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DECISION SUPPORT SYSTEM FOR THE MANAGEMENT OF WATER DISTRIBUTION NETWORKS A CASE STUDY OF TOURVILLE, ALGERIA

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ABSTRACT

The analysis of the current situation of water distribution networks (WDNs) is based on many alternatives that are technically feasible and implemented by decision makers. Taking the WDN of Tourville city as a case study, this paper combines a set of decision support systems (DSSs), including geographic information systems (GISs), multicriteria analysis and hydraulic simulation models, to establish a multicriteria decision-making aid method for the renovation and rehabilitation of water distribution networks. This combination creates an expert management system based on multicriteria decision making that strengthens the optimization of the management of water distribution networks in terms of renovation and rehabilitation. After dividing the water distribution network into three emergency levels, it was concluded that 26% of the network is in urgent need of rehabilitation.

Keywords: Multicriteria Analysis, Analytic Hierarchy Process, Modeling, Geographic Information Systems, Water Distribution Network, Management.

INTRODUCTION

A WDN is a complex hydraulic system because it consists of nodes linked by pipes with nonlinear hydraulic behavior. Decision making of this complex system requires data on the hydraulic state and many other variables (Duzinkiewicz and Ciminski, 2006; Hajebi et al., 2014). Preventing pipeline renewal and diagnosing the malfunctions of the network are real challenges and require network managers with proper decision-making tools. Decision support tools and problem solving are based on the use of models such as hydraulic simulation models, which are used to simulate the behavior of water distribution networks and assess their hydraulic state, and geographic information systems (GIS) to support decision-making in the management of WDNs (Abdelbaki et al., 2017; Abdelbaki and Touaibia, 2014; Berrezel et al., 2022). In their study, Patel and Mehta (2022) emphasized the importance of designing a water distribution network that can meet the increasing demand for water as the population grows. One key requirement of such a network is to ensure that suitable water is supplied with minimum pressure, velocity, and flow. To achieve continuous water supply services 24 hours a day, every day of the year, a water-efficient distribution system is needed.

The WDN deteriorates with time and must be replaced when it reaches a threshold of obsolescence. This aging generates dysfunctions that complicate the task of the manager. At this stage, managers start asking questions such as: Should I renew the pipes? Which parts should I renew? When should I start?

As noted by Pandey et al. (2022), while their study focuses on the implementation of a real-time smart water supply management and water quality monitoring system, the use of sensor technologies and IoT can be applied to monitor and detect the deterioration of water distribution networks. By continuously monitoring the water quality and flow rate and detecting defects in pipelines, maintenance and repair can be prioritized and implemented to prevent further deterioration and ensure a reliable water supply system.

Recently, decision making has depended on mathematical models, software and models that can assess the situation of the system (Greco et al., 2016; Tarigan et al., 2018; Amorocho-Daza et al., 2019). The analytic hierarchy process (AHP) method is useful for water management in terms of achieving a better understanding of water management strategies (Zyoud et al., 2016). (Blindu, 2004) worked on adding multicriteria analysis to geographic information systems to classify behavior rehabilitation programs in the short, medium, and long term. Additionally, Aşchilean et al. (2017) used and recommended the AHP method for ranking the priorities regarding the rehabilitation of a water distribution network.

The objective of this research is the creation of an expert management system that combines GIS, multicriteria analysis, and a hydraulic simulation model to make informed and strategic decisions in the renovation and rehabilitation of a water distribution network. The system aims to optimize the management of the network and avoid potential problems.

MATERIAL AND METHODS

Study area

This paper takes the water distribution network of Tourville city as a case study (Fig. 1), which is located 350 km west of Algiers and has a population of 86000 (ONS, 2019). The region is characterized by rugged topography with altitudes ranging between 1 and 90 m. The Tourville sector is supplied by an elevated tank. The length of the water distribution network (WDN) is approximately 35 km, and it is made up of cast iron, steel, and polyethylene high-density (PEHD), and the nominal diameters range between 63 and 300 mm.

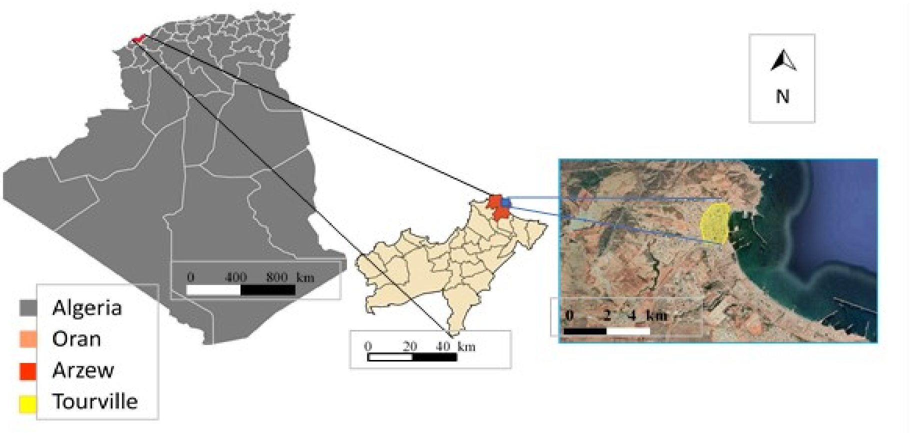

Figure 1: Geographical location of the study area (Tourville) (*Algeria Map-Resources | Simplemaps.Com*, n.d.) (*Google Earth*, n.d.)

Methodology

The developed methodology is divided into several steps in two main categories: data collection and decision making using several tools and methods from databases, GIS, hydraulic modeling of the network and multicriteria studies (Fig. 2).

Hydraulic modeling is fundamental in the design of databases for the management of the water distribution network. The collected characteristics of the components of the system, such as tanks, pipes, and junctions, were used to simulate the flow of water through the pipes, reflecting the physical characteristics of the system (Abrunhosa, 2015).

Mapping the data aids in identifying and categorizing the pipe sections in order of priority, resulting in significant progress in network management.

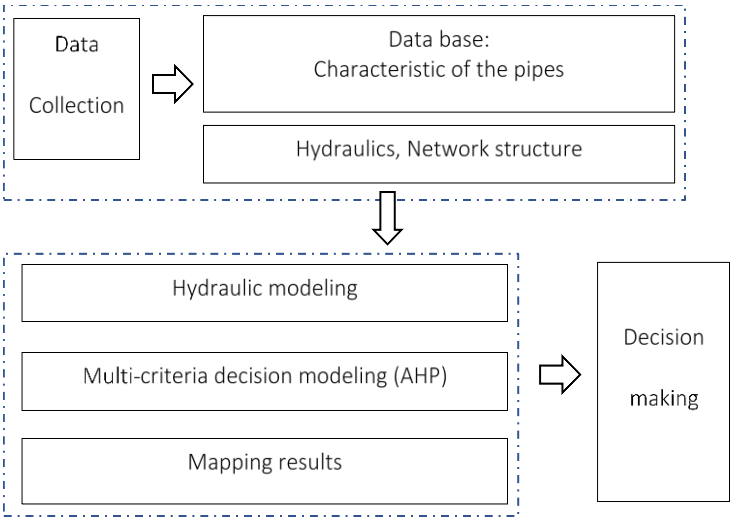

Figure 2: Schematic diagram reproducing the management logic of the DWS network.

Network behavior modeling

Mike Urban is one of the most efficient programs for modeling urban water, as it covers all water networks in a city, including water distribution, stormwater and sewer systems (Abrunhosa, 2015). Ingeduld et al. (2008) found that using MIKE URBAN to model the water distribution system in Dhaka, Bangladesh, was more effective than using standard EPANET-based models. This was due to the presence of low pressures and pipes without water in the city. The study showed that MIKE URBAN is effective for modeling complex and challenging water networks. According to Hountondji and Codo (2019), the use of EPANET software enabled the diagnosis of the current operation of the Monzoungoudo drinking water distribution network and the proposal of necessary interventions. The properties of the studied network, such as the digital elevation model and the characteristics of pipes, nodes and tanks, are provided by Oran Water and Sanitation Company (SEOR, 2021), which uses ArcGIS and MIKE Urban software. Mike Urban is an EPANET-based calculating model that has numerous advantages over typical modeling tools. such as standard data formats, the integrated interface under GIS and the calculation engine used for modeling is EPANET. Coupling Mike Urban with ArcGIS brings a number of new useful GIS functionalities oriented on topological data analysis (Metelka, 2006).

Multicriteria decision analysis (MCDA)

MCDA is a methodology designed for evaluating options considering decision-making objectives (Montibeller et al., 2006). Many methods have been developed. Velasquez and Hester, 2013 identified the following methods: multiattribute utility theory, analytic hierarchy process, fuzzy set theory, case-based reasoning, data envelopment analysis, simple multiattribute rating technique, goal programming, ELECTRE, PROMETHEE, simple additive weighting and technique for order of preference by similarity to ideal solution.

According to Tramarico et al. (2015), the analytic hierarchy process (AHP) is the most applied method in technology and scientific research fields. AHP has been used for comparisons, weighting, and ranking alternatives in 4 steps to make a decision in an organized way (Saaty, 2008): 1) defining and establishing the context of the problem; 2) decomposing the decision problem into hierarchy structure from the top with the goal of the decision, then identifying criteria and options and finally the lowest level, which is a set of the alternatives; 3) making pairwise comparison matrices and deriving the relative weights; and 4) checking the reliability of the pairwise comparisons by calculating the consistency index (CI) and the consistency ratio (CR).

The pairwise comparisons of various criteria were organized into a square matrix.

$$A=[a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \tag{1}$$

where A is the decision matrix, a_{ij} are comparisons between elements i and j for all i, j ∈ {1, 2,…. n}.

The comparison is made using a scale. Table 1 indicates which element is important to another element with respect to which they are compared. The nine-point scale includes [9, 8, 7,..., 1/7, 1/8, 1/9], where 9 means extreme importance, 7 means very strong importance, 5 means strong importance, and so on down to 1, which means no preference (Şener et al., 2010).

Table 1: Numerical scale for pairwise comparisons in AHP (Saaty, 1980)

Intensity of importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between two judgments
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i

The weight of each of the dimensions, criteria and indicators is calculated by summing the columns of the matrix and then dividing each of the values in the column by the sum of the columns. The weight is obtained by calculating the average of each row (Boukhari et al., 2018).

To check the reliability of the pairwise comparisons, (CI) and (CR) allow us to know at what point the judgments are consistent, and they are calculated by Equation (2):

$$CR = \frac{CI}{RI} \tag{2}$$

where:

RI = Random Consistency Index,

RI can be determined from Table 2

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{3}$$

where:

$\lambda_{\max}$ = the largest or the principal eigenvalue of the matrix.

N = the order of the matrix.

Table 2: Values of random of random index (Saaty, 1980)

n	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52

Generally, the judgments are consistent if $CR \leq 10\%$. If *CR* is larger than 10%, the evaluation of criteria judgments must be reviewed. Once the weights of the elements per level are calculated, the final weight is computed by simply multiplying the weights of the lowest level (the indicators) by the weights of the higher levels (the corresponding criteria and dimensions).

RESULTS AND DISCUSSION

The performance of the alternatives

To determine the performance of the alternatives and to identify the emergency level of the pipes concerning the rehabilitation of the water distribution network, five subcriteria (SC) are used based on the sections of the network: 1) the pipe material; 2) the laying date; 3) the diameter of the pipe; 4) water pressure; and 5) water velocity.

The criteria and indicators were used to define the emergency levels of pipes to rehabilitate the water distribution network. The hierarchy structure elements were determined by water supply managers and experts based on their experience and knowledge. In this paper, databases of the physical structure and the hydraulic behavior of the network were used.

Each of these subcriteria has 3 indicators, which means 15 indicators in total. The evaluation of the indicators is used to measure the performance of the alternatives. The evaluation is performed by using indicators (categories) attributed to each subcriteria related to each alternative instead of evaluating the alternatives by pairwise comparisons (Silva et al., 2010). The AHP enables the use of a hierarchical structure to display the preferences of alternatives relative to the objective (Amorocho-Daza et al., 2019).

The database contains many alternatives and related attributes, and all these features are important for the decision-making process; therefore, the rating approach is used when there are a large number of alternatives to be evaluated. The rating approach differs from the traditional AHP (relative measurement) because at the last level, the alternatives are not found or there are many alternatives to be evaluated.

Pairwise comparisons and weighting

The results of the application of the AHP method show that the classification of dimensions, criteria and indicators are represented in matrices of weights (table 3 to table 10). For example, the importance of the diameter is less than the laying date because the age of the pipe is directly related to the condition of the pipe. For the pressure criterion, the comparison was made using the interpolation of the pressures at the node level and the extraction of the pipes situated at each pressure point.

Table 3: Comparison of the main criteria; λ_{max}= 2 and *CR*=0

Criteria (c)	Hydraulic structure	Physical structure
Hydraulic structure	**1**	1/3
Physical structure	3	**1**

Table 4: Comparison of Subcriteria 1; λ_{max}= 3.0536 and *CR*=5.15

SC1	Materials	Pipe laying date	Diameter	Weight
Materials	**1**	1/2	3	0.333
Pipe laying date	2	**1**	3	0.528
Diameter	1/3	1/3	**1**	0.140

Table 5: Comparison of Subcriteria 2; λ_{max}= 2 and *CR*=0

SC2	Pressure	Velocity	Weight
Pressure	**1**	3	0.75
Velocity	1/3	**1**	0.25

Table 6: Comparison of indicator 1; λ_{max}=3.018 and *CR*=1.73

Indicator i1.1	PEHD	Cast Iron	Steel	Weight
PEHD	**1**	1/4	1/3	0.122
Cast Iron	4	**1**	2	0.558
Steel	3	1/2	**1**	0.320

Table 7: Comparison of indicator 2; λ_{max}= 3.038 and *CR* = 3.65

Indicator i1.2	10 years	15 years	20 years	Weight
10 years	**1**	1/3	1/5	0.105
15 years	3	**1**	1/3	0.258
20 years	5	3	**1**	0.637

Table 8: Comparison of indicator 3; λ_{max} = 3.0246 and *CR*=2.36

Indicator i1.3	<100mm	100≤D<150mm	150≤D<300mm	Weight
<100mm	**1**	1/4	1/5	0.097
100≤D<150mm	4	**1**	1/2	0.333
150≤D<300mm	5	2	**1**	0.570

Table 9: Comparison of indicator 4; λ_{max}= 3.0536 and *CR*=5.15

Indicator i2.1	P<2bar	2≤P<4.5bar	4.5≤P<7bar	Weight
P<2bar	**1**	2	1/3	0.249
2≤P<4.5bar	1/2	**1**	1/3	0.157
4.5≤P<7bar	3	3	**1**	0.594

Table 10: Comparison of indicator 5; λ_{max} = 3.0536 and *CR*=5.15

Indicator i2.2	v<0.5 m/s	0.5<v<1.5 m/s	1.5<v<3 m/s	Weight
v<0.5 m/s	**1**	3	2	0.528
0.5<v<1.5 m/s	1/3	**1**	1/3	0.140
1.5<v<3 m/s	1/2	3	**1**	0.333

Calculation of the emergency level of the sections

After calculating the weight of each indicator by the AHP model shown in Fig. 3, it is necessary to run the GIS integration step to classify and map out the sections in order of importance for the action of rehabilitation using the attribute table displayed in ArcGIS. The latter manages the physical entire water distribution network with its characteristics (diameter, materials, pipe laying date) with the superposition of the base plan obtained by aerial photos from the Oran Water and Sanitation Company (SEOR, 2021).

To rank the alternatives, ArcGIS is used to select features that match the selection criteria. One of the selection methods used to select features in a layer is to select features using an attribute query. Displaying the results as shown in Figure 4 helps to identify the sections and rank them in order of priority to generate real progress in network management.

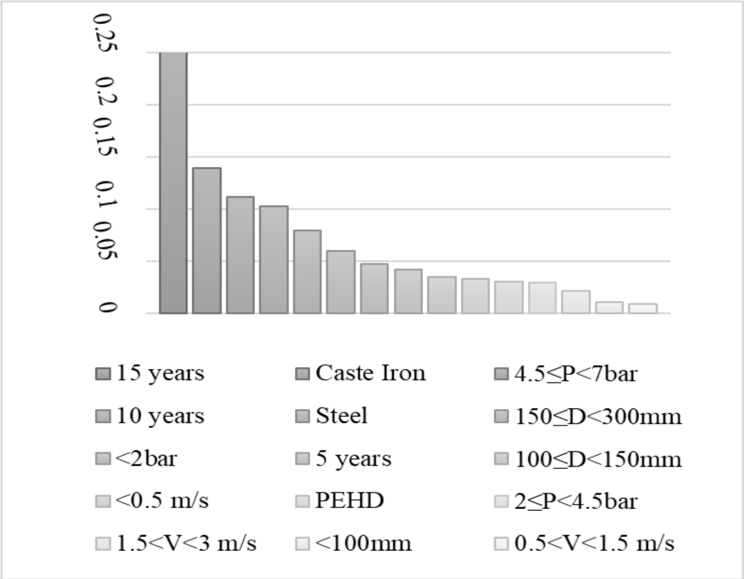

Figure 3: Ranking of all 15 indicators obtained by AHP

The priority sections for maintenance action can be identified according to the order and the emergency category and the colors, which include three classes, as shown in Fig. 4: level 3 low in yellow, level 2 medium in orange and level 1 high priority for intervention in red.

The network is a combination between loop main pipes and branched sections, and the looped sections have pipes with diameters ranging from 100 mm and larger. The branched sections are flowing ends with a decreasing diameter. After displaying the result, the linear of each category is divided into 3 levels. The concept of urgency level allowed us to classify the pipes in the short-, medium- and long-term to rehabilitate the water distribution network. The first level represents 26% of the length of the network, which is important in terms of criticality, and it must be rehabilitated first, so the focus was on this part, as shown in Fig. 5.

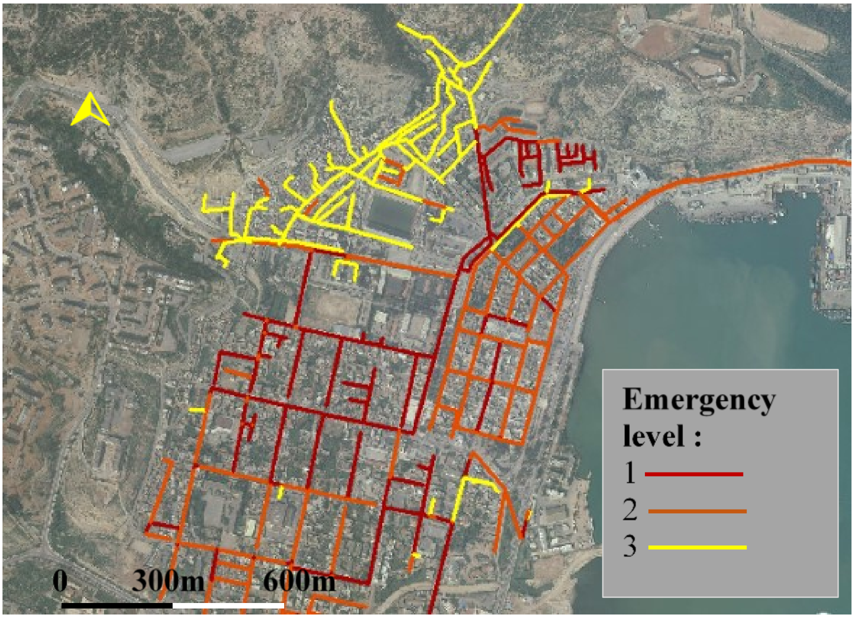

Figure 4: Ranking level of the sections.

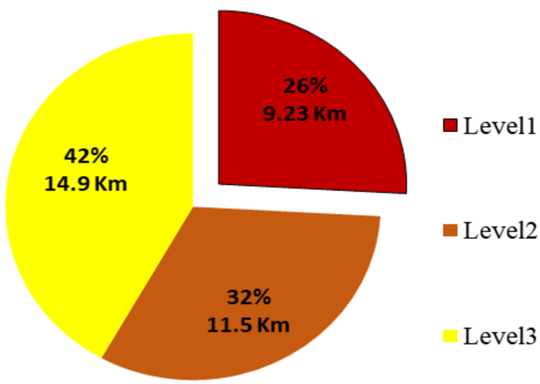

Figure 5: Linearity of sections by emergency level

Fig. 6 shows that 97% of the network in level 1 is made of cast iron, which represents 100% of the pipes ranging from 100 mm and below. Most of the failures occur in cast iron (CI) and steel (ST) pipes, which are currently no longer utilized in the water network. Fewer failures occur in the more up-to-date polyethylene (PE) pipes. Similar conclusions were observed in studies reported by (Tscheikner-Gratl et al., 2017).

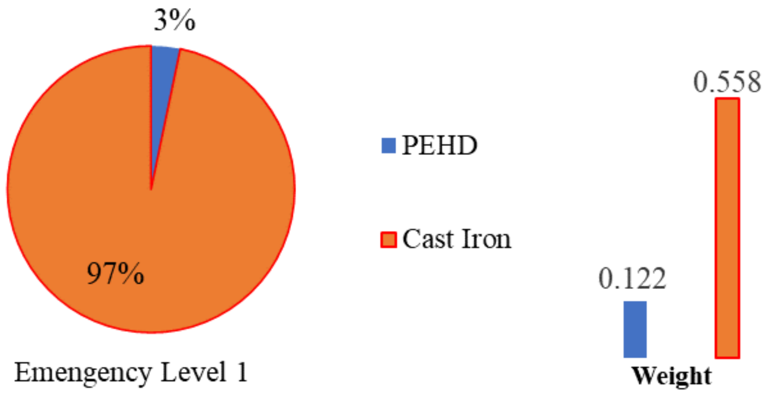

Figure 6: Percentage and weight of each material

The emergency level of pipes is illustrated in Fig. 7 and Fig. 8 using diameter and velocity as parameters, respectively. Fig. 10 combines the information from both figures and displays the various diameter sizes and their corresponding velocities. Over half of the pipes have velocities below 0.5 m/s and diameters under 100 mm. Pipes with low velocities and long stagnation times, such as distribution dead-end mains, are particularly susceptible to sedimentation (Barbeau et al., 2005). Research has shown that suspended materials in the pipe start to settle when the velocity drops below a threshold of approximately 0.06 m/s (Vreeburg and Boxall, 2007). Low flow conditions in pipes can also lead to increased corrosion, particulate buildup, and reduced disinfectant effectiveness. This is because if a finite volume of water spends more time within a pipe, it indicates low flow conditions, which may increase the precipitation and uptake of iron in metal pipes due to corrosion (Mutoti et al., 2007). Furthermore, the extended residence time also leads to a rapid reduction in disinfectant residuals that allow microbial pathogens to regrow (Abokifa et al., 2016). Analysis of the composition of suspended particles may detect aging pipes, as the concentrations of particulate elements between upstream and downstream of the pipe should increase (Fujita et al., 2014).

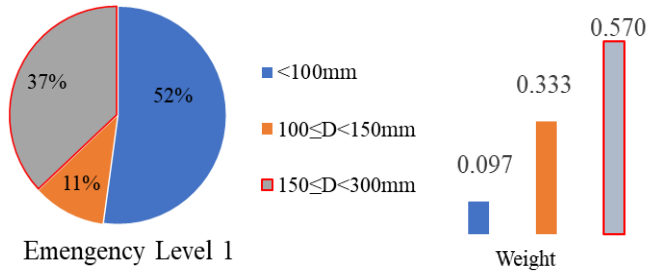

Figure 7: Percentage and weight of each diameter

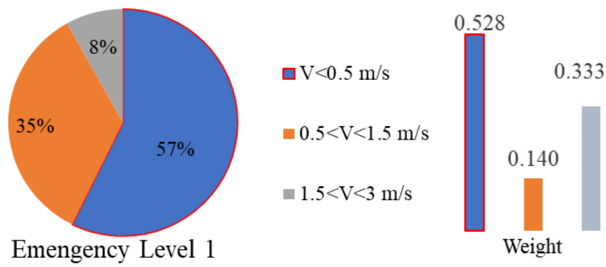

Figure 8: Percentage and weight of water velocity

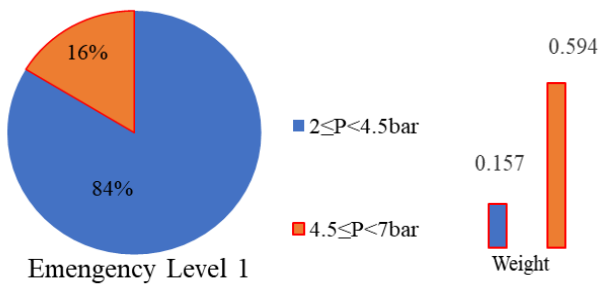

Figure 9: Percentage and weight of water pressure

The diameters that do not exceed 100 mm tend to present several stresses on the network. It is noted that more than 4.8 km of length is made of cast iron, and 2/3 of this length undergoes speeds lower than 0.5 m/s due to the number of branches (dead ends) on this part of the network. Concerning the pressure, Fig. 9 shows that 84% of the network has pressure standards between 2 and 4.5 bar. It is also noted that the minimal pressure in a network is generally set at 2 bar at the connexion point of a house or dwelling. Each of these indicators directly or indirectly affects the other indicator in a complex way, which means that the velocity can affect the aging of the pipe and material, the diameter affects the velocity and so on.

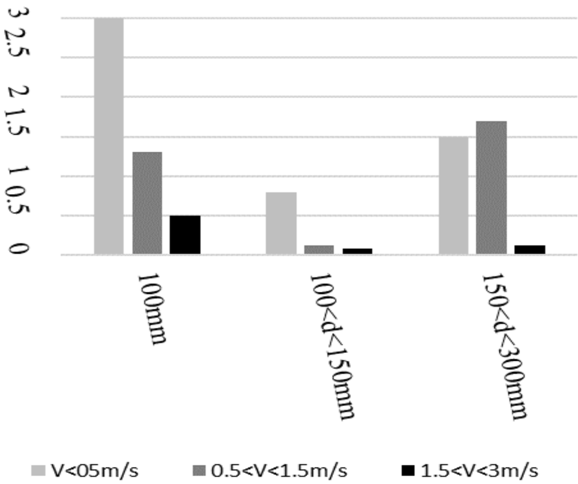

Figure 10: Range of different flow velocities in the pipes

After identifying the priority sections for maintenance action, it is important to check the reliability of the system and confirm that the results obtained by this method represent the real state of the network and that the choice of the 3 emergency levels is correct and trusted. The idea is to see the date of occurrence of leaks and their location. Since the leaks in the network are a sign of failure, in this study, they were used to check and confirm the sections that need current, medium and long-term maintenance in the studied system, so they were not introduced as an indicator. The appearance of leaks is directly related to the hydraulic and physical structure of the network (Pérez-Pérez et al., 2021). To reduce the leakage rate, a corrective and preventive application on the network is required (Carnero and Gómez, 2018). Leakage data were imported as nodes on ArcGIS, and these nodes have spatiotemporal data so we can know the location and the date of occurrence of each, which allowed us to quantify and classify them according to the urgency level calculated previously. Fig. 11 is obtained by summing all the leaks that are distributed over the 3 levels each; note that Emergency Level 1 is characterized by the highest number of leaks compared to the other 2 levels. Fig. 12 indicates the number of leaks over the past 8 years and shows at which level they were distributed.

It is noted that the gap between the number of leaks in the 3 levels of emergency decreases over time due to the repair and rehabilitation applications made on the networks. The results of this analysis show that the method used gives good consistency between the network evaluation and its actual state. The technical report of Oran Water and Sanitation Company SEOR (2021) was used to compare our results with his findings.

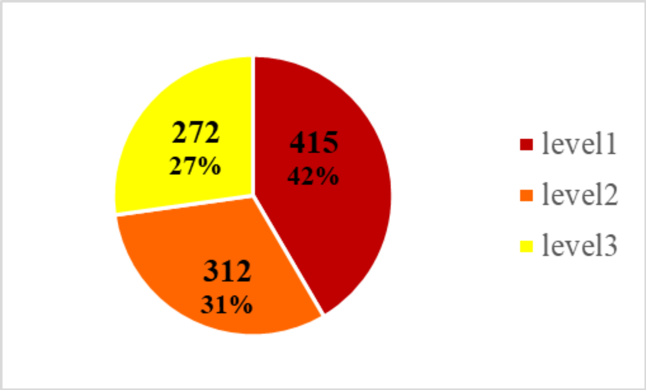

Figure 11: Number of leaks per level

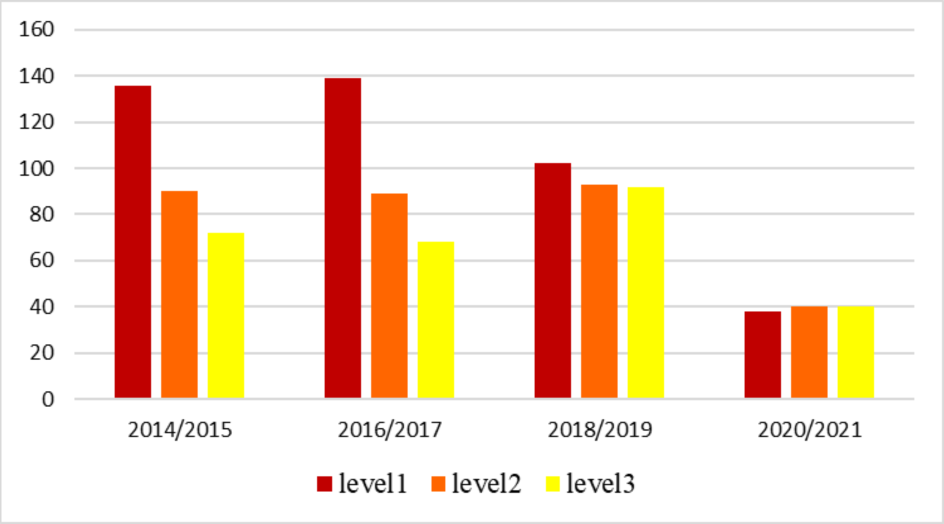

Figure 12: Number of leaks per year per level

CONCLUSION

This paper led to the establishment of a multicriteria decision-making aid method for the adequate renovation and rehabilitation of distribution water networks. The combination of a set of decision support tools, such as geographic information systems (GIS), multicriteria analysis and hydraulic simulation models, helps us to facilitate the complexity of the studied system because the difficulty is the determination of the specific sections to be renewed. The results of the application of the AHP method show the classification of dimensions, criteria, and indicators. The selection of criteria was made by taking into consideration the physical characteristics of pipes, such as the diameter, materials and laying date of the pipe, and the hydraulic structure of the network, such as the velocity and pressure of water. The priority sections for maintenance action can be identified according to the emergency level category and the colors, which include three classes: level 3 low, level 2 medium and level 1 high priority for intervention in red color. The results showed that the critical part represents 26% of the network that should be rehabilitated as soon as possible.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

ABDELBAKI C., BENCHAIB M.M., BENZIADA S., MAHMOUDI H., GOOSEN M. (2017). Management of a water distribution network by coupling GIS and hydraulic modeling: a case study of Chetouane in Algeria, Applied Water Science, Vol. 7, Issue 3, pp. 1561–1567. https://doi.org/10.1007/s13201-016-0416-1

ABDELBAKI C., TOUAIBIA B. (2014). Contribution of geographic information systems and hydraulic modeling in the management of drinking water supply networks: Case of the urban group of Tlemcen (Algeria), Techniques Sciences Méthodes, No 5, pp. 52–60. (In French). https://doi.org/10.1051/tsm/201405052

ABOKIFA A.A., YANG Y.J., LO C.S., BISWAS P. (2016). Water quality modeling in the dead end sections of drinking water distribution networks, Water Research, Vol. 89, pp. 107–117. https://doi.org/10.1016/j.watres.2015.11.025

ABRUNHOSA D. (2015). Comparison between a sustainable and a traditional urban drainage solution with Mike Urban, Buddinge case study, Master thesis, University of Porto, 116 p.

ALGERIA MAP - RESOURCES | Simplemaps.com. (n.d.). Retrieved 26 January 2019, from https://simplemaps.com/resources/svg-dz

AMOROCHO-DAZA H., CABRALES S., SANTOS R., SALDARRIAGA J. (2019). A new multicriteria decision analysis methodology for the selection of new water supply infrastructure, Water, Vol. 11, Issue 4, pp. 805. https://doi.org/10.3390/w11040805

AŞCHILEAN I., BADEA G., GIURCA I., NAGHIU G.S., ILOAIE F.G. (2017). Choosing the optimal technology to rehabilitate the pipes in water distribution systems using the AHP method, Energy Procedia, Vol. 112, pp. 19–26. https://doi.org/10.1016/j.egypro.2017.03.1109

BARBEAU B., GAUTHIER V., JULIENNE K., CARRIERE A. (2005). Dead-end flushing of a distribution system: Short and long-term effects on water quality, Water Science and Technology Water Supply, Vol. 54. Issue 6, pp. 371–383 https://doi.org/10.2166/aqua.2005.0035

BERREZEL Y.A., ABDELBAKI C., BENABDELKRIM M.E.A. (2022). Coupling of GIS and Hydraulic Modeling in Management of an Urban Water Distribution Network—A Case Study of Tlemcen (Algeria), In E. Heggy, V. Bermudez and M. Vermeersch (Eds.), Sustainable Energy-Water-Environment Nexus in Deserts, Springer International Publishing, pp. 253–258. https://doi.org/10.1007/978-3-030-76081-6_30

BLINDU I. (2004). Tool to help diagnose the drinking water network for the city of Chisinau by spatial and temporal analysis of hydraulic dysfunctions, PhD thesis, National School of Mines of Saint-Etienne, Jean Monnet University - Saint-Etienne, France, 304 p. (In French). https://tel.archives-ouvertes.fr/tel-00779032

BOUKHARI S., DJEBBAR Y., AMARCHI H., SOHANI A. (2018). Application of the analytic hierarchy process to sustainability of water supply and sanitation services: the case of Algeria, Water Supply, Vol. 18, Issue 4, pp. 1282–1293. https://doi.org/10.2166/ws.2017.194

CARNERO M.C., GÓMEZ A. (2018). Optimization of maintenance in production and storage systems for domestic water, Water Resources Management, Vol. 32, Issue 1, pp. 359–380. https://doi.org/10.1007/s11269-017-1815-2

DUZINKIEWICZ K., CIMINSKI A. (2006). Drinking water distribution system modelling - An approach to skeletonization, IFAC Proceedings Volumes, Vol. 39, Issue 14, pp. 244–249. https://doi.org/10.3182/20060830-2-SF-4903.00043

FUJITA M., ISHIWATARI Y., MISHIMA I., UTSUNO N., KATO T. (2014). Effect of aging of pipe and lining materials on elemental composition of suspended particles in a water distribution system, Water Resources Management, Vol. 28, Issue 6, pp. 1645–1653. https://doi.org/10.1007/s11269-014-0571-9

GOOGLE EARTH. (N.D.). Retrieved 26 July 2019, from https://earth.google.com/web/

GRECO S., EHRGOTT M., FIGUEIRA J.R. (2016). Multiple criteria decision analysis: state of the art surveys, Vol. 233, Springer, New York, USA. https://doi.org/10.1007/978-1-4939-3094-4

HAJEBI S., TEMATE S., BARRETT S., CLARKE A., CLARKE S. (2014). Water distribution network sectorisation using structural graph partitioning and multi-objective optimization, Procedia Engineering, Vol. 89, pp. 1144–1151. https://doi.org/10.1016/j.proeng.2014.11.238

HOUNTONDJI B., CODO F.P. (2019). Design of a hydraulic model for the Monzoungoudo water supply network in Benin, Larhyss Journal, No 38, pp. 71-91.

INGEDULD P., PRADHAN A., SVITAK Z., TERRAI A. (2008). Modelling Intermittent Water Supply Systems with EPANET, Water Distribution Systems Analysis Symposium, pp. 1–8. https://doi.org/10.1061/40941(247)37

METELKA T. (2006). Integrated urban water cycle modeling. In P. Hlavinek, T. Kukharchyk, J. Marsalek, and I. Mahrikova (Eds.), Integrated Urban Water Resources Management, Kluwer Academic Publishers, pp. 51–58. https://doi.org/10.1007/1-4020-4685-5_6

MONTIBELLER G., GUMMER H., TUMIDEI D. (2006). Combining scenario planning and multicriteria decision analysis in practice, Journal of Multi-Criteria Decision Analysis, Vol. 14, Issue 1–3, pp. 5–20. https://doi.org/10.1002/mcda.403

MUTOTI G., DIETZ J., IMRAN S., TAYLOR J. (2007). Pilot-Scale verification and analysis of iron release flux model, Journal of Environmental Engineering, Vol. 133, Issue 2. https://doi.org/10.1061/(ASCE)0733-9372(2007)133:2(173)

ONS. (2019). National Statistics Office, Technical report, Algeria.

PANDEY P., MISHRA R., CHAUHAN R.K. (2022). Future prospects in the implementation of a real-time smart water supply management and water quality monitoring system, Larhyss Journal, No 51, pp. 237-252.

PATEL K., MEHTA D. (2022). Design of the continuous water supply system using Watergems software: a case study of Surat city, Larhyss Journal, No 50, pp. 125-136.

PEREZ-PEREZ E.J., LOPEZ-ESTRADA F.R., VALENCIA-PALOMO G., TORRES L., PUIG V., MINA-ANTONIO J.D. (2021). Leak diagnosis in pipelines using a combined artificial neural network approach, Control Engineering Practice, Vol. 107, Paper 104677. https://doi.org/10.1016/j.conengprac.2020.104677

SAATY T.L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation, McGraw, New York, USA.

SAATY T.L. (2008). Decision making with the analytic hierarchy process, International Journal of Services Sciences, Vol. 1, Issue 1, pp. 83-98. https://doi.org/10.1504/IJSSCI.2008.017590

ŞENER Ş., ŞENER E., NAS B., KARAGÜZEL R. (2010). Combining AHP with GIS for landfill site selection: A case study in the Lake Beyşehir catchment area (Konya, Turkey), Waste Management, Vol. 30, Issue 11, pp. 2037–2046. https://doi.org/10.1016/j.wasman.2010.05.024

SILVA A.C.S. DA, BELDERRAIN M.C.N., PANTOJA F.C.M. (2010). Prioritization of R&D projects in the aerospace sector: AHP method with ratings, Journal of Aerospace Technology and Management, Vol. 2, Issue 3, pp. 339–348. https://doi.org/10.5028/jatm.2010.02039110

TARIGAN A.P.M., RAHMAD D., SEMBIRING R.A., ISKANDAR R. (2018). An application of the AHP in water resources management: a case study on urban drainage rehabilitation in Medan City, IOP Conference Series: Materials Science and Engineering, Vol. 309, Paper 012096. https://doi.org/10.1088/1757-899X/309/1/012096

TRAMARICO C.L., DANIELEMIZUNO, SALOMON V.A.P., MARINS F.A.S. (2015). Analytic Hierarchy Process and Supply Chain Management: A Bibliometric Study, Procedia Computer Science, Vol. 55, pp. 441–450. https://doi.org/10.1016/j.procs.2015.07.005

TSCHEIKNER-GRATL F., EGGER P., RAUCH W., KLEIDORFER M. (2017). Comparison of Multi-Criteria Decision Support Methods for Integrated Rehabilitation Prioritization, Water, Vol. 9, Issue 2, pp. 68. https://doi.org/10.3390/w9020068

VELASQUEZ M., HESTER P.T. (2013). An analysis of multicriteria decision making methods, International Journal of Operations Research, Vol. 10, Issue 2, pp. 56-66.

VREEBURG J., BOXALL J. (2007). Discolouration in potable water distribution systems: A review, Water Research, Vol. 41, pp. 519–529. https://doi.org/10.1016/j.watres.2006.09.028

ZYOUD S.H., SHAHEEN H., SAMHAN S., RABI A., AL-WADI F., FUCHS-HANUSCH D. (2016). Utilizing analytic hierarchy process (AHP) for decision making in water loss management of intermittent water supply systems, Journal of Water, Sanitation and Hygiene for Development, Vol. 6, Issue 4, pp. 534–546. https://doi.org/10.2166/washdev.2016.123