A COST-BENEFIT ANALYSIS OF FOUR LEAKAGE REDUCTION METHODS IN PEJA, KOSOVO: A REPLICATED STUDY

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Economics

Abstract

Water leaks are a concern for Kosovo's utilities, costing the nation €30 million annually. This thesis compares the costs and benefits of four leakage reduction methods in the Hidrodrini utility, Kosovo, to determine which one is the most cost-effective. These methods are (1) installing district metering areas (DMAs), (2) increasing leak-detection personnel, (3) installing pressure-reducing valves (PRVs) in existing DMAs, and (4) replacing aging pipelines. The results show that DMAs provide the greatest net present value (NPV), followed by increasing leak-detection personnel. PRVs and pipe replacements both exhibit negative NPVs, suggesting that these methods may be more costly to implement and provide fewer benefits in return. One-way sensitivity analysis of all methods showed that different values of the main assumptions did not change the order of most-to-least cost-effective strategies, although they slightly changed NPV values.

KEYWORDS: (real water losses; leakage reduction; district metering areas; leak-detection personnel; pressure reducing valves; pipe replacement)

ON MY HONOR, I HAVE NEITHER GIVEN NOR RECEIVED UNAUTHORIZED AID ON THIS THESIS

Signature

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Introduction

Non-revenue water, also known as water pumped but not accounted for, is an unavoidable component of water distribution systems and a concern in many nations throughout the world. Non-revenue water in distribution networks is estimated to cost developing nations 45 million cubic meters per day, which is enough to serve about 200 million people (The World Bank, 2016). In one such country, Kosovo, more than half of the water pumped is not invoiced, costing the nation more than €30 million in financial losses annually (ARRU, 2020: p. 4). Non-revenue water in Kosovo is classified into three categories: physical (real) water losses, commercial losses, and authorised non-revenue consumption. Physical losses encompass all losses caused by pipe system leaks. Water not accounted for owing to metering faults and water theft are examples of commercial losses. Authorized non-revenue water includes water used for firefighting, public hydrants, and public springs (Ibid: p. 6). There are seven water utilities in Kosovo, which in 2018 supplied 97% of Kosovo residents with water (ARRU, 2019, p.43). This paper will focus on physical water losses in one utility, Hidrodrini. Physical water losses provide a challenge for utilities not just in terms of financial losses, but also because of the utility image projected to customers. Stopping water service due to pipe breaks or other similar difficulties in the system undermines the utility's reputation for dependability, resulting in consumer dissatisfaction (Ahopelto & Vahala, 2020).

Despite the physical losses, Hidrodrini has done little to control them, owing to a lack of funds, a lack of understanding about the costs of non-revenue water, and a lack of support from other institutions (ARRU, 2020: p. 5). As a result, this thesis presents a cost-benefit analysis of four different approaches for reducing physical water leakages. While I will only be analysing one utility, the main objective is to provide guidelines on the most cost-effective ways for reducing physical losses not only to Hidrodrini but also to other water utilities in Kosovo. Kosovo is a small country, covering 4,203 mi^2 of land (The World Bank, 2022). Water production expenses are generally comparable for all utilities, and water is billed at a similar price. Hence, the outcomes of this study may be equally advantageous to other utilities. I analyse district metering, increase in leak-detection personnel, pressure reduction, and pipe replacements, all strategies recommended by Kosovo's Water Services Regulatory Authority (Ibid: p.18). By understanding the cost-effectiveness of each strategy, the utilities, particularly Hidrodrini, will be able to make decisions about which measures to implement first. I expect to show that district metering is the most cost-effective strategy to reduce physical water losses, based on the practicality of district metering demonstrated in previous research.

Leakage Reduction Strategies

District Metering. By blocking valves or connections, District Metering Areas (DMAs) divide the water network system into sub-regions. This enables more accurate monitoring of water input and consumption in a given region. If the water input exceeds the measured amount of water utilized by homeowners of that sub-region, there is either a leak, a metering fault, or consumers are unlawfully obtaining water (Ahopelto & Vahala, 2020).

Increased Leak-Detection Personnel. While the development of leak-detection devices is increasing, such equipment would represent a large expenditure for the Hidrodrini Utility (A. Dreshaj, personal communication, September 19, 2021). This strategy recommends increasing personnel who would employ traditional leak-detection methods, such as manual listening sticks and acoustic correlators.

Pressure Reduction. High pressure affects pipe leaks and water utilization. Installing Pressure Reducing Valves (PRVs) in existing DMA zones would be one method of reducing leaks. In the water distribution system, PRVs reduce high pressure to a desirable level (Ahopelto & Vahala, 2020).

Pipe Replacements. Because most leaks occur in water mains (KRU Hidrodrini, 2018), one method of preventing them is to replace high-leakage pipes with newer ones.

Methods

I first calculated the leakage reduction potential for the Hidrodrini utility, which presents how much a utility can truly reduce its leakages. To accomplish that, I employed a formula called the Infrastructure Leakage Index (ILI). This formula measures the ratio between current annual real losses (CARL), and unavoidable annual real losses (UARL) (Alegre et al, 2016: p. 222). If the ratio is bigger than 1, then there is potential for reducing leakages (Ahopelto & Vahala, 2020). While there was data available for CARL, I measured UARL with a formula originally published in 1999 and widely used thereafter. Length of mains, number of service connections, the average length of service connections, and average water pressure were used to determine the UARL (Alegre et al, 2016: p. 222).

Secondly, I calculated the net present value (NPV) for each leakage reduction strategy. The NPV is a financial measure that attempts to quantify the overall value of a potential investment. To calculate the NPV, I had to determine all the relevant costs and benefits related to the strategies, a suitable time frame for the analysis of the project, and a discount rate. All these factors were determined through literature review and interviews with the Hidrodrini water utility.

Lastly, I performed a sensitivity analysis to assess the results' reliability and determine which variables are more significant.

Data

The data used in this paper comes from the Hidrodrini water utility in Kosovo, which covers about 10% of the total population (Hidrodrini, 2020). Through interviews with utility personnel and report overviews, I gathered information about the utility's volume of water pumped, the water invoiced, water rates, physical losses, the number of households served, the number of connections, the network length for different pipe materials, age of different pipe materials, the number of pipe failures, pipe materials with the highest leakage level, energy consumption for water treatment and distribution, the marginal cost of water produced, water pressure in pipes, construction and management costs, leakage costs, and costs of pipe repairs, all for 2018. I determined the time frame and the discount rate for the NPV by consulting Hidrodrini and relying on literature.

The organization of this paper is as follows: Section II provides a literature review of the topic, highlighting a variety of studies that have conducted similar analyses and their findings, section III gives a detailed description of the methodology used, section IV presents and analyses results, and section V gives concluding remarks and implications.

Literature Review

Previous research has proven the significance of preventing water leaks. Farley and Liemberger (2005), for example, emphasized the need for leakage monitoring in achieving cost-effective and efficient leakage control. This would in turn decrease utility expenditures and boost customer satisfaction (Ibid).

This thesis is mainly based on Ahopelto & Vahala's paper from 2020, and Malm et al’s paper from 2015, which use a similar methodology to find the most cost-effective strategies for decreasing leakages in Finland and Sweden, respectively. In Ahopelto & Vahala’s study, the authors discover that district metering, pressure reductions, and pipe renovations have a negative NPV, which is not surprising given Finland's low leakage rates. Despite the negative net present value, the authors conclude that district metering is the most promising of the strategies studied. Malm et al, on the other hand, developed a cost-benefit analysis of four leak reduction strategies: (1) implement faster pipe replacements, (2) increase leak-detection personnel, (3) increase the number of acoustic loggers that detect leak noise, and (4) increase district metering areas (Malm et al., 2015). According to the research, both growing the workforce and expanding DMAs were viable options with favorable NPVs. Although option (2) showed the greatest NPV, the authors argued that district metering is almost as effective, if not better at times.

Increasing leak detection personnel has several advantages, according to Hamilton and Charalambous (2013). Leaks are difficult to detect, especially in sparsely inhabited areas. As per this study, a team of two employees covering 2.5 km each day may discover more than 90% of pipeline leaks. One advantage is that leaks are detected before they cause serious pipe bursts, avoiding the need to shut off water supplies for extended periods and working overtime (Ibid; Malm et al, 2015).

Several studies have demonstrated the effectiveness of pressure reduction. Research conducted in Bucharest, Romania, discovered that for every 1% reduction in pipe pressure, burst rates fall by 1.4% (Thornton and Lambert, 2007). Another study conducted in Iran found that when pressure is controlled and decreased to lower levels, physical water losses are considerably reduced (Tabesh et al., 2009). A case study by Gomes et al. (2011) showed that a 15 m decrease in water pressure with PRVs in a DMA decreased water losses by 8%, water production by 10.64%, and water billed by 0.83%.

Finally, changing pipes is another approach to reduce leaks. Pipes are one of the most expensive components of water supply systems, yet replacement is inevitable (Giustolisi et al., 2006). A key reason why real water losses in Japan dropped from 80% in 1945 to 4.2% in 2005 was the replacement of water mains (Fujimura, 2007). However, studies on the cost-effectiveness of this method have concluded that pipeline replacement is too costly in many countries and that a desirable level of restoration cannot be achieved without external environmental costs such as greenhouse gas emissions from polyethylene and diesel production (Venkatesh, 2012).

Since the majority of these studies have been conducted in Nordic and other Global North nations, this thesis fills a gap in the present literature by conducting a cost-benefit analysis of leakage reduction strategies in Kosovo, a country in the Global South. It will hopefully provide insights not only to water utilities in Kosovo, but also those in the surrounding countries such as Albania, Montenegro, Serbia, and Macedonia.

Theory and Methodology

The study presented in this thesis builds on the work of Ahopelto & Vahala (2020) and Malm et al. (2015). While these authors investigate the cost-effectiveness of leakage control strategies in Scandinavian countries, my research is focused on Kosovo, specifically the Hidrodrini Utility for 2018.

Methodology

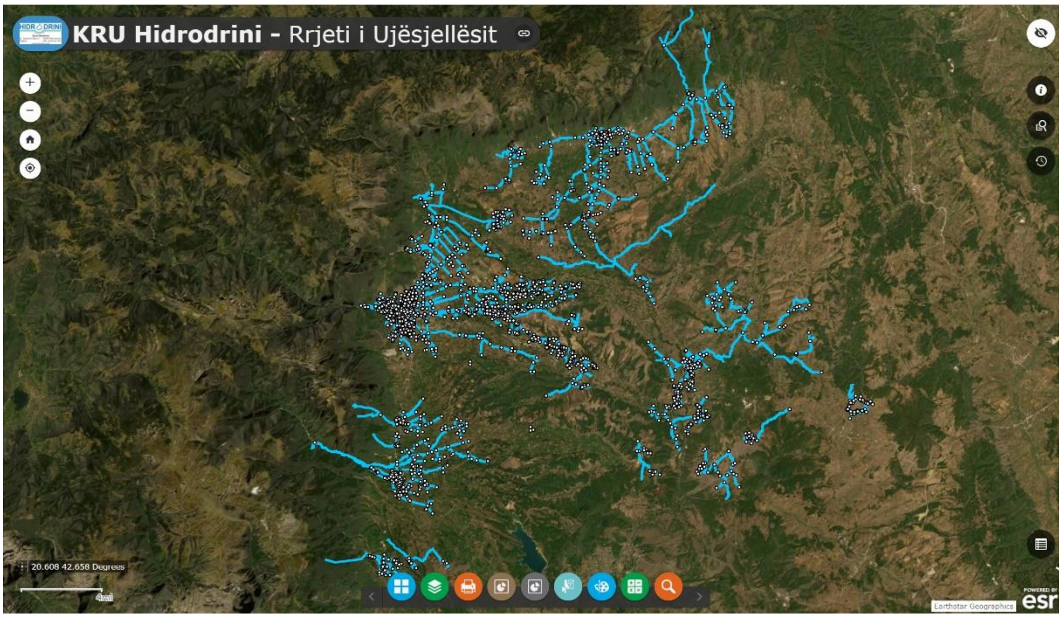
Study Area. This study was conducted with data from the Hidrodrini Utility, located in the municipality of Peja. In 2018, this utility supplied more than 187,000 residents with water, and had a network length of 996 km.

Figure 3.1. Water Utilities in Kosovo.

Source: ARRU, 2019.

During 2018, Hidrodrini produced 25,366,310 m^3 of water, billed 9,662,715 m^3, and lost 3,416,646 m^3 in physical losses. The remaining losses included commercial (75%) and authorized non-revenue water (3%) (ARRU, 2020). Over half of the pipe materials were made of polyethylene, 18% were high-density polyethylene, 16% polyvinyl chloride, 12% asbestos-cement, 1% steel, and 1% cast-iron. The oldest materials, which also have the highest number of leaks, are cast-iron and asbestos-cement, dating from the 1930s and 1960s, respectively. The newest material is polyvinyl chloride, which started being used after 2000. The pipe diameter spans from 40 to 800 mm, with 250 mm being the most common (A. Dreshaj, personal communication, September 13, 2021; KRU Hidrodrini, 2022). The pressure in water mains is high, ranging from 50 to 80 m. Hidrodrini has abundant water supplies and does not anticipate any future water shortages (A. Dreshaj, personal communication, September 13, 2021). This study area and the year were chosen because of the data available. Hidrodrini was also the only utility with a public GIS website, which made data collection easier.

Figure 3. 2: Snapshot from the Hidrodrini Water Network on GIS.



Source: KRU Hidrodrini, 2022.

Infrastructure Leakage Index. The infrastructure leakage index for the Hidrodrini utility was estimated using the following ratio:

$$ILI = \frac{CARL}{UARL} \tag{3.1}$$

Interviews and public utility reports were used to keep track of the current annual leakage levels (CARL) of Hidrodrini. Using the method below, I calculated the unavoidable annual real losses (UARL):

$$UARL\left(\frac{m^3}{year}\right) = ((6.67 \times L_m) + (0.256 \times N_c) + (9.13 \times L_t)) \times P \tag{3.2}$$

Where L_m = length of mains (km); N_c = number of service connections; L_t = total length of service connections (km); and P = average water pressure (m). This formula was first published by Lambert et al. (1999), and the units (6.67, 0.256, 9.13) represent a "rational yet flexible basis for predicting UARL values for a wide range of distribution systems". This formula has been widely used across many countries, including those of the Global South. Hence, I reasoned that it would work for a Kosovar utility too.

Net Present Value. To determine the costs and benefits of each leakage reduction strategy, I gathered information from public water utility reports as well as interviews. I considered the avoided cost of leakage and the avoided cost of pipe failure repairs to be benefits. I included direct construction and management expenditures in the costs. After calculating all the costs and benefits, I used the following formula from Malm et al. (2015) to calculate the net present value of each leakage reduction strategy:

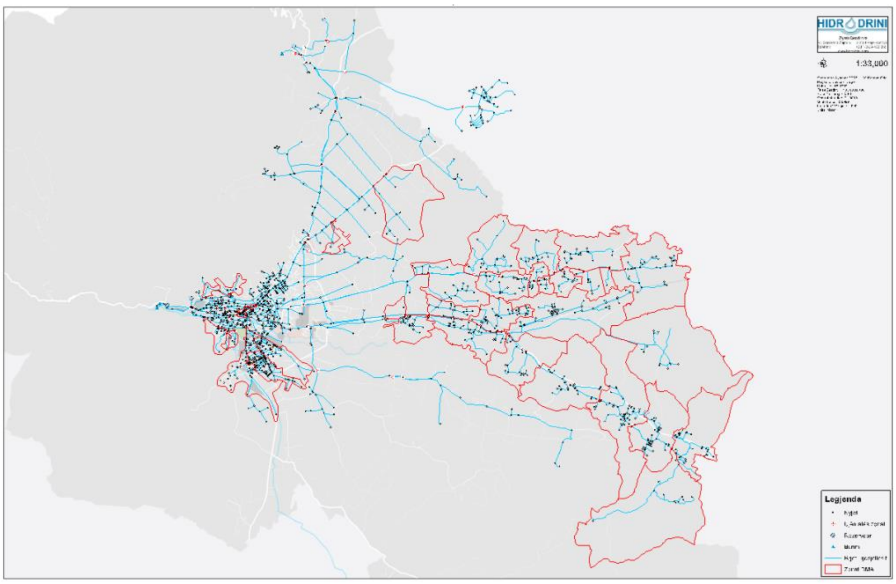
$$NPV_i = \sum_{t=1}^{T} \frac{1}{(1+r)^t} (B_{it} - C_{it}) \tag{3.3}$$

Where i represents the particular leakage reduction strategy, t represents time, T represents the terminal period of analysis, r represents the discount rate, B represents the benefits, and C the costs of the strategy.

Costs.

Strategy 1: District Metering. Hidrodrini planned and budgeted for the construction of 23 district metering areas (DMAs) in its water network in 2017, becoming Kosovo's first utility to do so (A. Dreshaj, personal communication, September 13, 2021). These DMAs have now been constructed; but, as seen in Figure 3.3, not every portion of the network is covered, and the utility may benefit from the addition of a few more DMAs.

Figure 3.3: Current DMA zones, outlined in red, in the Hidrodrini Water Network System.



Source: KRU Hidrodrini. 2019.

The costs of this strategy were determined by deciding how many more district meters are needed (Nr_{DM}) and what the cost of each meter is. The latter cost included planning (C_{PDM}), buying (C_{BDM}), installing (C_{IDM}), and management costs (C_{MDM}). The DMAs would be installed in 5 years, 1-2 per year. Their lifetime was set to 30 years (A. Dreshaj, personal communication, September 13, 2021). The resulting equation is:

$$C_{District\ metering,t} = (C_{PDM} + C_{BDM} + C_{IDM} + C_{MDM}) \times Nr_{DM} \quad (3.4)$$

Hidrodrini adheres to International Water Association (IWA) norms, which recommend one DMA for every 1,500 service connections (KRU Hidrodrini, 2018). Using this data and the number of service connections outside the existing DMAs, I concluded that installing 8 additional DMAs would be optimal. In 2017, the total cost of 23 DMAs was €350,000 (€381,879 in today's value) for 3 years (Ibid). I utilized this information, along with assistance from a Hidrodrini water engineer, to determine the costs of building 8 DMAs.

Strategy 2: Increased Leak-detection Personnel. Hidrodrini employs seasonal workers when there are major leaks. This strategy recommends that they employ full-time workers whose main role is leak detection. The main costs for this strategy are the worker salaries in €/year (C_S), the cost per employee of training workers once they are employed (C_T), and leak-fixing costs (C_{FL}), which present a fixed cost not dependent on the number of new employees. The latter cost is necessary as water can only be saved if the detected leaks are repaired. The cost function for the increased leak-detection personnel strategy is:

$$C_{Increased\ leak\ detection\ personnel,t} = ((C_S + C_T) \times Nr_{NE}) + C_{FL} \quad (3.5)$$

where Nr_{NE} is the number of new employees.

I determined the number of personnel necessary by considering the number of leaks each year and the time required to detect leaks. I assumed that leaks in m3/hour were 1.6 and that a two-person team covered 2 km of network every day (Hamilton and Charalambous 2013; A. Dreshaj, personal communication, September 13, 2021). Finally, I assessed the costs of hiring 4 additional employees for 5 consequent years.

Strategy 3: Pressure Reductions. Considering the high water pressure of Hidrodrini (51- 81.6m), I determined that a reduction of 15 m in network water pressure could be possible. The costs of this strategy included planning (C_{PPRV}), buying (C_{BRV}), installing (C_{IPRV}), and managing pressure-reducing valves (C_{MPRV}). I calculated the costs of installing 3 PRVs in each of the 23 DMAs during year 1. Their lifetime was set to 10 years (A. Dreshaj, personal communication, September 13, 2021).

$$C_{pressure\ reduction,t} = ((C_{PPRV} + C_{BPRV} + C_{IPRV} + C_{MPRV}) \times Nr_{PRV}) + C_{BWL} \quad (3.6)$$

Where Nr_{PRV} is the number of pressure-reducing valves needed to be purchased, and C_{BWL} is the loss in water bills incurred by the utility, as the water pressure also affects water consumption.

Strategy 4: Pipe Replacement. Old materials in the Hidrodrini water distribution network such as asbestos-cement and cast-iron have the highest percentage of bursts and are costly to replace. The costs of this strategy included the average cost of replacement in €/m for each material. This cost involved the starting cost (C_{RS}), pipe diameter (C_{RD}), and replacement distance (C_{RDIS}). Based on interviews, the lifetime of replaced pipes was assumed to be 30 years (A. Dreshaj, personal communication, September 13, 2021).

$$C_{pipe\ replacement,t} = C_{RS} + C_{RD} + C_{RDIS} \quad (3.7)$$

In 2017, Hidrodrini had budgeted for the replacement of 10,000 km asbestos-cement, and 5,000 km cast-iron (KRU Hidrodrini, 2018). This plan has not yet been implemented. I utilized this information, together with interviews, to calculate the current cost of such a replacement. I calculated a yearly replacement of 3333 km asbestos-cement for 3 years, and a yearly replacement of 1250 km cast-iron for 5 years.

Benefits.

Strategies 1 (District metering) and 2 (Increase leak-detection personnel). Considering the nature of these strategies, both had similar benefits. Benefits included cost reduction due to lower drinking water production and distribution including lower energy costs in €/m^3 (B_{WP}); the volume of drinking water saved by limiting leakage in m^3/year (V_W); savings due to the increased number of pre-located leak repairs per year in nr/km/year (N_{PLL}); and the benefits that accrue since, due to more leak-detection, the pipe break and leak repairs are performed within normal working hours with lower labor rates (B_{PR}) in €. Additionally, district metering also included reduced costs due to better knowledge of the water distribution systems (B_K), and increased leak-detection personnel included the benefit of reducing unemployment (B_{RU}). The formulas for calculating the benefits can be expressed as:

$$B_{District\ metering,t} = (B_{WP} \times V_W) + (N_{PPL} \times B_{PR}) + B_K \qquad (3.8)$$

$$B_{Increased\ leak\ detection\ personnel,t} = (B_{WP} \times V_W) + (N_{PPL} \times B_{PR}) + B_{RU} \qquad (3.9)$$

I made the following assumptions during these calculations: the leakage reduction potential of DMAs is 30% of the total leakage reduction potential (Ahopelto & Vahala, 2020; Malm et al., 2015); the N_{PLL} is 23% of total pipe leaks per year (Malm et al., 2015); water saved by increasing leak-detection personnel by 4 is 80% of real losses in distribution mains (A. Dreshaj, personal communication, September 19, 2021).

Strategy 3 – Pressure reduction. Pressure reduction is associated with decreased leakage with the assumption that the flow rate from leaks is also reduced (Ahopelto & Vahala, 2020). Kosovo utilities suggest that a high water pressure also increased the rate of pipe bursts (ARRU, 2020). For the benefits formula, the following variables were included: B_{WP}, V_W, and B_{APB} where the latter is the benefit of avoided pipe bursts.

$$B_{Pressure\ reduction,t} = (B_{WP} \times V_W) + B_{APB} \tag{3.10}$$

I assumed that decreasing pressure by 15 m can reduce losses by 8%, water production by 10%, and water billed by 0.83% (Gomes et al, 2011).

Strategy 4 – Pipe Replacement. The benefits to replacing asbestos-cement and cast-iron pipes would be the following:

$$B_{Pipe\ replacement,t} = (B_{WP} \times V_W) + (N_{PPL} \times B_{LR}) + B_M \tag{3.11}$$

Where B_{LR} is the avoided cost per leak repair (€) and B_M is the reduction in the cost of monitoring and maintaining newly replaced pipelines, including planning and analysis (€/year). I assumed that for new pipe materials, the new burst rate would be 0.03 km/year (Malm et al, 2015; A. Dreshaj, personal communication, February 3, 2022). Hidrodrini did not have data on the exact number of leaks for asbestos-cement and cast-iron pipes, but they estimated that they were around 30% higher than the average pipe bursts/km for all pipe materials (A. Dreshaj, personal communication, September 19, 2022).

Results and Analysis

The ILI for Hidrodrini was equal to 1.9, indicating that the utility has the potential to reduce 1,642,055 m^3 of leakages.

A calculation of the costs and benefits showed that for Hidrodrini, installing 8 new district metering areas and increasing leak-detection personnel by 2 teams of 2 employees each are the most cost-effective strategies to reduce leakages. As expected, pipe replacements showed to be the least cost-effective method of reducing leakages, and pressure reductions came close with an NPV value of -126,202.

Table 4.1: Benefit-Cost Analysis Results.

	DMA	Personnel	PRV	Replacements
Total Costs (€)	180,122	107,147	151,356	351,853
Total Benefits (€)	218,011	124,532	25,154	49,938
NPV	37,889	17,385	-126,202	-301,915
Benefit-cost ratio	1.21	1.16	0.17	0.14

The baseline discount rate for NPV calculations was set to 3%. A sensitivity analysis was performed to show if a different discount rate would give different results.

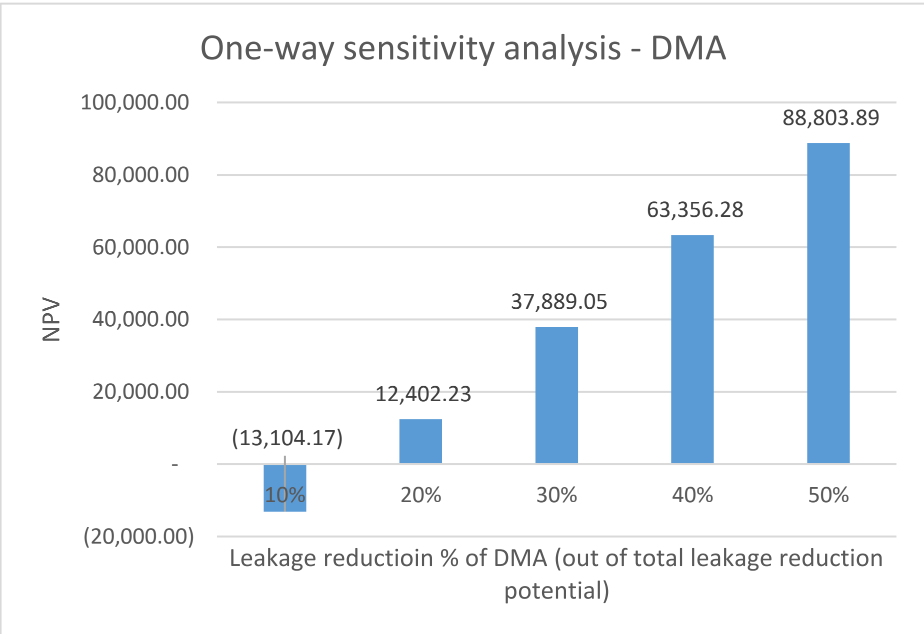
Table 4.2: Sensitivity analysis of the results.

	Alternatives	Costs	Benefits	NPV
1% discount rate	DMA	231,392	290,606	59,214
	Personnel	113,240	131,975	18,735
	PRV	306,785.51	27,929.44	-278,856
	Replacements	366,994.02	65,753.19	-301,241
3% discount rate	DMA	180,122	218,011	37,889
	Personnel	107,147	124,532	17,385
	PRV	151,356.48	25,154.27	-126,202
	Replacements	351,853.37	49,938.24	-301,915
5% discount rate	DMA	144,839	168,684	23,845
	Personnel	117,728	101,569	16,159
	PRV	250,816.31	22,770.22	-228,046
	Replacements	337,725.60	39,166.11	-298,559

As shown in Table 4.2, even though the values changed, district metering and increased leak-detection personnel had positive NPVs in all scenarios, whereas pressure reduction and pipe replacements had negative NPVs.

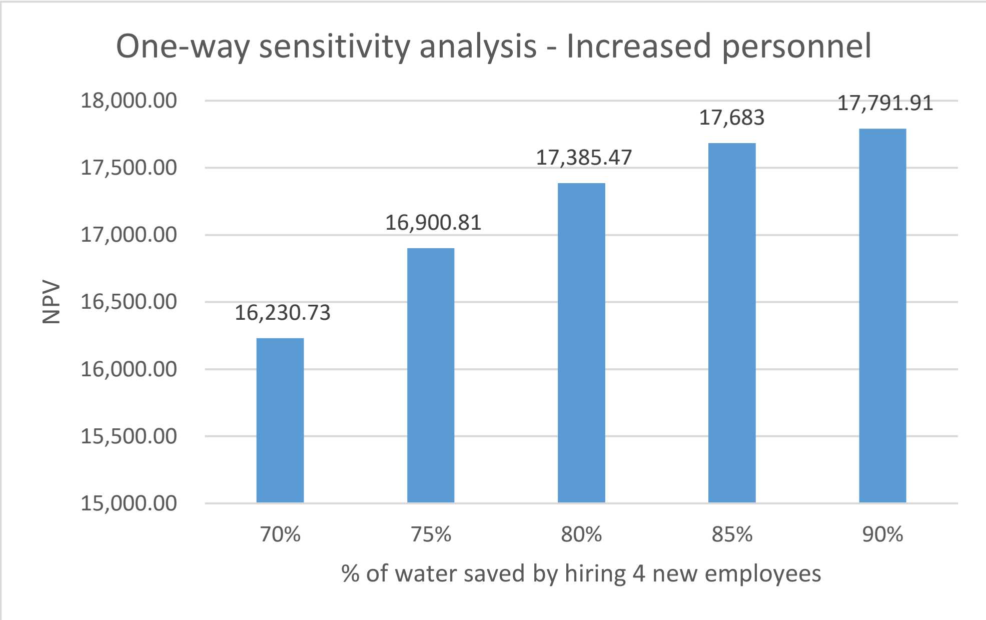
A one-way sensitivity analysis was performed to see how a range of values for the assumptions made would affect the conclusions. For DMA, I used 10, 20, 30, 40 and 50% leakage reduction potential, holding everything else constant. As Figure 4.1 demonstrates, a 10% DMA leakage reduction potential had a negative NPV, and the other scenarios all exhibited positive NPV values. Considering that DMAs help detect commercial losses too, it is unlikely that such a scenario of 10% leakage reduction potential would be possible. A sensitivity analysis was carried out for an assumption of increased numbers of pre-located leak repairs per year. However, the results were insignificant.

Figure 4.1: One-way sensitivity analysis for DMA leakage reduction potential.



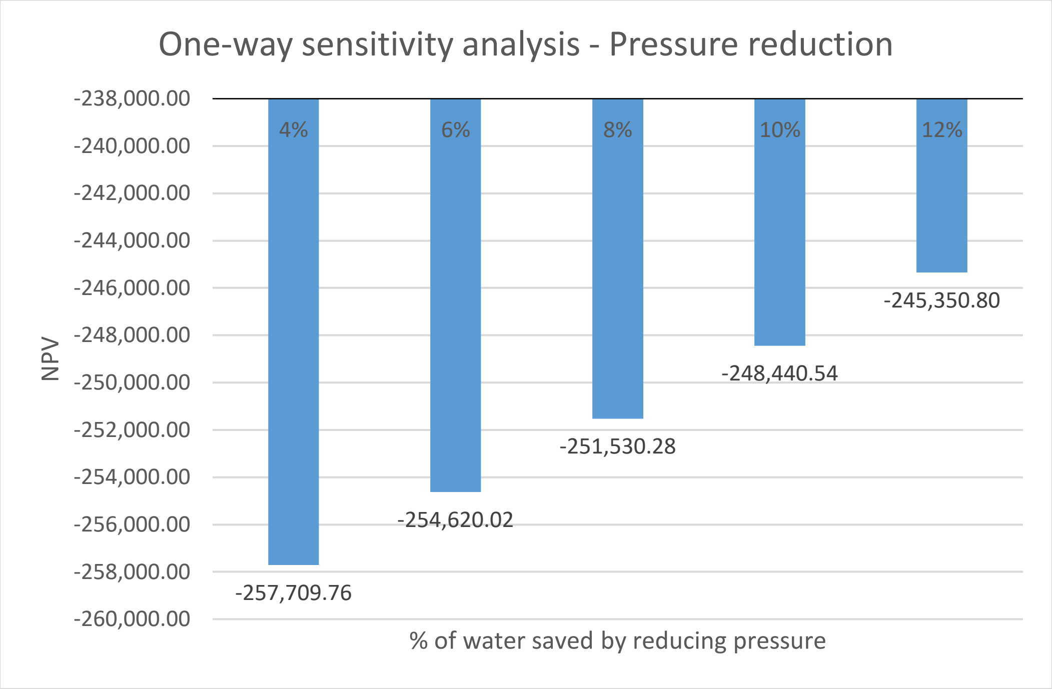
For increased leak-detection personnel, I used different values for the water saved by hiring 4 new leak-detection workers. The results showed that while lower percentages decreased the NPV, they did not affect it significantly. Other assumptions, such as leaks in m^3/hour, network coverage/day, and N_{PPL} were even less significant to the NPV results.

Figure 4.2: One-way sensitivity analysis of increased leak-detection personnel.



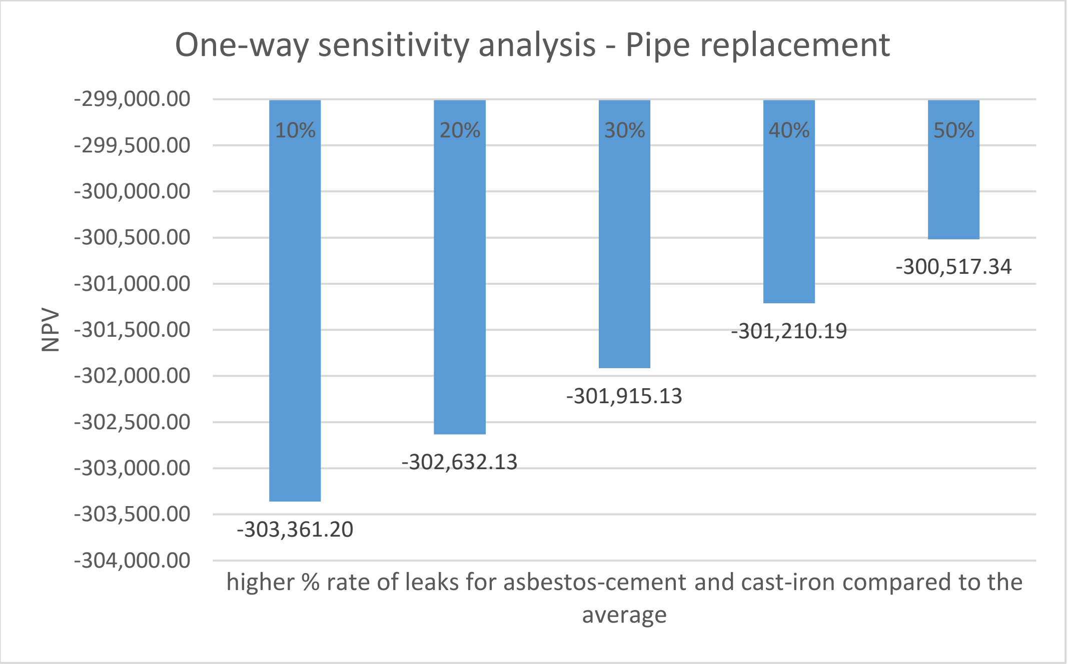
The main assumption when calculating the costs and benefits of pressure reduction was that decreasing pressure by 15 m would reduce losses by 8%. A sensitivity analysis of this variable showed that the NPV would be negative in all scenarios (Figure 4.3).

Figure 4.3: One-way sensitivity analysis of pressure reduction.



Lastly, the main assumption regarding pipe replacements was that the leaks for asbestos-cement and cast-iron were 30% higher than the average leaks across all construction materials. Unfortunately, even a 50% higher leak rate than the average had large negative NPVs, making this option cost-ineffective in all scenarios (Figure 4.4).

Figure 4.4: One-way sensitivity analysis of pipe replacement



This cost-benefit analysis was conducted considering only costs and benefits incurred by the utility. Due to the scope of the study, effects on society and the environment were not considered. In an ideal situation, the societal benefit of having fewer water interruptions, the environmental benefits of decreased energy and chemical use, and the environmental cost of greenhouse gas emissions during pipe replacements would also be included.

Furthermore, this paper relied on several assumptions when calculating costs and benefits, many of which came from countries of the Global North. Although all the assumptions were discussed with the Hidrodrini utility and considered reasonable, a more robust study would have actual data from the study area. Another alternative would be to use a Monte-Carlo simulation for sensitivity analysis, not the one-way approach. That would show how sensitive conclusions are to multiple assumptions without having to analyse one assumption at a time.

Some benefits were hard to quantify, such as the knowledge gained by installing and managing DMAs. Although Hidrodrini personnel claimed €500/year knowledge benefit for each additional DMA, I believe that this figure is greater because DMAs enable the detection of illegal connections and metering faults, which account for 75% of water losses in this utility. The real value of this method is yet to be determined as Hidrodrini continues to manage the newly installed 23 DMAs.

This thesis would have also benefited from a computation of the Economic Level of Leakages (ELL). The ELL identifies the leakage level at which the marginal costs of controlling leakages are equal to the marginal benefits of saving water. If leakages are reduced further, then the marginal costs will outweigh the marginal benefits (Ahopelto and Vahala, 2020). Hidrodrini personnel informed me that they use this measure to make decisions concerning non-revenue water in general (A. Dreshaj, personal communication, September 13, 2022). Hence, finding the ELL and utilizing it to calculate the costs and benefits of each option would add additional value to this utility. However, I found it challenging to do such an estimate due to a lack of data on real water losses for years before and after 2018.

When compared to the research I replicated, my results differ mostly in terms of values. According to Malm et al. (2015), increasing leak-detection employees had the greatest NPV with a value of €4,616,000. DMAs came in second, with an NPV of €3,826,000. The costs of living in Kosovo and Sweden might be the key cause for such discrepancies in outcomes (Numbeo, 2022). Kosovo's low cost of living allows for low manufacturing costs, and the value of benefits is likewise small. In Sweden, where the marginal cost of water is substantially higher (Malm et al., 2015), the benefit of conserving water is much greater. Furthermore, Malm et al. (2015) accounted for decreased wastewater treatment costs in their benefits. Because Kosovo does not yet have any wastewater treatment plants, such benefits were left out. I believe Malm et al. (2015) obtained a larger NPV for expanding leak-detection personnel because they regarded this approach as long-term, whereas I recognized the need for leak-detection personnel for 5 years. If I were to add 5 more years of lifetime to this strategy, the overall NPV would increase to €39,082, making increased leak-detection personnel more cost-effective than DMAs. However, Hidrodrini water engineer, Dreshaj, declared that they would not consider a long-run plan of this strategy, mainly because they want to target their budget on much-needed pipe replacements (A. Dreshaj, personal communication, September 13, 2022). Malm et al. (2015) also estimated the costs and benefits of installing and maintaining 70 DMAs. I think that the expenditures connected with 70 DMAs played a role in their NPV outcome for DMAs being lower than that of increased-leak detection personnel. Ahopelto and Vahala (2020) concluded that DMAs had a negative NPV of around -.3 €/m3. This is possible since the ILI in their study area, Finland, is less than one.

Conclusion

The purpose of this thesis was to find the most cost-effective leakage reduction strategies in the Hidrodrini utility in Kosovo. Cost-benefit analyses of installing and operating DMAs, increasing leak-detection personnel, installing and maintaining PRVs, and replacing aging pipelines showed that the most cost-effective strategy for Hidrodrini is installing and operating 8 additional DMAs. Increasing leak-detection personnel also had a positive NPV, whereas pipe replacements and PRVs were the least cost-effective methods with negative NPVs. Ideally, Hidrodrini could employ both DMAs and increased leak-detection personnel to reduce leakages to their desired level. However, lack of funding, which is prominent across water utilities in Kosovo, may limit Hidrodrini to only one strategy.

Given the commonalities of water utilities in Kosovo, I believe that other utilities would have very similar results when calculating the costs and benefits of the four strategies. Some, such as KRU Prishtina which faces 45% physical losses (ARRU, 2020), could highly benefit from a long-term increase in leak-detection personnel. Other utilities with substantial commercial losses could benefit from installing and operating DMAs that could identify these illegal connections more readily.

Future research could focus on determining the impact of a pressure decrease on saving water in Kosovo, the number of leaks that an additional worker can identify, the leakage rate of each material, and the advantages of DMA beyond physical losses. Moreover, quantifying the social and environmental impacts of leakage reduction strategies would be highly beneficial to Kosovo. In the region, no such study exists, and new data would help utilities make better decisions.

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