ensuring that the large majority of the water transportation network crossed well-protected corridors, and eradicating illegal water use for irrigation.

The primary water yield ranging from 38 to 55% (Fig. 3) for the Tlemcen urban group was definitely lower than that generally allowed for by international standards [28]. The current study has shown that these poor yields were due to the corrosion of the steel pipelines which were not provided with exterior protection upon installation, operating pressures exceeding the standards, insufficient detection and repair of water leaks, lack of replacement parts, and an absence of a system maintenance policy. Furthermore, Allal et al. [13] has reported that the government agencies responsible for water resources and WDNs in the Tlemcen urban area are aiming at achieving a primary yield of 80% by 2035. This means only a 20% loss due to leaks. Note that the current average primary yield is only about 48% (Fig. 3) and 43% based on a similar study by Allal et al. [13].

The high LLI, which varied between 23 and 46 m^3/day/km (Fig. 4), and the high linear index of repair, which varied from 2 to 45 repairs/yr/km (Fig. 5), show that there is a critical need for preventive and renewal measures to be taken including renewal of conduits, and installation of, for example, cathodic protection. Cole and Marney [36] in a recent literature review of the science of pipe corrosion have reported that electrochemical studies have shown that corrosion rates may decrease significantly with time with the development of oxide layers that limit oxygen diffusion to the metal surface. They went on to argue that in order to accurately model pipe corrosion in soils, it is necessary to understand the electrochemical processes that occur at metal surfaces, particularly the development of anodic and cathodic sites and the rate of reactions at these sites, how the development of an oxide layer may impact on this electrochemical activity, what form pore moisture/steel and pore moisture/air/soil interfaces take, and how this influences both the diffusion of species through the moisture layer to the metal surface, and the position of anodes/cathodes on the surface. Cathodic protection of WDN pipes is thus one area where further research is needed.

4. Concluding remarks

Technical indicators must be effectively integrated into a quality management approach to identify the strengths and weaknesses in the control of water service from an operational perspective. By modifying WDN instrument panels, for instance, to include technical indicator performance, administrators and operators will be ready to more efficiently manage such systems. The evolution and further improvement of these indicators will allow DWS network operators to enhance both efficiency and performance from an operational perspective. Finally, government departments that regulate WDNs must have a variety of indicators at their disposal, both technical and non-technical, in order for them to make not only timely but also informed decisions.

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