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Research Article

Analysis of network useful life and cost-benefits for sustainable water management

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ABSTRACT

Main lines and service connections in distribution systems are damaged due to various factors. The leakage volume, operating and repair costs increase depending on the density of damage. The cost-benefit and economic life analysis should be done for network renewal in distribution systems. In this study, a useful life analysis model was developed for pipes serving in distribution systems. The total number of failures in water distribution systems, failure repair costs, pipe diameter and material and leakage rates in the existing system and network characteristics are considered. The developed model was applied in 9 isolated regions with different properties in the application area. The useful lives have varied depending on the characteristics of the regions. The number of failures and the amount of water losses, as well as the length of the network and the type of new pipe play serious role in useful life analysis. Especially, it was observed that the type of pipe material to be used in network renewal has an effect on the useful life. It is thought that this study will constitute a reference for technical personnel, especially in deciding to renew the network.

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INTRODUCTION

Water distribution systems (WDSs) are the most important infrastructure systems. In such systems, it becomes difficult to manage the system due to reasons such as the age of the network and the lack of sufficient information about the pipes and their components. Another challenge is the high level of failures and real losses in WDSs. The most basic approaches applied to reduce and manage losses are generally the active leakage control (ALC) includes district metered area (DMA) design, minimum night flow (MNF) analysis and leak localization in field), pressure management (covers to control pressure fluctuation and high pressure in the system), leak repair speed and quality (reducing intervention time and improving fault repair quality) and pipe material management [1,2]. The network renewal is the most costly method. Therefore, it is necessary to protect the current network conditions by applying less costly methods and monitoring the system in order to reduce the initial investment cost and use resources more efficiently

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[3–8]. Francisque et al. [9] presented a user-friendly decision support tool based on life cycle cost analysis for decision makers in water utilities to decide and prioritize network monitoring strategies. The current failure rates, system operation, maintenance and repair costs should be analyzed and monitored in a distribution system where current network conditions are maintained. In addition, costs of the new water sources and energy, the initial investment and long-term operating costs that arise in case of network renewal should be considered in the related system. In such cases, the following questions should be sought: local replacement in case of piping failure? Or network renewal? [10-13]. Renewal of main lines or service connections in distribution systems creates high investment costs. These costs are generally pipe material, labor, excavation and filling costs.

On the other hand, high failure rates in old systems cause high failure maintenance-repair and operating costs. For this reason, in order to create a sustainable and efficient operation plan in WDSs, the system should be analyzed economically, benefit/cost analysis should be made for the applied methods, and the most appropriate replacement period should be determined by analyzing the economic life of the pipes. The failures in WDSs due to network age and environmental factors increase system operation and maintenance costs, decrease service quality and adversely affect water quality. It is necessary to evaluate the rehabilitation alternatives and determine the most appropriate strategy, considering the structural conditions, hydraulic capacity and time-related deterioration of the existing network due to the high renewal costs of the distribution network [14].

On the other hand, it is possible to transfer the network components to the geographical information system (GIS) database and monitor them, reducing the risk of failure leakage rate and operating cost with the renewal of the network [7,15]. The useful life of the network should be analyzed before the renewal activity. For this purpose, the point where the repair will be costlier than the replacement has been determined by calculating the economic life of the pipes in the WDSs [16]. The failure rate was analyzed to determine the leakage rate of the network in WDSs and defined a curve representing the relationship between pipe age and leakage amount [17]. defined reference costs for WDSs with different hydraulic and physical properties (flow rate, pump head and power, material, pressure and diameter) were defined and a strategy that allows cost-benefit analysis for the networks planned to be changed was presented [18]. Zangenehmadar et al. [19] developed a model based on the Levenberg - Marquardt algorithm that predicts the remaining useful life and deterioration rates of pipes in WDSs.

Pipeline deterioration in WDSs has an impact on water quality, hydraulic capacity and service quality. Planning the maintenance program of the pipes is quite important in terms of the minimizing health problems, providing better service, reducing operating costs and increasing efficiency. In addition, current status and performance should be analyzed and monitored for deciding on network maintenance, rehabilitation or pipe replacement programs and improving economy and technical efficiency [20]. A new failure rate prediction model was developed to provide the basic information needed for optimum ongoing maintenance/rehabilitation of a network with the extreme learning machine algorithm. The developed model has made significant gains in planning and budgeting for water network inspection, maintenance and rehabilitation [21]. A multi-criteria assessment model was proposed for risk assessment in WDSs, establishment of a network rehabilitation program, and analysis and evaluation within the scope of asset management [22].

Durmuşçelebi et al. [23] emphasized that economic analysis should be done in order to decide on the method to be applied and the path to be followed in the managing the water losses. In the study, economic analyzes were carried out for reducing water losses in WDSs, leakage management activities and network rehabilitation. It was seen that the average return period of network rehabilitation was between 13 and 17 years due to the high initial investment cost in the pilot regions. It was considered that the cost-benefit analyzes in detecting, reducing, preventing and controlling water losses in WDS is quite important. Pagano et al. [24] stated that the planning of rehabilitation and replacement activities in WDSs contains high complexity and has inherent uncertainties. Analytical Hierarchy Process (AHP) was used to create a decision support system and to select the regions to be rehabilitated by considering the variables including social effects. Regad et al. [25] analyzed the damages of polyethylene pipes used in WDSs by considering the factors such as pressure and corrosion and discussed the benefits to be obtained in rehabilitation situations. It was concluded that financial and physical analyzes should be made primarily to decide the alternatives of rehabilitation or repair of the network pipe. Salehi et al. [26] proposed a hybrid knowledge based method for planning the network mains in WDSs by considering the opinions of the expert planners. Nugroho et al. [27] applied a various statistical and mathematical methods to determine the most appropriate parameters for prediction of pipe failures in WDSs. Authors stated that life cycle cost analysis could significantly reduce long-term expenditures while improving the resilience and sustainability of the infrastructure. Ramos-Salgado et al. [28] developed a comprehensive framework for planning the short and long-term investments in WDSs based on five step asset management process.

As can be seen from the studies in the literature, the useful life concept for networks has been focused in general. This concept becomes quite important in cases where it is not economically manageable to control leaks through network repair, maintenance activities, pressure management or other basic methods. In other words, it can be considered as having completed its useful life for the network in cases where the cost spent for a unit pipe to operate the network is greater than the cost spent to replace the pipe. Local replacement or network renewal in case of failure of pipes? The answer to the questions will be more useful after determining this useful life. It is necessary to know the characteristics of the network, analyzing the operating conditions in the current conditions and defining the economic life of the pipes in order to answer to these questions.

Therefore, in this study, a cost-benefit analysis was carried out for the network rehabilitation method in order to define a sustainable operation plan in WDSs and to improve system efficiency. In addition, it is aimed to determine the economic life of the pipes currently in service by using the network characteristics (pipe diameter and material distribution), failure rates, pipe material and diameter properties to be used in case of new construction, and costs. Unlike previous studies, in this study, the initial investment cost and the costs of repairing the annual failures are considered depending on the length of the network and the type of pipe to be preferred in case of renewal of the network. In addition, the remaining useful lives are calculated by taking into account the inflation parameter. There is no other study that evaluates all these elements listed in water distribution systems together. The most important advantage of this study is that it is based on network characteristics and cost benefit analysis. For this, the methodology has been developed by considering the real field data. The developed methodology was tested using field data. Thus, it will be a reference for decision makers and technical personnel to make the most appropriate choice between network renewal and fault repair options. The useful life analysis is especially important for the establishment of annual network renewal plans, protective maintenance programs and operation plans in distribution systems. It also contributes to the budget planning for network renewal in the administration and the implementation of short-medium-long-term investment programs.

MATERIALS AND METHODS

In distribution systems, the network renewal method, which includes the replacement of pipes and fittings in the network, in many cases is costlier than other methods. However, failure rates with current network conditions and costs of the system operation, network maintenance, failure repair, and energy should be considered. In addition, the initial investment and mid-term and long-term operating costs in the case of network renewal should be also considered. Local repair or network renewal options should be compared based on a detailed cost-benefit analysis. For this, it is necessary to prefer alternative methods that are suitable for the network conditions and applicable to the system, to be applied in the field, and to reduce the impact of environmental and operational factors that cause leakage. In case the benefits cannot be obtained from these methods, determining the priority regions in network renewal will provide significant contributions in terms of resource efficiency [3,5–9, 29].

As can be seen from the studies in the literature, the useful life concept for networks has been focused in general. This concept becomes quite important in cases where it is not economically manageable to control leaks through network repair, maintenance activities, pressure management or other basic methods. In other words, in cases where the cost spent for a unit pipe to operate the network is greater than the cost spent to replace the pipe, it can be considered as having completed its useful life for the network. In the economic leakage level calculation, the useful life of the mains should be analyzed and the water loss reduction methods to be followed should be selected according to the system current conditions. In this context, the costs of rehabilitation, failure repair and leakage components are defined by considering the system fundamental data. The useful life recommended by [3] were determined in the MATLAB program [30]. In this study, the economic leakage level model proposed by Firat et al [30] for network rehabilitation cost-benefit analysis using Matlab program was considered. Mathematical structure of proposed model and Matlab codes can be obtained in Firat et al. [30].

$$failure\ repair\ costs\ (C_n) = \ Total\ failures\ per\ year * Repair\ cost \tag{4}$$

$$Loses\ total\ costs\ (F_n) = Nonrevenue\ water * \ Water\ production\ price \tag{5}$$

$$\sum Rehabilitation\ costs\ (R) = main\ length * \ pipe\ rate_n * pipe\ costs_n \tag{6}$$

$$Brk_n = \ ln(1+R)/ln(\frac{C_{n+1}}{F_n} + \frac{F_{n+1}}{F_n}) \tag{7}$$

$$BRK_n > BRK_{n+1}\ and\ BRK_n > BRK_{n-1} \tag{8}$$

Total failures are the total of the reported and unreported failure data in a DMA. Repair cost is the unit cost of the failure, failure repair cost is the cost of annual repairs. The unit of nonrevenue water is the cubic meter per year (m3/year), unit of water production price is the Turkish Lira per cubic meter (Lira/m3). Main length is the length of main pipes, the pipe rate is the ratio pipe with different diameter ranges [30]. The pipe costs are calculated for each pipe diameter and type by considering the system data [30]. A flowchart for useful life analysis was given in Figure 1.

The total rehabilitation cost of the network should be firstly calculated. For this, unit investment costs should be analyzed for each pipe diameter and type. Then, costs of the failures and water losses and rehabilitation should be calculated separately by considering the interest rates for each year in equation (7). The point where the calculations provided equation (8) denotes the useful life of the mains

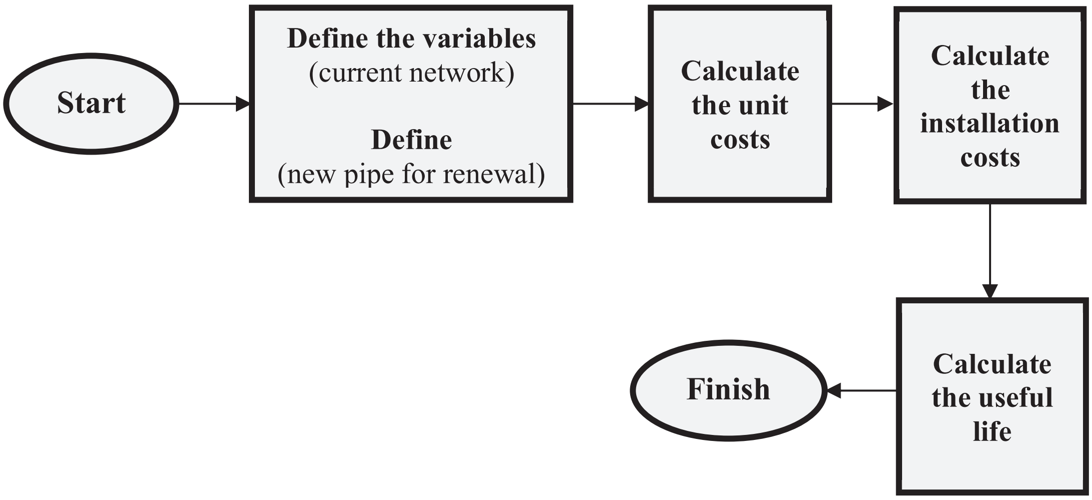

Figure 1. The flowchart for useful life analysis

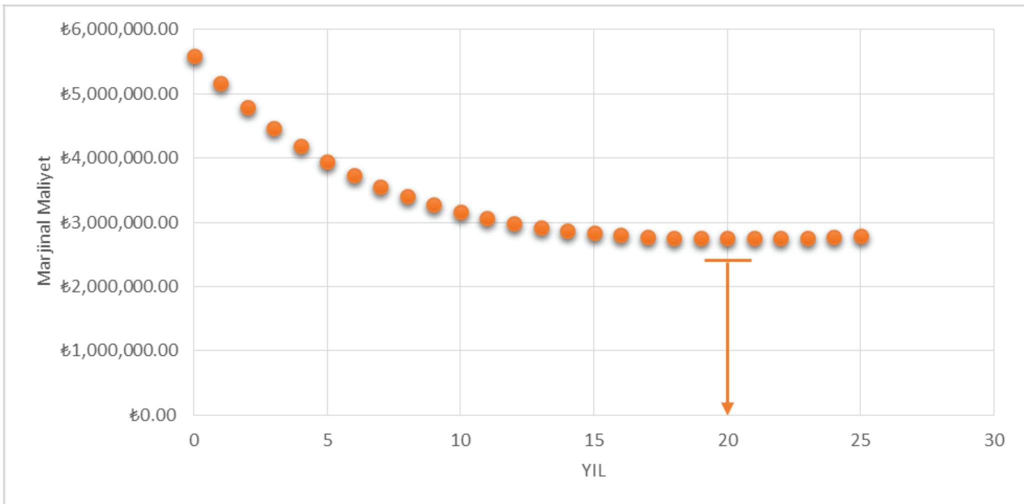

Figure 2. Calculation of Useful Life for Networks.

simultaneously. If the results do not fulfill the requirements indicated in equation (8) at any point, it is concluded that the system should be rehabilitated immediately [3, 30]. In other words, the point where the minimum point of the graph intersects the year is the remaining useful life (Figure 2).

Thus, the useful life of the mains is defined by using the current network situation, rehabilitation conditions and annual interest rates. If this peak point does not occur at all, if $BRK_n > BRK_{n+1}$ *ve* $BRK_n > BRK_{n-1}$ conditions are not provided at all, it means that the water distribution system has completed its economic life. In this case, the existing network should be rehabilitated at once. In this study, costs arising from pipe diameter and material type were determined according to field data, and a calculation tool was developed for systematic analysis (Table 1) [30]. In order to calculate this cost, the type of pipe that the users plan to use during rehabilitation, the average pipe diameters of the existing network should be defined in the developed calculation tool.

The total cost of network rehabilitation (F), the total cost of repair of faults (C1) and the total cost of losses due to leaks (C2) should be firstly calculated in order to perform the economic life analysis. In this context, parameters of the network main length, unit water production cost, annual numbers of the main and service connection failure, current annual real loss amount (CARL) and inflation rate should be determined.

In the analysis, the repair costs (TL/unit) for the mains line and service connection failures should be firstly calculated. For this reason, the costs defined with field data in this study are given in Table 1. Accordingly, the repair cost for one main fault at the work site was calculated as 1,850.00 TL/unit, and the repair cost for the service connection failure was calculated as 1,350.00 TL/unit. In a network where the number of failures is known, the C1 cost is calculated by multiplying these costs. The other basic cost to be calculated in the analysis is the total amount of loss due to leaks. In order to calculate this component, firstly the annual water loss amount (m3) should be calculated and the C2 cost is calculated by multiplying the unit water production amount (TL/m^3).

The most important cost component in economic life analysis is the total network replacement cost (F). The network total line length and pipe diameter distributions should be known for the calculation of this component. In addition, the new pipe material type to be used in case the network is renewed, is one of the important factors affecting the cost. Utilities choose one of the PVC, Ductile, HDPE or Steel pipes for the network renewal. The pipe costs, labor costs, excavation-filling costs and all other costs are defined for each pipe diameter and type (Table 1) in the calculation tool developed in this study. The costs are determined for different pipe diameter ranges and pipe materials. The total cost can be calculated according to the network characteristics and these costs.

Study Area

Malatya distribution system was chosen as the study area in order to calculate the remaining useful life of the network based on field data. Malatya, located in the eastern region of Turkey, has a network length of approximately 2,000 km and the 350,000 customers (MASKİ, 2020). In the application area, active leakage control activities in DMAs are applied in order manage the leaks. The flows and pressures in DMAs are regularly measured and monitored with SCADA integration. In addition, network information and characteristics are provided on the basis of a geographic

Table 1. Cost components of the economic analysis [30]

Repair Costs	**Unit**	**Value**
Mains Failure Repair Cost	TL/ No.	1,850.00
Customer Mains Failure Repair Cost	TL/ No.	1,350.00
Determining Network Renewal Costs	**Unit**	**Value**
Average Cost of Pipes (diameters of less than Ø 150 mm)		
Polyvinyl Chloride (PVC)	TL/m	110
HDPE	TL/m	125
Ductile	TL/m	250
Steel	TL/m	214
Average Cost of Pipes (Between Ø 150 mm - 300 mm diameters)		
PVC	TL/m	345
HDPE	TL/m	360
Ductile	TL/m	460
Steel	TL/m	420
Average Cost of Pipes (Between Ø 300 mm - 500 mm diameters)		
PVC	TL/m	600
HDPE	TL/m	640
Ductile	TL/m	810
Steel	TL/m	760
Average Cost of Pipes (Between Ø 500 mm - 700 mm diameters)		
PVC	TL/m	950
HDPE	TL/m	950
Ductile	TL/m	1200
Steel	TL/m	1100
Average Cost of Pipes (diameters of more than Ø 700 mm)		
PVC	TL/m	1350
HDPE	TL/m	1400
Ductile	TL/m	1750
Steel	TL/m	1600

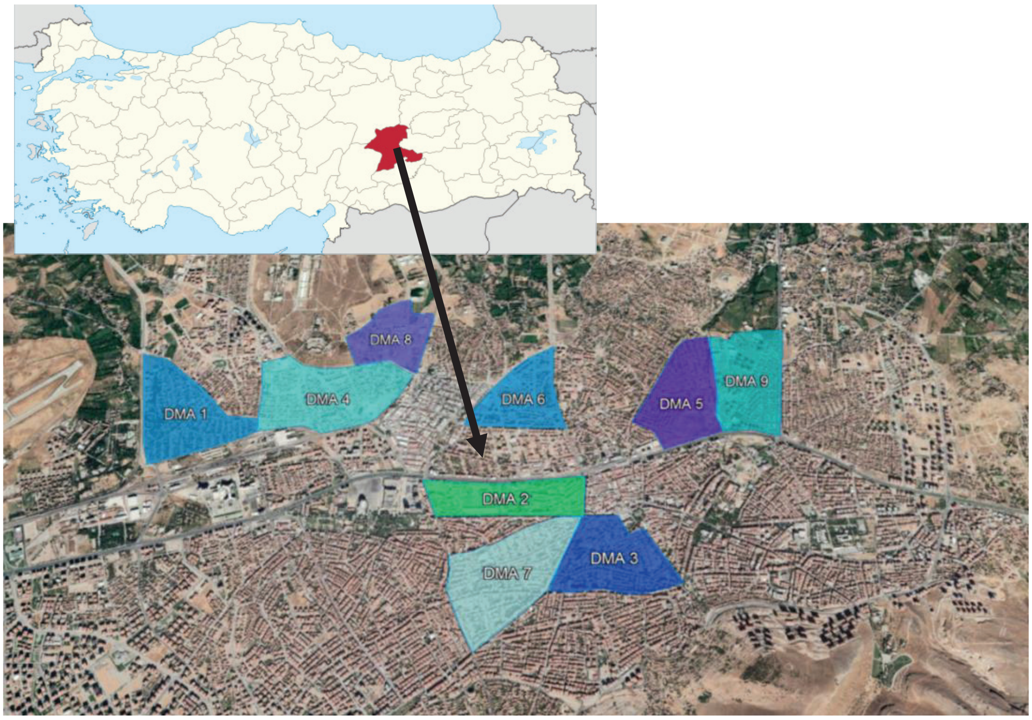

Figure 3. Application area and district metered areas.

Table 2. Useful Life Analysis in DMAs

Parameters	Unit	DMA1	DMA2	DMA3	DMA4	DMA5	DMA6	DMA7	DMA8	DMA9
Input volume (SIV)	m^3/day	1117	2658	1330	1168	3644	884	1540	1099	940
Billed metered consumption (BMC)	m^3/day	682	1314	970	330	2804	556	1136	963	710
Main length(Lm)	m	4780	5800	11010	15620	13480	3160	12800	3680	13200
Number of connections (Nc)	No.	315	500	517	526	1386	300	427	584	689
Water production cost (WPC)	TL/m^3	1.1	2.32	2.32	2.32	2.32	2.32	2.32	4.6	2.32
Number of network failures	No./year	8	19	5	18	7	11	15	5	9
Number of service connection failures	No./year	14	29	9	26	8	9	15	8	13
Inflation rate	%	12.75	12.75	12.75	12.75	12.75	12.75	12.75	12.75	12.75
Non-revenue water	m^3/day	435	1344	360	838	840	328	404	136	230
Non-revenue water rate	%	38.94	50.56	27.07	71.75	23.05	37.10	26.23	12.37	24.47
New Pipe Type	-	Ductile	PVC	HDPE	PVC	Steel	Steel	HDPE	Ductile	HDPE
Useful remaining life	Year	18	SBR*	26	9	29	15	17	18	23
Water Distribution System Data (Pipe Diameters)										
Rate of Pipes Lengths: diameters of less than Ø 150 mm	%	65	80	78	96	94	47	84	90	75
Rate of Pipes Lengths: Between Ø 150 mm - 300 mm diameters	%	35	15	14	4	6	35	14	10	14
Rate of Pipes Lengths: Between Ø 300 mm - 500 mm diameters	%	0	5	8	0	0	18	2	0	11
Rate of Pipes Lengths: Between Ø 500 mm - 700 mm diameters	%	0	0	0	0	0	0	0	0	0
Rate of Pipes Lengths: diameters of more than Ø 700 mm	%	0	0	0	0	0	0	0	0	0

*Should Be Rehabilitated

information system (GIS) database. The MNF analysis is performed in regions and unreported leaks are determined on site. In this context, basic network data and remaining life calculations are given for 9 selected DMA regions (Figure 3, Table 2). While selecting the DMAs for the network useful life calculation in the application area, attention has been paid to the fact that the zones have different characteristics (loss rate, fault density, network characteristics, etc.). Thus, the comparison of the regions with each other and a more accurate evaluation of the analysis were provided.

In study area, the average rate of inlet flow is the 2.70 cubic meters per second. The Malatya water distribution network has 249417 authorized customers (residential customer rate is 90.95%, commercial customer rate is 8.18%, public institution rate is 0.72%), total of 35 water reservoirs with capacity of 120000 cubic meter [30]. The pressure metered areas (pressure zones) are not defined in study area

The NRW rates in the DMAs selected for the analysis range from 12.37% to 71.75% (Table 2). It is seen that the network lengths and the number of service connections are within the acceptable limits recommended in the literature [23, 27]. In general, the failures occurring in the service connections are higher than the main line failures. While the water production cost is the lowest for DMA1, this cost is the highest for DMA8.

RESULTS AND DISCUSSION

In this study, the economic leakage level analysis model developed by Firat et al. [30] for network rehabilitation cost-benefit analysis using MATLAB program was considered. Based on this model, a useful life analysis was made for the networks serving in 9 DMAs (Table 2). Mathematical structure of this model and Matlab codes can be obtained in the article published by Firat et al. [30]. In this context, the costs of the rehabilitation, failure repair and leakage components are analyzed by using the network data [30]. The results obtained for DMA1 in the model developed for useful life analysis are shown in Figure 4.

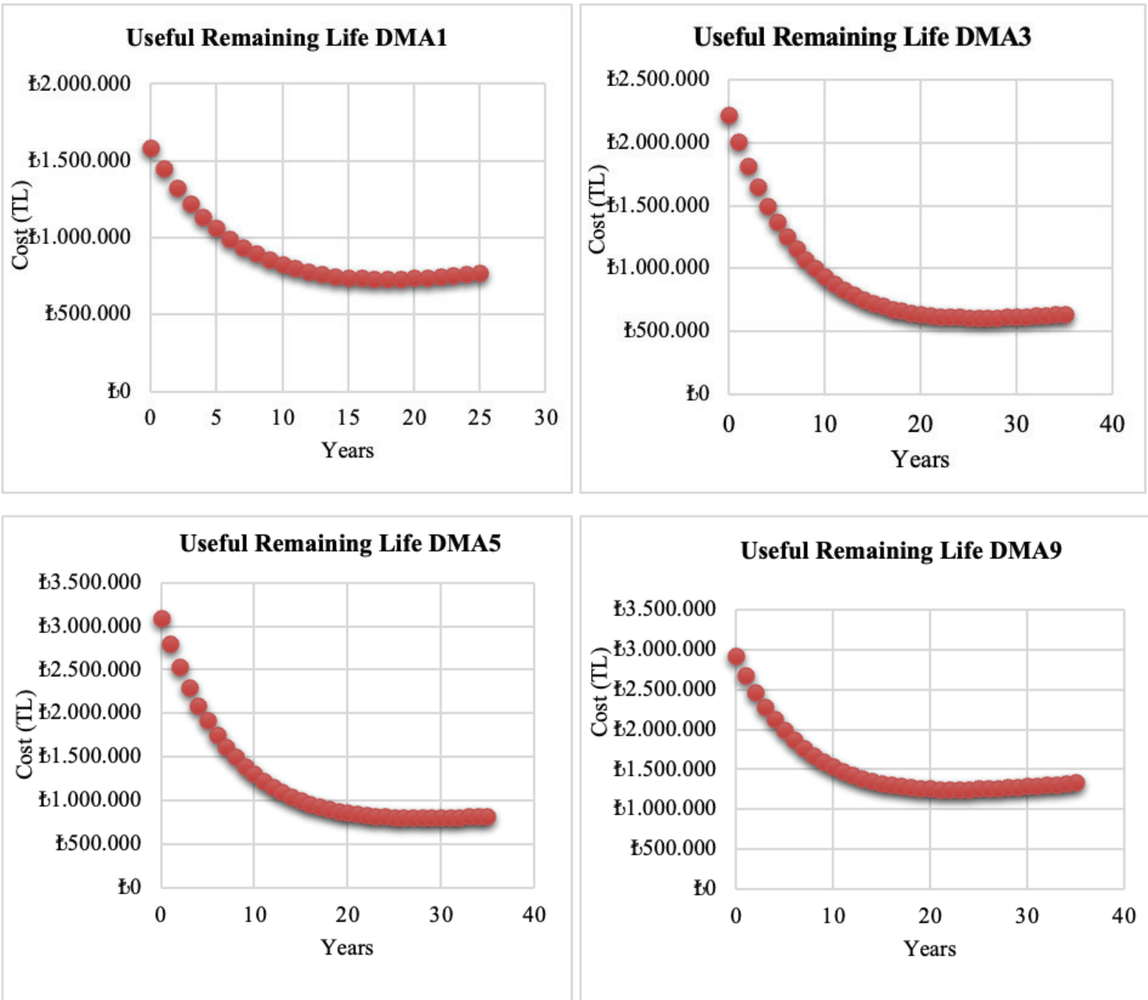

Figure 4. Useful Remaining Life for DMA1, DMA3, DMA5 and DMA9.

DMA1 with a network length of approximately 4.7 km has an NRW of 38.94% (5.03 l/s), and 22 failures occur annually. If the Ductile pipe material is chosen for the new line to be built in this region, the remaining useful life of the network is calculated as 18 years (Figure 4). In other words, the network can be operated economically for 18 more years under current conditions. In this region, basic methods such as active leakage control and pressure management should be applied in order to reduce leakage rates and manage the system more efficiently. Similarly, useful lives were calculated for the DMA3, DMA5 and DMA9 regions and are shown in Figures 4, 5 and 6, respectively.

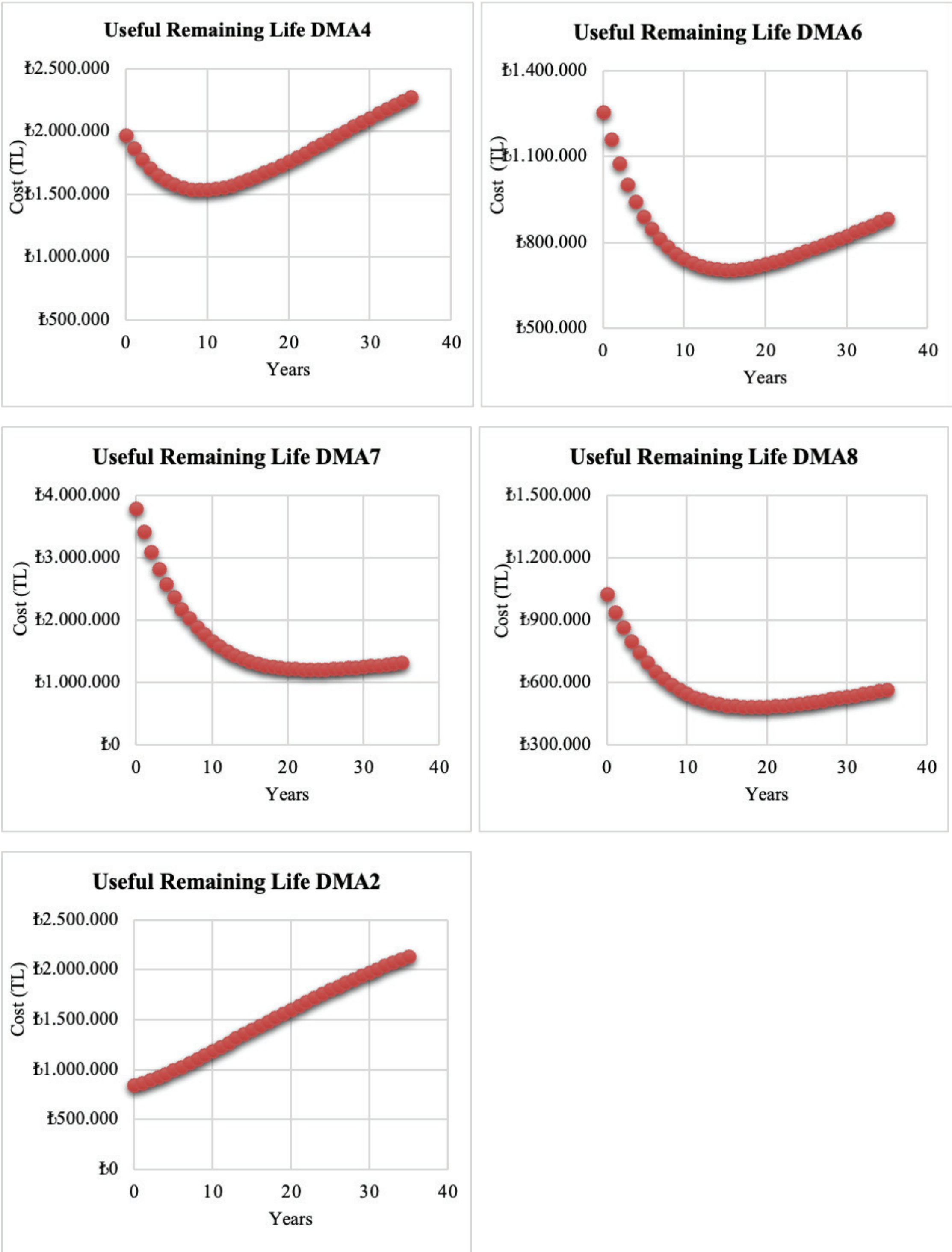

Figure 5. Useful Remaining Life in DMAs.

According to the model results, the remaining useful lives for the DMA3, DMA5 and DMA9 regions are very close to each other. In these regions, NRW rates (27%, 23% and 24%) and number of the failures (14, 15 and 22) are very close to each other. In addition, since the region network lengths are close to each other, the useful lives (26 years, 29 years and 23 years) are calculated similar to each other. These regions, with their current conditions, have been suitable for operation for many years without network renewal. On the other hand, useful lives were calculated for the DMA4, DMA6, DMA7 and DMA8 regions and are shown in Figure 5 respectively.

The calculated useful lives for the DMA4, DMA6, DMA7 and DMA8 regions were close to each other. The remaining useful life for the DMA4 region is 9 years (Figure 5), 15 years for the DMA6 region (Figure 5), 17 years for the DMA7 region (Figure 5), and 18 years for the DMA8 region (Figure 5). In the DMA4 region, the NRW rate (71.75%) and the number of failures (44 failures per year) are very high. Since PVC was chosen as the type of pipe to be used for rehabilitation in this region (it is relatively less costly than other pipes), the remaining useful life is 9 years. Short-term rehabilitation plans should be made for this region. On the other hand, for other regions (DMA6, 7 and 8), the average useful life is calculated as 17 years. It can be said that these regions can be operated for many years under current conditions. Especially by controlling environmental effects, pressure and other factors, the system can be managed efficiently. According to the results obtained, the useful life in isolated regions varies between 9 years and 29 years. The differences in water loss rates, number of failures and initial investment costs are effective in the fact that the remaining useful lives are so different from each other. Finally, the estimated useful life for DMA 2 in the study is shown in Figure 5.

Considering the current state of the network for the DMA2, the necessity of immediate rehabilitation of the network in the region has emerged. The fact that the water consumption is higher in the region compared to other regions, the high NRW rate (50.56%), the high number of annual failures (48 annual failures) and the low initial investment cost due to the small size of the network have been important factors as a result of the immediate rehabilitation of the region. It is envisaged to use PVC pipes for replacement in the region. Since this parameter reduces the initial investment cost (PVC pipe is cheaper than other pipes), it has reinforced the necessity of rehabilitation. Table 3 shows the calculations made in the case of selecting different pipes in the rehabilitation situation.

The lowest initial investment cost is achieved by using PVC pipes. If other pipe types are selected, this initial investment cost increases and the useful life is extended. Because the return time of the expenditures to the water administrations is getting longer [14]. If PVC pipe is selected, it is concluded that it can be rehabilitated immediately. However, if it is decided to build a ductile pipe, it is calculated that the region can be operated for about 9 more years under current conditions. Determining the initial investment cost in the studies to be carried out constitutes a very important stage for the strategy to be determined. When the calculations made and the results obtained are evaluated, since the renewal of the entire network causes serious costs, it is necessary to make a detailed analysis before the study. In the calculation of the remaining useful life of the networks,

Table 3. Alternative Solutions for DMA2 Region

Parameters	**Unit**	**DMA2**			
Input volume (SIV)	m^3/day	2658	2658	2658	2658
Billed metered consumption(BMC)	m^3/day	1314	1314	1314	1314
Main length(Lm)	m	5800	5800	5800	5800
Number of connections (Nc)	No.	500	500	500	500
Water production cost (WPC)	TL/m^3	2.32	2.32	2.32	2.32
Number Of Network Failures	No./ year	19	19	19	19
Number Of Subscriber Failures	No./ year	29	29	29	29
Inflation Rate	%	12.75	12.75	12.75	12.75
Non-Revenue Water	m^3/day	1344	1344	1344	1344
Non-Revenue Water Rate	%	**50.56**	**50.56**	**50.56**	**50.56**
New Pipe Type	-	**Ductil**	**PVC**	**HDPE**	**Stell**
WDS Change Cost	TL	1,795,100.00	984,550.00	1,078,800.00	1,578,760.00
Failure Repair Annual Cost	TL / Year	74,300.00	74,300.00	74,300.00	74,300.00
Non-Revenue Water Cost	TL / Year	37,416.96	37,416.96	37,416.96	37,416.96
Useful remaining life	**Year**	**9**	**SBR***	**3**	**8**

*Should Be Rehabilitated

factors such as the number of failures and the amount of water loss, as well as the length of the network and the type of new pipe, which play a serious role in determining the initial investment cost, should also be taken into account. Since the initial investment costs will vary according to the type of pipe to be selected, the remaining useful life of the network changes accordingly. In the plans to be made in a sustainable drinking water management, economic analyzes should be made in the regions where network rehabilitation is planned and a strategy should be developed in line with the results to be obtained.

As can be seen from the table, the useful lives of DMAs are calculated differently from each other. The main reason for this is the failure rates observed in the regions (service connection, main line) and the effect of other network characteristics (operational and physical). For example, the network in DMA2 should be renewed to the analysis results. It is observed that the failure rate in this region is higher than in other regions. In addition, the rate and amount of non-revenue water is higher than in other regions. On the other hand, the useful life in DMA5 is 29 years according to the analysis results. It is observed that the failure rates in this region are lower than in other regions. Moreover, the loss rate in this region, where the network length is longer, is lower than in other regions. As a result, it is recommended to protect the existing network conditions in the region. The useful life values calculated for other regions vary in parallel with the operating conditions and physical characteristics of the region. Accordingly, it can be said that the methodology proposed in this study takes into account the existing characteristics of the network and produces results suitable for the current situation.

CONCLUSION

In this study, a total of 9 regions with different network, fault and consumption values were selected and useful life calculations were made. The remaining useful life for the DMA4 region was calculated as 9 years. In this DMA, it is seen that the NRW rate (71.75%) and the number of failures (44 failures per year) are very high. Therefore, short-term rehabilitation plans should be made for this region. The useful lives for DMA6, DMA7 and DMA8 were obtained as 15, 17 and 18 years, respectively. According to the model results, the remaining useful lives for the DMA3, DMA5 and DMA9 regions are very close to each other. In these regions, NRW rates (27%, 23% and 24%) and number of the failures (14, 15 and 22) are very close to each other. In addition, since the region network lengths are close to each other, the useful lives (26 years, 29 years and 23 years) are calculated similar to each other. On the other hand, the DMA2 should be immediately renewed by considering the current state of the network. As a result, in order to create an effective water management strategy in water distribution systems, first of all, network useful remaining life calculations should be made. The network rehabilitation is a very costly and difficult water loss reduction method. Before applying this method, water utilities should definitely consider whether the network is operable under current conditions and, if available, alternative water loss reduction methods should be applied. It is thought that water utilities can create an effective water loss plan in the short, medium and long term water management strategies.

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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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