



**KRI DESIGN AND MITIGATION STRATEGY ON WATER DISTRIBUTION OF  
PERUMDA AIR MINUM MAKASSAR REGIONAL IV: A Case Study**

**Yan Herdianzah<sup>1</sup>, Taufiq Immawan<sup>2</sup>**

Master of Industrial Engineering, Faculty of Industrial Technology, Islamic University of  
Indonesia

Jl. Kaliurang Km. 14,5 Sleman, Yogyakarta 55584

E-mail: yan.herdianzah@umi.ac.id,taufiq.immawan@uii.ac.id

**ABSTRACT**

Municipal Waterworks Corporation (PERUMDA AIR MINUM) of Makassar city currently finds many common risks in water distribution process. The risks cause a lot of damage to the piping network system, so that the quantity of distributed water to customers is not optimal. Consequently, it is necessary to handle the risks. This study aims to determine the risks that occur in water distribution process by using Delphi method to identify potential risks. Then, House of Risk (HOR) is used at the risk analysis and evaluation stage to determine mitigation strategies and Key Risk Indicators (KRI) is designed to determine the Early Warning System (EWS). Based on the results known that there are 16 identified risk events and 24 risk agents. Furthermore, a mitigation strategy is carried out on the risk agent by using 18 preventive actions. Based on the selected risk, coded as A24 with the indicator value is Information (Field Team) has lower threshold of 5 hours and upper threshold of

8.19 hours. Water loss has lower threshold of 3,118,047 m<sup>3</sup> and upper threshold of 3,283,688 m<sup>3</sup>. A1 as Expired indicator value has lower threshold of 20 years and upper threshold of 26 years and leaking pipes replacement has lower threshold of 15 years and upper threshold of 16 years 3 months 2 weeks. Further research is expected to be able to design KRI for the risks that do not have EWS yet.

**Keywords:** Risk of water distribution, Delphi, House of Risk (HOR), Key Risk Indicators (KRI).

**Article History:**

Submit 19 Agustus 2020

Received in from 2 September 2020

Acceted 25 September 2020

Avilable online 23 November

**Published By:**

Fakultas Teknologi Industri  
Universitas Muslim Indonesia

**Address :**

Jl. UripSumoharjo Km. 5 (Kampus II UMI)  
Makassar Sulawesi Selatan.

**Email :**

[Jiem@umi.ac.id](mailto:Jiem@umi.ac.id)

**Phone :**

+6281341717729

+6281247526640

Liscensed by: <https://creativecommons.org/licenses/by-nc-sa/4.0/>

DOI : <http://dx.doi.org/10.33536/jiem.v5i2.672>



## 1. Introduction

Regional Water Utility Company (PERUMDA) is one of government business units which distributes clean water to public (Lagu, et al 2016). In its activities, PERUMDA is required to distribute clean water based on Regulation of Ministry of Health of Republic Indonesia; PERMENKES No.416/ Menkes/Per/IX/1990 about the requirements of clean water quality (Gusril, 2016). In clean water distribution system, water quality may decrease due to the growth of biofilm inside distribution pipes which can cause pathogen retention (Wang et al., 2018; Han et al., 2020). Disinfectants diffusion will be obstructed, then lead the process to proliferation that creates unpleasant tastes and odors (Waller et al., 2018). The growth of amoebae and bacteria in the distributed water can cause technical complications and diseases in humans (Yu et al., 2018; Perrin et al., 2019; Puzon, et al 2020).

PERUMDA of Makassar city is not yet optimum in distributing clean water to its consumers, because the distributions to district Tamalanrea still need extra quantity, around 30.01 lt/second. The risk source is the availability of raw water in Lakopancing river which decrease from around 30.90  $m^3/s$  to 0.986  $m^3/s$  in dry season, caused by high water loss at 57.68% as the obstruction factor, as well as pipe networks system that is no longer adequate for its service areas (Lagu et al., 2016).

One of the strategies to reduce the risk impact is doing transfer risk (Toppel & Trankler, 2019). It needs to consider resources during risk analysis, and knowing the level of feasibility and needs for risk mitigation strategies (Dadsena et al., 2019). In Toppel & Trankler's research (2019); Thons & Stewart, (2019); Ceres et al., (2019) stated that risk mitigation strategy uses 3 main characteristics for strategy designing, they are the cost for implementing the strategy, the probability of risk occurrence, and risk mitigation measures which based on 3 mitigation indicators. The indicators are: (1) Cost-based risk and optimization, (2) Measuring and ensuring the significance in risk reduction, (3) Measuring and ensuring the possibility of high cost efficiency.

Previous research was conducted by Chen et al., (2019) about selection of key indicators on the risk of damage on industrial oil and gas pipelines by using Delphi and Fuzzy Analytic Hierarchy Process (FAHP) methods to prevent and reduce human, production, asset, and environmental losses. House

of Risk (HOR) is a method for managing risk proactively, where the risk event which identified as the cause (risk agent) can be managed by making order based on the dimension of the impact (Magdalena & Vannie, 2019). Shi et al., (2018) who developed Key Risk Indicators (KRI) for accident evaluation on vehicle trajectories before accidents was using 3 metrics as basic indicators : (1) risk behavior, (2) risk avoidance, and (3) risk margin. KRI was designed to evaluate risk severity. The research used hybrid method and hierarchical indicators.

This study added variables that differentiate it from previous studies. The variables used as indicators for designing Key Risk Indicators (KRI) were (1) Understanding risk behavior by doing risk identification to determine risk events and risk agents, (2) Performing risk analysis, (3) Evaluating the risks, (4) Designing risk mitigation strategies, and (5) Determining KRI.

Water distribution risk in PERUMDA consists of several problems including cloudy water, turbidity, damaged water distribution meters, and leaking pipes with the average risk level is above 30% (Purba et al., 2015). Other problems are corroded pipe, unidentified micro cracks on pipe networks, low water discharge, blockages in distribution pipes, damage in water control valves, seepage in water tanks, damage in distribution pumps, illegal connections (water theft), so that water supply to consumers is obstructed (Putra et al., 2017). PERUMDA Makassar still does not have an optimal risk management system. Thus, it is important to know the continuous risks, means that monitoring the occurred risks is necessary.

This research was conducted to determine the risks that occur in water distribution by using Delphi and HOR phase 1 methods, to propose mitigation strategies for reducing the impact of water distribution risk by using HOR phase 2, and to design KRI which can be used as the initial sensor for risk treatment of water distribution in Region IV Ratulangi of PERUMDA Makassar. By doing this research, it is possible to picture the risks in water distribution and to evaluate the efforts.

## 2. Research Method

This research was conducted at PERUMDA Makassar Region IV, South Sulawesi, Indonesia. The focus of this research was to identify risks in water distribution by using Delphi, then to measure, evaluate, and design the mitigation strategies by

using House of Risk (HOR) approach, as well as to design Key Risk Indicators (KRI).

## 2.1. Type of Data

### 2.1.1. Primary Data

The primary data in this research were obtained directly from sources or experts through observation, interviews, questionnaires, brainstorming, and focus group discussions (FGD) with a team led by Head Division of Distribution, Section Chief of Maintenance, Head Division of Engineering Planning, and Section Chief of Planning & Supervision of PERUMDA Makassar regarding risks potential in water distribution process, severity evaluation (risk event), occurrence (risk agent), correlation between risk events and risk agents, determining and weighting the difficulty level of mitigation strategies, determining Key Risk Indicators (KRI) matrix, and weighting The Gap Assessment Tool.

### 2.1.2. Secondary Data

Secondary data were obtained not directly from the company, but through other sources, such as company documentation in form of company photos, journals from 2000 to 2020, books, so on. The secondary data supported primary data.

## 2.2. Methods of Data Processing and Analysis

Data processing in this study used Delphi method to identify potential risks in water distribution with the indicators were consisted of piping, supply / storage, facilities, planning, and monitoring. Furthermore, statistical data processing was carried out, which was determining the average value (mean), middle value (median), standard deviation, and Inter-Quartile Range (IQR).

The next step was using House of Risk (HOR) phase 1 to weight the severity of risk event and the occurrence of risk agent as well as the correlation evaluation from both to obtain Aggregate Risk Priority (ARP). HOR phase 2 determined the mitigation strategy, as well as the evaluation of difficulty level in each treatment obtained from the results of focus group discussions (FGD) with experts.

The last step in determining key risk indicators (KRI) was by performing rootcause analysis to determine matrix and weighting indicators in the gap assessment tool, so that further analysis can be carried out to determine early warning system (EWS).

The indicators that used to identify potential risks in water distribution process were as follows:

**Table 1. Indicator and Risk Potential of Water Distribution**

| Indicators             | Risk Potential                                                            |
|------------------------|---------------------------------------------------------------------------|
| Piping                 | Corrosion in distributing pipe                                            |
|                        | Damage in water distribution pipe to customer's house                     |
|                        | Underground installed pipes are dented and difficult to identify          |
|                        | Micro cracks in the distribution pipe network which difficult to identify |
|                        | Depletion of wall of distribution pipe                                    |
|                        | The water discharge obtained by the customer is low                       |
|                        | Clogs in distribution pipe                                                |
|                        | Damage in water control valve                                             |
| Supplies/Storage       | Accidental damage of a single pipe (pipe burst)                           |
|                        | Leakage in pipe connection                                                |
|                        | Water discharge in the reservoir decreases                                |
| Facilities             | Damage in distribution pump                                               |
|                        | Damage in water distribution meter                                        |
| Planning & Supervising | Premature aging of water distribution equipment                           |
|                        | The occurrence of illegal connections (water theft)                       |
|                        | Water loss in distribution process                                        |

## 3. Result and Discussion

### 3.1. Risk Identification

The identification of risk event in water distribution used HOR phase 1. Based on Delphi

consensus, 16 risk events were obtained. Table 2 showed the result of risk identification.

**Table 2. List of Risk Event and Severity Evaluation**

| No | Risk Event                                                                | Code | Severity |
|----|---------------------------------------------------------------------------|------|----------|
| 1  | Corrosion on distribution pipe                                            | E1   | 6        |
| 2  | Damage in water distribution pipe to customer's house                     | E2   | 8        |
| 3  | Underground installed pipes are dented and difficult to identify          | E3   | 6        |
| 4  | Micro cracks in the distribution pipe network which difficult to identify | E4   | 6        |
| 5  | Depletion of wall of distribution pipe                                    | E5   | 5        |
| 6  | The water discharge obtained by the customer is low                       | E6   | 9        |
| 7  | Clogs in distribution pipe                                                | E7   | 7        |
| 8  | Damage in water control valve                                             | E8   | 6        |
| 9  | Accidental damage of a single pipe (pipe burst)                           | E9   | 9        |
| 10 | Leakage in pipe connection                                                | E10  | 6        |
| 11 | Water discharge in the reservoir decreases                                | E11  | 5        |
| 12 | Damage in distribution pump                                               | E12  | 7        |
| 13 | Damage in water distribution meter                                        | E13  | 6        |
| 14 | Premature aging of water distribution equipment                           | E14  | 5        |
| 15 | The occurrence of illegal connections (water theft)                       | E15  | 10       |
| 16 | Water loss in distribution process                                        | E16  | 8        |

Table 2 above shows the weighted results of severity value of each risk event. After perceiving the category of each risk, the next step determined

the source of risk (risk agent). The following table 3 is a list of risk sources for each risk event and weighting of occurrence value.

**Table 3. List of Risk Agent and Occurrence Weighting**

| No | Risk Agent                                                          | Code | Occurrence |
|----|---------------------------------------------------------------------|------|------------|
| 1  | The technical life of pipes passed its usage limit                  | A1   | 5          |
| 2  | Drainage excavation                                                 | A2   | 6          |
| 3  | Excavation of cable installation from external parties              | A3   | 5          |
| 4  | Load vibration from the surface                                     | A4   | 5          |
| 5  | Lackness in automatic pipe monitoring system                        | A5   | 8          |
| 6  | Does not have early warning system                                  | A6   | 7          |
| 7  | Erosion Corrosion (Erosion of pipe walls)                           | A7   | 5          |
| 8  | Numbers of damaged water control valves                             | A8   | 4          |
| 9  | Damage in water treatment plant                                     | A9   | 4          |
| 10 | Lack of water pressure                                              | A10  | 6          |
| 11 | Considerable amount of material carried away when heavy flow        | A11  | 4          |
| 12 | Clogged by tree roots                                               | A12  | 4          |
| 13 | The valves passed its useful limit                                  | A13  | 9          |
| 14 | High pressure from the outside part                                 | A14  | 4          |
| 15 | Pipes quality does not meet the standard                            | A15  | 3          |
| 16 | Pipelines that doesn't set under supervision                        | A16  | 4          |
| 17 | Leaks or seepage on reservoir                                       | A17  | 5          |
| 18 | Unstable electrical voltage from PLN (National Electricity Company) | A18  | 4          |
| 19 | Pumps exceeded its service limit                                    | A19  | 2          |
| 20 | The water meter is too old                                          | A20  | 9          |
| 21 | Lackness in equipment maintenance                                   | A21  | 5          |
| 22 | Lack of supervision from internal company parties                   | A22  | 10         |
| 23 | In-house pipe installations                                         | A23  | 4          |
| 24 | Undetected leakage                                                  | A24  | 8          |

From the table above known that there were 24 risk agents with the occurrence value of each risk agent. The occurrence values and the severity values

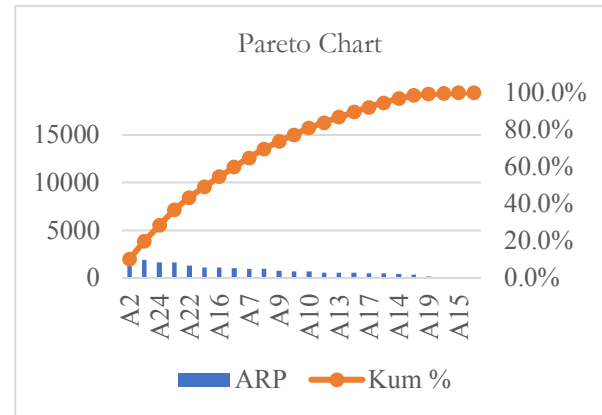
of risk event became the input for house of risk phase 1. Furthermore, it also used the correlation values between risk event and risk agent.

### 3.2. Risk Analysis

Risk identification was the last step of HOR phase 1. Based on the measurement in table of HOR phase 1, severity value of risk event, occurrence value of risk agent, and correlation between risk event and risk agent were shown. In addition, Aggregate Risk Potential (ARP) values and the ranking of risk agents which being prioritized for risk mitigation were obtained. From the identification results, there were 16 risk events and 24 risk agents. The calculations of ARP values were carried out to determine the prioritized risk agents to be mitigated. The results of ARP formed in pareto chart with the principle ratio was 80:20.

### 3.3. Risk Evaluation

Based on obtained ARP value from the measurement on HOR phase 1, the next step was determining dominant risk agent with pareto chart. The measurement was to determine the source of dominant risk. Pareto chart was made by using cumulative percentage of each ARP values of risk agent. Picture 1 below shows the pareto chart of risk agents.



**Figure 1. Pareto Chart of Risk Agent**

The basis of risk evaluation in HOR phase 1 was a pareto diagram based on ARP value of risk agents which were prioritized for treatment. 80:20 principle ratio was used in this risk evaluation. 77.3% risk agents were taken to design handling strategy which was expected to help the improvement of other 22.7% risk agents. There were 12 dominant risk agents out of a total of 24 risk agents in water distribution activities. The following table 4 contains the lists of dominant risk sources.

**Table 4. Dominant Risk Agent Before Treatment**

| No | Code | Risk Agent                                             | ARP  | Severity | Occurrence |
|----|------|--------------------------------------------------------|------|----------|------------|
| 1  | A2   | Drainage excavation                                    | 1980 | 9        | 6          |
| 2  | A5   | Lackness in automatic pipe monitoring system           | 1904 | 7        | 8          |
| 3  | A24  | Undetected leakage                                     | 1656 | 9        | 8          |
| 4  | A12  | Clogged by tree roots                                  | 1608 | 8        | 4          |
| 5  | A22  | Lack of supervision from internal company parties      | 1300 | 8        | 10         |
| 6  | A3   | Excavation of cable installation from external parties | 1110 | 6        | 5          |
| 7  | A16  | Pipelines that doesn't set under supervision           | 1068 | 7        | 4          |
| 8  | A23  | In-house pipe installations                            | 1004 | 7        | 4          |
| 9  | A7   | Erosion Corrosion (Erosion of pipe walls)              | 975  | 7        | 5          |
| 10 | A1   | The technical life of pipes passed its usage limit     | 960  | 9        | 5          |
| 11 | A9   | Damage in water treatment plant                        | 780  | 7        | 4          |
| 12 | A6   | Does not have early warning system                     | 700  | 6        | 7          |

After knowing the list of prioritized risk sources, a dominant risk mapping was carried out with the aim of seeing risk conditions before

mitigation. The mapping aimed to see risk conditions before mitigation. The position of dominant risk source shown in Figure 2 below:

|                         |           |                   |     |        |                   |           |
|-------------------------|-----------|-------------------|-----|--------|-------------------|-----------|
| Probability (Occurance) | Very High |                   |     |        | A22               |           |
|                         | High      |                   |     | A6     | A5                | A24       |
|                         | Medium    |                   |     |        |                   | A2        |
|                         | Low       |                   |     | A3     | A7                | A1        |
|                         | Very Low  |                   |     |        | A12, A16, A23, A9 |           |
|                         |           | Very Low          | Low | Medium | High              | Very High |
|                         |           | Impact (Severity) |     |        |                   |           |

**Figure 3. Risk Map Before Mitigation**

In Figure 3 above, there are 3 levels of risk. Red means high risk, yellow is medium risk, and green is low risk. The map shows that the agents with codes A24, A2, A1, A22, A5, A7, and A6 are considered as high so that they needed to be handled as soon as possible. Meanwhile, risk agents with codes A12, A16, A23, A9, and A3 are medium, thus necessary to carry out routine handling and effective control. From this map can be concluded that to design a mitigation strategy in PERUMDA Makassar is necessary, so that water distribution is properly done.

### 3.4. Designing Mitigation Strategy

There are several prioritized mitigation that need to be carried out to reduce the impact of risk sources. The following is the sequences of mitigation priority based on calculations using the house of risk (HOR) table phase 2, in table 5:

**Table 5. Prioritas Strategi Mitigasi Risk Agent**

| No | Preventive Action                                               | Code |
|----|-----------------------------------------------------------------|------|
| 1  | Direct field supervision                                        | PA2  |
| 2  | Provision of Leak Noise Correlator for active search of leakage | PA3  |
| 3  | Periodic pipelines inspection                                   | PA5  |
| 4  | Increasing internal supervision of the company                  | PA8  |
| 5  | Implementing fines in accordance with company regulations       | PA10 |
| 6  | Supervision toward PERUMDA external project activities          | PA12 |
| 7  | Perform calibration on customer's water meter                   | PA13 |
| 8  | Install valves in each distributary pipe to detect leakage      | PA4  |
| 9  | Replacing potentially damaged pipes                             | PA6  |
| 10 | Rehabilitation of new pipes to replace improper pipes           | PA15 |

| No | Preventive Action                                                                            | Code |
|----|----------------------------------------------------------------------------------------------|------|
| 11 | External parties are required to coordinate with PERUMDA before operation in the piping area | PA11 |
| 12 | Discipline in carrying out routine maintenance                                               | PA17 |
| 13 | Regular monitoring of corrosion potential                                                    | PA14 |
| 14 | Coordinating with the drainage improvement company                                           | PA1  |
| 15 | Taking a decisive action by cutting illegal connections                                      | PA9  |
| 16 | Implementing effective pipeline supervision scheduling                                       | PA7  |
| 17 | Combing the pipe networks when water pressure is stable (at night)                           | PA18 |
| 18 | Creating a database of pipe age for early warning system                                     | PA16 |

After prioritizing the treatment based on the effectiveness level of implementation, the experts then performed severity and occurrence assessment when the given handling strategy was implemented. The following figure 4 is the risk maps after mitigation strategy being carried out:

|                         |           |                   |         |              |        |           |
|-------------------------|-----------|-------------------|---------|--------------|--------|-----------|
| Probability (Occurance) | Very High |                   |         |              |        |           |
|                         | High      |                   | A5, A6  |              |        |           |
|                         | Medium    |                   |         | A22          |        |           |
|                         | Low       |                   |         | A2, A24      |        |           |
|                         | Very Low  |                   | A23, A3 | A16, A9, A12 | A7, A1 |           |
|                         |           | Very Low          | Low     | Medium       | High   | Very High |
|                         |           | Impact (Severity) |         |              |        |           |

**Figure 3. Risk Map After Mitigation**

Figure 4 above shows map risk after designing treatment priorities. Risk agents with codes A24, A2, A1, A22, A5, A7, and A6 were initially in the red area which indicated high risk before mitigation implementation. After mitigation, the codes shifted down to the yellow area which indicated medium category, so they still need to be managed regularly and put under effective control, as well as implementing the designed treatment strategies. Meanwhile, risk agents with codes A12, A16, A23, A9, and A3 which in the yellow area before mitigation were shifted down to the green area, indicated that the risks already in the low

category so that routine monitoring and normal control were sufficient.

### 3.5. Determining Key Risk Indicators

This was last stage of designing key risk indicators, which the selected risks based on expert agreement were : (1) Undetected leakage (A24), and (2) Technical life of pipes had passed its usage limit (A1).

#### 3.5.1. Identification of Indicator Matrix

This was the identification process of root cause analysis matrix upon the risk, referred to the company's vision and mission. The results of determining indikator matrix on the risk of undetected leakage (A24) were : (1) Customer complaints, (2) Coordination of external parties, (3) Informations (field team), (4) Low water discharge, (5) Water quality (smell), (6) Water loss. Furthermore, on A1 risk (technical life of pipes passed its usage limit) were : (1) Road load pressure, (2) Expired (3) Pipe replacement time, (4) Pipe repair time, (5) Data of leaking pipe replacement, (6) Customer meter data.

#### 3.5.2. Determination of The Gap Assessment Tool

After determining indikator matrix on KRI, the next step was evaluating the feasibility and effectivity of each indikator matrix based on the dimension of Gap Assessment, which were : Frequency, (2) Trigger Level, (3) Evaluation criteria, (4) Leading/lagging, (5) Ownership, (6) Historical data, and (7) Data Accuracy. From the determination results were obtained 2 indikator matrix on A24 risk : (1) Information (field team) with value of 4.7, and (2) Water loss with value of 4.6. Then A1 : (1) Expired with value of 4.6, and (2) Leaking pipe replacement with value of 4.4, which then used as the basis to determine the threshold.

#### 3.5.3. Determination of KRI Threshold

Based on selected indikator matrix from risks A24 and A1, the next step was determining the threshold of KRI. Table 6 is the result of determining the threshold :

**Table 6. Threshold Key Risk Indicators**

| Key Risk Indicator           | Parameter       |                 | Measuring Unit |
|------------------------------|-----------------|-----------------|----------------|
|                              | Lower Threshold | Upper Threshold |                |
| Information (Field Team)     | 5               | 8, 19           | Hour           |
| Water Loss                   | 3.118.047       | 3.283.688       | M <sup>3</sup> |
| Expired Data of Leaking Pipe | 20              | 26              | Year           |
| Replacement                  | 15              | 16,32           | Year           |

Based on the results of determining KRI Threshold in table 6 were discovered that information indicator (Field Team) had lower threshold of 5 hours and an upper threshold of 8.19 hours. Water loss indicator had lower threshold of 3,118,047 m3 and an upper threshold of 3,283,688 m3. By the early warning at risk indicator A24, anticipation can be done to reduce the impact of the risk that occurs if the handling is still within control. Furthermore, Expired indicator had lower threshold of 20 years and upper threshold of 26 years of distribution pipes use at normal times, then, the indicator for leaking pipe replacement had lower threshold of 15 years and upper threshold of 16 years 3 months 2 weeks applied on distribution pipes replacement. The using of pipes which not reaching its usage limit mainly caused by beyond control incident.

## 4. Conclusions and Suggestions

### 4.1. Conclusion

From the evaluation result of risk determination of water distribution in PERUMDA Makassar Region IV can be concluded that there are 16 identified risk events and 24 risk agents. Furthermore, mitigation strategy was carried out upon risk agent by using 18 preventive actions. The first selected risk was A24 with the value of Information indicator (Field Team) had lower threshold of 5 hours and upper threshold of 8.19 hours. Water loss had lower threshold of 3,118,047 m3 and upper threshold of 3,283,688 m3. The second was A1 with Expired as the indicator value whose lower threshold is 20 years and upper threshold of 26 years, and leaking pipe replacement with lower threshold of 15 years and upper threshold of 16 years 3 months 2 weeks.

## 4.2. Suggestions

Regarding the result of this research, the first suggestions is for PERUMDA Makassar Region IV Ratulangi to implement the prioritized mitigation strategy to reduce risk impact. Next is for further research to design key risk indicators (KRI) upon risk that is not having EWS yet.

## Reference

- Ceres, R. L., Forest, C. E., Keller, K. 2019. Optimization of multiple storm surge risk mitigation strategies for an island city on a wedge. *Environmental Modelling & Software*, Vol. 119, pp. 341-353.
- Chen, X., Wu, Z., Chen, W., Kang, R., He, X., Miao, Y. 2019. Selection of key indicators for reputation loss in oil and gas pipeline failure event. *Engineering Failure Analysis*, Vol. 99, pp. 69-84.
- Dadsena, K. K., Sarmah, S. P., Naikan, V. N. A., Jena, S. K. 2019. Optimal budget allocation for risk mitigation strategy in trucking industry: an integrated approach. *Transportation Research Part A: Policy and Practice*, Vol. 121, pp. 37-55.
- Gusril, H. 2016. Studi kualitas air minum PDAM di kota Duri Riau. *Jurnal Geografi*, Vol. 8, No. 2, pp. 190-196.
- Han, X., Ji, X., Ma, X., Liu, J. L., He, Z. Y., Chang, W., Tang, F., Liu, A. L. 2020. An investigation of changes in water quality throughout the drinking water production/distribution chain using toxicological and fluorescence analyses. *Journal Environmental Science*, Vol. 87, pp. 310-318.
- Lagu, A. M. H. R., Amansyah, M., Mubarak, F. 2016. Gambaran penyediaan air bersih PDAM kota Makassar tahun 2015. *Public Health Science Journal*, Vol. 8, No. 2, pp. 171-179.
- Magdalena, R., & Vannie. 2019. Analisis risiko supply chain dengan model house of risk (hor) pada pt tatalogam lestari. *Jurnal Teknik Industri*, Vol. 14, No. 2, pp. 53-62.
- Perrin, Y., Bouchon, D., Delafont, V., Moulin, L., Hechard, Y. 2019. Microbiome of drinking water: a full-scale spatio-temporal study to monitor water quality in the Paris distribution system. *Water Research*, Vol. 149, pp. 375-385.
- Purba, E. A., Kurnia, B. A. K., Handayani, J. U. D., Kistiani, F. 2015. Analisa manajemen risiko pada proyek PDAM Semarang (studi kasus: proyek pemipaan ipa kaligarang Semarang barat). *Jurnal Karya Teknik Sipil*, Vol. 4, No. 4, pp. 274-282.
- Putra, Z., Chan, S., Iha, M. 2017. Desain manajemen risiko berbasis ISO 31000 pada PDAM tirta Meulaboh. *Prosiding Seminar Nasional Manajemen dan Ekonomi Bisnis*, Vol. 1, pp. 1-16.
- Puzon, G. J., Miller, H. C., Malnowski, N., Walsh, T., Morgan, M. J. 2020. Naegleria fowleri in drinking water distribution systems. *Current Opinion in Environmental Science & Health*, Vol. 16, pp. 22-27.
- Waller, S. A., Packman, A. I., Hausner, M. 2018. Comparison of biofilm cell quantification methods for drinking water distribution systems. *Journal of Microbiological Methods*, Vol. 144, pp. 8-21.
- Wang, H., Hu, C., Zhang, S., Liu, L., Xing, X. 2018. Effects of O3/Cl2 disinfection on corrosion and opportunistic pathogens growth in drinking water distribution systems. *Journal Environmental Science*, Vol. 73, pp. 38-46.
- Yu, Z., Miller, H. C., Puzon, G. J., Clowers, B. H. 2018. Application of untargeted metabolomics for the detection of pathogenic Naegleria fowleri in an operational drinking water distribution system. *Water Research*, Vol. 145, pp. 678-686.