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Research Article

Using the Infrastructure Leakage Index (ILI) indicator for effective and sustainable leakage management: importance, advantages and challenges

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ABSTRACT

Leaks occurring in distribution systems constitute a significant part of water losses. Active leak control methods (district metered area, minimum night flow analysis, repair speed and quality) are applied to manage and control the leaks. It is very important to use appropriate indicators to determine and monitor the performance in the process, and compare the systems with each other. In this study, it was aimed to use the infrastructure leakage index (ILI) proposed by International Water Association (IWA) and considered as the unique indicator that is used to compare systems with each other in order to analyze and monitor system performance in leakage management for pilot regions. However, the use of this indicator, which is preferred by a limited number of utilities in Turkey due to the lack of information and awareness, and lack of technical infrastructure, requires basic data representing the system characteristics. Based on the pilot case studies, the role and advantage of this indicator in leakage management, the problems experienced and the interpretation of the results were discussed. With this indicator, it is possible to determine the leakage level in the current conditions and to determine the most suitable process accordingly. It is thought that this study will make a significant contribution to technical personnel in terms of leakage management.

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INTRODUCTION

In water distribution systems (WDSs), network physical and system operation and environmental factors cause malfunctions at various rates. While some of these leaks reach the surface, a significant portion of them do not come to the surface depending on factors such as the location of the fault, crack diameter, system pressure and soil thickness

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on the pipe. Active leakage control methods should be applied to prevent and reduce these leaks. Depending on the application of active leakage control, it is possible to control leaks and improve system performance. In order to monitor the performance of the system in terms of leakage management in WDSs, many indicators based on the percentage of system input volume, network length and number of service connections are used [1-8]. However, the only indicator used in analyzing leaks, evaluating system performance and comparing systems with each other is the infrastructure leakage index (ILI) indicator [1, 9, 10, 11]. ILI is known to make a significant contribution the monitoring the effects of methods (improving pipe material, failure repair speed and quality, reducing leaks) [12]. ILI is a performance indicator that shows the control level of leaks in a system where active and passive leak control methods are applied at the current working pressure [13]. Especially in systems where non-revenue water (NRW) rates are relatively low, it provides significant benefits in determining which of the active leakage methods give more effective results [14].

Lambert et al [1] examined the performance indicators used within the scope of water loss management (WLM) and emphasized that the ILI indicator makes a significant contribution to monitor the effects of active leakage control methods (improving the pipe material, fault repair speed and quality, minimizing night flow and leakage). McKenzie and Seago [12] conducted a literature review and analyzed the indicators and calculation tools used in WLM. In the studies conducted in the last 10 years, it has been stated that the bursts and background estimates (BABE) and fixed and varied area discharge (FAVAD) equations proposed by IWA are accepted in leakage analysis and management [1, 4, 9, 10, 11, 14, 15]. In addition, it was stated that the ILI indicator made significant contributions to the comparison of the performance of the systems with each other.

Neamtu [16] used the water balance method to determine and analyze water loss rates in distribution systems. It was emphasized that by monitoring leakage performance in WLM, it would be possible to reduce leaks, decrease costs, and increase service quality. Ociepa et al. [16] stated that one of the most important problems in WDSs is the high level of failure rates and the resulting increase in leaks. For this reason, it was stated that the distribution system should be analyzed in detail, the most appropriate prevention and monitoring methods should be used, and system performance should be monitored with ILI and annual unavoidable physical loss volume (UARL) indicators in order to reduce the failure rate and leakages. Ociepa et al. [15] aimed to evaluated water loss rates in pilot 3 WDSs and analyze water loss rates. For this purpose, different performance indicators for WDSs have been calculated and monitored. In the study, it was reported that the implementation of active leakage control, determination of the leak location with minimum night flow analysis made significant contributions to leakage management. Lenzi et al. [18] used the ILI indicator to evaluate the performance of WDSs in leakage management. In the study, it was emphasized that this indicator is very sensitive to pressure. Durmuşçelebi et al. [19] expressed that the dividing the system into smaller and measurable sub-regions (District Metered Area, DMA), separate evaluation of flow rate, number of customers, consumptions, water thief and leakages in each system will provide an important advantage order to provide a more effective strategy in water loss management and to manage the system better.

The purpose of this study is to use the ILI indicator in analyzing system performance in different network properties in leakage management and discuss the role, effect and benefits of this indicator in leakage management. For this purpose, leakage analysis was performed for the pilot regions based on the ILI indicator and the change and behavior of the indicator according to the system parameters were analyzed.

MATERIALS AND METHOD

The leakage volume and level vary depending on the characteristics of the distribution system and operating conditions. The increase or decrease of this ratio depends on the application of the most appropriate reduction methods, the analysis of the components and the effective factors. It is stated that the four main components that are pressure management, active leakage control, repair quality and speed and pipe material management methods, given in Figure 1 in leakage management are effective on the leakage volume [1, 2, 9, 20]. The annual current real loss volume (CARL) proposed for component analysis and indicated by the large rectangle in the Figure 1 represents the total volume of physical loss in a WDS and decreases or increases depending on the application of prevention methods. On the other hand UARL, which represents the technically lowest leakage level in a distribution system and the inevitable leakage rate that can be observed even

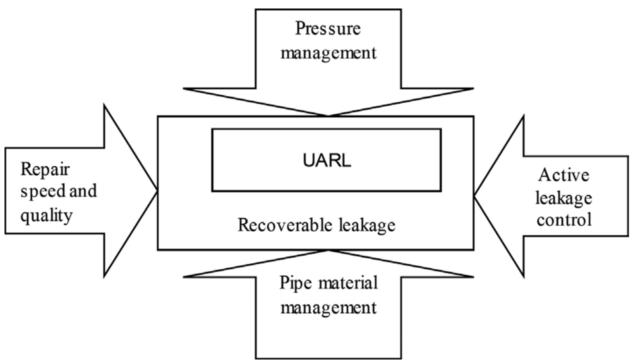

Figure 1. Basic methods for managing the leakages [1, 20].

Table 1. Components taken into account in developing the UARL equation [1]

Components	Background leakages	Reported Leakages	Unreported Leakages
Main	20 liters/km/h	0.124 failure / km / year 12 m3/h / failure* Failure duration: 3 days = 864 m3/failure	0.006 failure / km / year 6 m3/h / failure* Failure duration: 50 days =7200 m3/ failure
Service connections (main to parcel boundary)	1.25 liters/conn./h	2.25 failure/1000 conn./ year 1.6 m3/h / failure* Failure duration: 8 days = 307 m3/failure	0.75 failure/1000 conn./ year 1.6 m3/h/ failure * Failure duration: 100 days =3840 m3/ failure
Service connections on private property	0.5 liters /conn./h (for 15 m length)	1.5 failure/1000 conn./ year 1.6 m3/h / failure* Failure duration: 9 days = 346 m3/failure	0.5 failure/1000 conn./ year 1.6 m3/h / failure* Failure duration: 101 days =3878 m3/failure

in a well-managed system, has been proposed [1, 18]. Even in a new network, UARL consists of workmanship errors (especially at connection points) during manufacturing and hairline cracks that occur during the transportation of the pipe material [1, 9, 10]. In a WDS, UARL includes uncertain, reported and unreported leaks occurring at the mains, service connections (main pipe to parcel boundary) and service connections on private property (between parcel boundary and building) [1, 20]. When developing the UARL equation, for each fault component, the number of failures, response time, and the unit leakage flow rate (under 50 m pressure) at a failure were taken into account [1, 4, 20,] (Table 1).

Using the values of the components given in Table 1, the UARL (liter/day) occurring in a WDS depending on the network characteristics and pressure is calculated with equation (1) [1].

$$UARL = (18\,xLm + 0.8x\,Nc + 25xLp) \times P \qquad (1)$$

Here, P; average pressure (m), Lm; network main line length (km), Nc; number of service connections and Lp; is the total pipe length (km) on the private property. In this equation, pressure refers to the average operating pressure in the system. For this, measurements should be made regularly by pressure gauges in the isolated area. The average pressure representing the region is obtained by taking the average of these pressures measured regularly in the isolated area. In this study, the pressure obtained regularly by pressure gauges in regions was used.

The number of failures in the table shows the technically lowest level in a well-managed distribution system. On the other hand, based on field studies, intervention times and flow rates were determined for reported and not reported failures in network and service connections. This equation can be expressed as follows; under unit pressure, (i) leakage at unit network length 18 liters / main length (km) / day / pressure (m), (ii) leakage per connection (up to parcel boundary) 0.8 liter / number of service connections / day / pressure (m), (iii) the leakage occurring at the unit service connection length (between parcel boundary and customer water meter) in private property is 25 liters / conn. length (km) / day / pressure (m).

The ILI is calculated as the ratio of the CARL to the UARL value, as given in equation (2) [1]. This indicator is especially used to monitor system performance in the process and to analyze the change in leakage level depending on the application of basic components.

$$ILI = \frac{CARL}{UARL} \qquad (2)$$

The ILI indicator shows how much CARL currently occurs in a system compared to UARL, which indicates the lowest technically occurring leak in the system. That is, the value taken by the ILI indicator expresses how many times the UARL is leaking in the system. The ILI indicator is not only used for comparing systems or monitoring performance changes in the system, but also the class in which the system is located is determined according to the limit values recommended in IWA and literature [1, 4, 20]. According to this class, the processes that should be applied to improve the system are proposed (Table 2). As can be seen from the evaluation table, the ILI indicator classifies it in two different ways as "developing countries" and "developed countries". While calculating the ILI indicator, since the UARL is taken into account in a system and CARL is proportioned to the UARL, ILI takes the lowest value of 1. According to the ILI values, leakage amounts per service connection at different pressure levels in the class in which the system is located are determined.

Table 2. Physical Loss Target Matrix [10, 20]

Technical performance category		ILI	Real Losses in liters/connection/day (at average pressure)				
			10 m	20 m	30 m	40 m	50 m
Developed Countries	A	1-2		<50	<75	<100	<125
	B	2-4		50–100	75–150	100–200	125–250
	C	4-8		100–200	150–300	200–400	250–500
	D	>8		>200	>300	>400	>500
Developing Countries	A	1–4	<50	<100	<150	<200	<250
	B	4–8	50–100	100–200	150–300	200–400	250–500
	C	8–16	100–200	200–400	300–600	400–800	500–1000
	D	>16	>200	>400	>600	>800	>1000

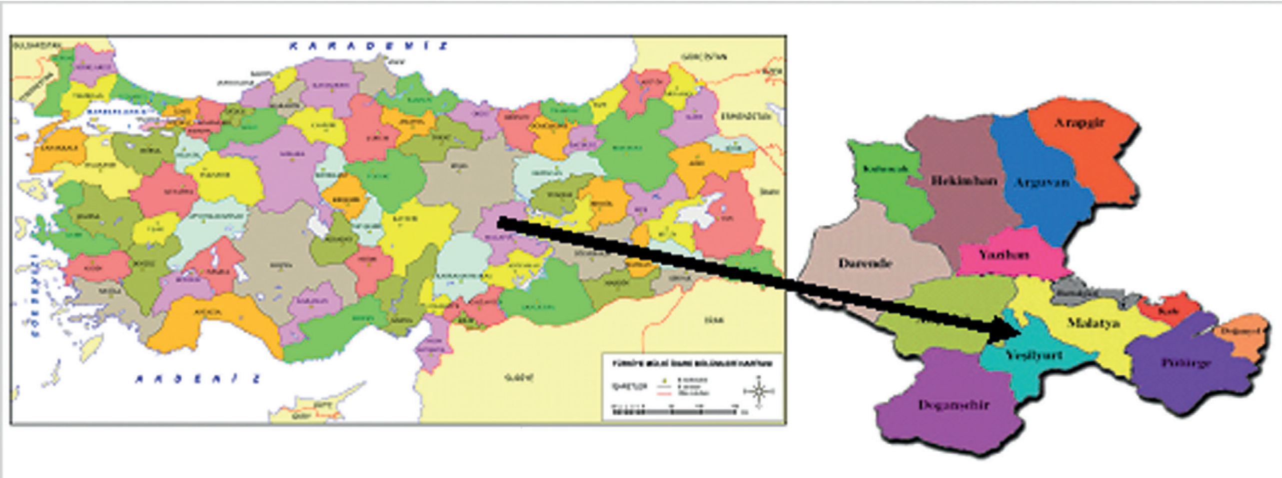

Figure 2. Study Area.

STUDY AREA

In order to use the ILI indicator in leakage management, 10 isolated measurement zones (DMA) in the central WDS of Malatya were determined as pilot areas (Figure 2, Table 3). DMA design and applications were carried out by the Water Utility (MASKI) in the application area between years 2016-2018 to ensure sustainable WLM. The pipes in the WDS currently serving in the application area were laid at different times and DMA was planned in areas where the failure rate is generally high. Within the scope of this study, leakage rates are at high levels in the selected pilot areas, and reduction and prevention activities have been carried out by the administration by applying an active leakage control strategy. As a result of these efforts the NRW rate, which was 65-70% in 2015, was reduced to 45-50% in 2018 [21].

ANALYSIS AND DISCUSSION

In this study, an application was carried out for 10 pilot regions in the application area (Table 3) in order to use the ILI indicator in leakage management, to discuss its advantages and the problems encountered in the calculation of this indicator. The main components of water balance that are system input volume, billed authorized consumption, unbilled authorized consumption, apparent and real losses, total water losses and non-revenue water volume, in pilot regions are given Table 3. The system input volume for each region are regularly measured and saved by using flow meters located at entrance of the regions. The billed authorized consumptions is obtained from the customer management system. The NRW volume is calculated by subtracting the billed authorized consumptions from the system input volume. The unbilled authorized consumption (use of mosques and parks) in isolated areas is monitored with water meters. The unbilled unmetered consumptions are taken as zero because there are no unmetered unbilled usage in the regions. The inaccuracies in customer water meters should be determined to calculate the losses due to meter errors. For this purpose, randomly selected samples from authorized customer's meters in study area were tested in the laboratory. Losses due to meter errors were calculated by multiplying these inaccuracy rates with the billed authorized consumption in the region.

The most important problem in the determination of this indicator is to calculate the UARL parameter. In the following sections, the problems encountered in ILI and UARL analyzes are discussed in detail. In order to calculate the ILI indicator correctly, the values of UARL and CARL parameters should be obtained in the same measurement period and in the same unit. Monthly water budget data were taken into account for these analyzes. In the table, besides comparing the regions according to the ILI indicator, the CARL and UARL parameters were calculated according to the service connection and main length and the results obtained were discussed. As can be seen from the equation, UARL is very sensitive to pressure and increases depending on the increase in pressure. When the basic components given in Figure 1 are analyzed, the UARL value decreases or increases depending on the application of pressure management. In addition, considering the FAVAD equation proposed by May [18] to express the relationship between total CARL and pressure, the value of CARL also decreases due to the pressure reduction. If pressure management is applied in these regions, there will be different rates of decrease in leakages depending on the pipe type of the network. As given in the FAVAD equation, the leakage volume decreases due to the decrease in pressure and the coefficient N1 (according to the pipe material in the area). This will also occur in pressure management studies applied or planned to be applied in these regions.

Since the ILI indicator is the ratio of these two parameters, the change in pressure has a similar effect on both parameters, and the change in the ILI value may not be observed in pressure management. If only the ILI parameter is used as a performance indicator in leakage management in the isolated area where pressure management is applied, the accuracy of the method and the performance of the system will not be interpreted correctly. For this reason, alternative performance indicators (eg leakage volume per unit line length or per unit service connection) should be used in the regions where pressure management is applied. However, the speed and quality of fault repair or the implementation of active leakage control does not have an effect on UARL, but has an effect on the decrease of the CARL value. In particular, an improvement in the ILI indicator in the system is expected due to the continuous application of the other three basic components other than pressure management. According to these evaluations, the following interpretations can be made; because the application of pressure management has the effect of decreasing the UARL and CARL values, a decrease in the ILI value may not always be observed due to pressure management [4, 19, 20]. For this reason, it is very important not to use the ILI indicator alone or to interpret the results well, especially in pressure management systems.

According to the results given in Table 3, when ILI indicators are compared, it can be said that the performance of only a few regions is good, where the values calculated for the regions are generally quite high. Especially in regions where network physical conditions are good, A (DMA 6 and 8) and B (DMA 4 and 10) classes were obtained. Here, class A is interpreted as follows; the area is at a very good level in terms of leakage and network components management, and it may not be economical to carry out prevention activities by investing more. Therefore, the preservation of the current situation can be taken as a basis only by applying a monitoring policy [1, 4]. On the other hand, in case of class B, the following recommendations are made for the Utilities: the system is in good condition in terms of leakage management. The further methods for reduction of leakages should be applied based on economic analysis [1, 4]. Moreover, according to the results given in the table, Class D, which includes many regions, is interpreted as follows; the system is in a very bad situation in terms of the management of leaks and components, the requirements should be determined by making current situation analysis and the basic methods should be applied as soon as possible [1,4]. Finally, the following evaluation can be made for systems in Class C; the system is undistinguished in managing leaks and components. If there is no water supply problem in the system or energy is not consumed in the supply of the water source, the current situation can be managed for a certain period of time. However, a prevention strategy should be put forward in terms of long-term sustainable water management. In this way, processes are recommended for decision makers and technical personnel according to the class in which the system is located.

As can be seen, the ILI indicator can be considered as a tool that takes into account the physical components of the system, generates information that will set a reference in terms of leakage management and provides a roadmap according to the results, rather than just a dimensionless evaluation criterion. In the table 3, the UARL and CARL parameters are also calculated in different units as “loss per service connection” and “loss per main length (km)”. These calculated values provide the opportunity to evaluate how much the current leakage (CARL) in the system is above the technically lowest leakage level (UARL). For example, if the values calculated in units of (l / day) for these two parameters are interpreted for DMA 1 and DMA 2, it can be said that the CARL value is approximately 4 and 6 times higher than the UARL value, respectively. In other words, it is seen that the current leakage in the system for DMA 1 is technically 4 times higher than the lowest leakage level and preventive methods should be applied to reduce this rate and reduce leaks.

On the other hand, these two parameters are calculated according to network physical properties (liters / conn. / day and liters / main length / day). The indicators calculated according to these two units are used and interpreted

Table 3. Attributes and ILI values for pilot DMAs

Parameters	Unit	DMA1	DMA2	DMA3	DMA4	DMA5	DMA6	DMA7	DMA8	DMA9	DMA10
Number of customers	No.	3391	3384	1046	2337	1208	2717	4208	1514	2895	7032
Main length	km	5,8	6,2	4,78	11,01	3,16	3,68	15,62	13,12	6,9	13,48
Number of service connections	No.	500	522	315	517	300	384	526	689	427	1386
service connections on private property	km	3.9	4.2	2.52	2.14	2.4	3.07	4.21	5.51	3.41	9.76
Pressure	m	38	41	45	55	52	45	51	50	60	55
Water supply duration	h	24	24	24	24	24	24	24	24	24	24
Total input volume	m3/month	79762	128720	33531	39908	26540	32984	35050	25225	46220	109340
Billed metered consumption	m3/month	39439	63890	11446	29123	16700	28911	9900	18022	34080	84144
Unbilled metered consumption	m3/month	1500	1900	500	600	400	500	600	380	690	1650
Apparent Losses (due to water meters)	m3/month	4000	5600	1450	1740	1160	1400	1400	1100	2020	4300
CARL (leakage volume per month)	m3/month	34823	57330	20135	8445	8280	2173	23150	5723	9430	19246
Water losses	m3/month	38823	62930	21585	10185	9440	3573	24550	6823	11450	23546
Non-revenue water volume	m3/month	40323	64830	22085	10785	9840	4073	25150	7203	12140	25196
CARL (leakage per connection)	liters/conn./day	2322	3661	2131	544	920	189	1467	277	736	463
NRW rate	%	**51**	**50**	**66**	**27**	**37**	**12**	**72**	**29**	**26**	**23**
CARL rate	%	**44**	**45**	**60**	**21**	**31**	**7**	**66**	**23**	**20**	**18**
CARL (per day)	liters/day	1123323	1849355	649516	272419	267097	70097	746774	184613	304194	620839
UARL (per day)	liters/day	22872	26002	18047	36590	18558	20259	41168	46256	33063	87749
CARL (per connection)		191	301	175	45	76	16	121	23	61	38
UARL (per connection)	liters/conn./day	46	50	57	71	62	53	78	67	77	63
CARL (per main length)		193676	298283	135882	24743	84524	19048	47809	14071	44086	46056
UARL (per main length)	liters/km/day	3943	4194	3775	3323	5873	5505	2636	3526	4792	6510
ILI	-	49	71	36	7	14	3	18	4	9	7
ILI class		**D**	**D**	**D**	**B**	**C**	**A**	**D**	**A**	**C**	**B**

as follows; in a system, the values obtained after the current leakage amounts are calculated according to these two units are taken as a reference and the change in the process is monitored by applying active leakage control. In other words, after the leakage amount per unit line length is calculated at the beginning of the study, it is recalculated after the prevention methods are applied and the performance change in the process is analyzed and the gains obtained are determined. In the literature, it is recommended to calculate the service connection density (number of service connections / network length) rather than using these two units at the same time. It is recommended to use the indicator (liters / main length / day) in case of service connection density (<20 / km), otherwise (liters / conn. / day) indicator [1, 4] .

The ILI and UARL indicators take into account the physical characteristics of the network (main length, number of service connections, and service connection length in private property) and the most basic operating data, the pressure parameter. Thus, it can be said that these indicators, calculated using the most basic data representing the system, have a significant advantage in analyzing leaks, monitoring changes in the process, and most importantly, producing results that will represent the field. In addition, the fact that the ILI indicator is the only indicator used to compare different systems with each other can be shown as another important advantage. The problem of a network monitored with only NRW performance indicator is that its performance appears to have increased as a result of the decrease in system input flow rate due to consumption, although there is no loss reduction study. As a result, the ILI and UARL indicators in leakage management produce important information for decision makers and technical personnel, and it is thought that they make important contributions to the analysis and comparison of system performance and the development of improvement strategy.

Problems and Recommendations in ILI and UARL Calculation

Two basic parameters, CARL and UARL, are used in the calculation of the ILI indicator. In this section, the problems encountered in calculating and using the ILI indicator within the framework of these two parameters are discussed. The CARL parameter represents the amount of leakage in a system and needs to be determined based on water balance or component analysis. The problems encountered in determining the CARL parameter are basically given;(i) the need for data measured in too many fields for CARL calculation, (ii) if the water balance is filled according to the top-down approach, the calculations made before the CARL calculation (apparent loss, unbilled unmetered components, etc.) are not made according to field data or based on forecast data, (iii) In case the CARL parameter is determined according to component analysis or bottom-up approach, a large number of data is needed and in many cases it is difficult to obtain these data, and technical and equipment infrastructure is required for these methods. Here, in the precise determination of the CARL parameter, a combination of component analysis, bottom-up methods and calibration can be followed by comparison with the top-down method. Thus, CARL is determined with approaches that represent the field and whose data has been verified. On the other hand, the main problems in the UARL calculation can be given as; (i) the decision-makers or technical personnel lack confidence or awareness of the results of this empirical equation, (ii) lack of background required to measure the components in the UARL equation in the field and transfer them to the geographical information systems (GIS) database, (iii) difficulty of determining service connection length on private property, (iv) failure to measure pressure, one of the most important parameters in the equation, or difficulties in measuring the mean pressure representing the zone and lack of information. The most important point here is to accurately determine the point where the pressure is measured and calculate the average pressure according to this point. In this study, pressure refers to the average operating pressure in the system. For this, measurements should be made regularly by pressure gauges in the isolated area. The average pressure representing the region is obtained by taking the average of these pressures measured regularly in the isolated area. In this study, the pressure obtained regularly by pressure gauges in regions was used. For the UARL equation, it is recommended to take the pressure measured at the average zone point. In order to obtain and monitor these data continuously and accurately, the GIS database should be updated regularly and the hydraulic data should be monitored with the Supervisory control and data acquisition (SCADA) system. It should not be forgotten that the establishment and operation of these systems require technical, technological, personnel and economic requirements.

CONCLUSIONS

In this study, it was aimed to use the ILI indicator in analyzing system performance in different network properties in leakage management, and the role, effect and benefits of this indicator in leakage management are discussed. For this purpose, leakage analysis was performed for the pilot regions, the ILI indicator was calculated, and the change and behavior of the indicator according to the system parameters were analyzed. When ILI indicators are compared, it can be said that the performance of only a few regions is good, where the values calculated for the regions are generally quite high. As a result of the calculations, it was seen that only 2 regions (DMA6 - DMA8) were in the best class (A) for developing countries according to the ILI indicator. Especially in regions where network physical conditions are good, A (DMA 6 and 8) and B (DMA 4 and 10) classes were obtained. The ILI indicator can be considered as a tool that takes into account the physical components of the system, generates information that will set a reference in terms of leakage management and provides a roadmap according to the results, rather than just a dimensionless evaluation criterion. The most important problem in the calculation of this indicator can be shown to perform the CARL and UARL calculations. In the precise determination of the CARL parameter, a combination of component analysis, bottom-up methods and calibration can be followed by comparison with the top-down method. Thus, CARL is determined with approaches that represent the field and whose data has been verified. The most important point here is to accurately determine the point where the pressure is measured and calculate the average pressure according to this point. For the UARL equation, it is recommended to take the pressure measured at the zone midpoint (AZP) of the pressure. In order to obtain and monitor these data continuously and accurately, the GIS database should be updated regularly and the hydraulic data should be monitored with the SCADA system. It should not be forgotten that the establishment and operation of these systems require technical, technological, personnel and economic requirements. As a result, the ILI and UARL indicators in leakage management produce important information for decision makers and technical personnel, and it is thought that they make important contributions to the analysis and comparison of system performance and the development of improvement strategy.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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