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# Water Network Improvement Using Infrastructure Leakage Index and Geographic Information System

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**Abstract** This study aimed at determining Infrastructure Leakage Index (ILI) supported by Geographic Information System (GIS) to facilitate strategy determination, map problems, and determine potential revenue for actions to solve leakage realistically, effectively and efficiently. Economic analysis was carried out to determine investment feasibility of corrective actions for leakage of clean water network infrastructure. More importantly, variables in this study were obtained from literature review. Primary and secondary data were then collected and analyzed statistically, and other economic analysis tools were also used. This study used a quantitative method with a population of 11 (eleven) service zones involving 35 leaders, executors and staff of leakage team. All populations of service zone were taken as research sample, while for leakage team, sample was taken using Slovin formula which obtained 32 respondents. Questionnaires were distributed to find the main affecting factors using AHP (Analytical Hierarchy Process) method with the help of Expert Choice software Results of this study indicated that there were basically five main factors causing water loss due to infrastructure leakage. Handling infrastructure leakage could reduce rate of physical water leakage by 48.5% (from 11.38% to 5.86%) of the total physical losses per year. In addition, return on investment was obtained in year 3, while profits were earned in year 4.

**Keyword** Infrastructure Leakage, Costs, Clean Water Network, GIS

## 1. Introduction

One of the strategic issues in infrastructure development framework of the Ministry of National Development Planning/National Development Planning Agency – BAPPENAS (BPPSPAM, 2017) until 2024 is increasing water, food and energy security. Here, target of National Medium-Term Development Plan (RPJMN) is that raw water capacity is 118.3m$^3$/second. The existence of strategies and policies; improving network services and fulfilling quality of raw water services, is expected to accelerate process of achieving target of 100% clean water access and 15% safe drinking water target as mandated by the 2020-2024 RPJMN. However, many drinking water companies in developing countries, including Indonesia, are still struggling to ensure that their customers receive an adequate supply of safe clean water, which is often channeled through inadequate pipelines with weak record systems and low levels of technical and technological skills. This resulted in significant loss of clean water, known as Non-Revenue Water (NRW) [1]. Infrastructure leakage is one of indicators of poor infrastructure planning and construction [2]. Infrastructure Leakage Index (ILI) is an excellent indicator of physical loss that considers how clean water network infrastructure is managed. The index is especially useful in networks where Non-Revenue Water (NRW) is relatively low, for example below 20%, as the index can help to identify which areas should be reduced further [3]. Furthermore, sustainable infrastructure is an important investment. Improving operational efficiency is one of points that need to be answered [4]. Infrastructure development and maintenance policies are basically responsibility of government, which can also work in synergy with private sectors aimed at achieving community welfare [5]. Efficient and extensive infrastructure aims to ensure effectiveness of economic function [6]. Infrastructure development is expected to increase accessibility, competitiveness of a region, and integrate domestic and international markets at competitive costs and on time [7]. Chronic losses from leakage have characterized most water companies in most parts of the world over the past few decades [8]. This may not be a big concern since it is still assumed to be an era of abundance of water resources [1]. This study is necessary considering facts that the aging infrastructure is a problem that must be resolved; there is an increase in the need for clean water supply for the community; availability of funds is limited; and there is a refocus of budget to other areas that are also urgent [9].

## 2. Methods

This study is a descriptive quantitative and qualitative research involving a population of 11 service zones (Table 1). It involved 35 leaders, executors and staff of leakage team as respondents. All of service zones were taken as the research sample, while for leakage team, sample was taken using the Slovin formula which obtained 32 respondents. Questionnaires were distributed to find the main affecting factors using AHP (Analytical Hierarchy Process) method with the help of Expert Choice software. The service zone data can see below:

**Table 1**. Production Capacity and Service Zone

| No | Name of Water Treatment Plant (WTP) | Production Capacity (Liter/ Second) | Location | Service Zone |
|---|---|---|---|---|
| 1 | Cikokol WTP | 1575 | Cikokol | Zone Kota - B |
| 2 | Perumnas WTP | 120 | Perumnas 1 | Zone A |
| 3 | Serpong WTP | 3000 | Serpong | Zone A - F - D |
| 4 | Babakan WTP | 80 | Babakan | Zone A - B |
| 5 | Bojong Renget WTP | 200 | Bojong Renged | Zone B-C |
| 6 | Solear WTP | 200 | Solear | Zone E |
| 7 | Kronjo WTP | 7,5 | Kronjo | Zone C |
| 8 | Pasar Kemis WTP | 2,5 | Pasar Kemis | Zone C |
| 9 | Kresek WTP | 15 | Kresek | Zone C |
| 10 | Mauk WTP | 15 | Mauk | Zone C |
| 11 | Rajeg WTP | 25 | Rajeg | Zone C |
| | | 5240 | | |

Quantitative data were obtained by conducting water balance analysis due to physical loss of water caused by infrastructure leakage. Besides, qualitative data were obtained from questionnaire distribution to respondents who had previously tested validity and reliability with the help of SPSS (Statistical Product and Service Solutions) software.

## 3. Results and Discussion

### 3.1. Affecting Factors

Factors affecting physical leakage can be seen in Figure 1. In the diagram, there are factors that can affect physical losses that have potential to recover and physical losses that can be minimally achieved. There are four pillars of a leakage management strategy including pressure management, speed and quality of repair, active leakage control, and asset management (Figure 1). These factors influence how much leakage is managed in terms of volume and economic value at any distribution network utility [10]. Analytic Hierarchy Process (AHP) approach proposed by Saaty in 1980 is applied for evaluation of technical performance of each water pipe in a water distribution system (WDS) [11].

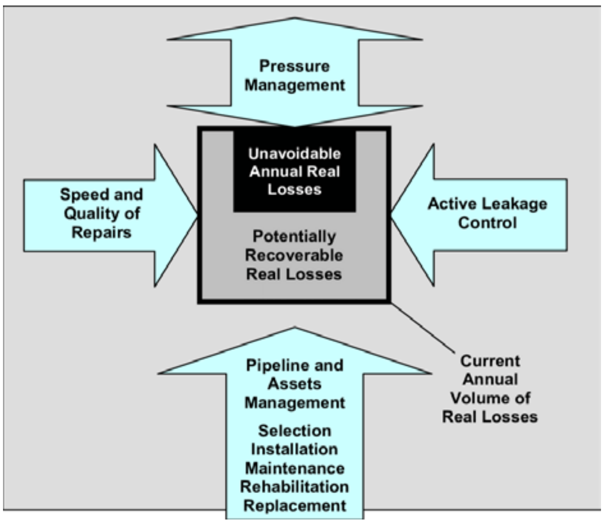


**Figure 1.** Affecting Factors

### 3.2. Main Affecting Factors

In this study [12], main affecting factors were analyzed by distributing questionnaires and using Analytic Hierarchy Process (AHP) with the help of Expert Choice software with the following results:

**Table 2**. Ranks of Main Influential Sub Factor

| Rank | Main Factors | Weight |
|---|---|---|
| 1 | Active Leakage Control | 0.488 |
| 2 | Speed and Quality of Repair | 0.251 |
| 3 | Pressure Management | 0.157 |
| 4 | Asset Management | 0.103 |

Based on Table 2, it is known that active leakage control received the highest score of 48.8%, followed by speed and quality of repair obtaining 25.1%, pressure management obtaining 15.7% and asset management obtaining 10.3%. Those are the order of factors affecting physical leakage which is infrastructure leakage of service network. Active leakage control means that efforts to overcome leakage are actively and not passively waiting for leakage report, which is the highest factor that must be done to overcome infrastructure leakage of clean water networks.

### 3.3. Affecting Sub-Factors

Based on four main factors (Table 3), there are 10 sub-factors affecting those four main factors, with the top 5 factors including unreported leakage of 23.3%, average pressure of 12%, reported leakage of 9.8%, pump operation control of 7.5%, and Average flow in leakage of main pipe and connection of 7.3%.

### 3.4. Infrastructure Leakage Index (ILI)

This index is principally used to predict level of infrastructure leakage so that management can get an overview of what actions to take when index calculation results are obtained. The following table (Table 4) is ILI value and interpretation of ILI value to assess condition of network infrastructure leakage level.

**Table 3**. Affecting Sub-Factors

| Rank | Sub-Factors | Main Factors | Weight | Percentage |
|---|---|---|---|---|
| 1 | Unreported Leakage | Active Leakage Control | 0.233 | 22% |
| 2 | Average Pressure | Speed and Quality of Repair | 0.120 | 11% |
| 3 | Reported Leakage | Active Leakage Control | 0.098 | 13% |
| 4 | Pump Operation Control | Pressure Management | 0.075 | 10% |
| 5 | Average flow in leakage of main pipe and connection | Speed and Quality of Repair | 0.073 | 10% |
| 6 | Background Losses | Active Leakage Control | 0.062 | 8% |
| 7 | Repair time for service pipe and connection leakage | Speed and Quality of Repair | 0.055 | 7% |
| 8 | Pipe Network Installation | Asset Management | 0.049 | 7% |
| 9 | Number of Unreported and Reported Leakage at main and service pipes | Speed and Quality of Repair | 0.047 | 7% |
| 10 | Average hours of service | Speed and Quality of Repair | 0.043 | 6% |

**Table 4**. ILI Value and Its Interpretation

| ILI Value | Interpretation of Value |
|---|---|
| < 3 | Repair of Leakage Will Not Be Economical, unless raw water is very less available. |
| 3 - < 4 | |
| 4 - < 6 | It is potential to handle leakage with economic level analysis. |
| 6 - < 8 | |
| 8 - < 12 | Bad leakage is tolerated only when abundant water is available. |
| 12 - < 16 | |
| 16 - < 24 | Too bad, a high priority leakage treatment program |
| 24 < | |

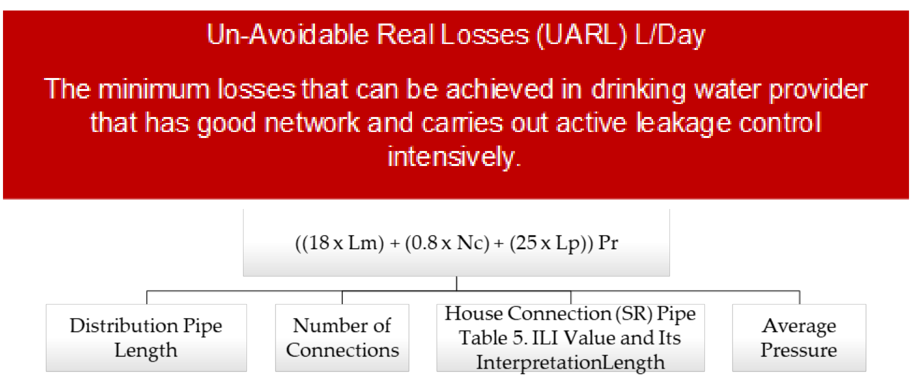


**Figure 2**. Component of Calculation of Infrastructure Leakage Index Value

Data base components as in Figure 2 above in this study were collected, which were then calculated in leakage Infrastructure Index calculation formula shown in Equation 1 below.

$$\frac{CARL;Current\ Annual\ Physical\ Losses}{UARL;Un-Avoidable\ Real\ Loses} \quad (1)$$

$$UARL = ((18\ x\ Lm) + (0.8\ \text{x Nc}) + 25\ \text{Lp})\ \text{x Pr}$$

Description:
Pr = Pressure, average pressure of distribution (meter)
Lm= pipe length (meter)
Nc = Number of customer connections
Lp = Total customer pipeline

**Table 5**. Zone Order with Highest to Lowest ILI Value

| Order | Zone | ILI Value |
|---|---|---|
| 1 | Zone A | 7.95 |
| 2 | Zone B | 7.71 |
| 3 | City Zone | 7.51 |
| 4 | Zone D | 5.63 |
| 5 | Zone E | 5.61 |
| 6 | Zone F | 5.41 |
| 7 | Zone C | 5.03 |

Referring to Table 5, it is known that the highest leakage index value is located in Zone A area (Perumnas Tangerang, some areas in Babakan, and some areas in Serpong) with a leakage index value of 7.95, followed by Zone B area of 7.71 (Soekarno Hatta Airport, Teluk Naga, etc). It is then followed by City Zone area (covering Tangerang, Karawaci, Cikokol, etc.). For other areas, leakage index value is below 6 (<6), which is relatively not bad since infrastructure network is newer than zones A, B and City. Since water leakage is underground water where it is not clearly visible, we cannot determine its movement direction, if we do not dig and drill to it [23]

### 3.5. Geographic Information System (GIS)

Before utilizing spatial data, Regional Drinking Water Company (PDAM) relied on data in the form of printed technical drawings, Computer-Aided Design (CAD), memories from senior staff, and tabular meter recording data [13]. GIS technology in this research is using QGIS 3.10.10 Grass 7.8.3. Geographic Information System (GIS) is categorized as a powerful tool among all information technologies as it integrates multiple cross-sectoral environments to be combined. GIS allows all interconnected spatial and non-spatial data in water supply network to be stored on a unique basis. This allows respective utilities to be managed and supports planning process. Accordingly, implementing GIS allows management to provide services in an efficient procedure [14].

Figure 3 shows a map that has divided service area into appropriate service zones, but it only shows coverage area of the service area.


**Figure 3**. GIS Map Prior to This Study

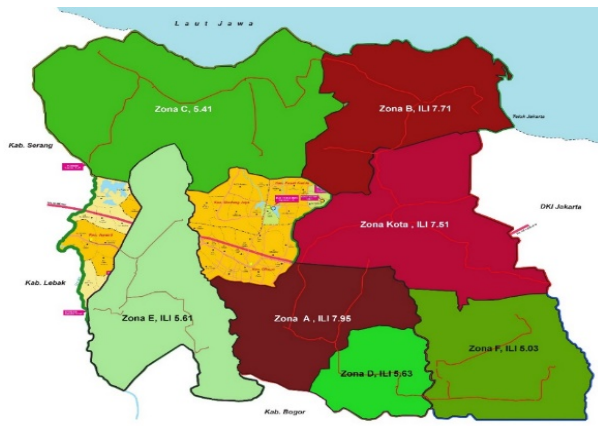


**Figure 4**. GIS Map After This Study

Figure 4 demonstrates that service zone coverage map is provided with a stain according to infrastructure leakage index value for clean water network. It describes condition of complete distribution network with its index value to get important attention in maintaining network infrastructure. The geospatial information is important to maintain sustainability of clean water infrastructure network in serving needs of wider community.

### 3.6. Economic Analysis

#### 3.6.1 Economic Level of Leakage

Economic level of leakage is basically level of leakage that is no longer economical if the level is below the level of water loss, meaning that the cost of reducing water loss is greater than benefits that can be obtained [15]. Thus, level of leakage of clean water infrastructure network currently occurring still has great potential for reduction. However, reduction of water loss entails costs for investment as well as for water loss reduction operation [16]. In fact, management of drinking water providers must have a degree of limitation in providing costs [17]. This research found that level of leakage which is still economical for repair to continue is 48.5% of the total physical loss. Figure 5 illustrates cost and water loss relation

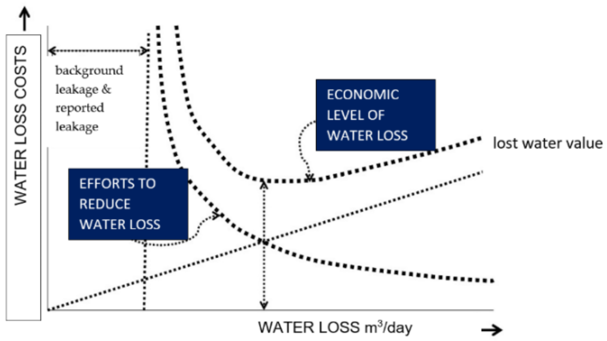


**Figure 5**. Economic Level of Leakage

3.6.2. Internal Rate of Return (IRR) Analysis

IRR is used to determine feasibility of an investment plan and corresponds to discount rate used to make net present value equal to zero. Project is considered feasible if the IRR is greater than cost of project financing (financing interest) [18]. On the other hand, project is not feasible if IRR value is greater than financing interest. IRR is also able to be compared with rate of return that will be obtained from an investment if it is chosen to put money into a number of investment portfolios [19]. However, calculating IRR can be complicated for projects whose costs and revenues are spread over several periods. It is because the calculation solution involves root of a polynomial whose degree corresponds to number of periods discounted [20]. Equation 2 below is IRR calculation formula.

$$IRR = \frac{(\text{Cash flows})}{(1+r)^i} - \text{Initial Investment} \quad (2)$$

Where:
Cash Flow = Net cash inflow during the period i
r = Discount Rate
IRR = Internal Rate of Return
i= Time Period

Table 6 is IRR calculation using spreadsheet excel for investment in handling infrastructure leakage of clean water networks in this study.

Investments in handling leakage are medium or long term investments (the Ministry of Public Works and Housing, 2018). Most physical leakage infrastructure problems are not profitable in short term. Consequently, dealing with physical leakage is not attractive to several clean water company management [21]. It can be seen in Table 6 above that in years 1, 2 and 3, investment is still losing. Entering year 4 onwards, investment in handling leakage has begun to show positive revenue results. Moreover, in year 4, even though the investment is positive, it is still below bank interest rate of 14%. Therefore, by calculating the IRR, year 3 still experiences a loss or is not feasible. Years 4 onwards, based on IRR, are feasible and profitable. Many strategies were adopted, the most important strategies related to this concept are reducing the natural resources consumption, reusing and recycling water and waste, and promoting the use of smart technologies [22].

**Table 6**. Internal Rate of Return

| Year | Revenue | Return | IRR |
|---|---|---|---|
| 0 | -20.084.111.319,00 | -20.084.111.319,00 | 0 |
| 1 | 7.210.707.091,83 | -12.873.404.227,17 | -64% |
| 2 | 6.514.937.109,29 | -6.358.467.117,88 | -22% |
| 3 | 5.886.302.826,81 | -472.164.291,06 | -1% |
| 4 | 5.318.326.238,26 | 4.846.161.947,20 | 10% |
| 5 | 4.805.154.408,25 | 9.651.316.355,45 | 16% |
| 6 | 4.341.499.158,33 | 13.992.815.513,79 | 20% |
| 7 | 3.922.582.572,88 | 17.915.398.086,67 | 22% |
| 8 | 3.544.087.763,22 | 21.459.485.849,89 | 23% |
| 9 | 3.202.114.382,56 | 24.661.600.232,44 | 24% |
| 10 | 2.893.138.433,36 | 27.554.738.665,80 | 25% |

# 4. Conclusions

Referring to results of analysis of factors of how the index is applied using AHP method, the most dominant factor is Active Leakage Control with affecting sub-factors, sequentially, including unreported leakage, reported leakage and background losses. In addition, analysis of realistic strategic designs is used to handle or mitigate infrastructure leakage effectively and efficiently. Thus, it is found that level of leakage which is still economical for repair to continue is 48.5% of the total physical loss.

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