Potential Risk Analysis of Water Loss in Water Distribution Networks

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Abstract. Water loss is a serious problem in the world of drinking water management. In addition to disrupting services that result in economic losses, pipe leaks can cause health problems if contamination occurs. In this paper, the author will conduct a potential risk analysis causing water loss to address technical problems in the management of transmission and distribution pipelines in the Regional Water Supply System of Bregas in Central Java, Indonesia. The author tries to present a simple method for assessing the potential risk of water loss from the physical aspects of the network and the environment with passive control. Passive control is a reaction to leaks that are usually reported by customers or recorded by company staff. This study concludes that the pipe condition had the highest potential risk compared to other factors. Transmission pipelines from Kaligiri and Gombong springs are considered to have the highest risk of water loss. Although incomplete, this research can be a valuable reference source for practitioners and researchers dealing with water loss management in distribution systems and providing a road map for future research.

1. Introduction

Water loss in the water distribution network is a serious problem in drinking water management in the world [1]. Farley [2] said leakage is one of the crucial issues that must be faced to improve the efficiency and effectiveness of water and sanitation services. Leakage results in economic losses [3] and also cause health problems when contamination occurs in the water distribution network [4]. In this paper, the author will conduct a potential risk analysis causing water loss to address technical problems in the management of transmission and distribution pipelines in the Regional Water Supply System (RWSS) of Bregas in Central Java, Indonesia.

The standard approach in defining and measuring the components of water loss in the world is using water balance (table 1). Many factors contribute to water loss such as aging infrastructure, high pressure, corrosion to the external and internal pipes, poorly designed and constructed water distribution networks, measurement errors, illegal use, and poor operation and maintenance [4]. In the potential risk of water loss analysis, the authors focus on physical losses by considering several factors causing water loss include: operational pressure, soil movement, pipe conditions, poor quality of pipes, fittings and construction work, soil character, traffic loading and age [2].
### Table 1. The international water balance

| System Input Volume | Authorized Consumption | Unbilled Authorized Consumption | Billed Authorized Consumption | Revenue Water |
|---------------------|------------------------|---------------------------------|-------------------------------|---------------|
|                     | • Billed Metered Consumption | • Unbilled Metered Consumption  | • Billed Unmetered Consumption | Non-Revenue Water |
|                     | • Unbilled Unmetered Consumption | • Unauthorized Consumption   | • Metering Inaccuracies and Data Handling Errors |   |
|                     | • Leakage on Transmission and/or Distribution Mains | • Leakage and Overflows at Utility’s Storage Tanks | • Leakage on Service Connections up to Point of Customer Metering |   |

Source: International Water Association

2. Passive control

Passive control is a reaction to a leak seen due to bursting or falling pressure, which is usually reported by customers or recorded by company staff [2]. This method can be justified in areas with plentiful supplies or low cost, and often practiced in less developed supply systems where underground leaks are not so well understood. No previous studies have conducted a potential risk assessment of the water distribution network. Considering the different characteristics of the water distribution network in each country, the author tries to present a simple method for assessing the potential risk of water loss from the physical aspects of the network and the surrounding environment in order to provide recommendations for the next steps related to pipe repair or replacement.

In this passive control, three parameters are assessed for the factors that contribute to physical losses in the water distribution network under study. High level if these factors have the potential to occur frequently. Medium level indicates that the factors considered rarely contribute to water loss. While low level means there was a little effect or no effect on water loss. The results of the potential risk of water loss analysis are paired with the number of repairs at each location.

3. Bregas Regional Water Supply System (RWSS)

Drinking water services by the Perusahaan Daerah Air Bersih (PDAB) Tirta Utama which is the Regional Water Company of Central Java Province in the area of Brebes Regency, Tegal City and Tegal Regency, which are then called Bregas Regional Water Supply System (RWSS), are one of the government's solutions to address drinking water needs in the region, especially Tegal City which has no potential source of raw water. The total production capacity of 850 liters/second is taken from 6 springs on the slopes of Mount Slamet, namely Kaligiri springs, Gombong springs, Banyumudal springs, Suci springs, Serang springs, and Suniarisih springs. Each of them has a capacity of 225 liters/second, 65 liters/second, 130 liters/second, 250 liters/second, 135 liters/second and 45 liters/second. The location of the six springs is at an altitude of 700 - 1800 meters above sea level. Full gravity flow systems utilize different heights to serve service areas at elevations of 1 - 50 meters above sea level. There are 32 pressure releaser tanks spread over each spring, two collecting tanks, and three reservoirs with a total capacity of 11,000 cubic meters. The total length of the Bregas Regional Water Supply System's transmission and distribution pipeline is 164,711 m using various types of pipe material including asbestos, polyvinyl chloride (PVC), polyethylene (PE), and galvanized.

Bregas RWSS serves around 250,000 people in the service area of Brebes Regency, Tegal City, and Tegal Regency, around 7.14% of the total administrative population in the region. In addition, to receive services from PDAB, the three regions have their own distribution networks to serve their
communities. The recorded water loss is based on water balance data in the Kaligiri Cs. (consist of Kaligiri and Gombong springs) by 41.38%. While in the Banyumudal Cs. pipeline network (consist of Banyumudal, Suci, Serang, and Suniarish springs) water loss reached 18.75%. This was the author's reason in doing research in order to determine appropriate and economic steps to reduce water loss.

![Contour-Based of Bregas RWSS transmission and distribution Network Map with 50-meter intervals](image)

**Figure 1.** Contour-Based of Bregas RWSS transmission and distribution Network Map with 50-meter intervals

4. **Results and discussion**
A passive control assessment was carried out on events in the field and literature understanding. The Bregas RWSS network has been assessed based on factors that potentially cause leakage risks.
4.1. Operational pressure
High pressure is potentially causing pipe leaks in pipe joints and weak pipe sections. High pressure caused by hydraulic transients can cause pipe break, negative pressure can cause pipe collapse, cavitation can cause pipe erosion and damage to the pump impeller, and the transient force can loosen the pipe connection [5].

Placement of pressure releaser tanks in Bregas RWSS pipeline reduces the pressure load on the transmission pipeline. The pressure returns to zero. The maximum pressure under normal conditions can be predicted because the flow uses a gravity system, but the pressure can increase if there is air blockage in the pipe. Potential water loss caused by operational pressure is assessed to occur in the distribution pipeline at night, which has minimum flow. A typical pressure-demand relationship in a water distribution network where (average) pressure drops when there is high demand and rises when there is less demand, at night or morning [6]. Gravity system puts the potential risk of loss of water in the medium level.

4.2. Soil movement
Soil movement occurs due to increased water content in the soil, especially for the soil type of clay. If it occurs at a sloped location, the clay will move down. The pipe could be broken, or the pipe connection is separated due to soil movement. The same thing can also occur in fault areas. The right combination of welding joints and gaskets can offer a good solution for buried steel pipes built in earthquake zones [7]. The use of galvanized pipe types is recommended to be used if the pipeline network requires passing through areas with soil movement. With a strong structure, galvanized pipes can withstand temporarily in the event of soil or fault movement, giving workers less time to provide handling.

Potential damage to the pipe in the event of a pipe shift at Bregas RWSS occurred in the transmission pipeline segment of the Kaligiri spring along 3.2 kilometers in Dukuhbenda Village, Tegal Regency. Land movement also occurs in the Gombong spring complex in Muncanglarang Village, Tegal Regency. The water catchment building is damaged and utilizing a temporary catching building with close supervision to guard external contamination. In another transmission system, the transmission pipeline network from the Suci spring passes through a fault area in the Kalibakung Village, Tegal Regency. This land fault occurred with an 8-year return. The last incident occurred in 2015.

4.3. Pipe conditions
The problem that must be considered is the corrosion of the iron pipe, both inside or outside the pipe. The asbestos pipe is also susceptible to corrosion regarding sulfate content in soil and water. Basically, failure type of identification depends on the pipe around it, the material of the pipe, and the mechanism and pressure that supports the pipe [8]. Pipelines that have high potential risk for corrosion are in the transmission and distribution pipelines of the Kaligiri spring and Gombong springs. The high potential risk for corrosion occurs due to the type of pipe material used for this network: iron (20%) and asbestos (80%).

4.4. Poor quality of pipes, fittings and construction work
In this category, there are many kinds of equipment cause losses both at the customer's location and on the pipeline. Broken faucet, bad air valve, and overflow at pressure releaser tank will disrupt the system and service to customers. System and service disruption is caused by poor operation and maintenance, lack of active leakage control, and poor quality of underground assets [1]. Routine inspection and immediate repair of equipment that is not properly functioning will reduce the potential for water loss. PDAB officers check equipment and buildings periodically so that any findings of damage can be handled immediately.
4.5. Soil character

Sandy soil with high porosity will not bring water to the surface if a leak occurs. Water that leaks will immediately seep into the ground. While the type of soil with low porosity will quickly saturate, and water will immediately appear to the surface [2]. Based on the Geological Map of the Purwokerto and Tegal Quadrangles from the Indonesian Geological Research and Development Center, the soil character in the transmission pipeline is in the form of volcanic breccia, lava, tuff, and lava with lumps of rock andesite. While the distribution pipelines are in the alluvium zone in the form of gravel, sand, silt, and clay. From this information, water leaks in the transmission and distribution network can be immediately detected.

4.6. Traffic loading

The impact of heavy vehicle vibrations causes a serious rupture of pipes embedded under the highway. The buried pipe depth and traffic load are important determinants of stress distribution. Weight, speed, and the pattern of car size settings play an important role in causing variations pressure in the pipe [9]. Along with the development of settlements and road infrastructure in several sections which have widened, resulting in pipelines that were previously buried on the edge of the road to be directly under vehicle traffic. The transmission and distribution networks of the Kaligiri and Gombong springs are potentially damaged because the pipeline is affected by road widening while the installation of transmission and distribution pipelines from other springs has been buried in a safe position from the influence of traffic loads.

| Location of pipe | The level of potential risk of pipe leakage | Number of repairs in 2018 (PDAB) |
|------------------|------------------------------------------|---------------------------------|
| **Transmission pipelines from Kaligiri Cs.** | | |
| Operational pressure | Ground movement | Pipe Condition | Poor quality of pipes, fittings and construction work | Soil character | Traffic load | Age | |
| Low | High | High (Steel) | Low | Low | High (32 yo) | 301 |
| Medium | Low | High (Asbestos) | Low | Low | High (32 yo) | 131 |
| **Transmission pipelines from Banyumudal Cs.** | | |
| Operational pressure | Ground movement | Pipe Condition | Poor quality of pipes, fittings and construction work | Soil character | Traffic load | Age | |
| Low | Medium | Low (Galvanized) | Low | Low | Low | 11 |
| Medium | Low | Medium (PVC) | Low | Low | Low | 19 |

| **Distribution pipelines from Banyumudal Cs.** | | |
| Operational pressure | Ground movement | Pipe Condition | Poor quality of pipes, fittings and construction work | Soil character | Traffic load | Age | |
| Medium | Low | Medium (PVC) | Low | Low | Low | 19 |

1 Kaligiri Cs. consist of Kaligiri and Gombong springs
2 Banyumudal Cs. consist of Banyumudal, Suci, Serang and Suniarisih springs

4.7. Age

The potential for pipe damage will be greater as the age of the pipe gets older. Thus, the age of the pipe can be the most significant factor causing pipe leakage. But not all pipes will fail in the future [10]. The Bregas RWSS transmission and distribution pipeline from the Kaligiri spring has been 32 years old since it was built in 1987. Then in 2002, the Gombong spring was extracted for the Kaligiri supply. While the development of Bregas RWSS from other springs was built in stages from 2012 to 2016. This system is relatively new. From the age category, leakage potential will most likely occur in the transmission and distribution network of the Kaligiri Cs. spring.
Factors that are potentially causing leakage in the Bregas RWSS transmission and distribution pipeline are summarized in Table 2. From the analysis of some potential pipeline leak risks, it can be concluded that the level of risk is directly proportional to the number of repairs based on the location of the leak. Pipeline conditions, pipe conditions, traffic loads and pipe life are the most potential factors causing the risk of water loss raised. A total of 432 leak repair works in one year were carried out by PDAB in the Kaligiri Cs. water distribution network. Soil movements in the Kaligiri Cs. transmission pipeline needs special attention by the manager because the potential risk is very high. The condition of this pipeline is considered to be the factor with the highest potential risk than other factors.

5. Conclusion
A passive control method is used to assess the potential risk of water loss in the Bregas RWSS transmission and distribution pipeline in Indonesia. This simple method is taken as a first step in determining the policy of operational planning and maintenance of the system in the future. Based on the passive control assessment, the Kaligiri Cs. transmission pipeline obtained 4 high-level potential risk factors for water loss from the seven existing factors. Potential risk factors for water loss is linear with the number of repairs carried out at that location. Pipeline conditions have the highest potential risk compared to other factors. So, it can be concluded that the handling of pipes in the Kaligiri Cs. transmission pipeline becomes the main priority by the manager to be repaired or replaced.

Water distribution network unique characteristics to the various problems that arise, prompting the authors to analyze the potential risk of water loss beforehand. In contrast to some previous studies conducted under normal conditions. Although simple, the authors believe the passive control method used in this study could assist the government or management in determining priority steps in dealing with the problem of water loss. Although incomplete, this research can be a valuable reference source for practitioners and researchers dealing with water loss management in distribution systems and providing a road map for future research.

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