Coupling Decision Support Systems For The Optimization of The Management of Water Distribution Networks

Yacine Abdelbaset Berrezel

University of Tlemcen

Chérifa Abdelbaki

University of Tlemcen

Bouchrit Rouissat

University of Tlemcen

Tarik Boumaaza

Oran water and sanitation company

Khaldoon A Mourad (✉ khaldoonmourad@yahoo.com)

Swedish National Road and Transport Research Institute <https://orcid.org/0000-0001-5358-2217>

Research Article

Keywords: Multi-criteria Analysis, Analytic Hierarchy Process, Modeling, Water distribution network, Management.

Posted Date: January 14th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1038410/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Coupling Decision Support Systems for the optimization of the management of water distribution networks

Yacine Abdelbaset Berrezel^{1,2}, Chérifa Abdelbaki^{1,2}, Bouchrit Rouissat^{1,3}, Tarik Boumaaza⁴
and Khaldoun A. Mourad^{5*}

¹Department of Hydraulics, Faculty of Technology, University of Tlemcen, P.B. 230 Tlemcen, 13000, Algeria; berrezel.yacine@gmail.com

² Laboratoire EOLE, University of Tlemcen, P.B. 230 Tlemcen, 13000, Algeria, ORCID : 0000-0002-7100-7467, cherifa.abdelbaki@univ-tlemcen.dz

³RISAM Laboratory, University of Tlemcen, P.B. 230 Tlemcen, 13000, Algeria, b_rouissat@yahoo.fr

⁴ Oran water and sanitation company, Oran, 31000, Algeria; tboumazza@seor.dz

^{5*}Swedish National Road and Transport Research Institute, 583 30 Linköping, Sweden: ORCID: 0000-0001-5358-2217; khaldounmourad@yahoo.com

Abstract

The analysis of the current situation of water distribution networks is based on all the alternatives that are technically feasible and implemented from the decision-maker's point of view. Taking the water distribution network of Tourville city as a case study, this paper combines a set of Decision Support Systems (DSS) including the Geographic Information Systems (GIS), multi-criteria analysis and hydraulic simulation models to establish a multi-criteria decision-making aid method for renovation and rehabilitation of water distribution networks. This combination creates an expert management system based on multi-criteria 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:

Multi-criteria Analysis, Analytic Hierarchy Process, Modeling, Water distribution network, Management.

1. Introduction

1.1. Background

A water distribution network 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 about the hydraulic state and many other variables (Duzinkiewicz & 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. Over time the Distribution Water System (DWS) ages and it is necessary to renew it when it reaches a threshold of

obsolescence. This ageing generates dysfunctions that complicate the task of the manager. At this stage, managers start asking questions like: Should I renew the pipes? Which parts should I renew? When should I start?

Recently, decision making depends on mathematical science, software and models that can assess the situation of the system (Greco et al. 2016; Zyoud et al. 2016; Tarigan et al. 2018; Amorocho-Daza et al. 2019). Noted that the use of the Analytic Hierarchy Process (AHP) method is useful to water management in term of achieving a better understating of water management strategies. Blindu (2013) worked on adding the multi-criteria analysis to the Geographic Information Systems (GIS) to classify the behaviors rehabilitation programs in the short, medium, and long term.

This paper creates an expert management system to make multi-criteria decisions by combines GIS, multi-criteria analysis and hydraulic simulation model, allowing the renovation and rehabilitation of water distribution network to have a strategic vision and prevent scenarios for optimizing the management of distribution networks.

1.2. 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 with a population of 86,000 (ONS 2019). The region is characterized by rugged topography whose altitude ranges between 1 and 90 m. The Tourville sector is supplied by an elevated tank 40 m high. The length of the drinking water system (DWS) is about 35 km and it was made up of cast iron, steel and polyethylene high-density (PEHD) and the nominal diameters ranged between 63 and 300 mm.

Fig.1 Geographical location of Arzew city and the study area Tourville. After: (*Algeria Map - Resources | Simplemaps.Com, n.d.; Google Earth, n.d.*)

2. 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 multi-criteria studies, Fig. 2.

Data modeling is fundamental in the design of databases that will be used for the management of the water distribution network. Mike Urban software requires creating a diagram reflecting the physical characteristics of the components of the system: tanks, pipes, and junctions. Therefore, the characteristics of these components were collected (Abrunhosa 2015).

Mapping the results helps to identify and classify the sections by order of priority to generate real progress in managing the network.

Fig.2 Schematic diagram reproducing the logic of management of the DWS network.

2.1. 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). The properties of the studied network like the digital elevation model, characteristics of pipes, nodes and tanks are given by Oran Water and Sanitation Company that uses ArcGIS and Mike Urban software.

Mike Urban is a calculation model offers many advantages compared to traditional 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).

2.2. Multi-criteria decision analysis (MCDA)

MCDA is a methodology designed for evaluating options considering decision-making objectives (Montibeller et al., 2006). Many methods have been developed, in their review, Velasquez and Hester (2013) identified the following methods: Multi-Attribute Utility Theory,

Analytic Hierarchy Process, Fuzzy Set Theory, Case-based Reasoning, Data Envelopment Analysis, Simple Multi-Attribute 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 rankings 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 of the decision problem into hierarchy structure the 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.

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

(1)

where; A is the decision matrix, a_{ij} are comparisons between elements i and j for all $i, j \in \{1, 2, \dots, n\}$.

The comparison is made using a scale, Table 1, to indicate 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: Saaty 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 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):

$$CR = \frac{CI}{RI} \quad (2)$$

where:

RI: Random Consistency Index,

(RI) can be determined from Table 2

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3)$$

where:

λ_{max} : the largest or the principal eigenvalue of the matrix.

n: the order of the matrix.

Table 2: Saaty 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 $CR \leq 10\%$. In case 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).

3.Results and Discussions

3.1. The performance of the alternatives

Since the DWN is characterized by its complexity, the best way to understand this system is to break it down into hierarchical structure elements. The dimensions, 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 are used.

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 sub-criteria (SC) are used based on the sections of the network: 1) the used materials; 2) the laying date; 3) the diameter of the pipe; 4) water pressure; and 5) water velocity.

Each of these sub-criteria 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 sub-criteria 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, 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.

3.2. Pairwise comparisons and weighting

The results of the application of the AHP method show the classifying of dimensions, criteria and indicators and represented in matrices of weights (from table 3 to table 10) for example, the importance of the size 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.

To demonstrate how the pairwise comparisons of various criteria were calculated, the following steps illustrate the Comparison of indicator 1 in Table 6 for example:

The elements of table 6 are regrouped in matrix A.

$$\mathbf{A} = \begin{bmatrix} 1 & 1/4 & 1/3 \\ 4 & 1 & 2 \\ 3 & 1/2 & 1 \end{bmatrix} \quad (4)$$

The weight of these elements is calculated by summing the columns of matrix A 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.

The sum of each column: [8 1.75 3.33] (5)

Dividing each of the values in the column by the sum of the columns:

$$\begin{bmatrix} 0,13 & 0,14 & 0,10 \\ 0,50 & 0,57 & 0,60 \\ 0,38 & 0,29 & 0,30 \end{bmatrix} \quad (6)$$

The weight is the average of each row:

$$\begin{bmatrix} 0,122 \\ 0,558 \\ 0,320 \end{bmatrix} \quad (7)$$

Table 3: Comparison of the main criteria

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

$\lambda_{\max}=2$ and $CR=0$

Table 4: Comparison of Sub-criteria 1

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

$\lambda_{\max}=3,0536$ and $CR\%=5,15$

Table 5: Comparison of Sub-criteria 2

SC2	Pressure	Velocity	Weight
Pressure	1	3	0,75
Velocity	1/3	1	0,25

$\lambda_{\max}=2$ and $CR\%=0$

Table 6: Comparison of indicator 1

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

$\lambda_{\max}=3,018$ and $CR\%=1,73$

Table7: Comparison of indicator 2

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

$$\lambda_{\max}=3,038 \text{ and CR\%}=3,65$$

Table 8: Comparison of indicator 3

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

$$\lambda_{\max}=3,0246 \text{ and CR\%}=2,36$$

Table 9: Comparison of indicator 4

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

$$\lambda_{\max}=3,0536 \text{ and CR\%}=5,15$$

Table 10: Comparison of indicator 5

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

$$\lambda_{\max}=3,0536 \text{ and CR\%}=5,15$$

3.3. 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 characteristic (diameter, materials, Pipe laying date) with the superposition of the base plan obtained by aerial photos of SEOR (Oran water and sanitation company).

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.

Step 1: Selecting features (indicators) using an attribute query

Step 2: In the table of contents, set the value of each weight in the corresponding column.

Step 3: Know that the lines represent the sections that are the alternatives so to get the priority of each section summing weights of each line is required.

Step 4: Defining levels by using the priorities obtained in step 3.

Displaying the results as shown in Fig. 4 helps us to identify the sections and rank them in order of priority to generate real progress in network management. The priority sections for maintenance action can be identified according to the order and the emergency category and the colors, it includes three classes: level 3 low in yellow color, level 2 medium in orange color and level 1 high priority for intervention in red color.

Fig. 3. Ranking of all 15 indicators which were obtained by AHP.

Fig. 4. Ranking level of the sections.

The network is a combination between loop main pipes and branched sections, 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, Fig 5, the concept of urgency level allows us to classify of 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 the important one in term of criticality and it must be rehabilitated at first, so the focus was on this part.

Fig. 5. Linear of sections by emergency level.

Fig. 6 shows that 97% of the network in level 1 are made of cast iron which represents 100% of the pipes ranging from 100 mm and below. Most of the failures happen in cast iron (CI) and steel (ST) pipes, which are these days not utilized any longer in the water network. Fewer failures happen in the more up to date polyethylene (PE) pipes (Tscheikner-Gratl et al. 2017).

Fig. 6. Percentage and weight of each material

Fig. 7 and Fig. 8 show the emergency level of the pipes based on the diameter and the flow velocity, respectively. Fig. 10 is obtained by combining results from Fig. 7 and Fig. 8 and it represents the different size of diameters with a range of different flow velocities, more than 50% of the linear length of pipes are characterized with low velocities under 0.5m/s with diameters ranging from 100 mm and under. Distribution dead-end mains are known by low flow velocities and stagnation times (Barbeau et al. 2005). Suspended materials in the pipe start to settle when the flow velocity drops below a threshold that is around 0.06 m/s (Vreeburg & Boxall 2007). If a finite volume of water spends more time within a pipe indicates low flow conditions that may increase the precipitation and uptake of iron in metal pipes due to corrosion (Mutoti et al., 2007), residence time also leads to a rapid reduction of disinfectant residuals that allow microbial pathogens to regrow (Abokifa et al. 2016). The concentrations of particulate

elements, between upstream and downstream of the pipe should increase, an analysis of the composition of suspended particles may detect aging pipes (Fujita et al. 2014).

Fig. 7. Percentage and weight of each Diameter

Fig. 8. Percentage and weight of velocity

Fig. 9. Percentage and weight of precision

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 2/3 of this length undergoes speeds lower than 0.5m/s it is 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 affects directly or indirectly the other one in a complex way which means the velocity can affect the aging of pipe and material, the diameter affects the velocity and so on.

Fig. 10. Range of different flow velocities in the pipes

CONCLUSIONS:

This paper leads to the establishment of a multi-criteria 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), multi-criteria analysis and hydraulic simulation model, help 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 classifying of dimensions, criteria and indicators. The selection of criteria was made by taking into consideration the physical characteristics of

pipes as the diameter, materials and the laying date of the pipe, the hydraulic structure of the network as the velocity and the pressure of water. The priority sections for maintenance action can be identified according to the emergency levels category and the colors, it includes three classes: level 3 low, level 2 medium and level 1 high priority for intervention in red color. The result showed that the critical part represents 26% of the network that should be rehabilitated as soon as possible.

Declarations

Ethical Approval: Not applicable

Consent to Participate: All the authors of this article have agreed to participate in this research study.

Consent to Publish: We give our consent for the publication of all related materials to be published in the above Journal and Article.

Authors Contributions: Y.A.B. Literature, methods and results; C.A. introduction and supervision; B.R. Analysis and assessment; T.B. methods and analysis; K.A.M. reviewing, submission and following up.

Funding: Not applicable

Competing Interests

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.

Availability of data and materials: All the used data are included in the manuscript

REFERENCES:

- Abokifa A. A., Yang Y. J., Lo C. S. & Biswas, P. 2006 Water quality modeling in the dead end sections of drinking water distribution networks. *Water Research*, 89, 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*. University of Porto.

- 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 Multi-Criteria Decision Analysis Methodology for the Selection of New Water Supply Infrastructure. *Water*, 11(4), 805. <https://doi.org/10.3390/w11040805>
- Barbeau B., Gauthier V., Julien K. & Carrière A. 2005 Dead-end flushing of a distribution system: Short and long-term effects on water quality. *Water Science & Technology Water Supply*, 54. <https://doi.org/10.2166/aqua.2005.0035>
- Blindu I. 2013 *Outil d'aide au diagnostic du réseau d'eau potable pour la ville de Chisinau par analyse spatiale et temporelle des dysfonctionnements hydrauliques*. Saint Etienne National School of Mines.
- 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*, 18(4), 1282–1293. <https://doi.org/10.2166/ws.2017.194>
- Duzinkiewicz K. & Ciminski A. 2006 Drinking water distribution system modeling- An approach to skeletonization. *IFAC Proceedings Volumes*, 39(14), 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 Ageing of Pipe and Lining Materials on Elemental Composition of Suspended Particles in a Water Distribution System. *Water Resources Management*, 28(6), 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. <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*, 89, 1144–1151. <https://doi.org/10.1016/j.proeng.2014.11.238>
- Metelka T. 2006 Integrated urban water cycle modeling. In Hlavinek, P., Kukharchyk, T., Marsalek, J., Mahrikova, I., (Eds.), *Integrated Urban Water Resources Management* (pp. 51–58). Kluwer Academic Publishers. https://doi.org/10.1007/1-4020-4685-5_6

- Montibeller G., Gummer H. & Tumidei, D. 2006. Combining scenario planning and multi-criteria decision analysis in practice. *Journal of Multi-Criteria Decision Analysis*, 14(1–3), 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*, 133. [https://doi.org/10.1061/\(ASCE\)0733-9372\(2007\)133:2\(173\)](https://doi.org/10.1061/(ASCE)0733-9372(2007)133:2(173))
- ONS 2019 ONS: Office National des Statistiques . <https://www.ons.dz/> (accessed 29 March 2021)
- Saaty T. L. 1980 *The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation*. McGraw, New York.
- Saaty T. L. 2008. Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83. <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*, 30(11), 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*, 2(3), 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*, 309, 012096. <https://doi.org/10.1088/1757-899X/309/1/012096>
- Tramarico, C. L., Daniele Mizuno, Salomon, V. A. P., Marins, F. A. S., 2015. Analytic Hierarchy Process and Supply Chain Management: A Bibliometric Study. *Procedia Computer Science*, 55, 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*, 9(2), 68. <https://doi.org/10.3390/w9020068>
- Velasquez M. & Hester P. T. 2013 *An Analysis of Multi-Criteria Decision-Making Methods*. 10(2), 12.
- Vreeburg J. & Boxall, J. 2007 Discolouration in potable water distribution systems: A review. *Water Research*, 41, 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*, 6(4), 534–546. <https://doi.org/10.2166/washdev.2016.123>