A method for ranking of leakage localization techniques in the pipelineusing multicriteria decision making matrix

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Abstract: Pipeline leakage is a very serious issue for the present civilization. Due to leakage, loss of water and water pollution takes place. It is very important to localize leakage in the pipeline in right time. There are numerous techniques to detect leakage in pipeline. Using suitable method to localize leakage is very crucial. Improper localization of leakage may cause total failure of pipeline and that will impact on environment also.This paper presents a technique to choose appropriate method by using Multicriteria decision making matrix. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method and Analytic Hierarchy Process(AHP) is used for the Multicriteria decision making matrix. In this research three different criterion of leakage localization techniques viz. Applicable for above or buried pipeline; Applicable for long or short distance pipeline; cost effectiveness are chosen. AHP is use to get calculated weights for above three criteria and those weights are further used in TOPSIS for ranking of leakage localization techniques.From the analysis, it is found that Mobile sensor network (MSN) technique is a suitable technique andhas got first rank among the other leakage localization techniques.

Keywords: Analytic Hierarchy Process,Leakage localization, Multicriteria decision making matrix, Ranking, Technique for Order Preference by Similarity to Ideal Solution method,Weightage.

Introduction

Leakage in a pipeline causes substantial wastage of water and allow to pollute water by mixing harmful chemicals. This is not only an environmental issue but also causes economic loss.Different techniques are used to localize leak in water pipeline.Acoustic emission technique is very efficient non-destructive technique for the detection of leakage (Banjara et al., 2020). For long distance pipeline, permanent acoustic sensors are very useful but proper positioning of sensors are required in this technique. To overcome the problem, an inline-inspection acoustic device is developed that comprises of acoustic sensors. This device can travel by the flow of water and captures different signals and detect the leakage location in water pipeline (Kumar et al.,2017).To predict the leak location using acoustic signal analysis with higher accuracy an Artificial Neural Network model (ANN) was also developed (Wang et al.,2021;Kamalakkannan et al., 2022; Steidl et al., 2023).Wastage of water through leakage from buried pipeline is an immense problem for the society.For the localization of leakage, an algorithm was developed that uses vibration signals from accelerometer attached with the pipeline surface.In this method, a convolutional neural network (CNN) model is used for the detection of leakage in pipeline (Shukla and Piratla, 2020; Zahab et al., 2016).For the detection of leakage in large area, Mobile sensor networks (MSN) plays a vital role and can locate leakage precisely. Sensors are inserted into the pipeline and can move through the water flow (Suresh et al.,2014; Dhongdi, 2022). All the information regarding the leakage is captured and is transmitted to wireless access points (Gong et al., 2016). For detecting and locating leaks in buried pipelines, ground penetrating radar (GPR) and infrared photography (IR) method is used (Atef et al., 2016).The optical frequency domain reflectometry (OFDR) technique is an important technique for pipeline monitoring (Ren et al.,2018).OFDR technique is applicable for monitoring leakage and corrosion both.However, this technique is applicable for long distance pipelines.Optic-Based Pressure Sensor is another efficient leak detection method in water pipeline (Wong et al., 2018). For monitoring internal water pressure, optical fibre device is used. In this method, the leak detection is based on hydrostatic and pressure transient responses of the optical fibre pressure sensor.Using reflectometry technique for the detection of leakage in water pipeline, it is observed that only low frequency waves can travel in long distance pipeline. To overcome this problem, comprehensive sensing based super-resolved impulse response technique is developed. This technique is also applicable for closely spaced leakage and blockage detection in pipeline (Li et al., 2021). For the localization of leakages in buried pipelines this method is pretty acceptable. A programmable logic controller-based leak detection technique is another efficient method for detection leakage in pipeline (Aziz et al., 2021). In this method combination of Volume Based Method (VBM) and Pressure Point Analysis (PPA) are used. Negative Pressure Wave (NPW) method is used here for achieving accuracy in Leakage localization.For underground pipelines, TDR Based leakage detection is an efficient way. Multiple leakage points can be detected by using the above method, where TDR sensor is in contact with only in one point. It is found thatTDR Based leakage detection is much accurate as compare to traditional method of acoustic leak detection(Aghda et al., 2018).For the leakage localization in pipeline using transient analysis, bootstrap method is used to predict the leak locations. Similarly for pipeline maintenance, this method provides the informationwhich are also important for the decision making (Wang et al., 2022; Wang, 2022).

Methodology

This research shows the ranking of leakage localization technique using Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. Initially using AHP a pair wise comparison matrix will be formed where weightage related to different criteria,consistency ratio(*CR*) andconsistency index(*CI*)will be calculated (Fig.1) The Eigen vectors (δ) are taken as weights for each criterion(Fig.2). The weights are further used in Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method for final ranking of leakage localization techniques.

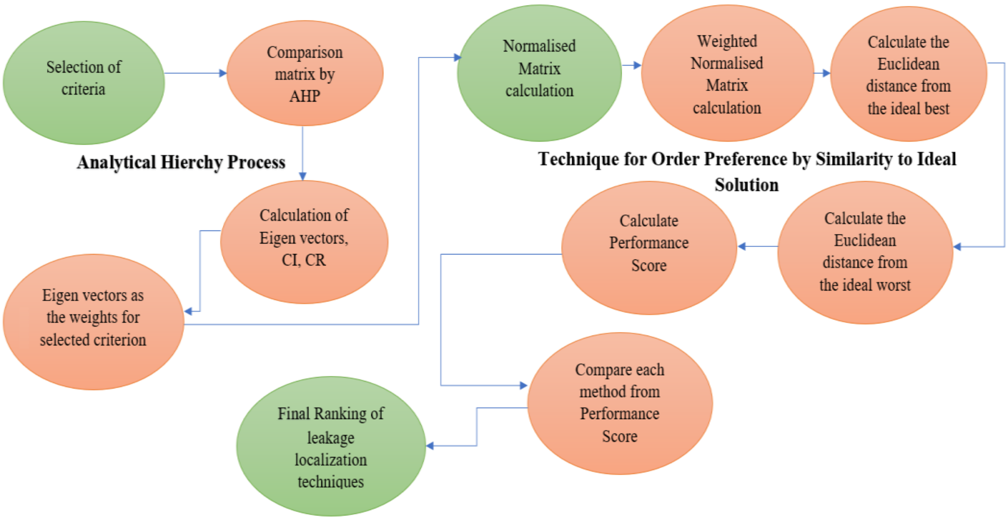
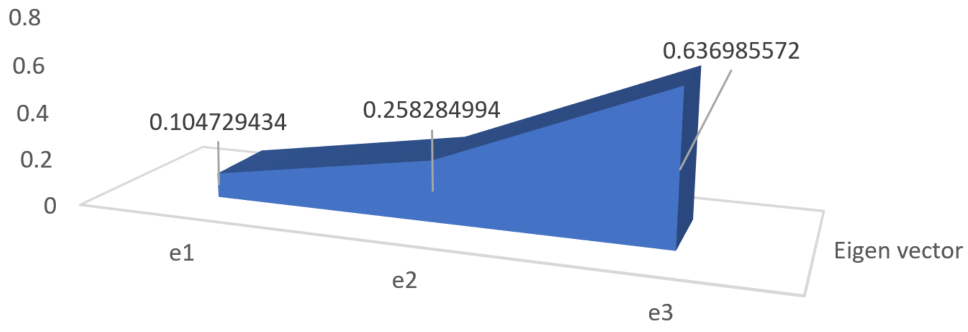


Fig .1 Ranking method of leakage localization techniques



e1	e2	e3
0.104729434	0.258284994	0.636985572

Fig.2 Weights for various criteria

In AHP (Duleba, 2022),a pairwise comparison matrix is designed where‘*m*’ elements are compared. In this research three different criteria are considered as ‘*m*’ elements.The weights of each criteria are given as per AHP scale (Zhang et al.,2022). Eigen vectors(δ) have been calculated from weightage of different criteria. Eigen vectors are further multiplied with weightage of different criteria and gives a new vector. The new vector again divided by eigen vector and gives eigen value(ξ). The maximum eigen value is considered for the calculation of Consistency Index(*CI*)(Eqn.1).

$$CI = \frac{(\xi_{max} - m)}{m-1} \quad (1)$$

For the calculation of Consistency Ratio (CR) the following equation is used (Eqn.2)

$CR = CI/0.58$(2)

In the above equation, corresponding index of consistency for random judgments (for *m*=3) is 0.58. CR should be always less than 0.1 for trustworthy result (Duleba, 2022). Whereas for TOPSIS, the following steps are involved for ranking of leakage localisation techniques (Kanagaraju et al., 2022; Prabhuram et al., 2022; Wang et al.,2022; Chakraborty, 2022; Amorocho and Hartmann, 2022).

*a)*Normalised Matrix(*M*) calculation (Eqn.3)

$$M = \frac{X_{ij}}{\sqrt{\sum X_{ij}^2}} \quad (3)$$

X_{ij} is score of alternative where$i$= 1……10 and j= 1….3

b) Weighted Normalised Matrix (V_{ij}) calculation(Eqn.4)

$$(4)\ V_{ij} = M \times W_j$$

W_j is weight of various criteria calculated by Analytic Hierarchy Process.

c) Ideal best (V_j^+) and ideal worst (V_j^-) value calculation.

d) Calculate the Euclidean distancefrom the ideal best (S_i^+)(Eqn.5)

$$S_i^+ = \sqrt{\left[\sum_{j=1}^{m} (V_{ij} - V_j^+)^2\right]} \quad (5)$$

*e)*Calculate the Euclidean distance from the ideal worst (S_i^-)(Eqn.6)

$$S_i^- = \sqrt{\left[\sum_{j=1}^{m} (V_{ij} - V_j^-)^2\right]} \quad (6)$$

*f)*Calculate Performance Score (*P*) (Eqn.7)

$$P = \frac{S_i^-}{S_i^+ + S_i^-} (7)$$

g) Ranking of different leakage localization techniques.

Result and discussion

At the very beginning of the process different criterion are chosen. In this research three different criterion of leakage localization techniques viz. Applicable for above or buried pipeline(e_1); Applicable for long or short distance pipeline(e_2); cost effective(e_3) are chosen(Table.1). A comparison matrix has been formed using AHP(Table.2).Eigen vectors(δ) and Eigen values(ξ) are calculated. Simultaneously CI and CR has been calculated to check the consistency of results.CR should be less than 0.1 so that the Eigen vectors (δ) are taken as weights for each criterion in TOPSIS.

Table 1. Comparison of leakage localisation techniques

Sl no.	Leakage localization techniques	Applicable for(e_1)		Applicable for(e_2)		Cost effective(e_3)
		Above pipeline	Buried pipeline	Long distance pipeline	Short distance pipeline	
1	Acoustic emission technique (Kumar et al.,2017; Banjara, Sasmal and Voggu, 2020; Wang et al.,2021; Yang et al., 2006)	Yes	--	Yes	--	--
2	Accelerometer technique (Shukla and Piratla, 2020)(Zahab et al., 2016)	Yes	Yes	--	Yes	--
3	Mobile sensor networks (Gong et al., 2016)	Yes	Yes	Yes	Yes	Yes
4	Ground penetrating radar (GPR) and infrared	--	Yes	--	Yes	--

	photography (IR)(Atef et al., 2016)					
5	The optical frequency domain reflectometry (OFDR)(Ren et al.,2018)	Yes	Yes	Yes	--	--
6	Optic-Based Pressure Sensor (Wong et al., 2018)	Yes	Yes	Yes	--	--
7	Super-resolved impulse response technique (Li et al., 2021)	--	Yes	Yes	Yes	--
8	Programmable logic controller-based leak detection technique (Aziz et al., 2021)	--	Yes	Yes	--	--
9	TDR Based leakage detection (Aghda et al., 2018)	--	Yes	Yes	--	Yes
10	Bootstrap method (Wang et al., 2022; Wang, 2022)	Yes	Yes	Yes	--	--

In TOPSIS, various leakage localization techniques viz. Acoustic emission technique (l_1); Accelerometer technique(l_2); Mobile sensor network technique(l_3); Ground penetrating radar and infrared photography technique(l_4); The optical frequency domain reflectometry technique(l_5); Optic-Based Pressure Sensor technique(l_6); Super-resolved impulse response technique(l_7); Programmable logic controller-based leak detection technique(l_8); TDR Based leakage detection technique(l_9); Bootstrap method(l_{10}) are chosen as an alternatives.

Table 2.Comparison matrix using AHP

	e1	*e2*	*e3*	δ	*New vector*	ξ	ξ_{max}	Consistency Index (*CI*)	Consistency Ratio (*CR*)
e1	1.00	0.33	0.20	0.104729434	0.318222	3.038511	3.038511	0.019255545	0.033199216
e2	3.00	1.00	0.33	0.258284994	0.784802	3.038511			
e3	5.00	3.00	1.00	0.636985572	1.935488	3.038511			

Using this alternatives and weights from AHP a multicriteria decision making matrix (MCDM) has been formed(Table.2). Euclidean distance from the ideal best (S_i^+) and Euclidean distance from the ideal worst (S_i^-), Performance Score (*P*) has been calculated as shown in Table.3.

Table 3. Performance score of leakage localization techniques

Leakage localisation techniques		*e1*	*e2*	*e3*	S_i^+	S_i^-	P	Rank
	Alternatives	0.104729	0.258285	0.636986				
Acoustic emission technique (l_1)	*l1*	5	5	3	0.075880918	0.069492	0.478024295	5
Accelerometer technique(l_2)	*l2*	7	4	3	0.08360482	0.068393	0.44995958	6
Mobile sensor network technique(l_3)	*l3*	7	5	4	0.032868561	0.136472	0.805902765	1
Ground penetrating radar and infrared photography technique(l_4)	*l4*	5	4	3	0.084310982	0.06752	0.444706248	7
The optical frequency domain reflectometry technique(l_5)	*l5*	7	4	2	0.143759358	0.010889	0.070412843	10
Optic-Based Pressure Sensor technique(l_6)	*l6*	7	5	3	0.075095526	0.07034	0.483649263	4
Super-resolved impulse response technique(l_7)	*l7*	5	7	3	0.068392773	0.083605	0.55004042	3

Programmable logic controller-based leak detection technique(l_8)	*l8*	5	5	2	0.1394 09113	0.01 6434	0.1054 53816	9
TDR Based leakage detection technique(l_9)	*l9*	5	5	4	0.0346 25396	0.13 6037	0.7971 11757	2
Bootstrap method(l_{10})	*l10*	7	5	2	0.1389 83183	0.01 9714	0.1242 26737	8

Using the performance score(P) final ranking of leakage localisation techniques is performed (Fig.3).

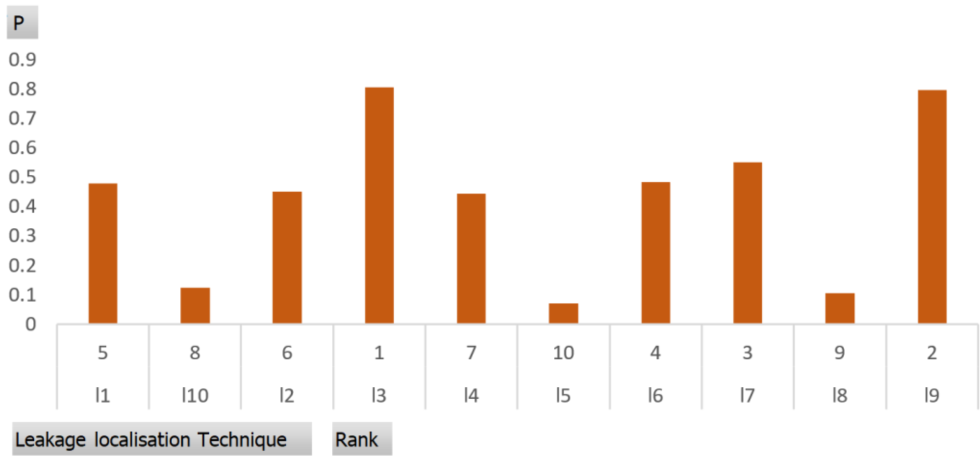


Fig.3 Performance score and rank of different leakage localization techniques

From the result it is observed that Mobile sensor network technique has got first rankamong the other techniques of leakage localization(Table 3).

Conclusion

Among all leakage localization techniques, the combination of AHP and TOPSIS play a vital role to show the ranking of the techniques. Leakage is a primary concern of environmental engineers. Due to leakage, water pollution as well as environment pollution occur. In this research the suitable and effective leakage localization techniques are being ranked. As a result, Engineers and researcher can easily apply those techniques in required places. In this research, it is found that Mobile sensor network technique has got first rank whereas Optical frequency domain reflectometry technique has got 10^{th} rank among all. Although the combination of AHP and TOPSIS gives satisfactory result for the calculation of weightage and performance score(P)but for more precise result inweightage calculation of different criteria, usingGenetic Algorithm (GA) technique can be beneficial.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed equally to the study conception and design mtrl preparation, data collection and analysis.

Reference

1. Aghda, S.F., Ganjali Pour, K. and Nabiollahi, K. 2018 Assessing the accuracy of TDR-based water leak detection system. Results in physics, 8, 939-948.
2. Amorocho, J.A.P. and Hartmann, T. 2022 A multi-criteria decision-making framework for residential building renovation using pairwise comparison and TOPSIS methods. Journal of Building Engineering, 53, 104596.
3. Atef, A., Zayed, T., Hawari, A., Khader, M. and Moselhi, O. 2016 Multi-tier method using infrared photography and GPR to detect and locate water leaks. Automation in Construction, 61,162-170.
4. Aziz, N., Tanoli, S.A.K. and Nawaz, F. 2021 A programmable logic controller based remote pipeline monitoring system. Process Safety and Environmental Protection, 149, 894. DOI:10.1016/j.psep.2021.03.045.

5. Banjara, N.K., Sasmal, S. and Voggu, S. 2020 Machine learning supported acoustic emission technique for leakage detection in pipelines. International Journal of Pressure Vessels and Piping, 188, 104243.
6. Chakraborty, S. 2022 TOPSIS and Modified TOPSIS: A comparative analysis. Decision Analytics Journal, 2, 100021.
7. Dhongdi, S.C. 2022 Review of Underwater Mobile Sensor Network for ocean phenomena monitoring. Journal of Network and Computer Applications, 103418.
8. Duleba, S. 2022 Introduction and comparative analysis of the multi-level parsimonious AHP methodology in a public transport development decision problem. Journal of the Operational Research Society, 73, 230.
9. Gong, W., Suresh, M.A., Smith, L., Ostfeld, A., Stoleru, R., Rasekh, A. Banks, M.K. 2016 Mobile sensor networks for optimal leak and backflow detection and localization in municipal water networks. Environmental modelling & software, 80, 306-321.
10. Kamalakkannan, D., Ramakrishna Kolikipogu, D.S.D., Venkatesh Murthy, B.S., Swarnalatha, S.R., Venkatesh, P. 2022 Artificial Intelligence based traffic prediction system for autonomous vehicles. Journal of Pharmaceutical Negative Results, 3366-3373.
11. Kanagaraju, T., Gowthaman, B., Arunkumar, A. and Akash, S. 2022 Optimization of Machining parameters in wet and cryogenic Machining using TOPSIS approach. Materials Today: Proceedings.https://doi.org/10.1016/j.matpr.2022.04.346.
12. Kumar, D., Tu, D., Zhu, N., Hou, D. and Zhang, H. 2017 In-line acoustic device inspection of leakage in water distribution pipes based on wavelet and neural network. Journal of Sensors. DOI:10.1155/2017/5789510.
13. Li, Z., Lee, P. and Murch, R. 2021 Compressive-sensing based super-resolution detection for leakage and uniform blockage in water pipelines. Mechanical Systems and Signal Processing, 158, 107686.
14. Prabhuram, T., Singh, S.P., Durairaj, J.I., Elilraja, D., Das, M.C. and Sunderraj, D.A.J. 2022 Optimization of operation parameters in machining of functionally graded metal matrix composite using TOPSIS. Materials Today: Proceedings.https://doi.org/10.1016/j.matpr.2022.03.562.
15. Ren, L., Jiang, T., Jia, Z.G., Li, D.S., Yuan, C.L. and Li, H.N. 2018 Pipeline corrosion and leakage monitoring based on the distributed optical fiber sensing technology. Measurement, 122, 57-65.

16. Shukla, H. and Piratla, K. 2020 Leakage detection in water pipelines using supervised classification of acceleration signals. Automation in Construction, 117, 103256.
17. Steidl, M., Felderer, M. and Ramler, R. 2023 The pipeline for the continuous development of artificial intelligence models—Current state of research and practice. Journal of Systems and Software, 111615.
18. Suresh, M.A., Smith, L., Rasekh, A., Stoleru, R., Banks, M.K. and Shihada, B.2014 Mobile sensor networks for leak and backflow detection in water distribution systems. In 2014 IEEE 28th International Conference on Advanced Information Networking and Applications, 673.
19. Wang, W., Sun, H., Guo, J., Lao, L., Wu, S. and Zhang, J. 2021 Experimental Study on Water Pipeline Leak Using In-Pipe Acoustic Signal Analysis and Artificial Neural Network Prediction. Measurement, 110094.
20. Wang, X. 2022 Pipeline leakage alarm via bootstrap-based hypothesis testing. Mechanical Systems and Signal Processing, 179, 109334.
21. Wang, X., Ghidaoui, M.S. and Lin, J. 2022 Confidence interval localization of pipeline leakage via the bootstrap method. Mechanical Systems and Signal Processing, 167, 108580. DOI:10.1016/j.ymssp.2021.108580.
22. Wang, Y., Liu, P. and Yao, Y. 2022 BMW-TOPSIS: a generalized TOPSIS model based on three-way decision. Information Sciences.https://doi.org/10.1016/j.ins.2022.06.018.
23. Wong, L., Deo, R., Rathnayaka, S., Shannon, B., Zhang, C., Chiu, W.K., Kodikara, J. and Widyastuti, H. 2018 Leak detection in water pipes using submersible optical optic-based pressure sensor. Sensors, 18, 4192.
24. Zahab, S.E., Mosleh, F. and Zayed, T. 2016 An accelerometer-based real-time monitoring and leak detection system for pressurized water pipelines. Pipelines 2016 , 257. DOI:10.1061/9780784479957.025.
25. Zhang, L., Wang, Y., Zhang, J., Zhang, S. and Guo, Q. 2022 Rockfall hazard assessment of the slope of Mogao Grottoes, China based on AHP, F-AHP and AHP-TOPSIS. Environmental Earth Sciences, 81(14), 1-16.