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Risk assessment of drinking water supply system in the tidal inundation area of Semarang - Indonesia

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Abstract

Tidal inundation is a flood that usually occurs in the coastal region. It will impact water quality, which may lead to health problem. A semi-quantitative tool was used to assess water quality in Bandarharjo Village, a tidal inundation affected area. Total coliform was also performed to assess bacterial contamination. The assessment was conducted at three sites of drinking water supply system: source/provider, distribution, and customer levels. The result showed that both provider and distribution levels have very high risk of contamination, while customer level has a high risk. Water from either source/provider and customer level contained bacterial contamination.

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1. Introduction

According to the recent document of Drainage Masterplan of Semarang City, highest high water level (HHWL) of Semarang is 68, while its mean sea level (MSL) is 23 cm. Therefore the position of HHWL of Semarang is 45 cm above its MSL. A shore with 45 cm difference between HHWL and MSL is expected to be submerged by tidal inundation [1]. In 2011, tidal inundation in Semarang an area of 1,538.8 hectares. The tidal inundation mostly affected North Semarang, i.e. 508.28 hectares [2], because mainland of North Semarang has 50 cm elevation from surface sea level and is closely located to the ocean [3]. The height of tidal inundation has a significant relationship with basics sanitation condition in Bandarharjo and Tanjung Emas, two villages in North Semarang [4]. Bandarharjo has 12 RW (sub-village), and population in 10 out of the 12 sub-villages consume artesian water (deep ground water) for drinking and cooking. There are 92.24% households (3,421 out of 4,330 households) in Bandarharjo that

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use deep ground water, compare to only 7.76% (288 hh) that use local government drinking water supply (called PDAM) [3]. As a comparison, most of households (92.5% from 7,525 households) in the nearest village, Tanjung Emas, use PDAM [5].

Tidal inundation affects the quality of clean water in the community [6]. Our previous study showed that 59.0% (23 out of 39) water sampel in Bandarharjo had poor quality due to tidal inundation [7]. It is because the flooding of tidal inundation can contaminate drinking water with run-off from sewage lines, containment lagoons (such as at animal-feeding operations), or conventional (non-point-source) pollution from across watersheds [8]. Recent study in Bandarharjo proved more than a half of water sample (55%) contained *Escherichia coli* [9]. Tidal inundation is also a potential vehicle to transmit water borne disease. Diarrhea, the most common water borne disease, in Semarang tend to decrease from 2011 to 2013 [10]. However, diarrhea in Bandarharjo remained stagnant, around 21-40 cases/1000 population [11]. The same feature also can be seen in leptospirosis cases, another water-borne disease. Incidence Rate (IR) of Leptospirosis in Semarang ranged 0.1-10/100,000 population, while in Bandarharjo is more than 10/100,000 population [10].

However, there is no research has been done to analyze the contamination risk of water supply system in Bandarharjo which may associated with tidal inundation. Therefore, this study was done to measure and assess the risk of water quality. Observation method was carried out to assess the risk of contamination by using observation sheet. The observation was done on components of drinking water system according to guideline of Water Safety Plans from World Health Organization [12]. Components of drinking water supply system that were assessed include source/provider, distribution and consumer systems. Risk assessment in this study refers to the risk of drinking water contamination by biological, chemical, and physical agents

2. Materials and Methods

2.1. Study design

Observational study was carried out to assess the risk of contamination on drinking water system in Bandarharjo, an area that is affected by tidal inundation in Semarang City [2].

2.2. Preliminary water quality survey

There were 20 sources/providers of drinking water system in Bandarharjo. Water samples from all 20 providers were examined for bacteriological quality (total coliform examination). The result showed 7 out of 20 water samples had poor quality due to higher total coliform than standard.

2.3. Location

Drinking water system in RW 2 was selected to be assessed. The selection was based on our preliminary survey that showed water sample from source/provider of RW 2 had highest total coliform compared to other providers. Drinking water system in RW 2 consisted of 1 source/provider with 86 customers. Observation of contamination risk was conducted at several points, which are components on water supply system. The components that were assessed include source/provider, processing, distribution and consumer systems..

2.4. Instrument for observation

Instrument for observation and assessment consists of several items to identify that risk of contamination on drinking water supply system. A semi-quantitative risk matrix was used to assess water quality, consisted of 5 columns and 5 rows. The columns showed degree of severity (consequences), whereas the rows showed frequency of risk [13].

Value for frequency of occurrence was as follows:

- Once a day = 5

- Once a week = 4
- Once in a month = 3
- Once a year = 2
- Once in 5 years = 1;

Value for degree of severity was as follows:

- No effect = 1
- Small impact of compliance = 2
- Medium impact of aesthetic = 3
- Impact on regulation = 4
- Impact (disaster) on public health = 5

Degree of contamination risk was calculated by multiplying the frequency of occurrence with the degree of severity, and then determined as follows:

- Low risk = < 6
- Medium risk = 6-9
- High risk = 10-15
- Very high risk = >15.

2.5. Laboratory examination

Water samples were taken from source/provider and customer systems. One water sample was taken from the source/provider system. At customer system, 40 drinking water samples were randomly selected. Parameters of drinking water examination consisted of total coliform, turbidity, pH, biological oxygen demand (BOD) and salinity. Total coliform was examined by MPN coliform method and was expressed in number of coliform per 100 mL. Turbidity was examined by nephelometric turbidity unit and was expressed in NTU scale. BOD was examined by iodometric method and was expressed in mg/L. pH was examined by potentiometric method. Salinity was also examined by potentiometric method and was expressed in mg/L. All examination was conducted at Laboratory of Central Java Provincial Health. Results of laboratory examination were considered as qualify the standard of drinking water quality if the values were 10/100mL, 25 NTU, 6 mg/L, 6,5-9,0, <650 for total coliform, turbidity, BOD, pH and salinity respectively.

3. Results and Discussion

3.1. Laboratory examination for water quality

Water sample from source system contained 75/100 mL total coliform, which is higher than allowable limit. According to Ministry of Health Republic of Indonesia maximum number of total coliform is 10/100 ml sample (piping water) and 50/100 ml sample (non piping water). At customer system, only 15% of water samples qualified the requirement. Turbidity, pH and salinity parameters showed value of 0.18-65.9 NTU, 7, 0.018-0.118 respectively. All parameters of pH and salinity met the standard of MoH. On the contrary, parameter of turbidity found 2 of 40 samples (5%) did not qualify, i.e. > 25 mg/litre.

Table 1 Bacteriological quality of water on customer (household connections)

Total Coliform	n=40	%
≤10	6	15
>10	34	85

The total coliform test is considered an indicator, since the presence of bacteria in this group indicates the possibility, but not the certainty, that disease organisms may also be present in the water. When total coliforms are absent there is a very low probability of disease organisms being present in the water. The ability of the total coliform test to reliably predict the bacterial safety of drinking water relative to the hundreds of possible diseases is critical since it is impossible, in a practical sense, to frequently check for every type of disease-causing organism

3.2. Risk assessment

Table 2 Risk assessment of the drinking water supply system

Water Supply System Components	Step of Process (units)	Events of Hazard	Type of Emerging Hazard	Frequency of Occurrence	Degrees of Severity	Risk Value	Degree of Risk	Description
A. Source	Upper water reservoir	Space between reservoir and lid	Contamination	5	5	25	Very high	Dust and animal waste contain bacteria into water reservoir (through space)
	Upper water reservoir	Never drained	Dirty (moss and sandy)	5	3	15	High	Reservoir without drained, moss thrives, those being impurity
B. Process	No water treatment	Proliferation of bacterial	Total coliform exceeds standard	5	5	25	Very high	-
C. Distribution	Distribution pipe	Submerged, no leakage	Potential contamination	5	1	5	Low	The distribution pipe was submerged but no leaking, so that the contamination might not happen
D. Costumer/ Household connection	Water meter	Submerged, seepage	Potential bacterial contamination	5	5	25	Very high	Tidal water, gutter and land contain many pathogen. When the water meter submerged, the pathogen may infiltrate.
	Water	Source (wells) and distribution pipe was dirty	Dirt	5	3	15	High	Dirt at distribution pipe and source (wells) was delivered to customer

Table 2 shows a very high degree of risk at source system (risk value=25), caused by the presence of holes (space) between lid and reservoir. The space allows contamination of dust and animal feces such as birds, cockroaches, rats. Moreover, the reservoir is located near pigeon cage. Because Bandarharjo Village is located near beach with a daily strong wind, the wind may spread pigeon droppings into reservoir. Previous studies proved primary source of fecal bacteria pollution in water supply system comes from feces of humans [17], domestic/wild animals [17] [18], agricultural run-off, and sewage [18] through the wind [17] [18]. This is likely to influence the high number of total coliform in the reservoir. Therefore, reservoir should be sealed, even better with concrete to prevent contamination.

In term of turbidity, reservoir has a high degree of risk (risk value 15) due to the existence of dust, moss, and spore contaminants. The owner of sumur artesis never drain reservoir, which contributes to the dirt of reservoir wall and lead to high number of total coliform. Mekanisme tidak dikuras menjadi total coliform (referensi). Drainage of reservoir a year before sampling may prevent contamination in reservoir. A tight lid of reservoir also useful [19].

At processing system, we found a very high degree of risk (value 25). The cause is lack of disinfection as a minimum requirement process of drinking water treatment. Complete drinking water treatment ranging from screening, coagulation, sedimentation, filtration, disinfection and distribution. One way to disinfect water is using

chlorine, a very effective disinfection to kill bacteria, viruses and protozoa [20]. The owner of artesian well does not perform disinfection because of resistance from her costumers. We performed indepth interview to 25 head of households, all rejected the chlorine disinfection due to smell and turbid. Event after a sanitarian officer of Bandarharjo PHC had explained the benefits of disinfection, they remained reluctant. They argued water with chlorine takes 1-2 to be precipitated. They also reluctant with the pungent odor of chlorine.

At distribution system, we obtained a high degree of risk (value 15). All distribution pipes from source to customers were 1dm in size. Pipes were located at roadside, and several of them pass through sewers or buried until more than 50-100 cm. This condition happened because community elevates the road periodically due to *rob*/tidal inundation. In addition, our spot check by cutting distribution pipes found the pipes has a lot of stick impurity deposition on their inner wall. According to the US EPA, problems that often occur in the distribution system, among others, the presence of microbial growth and biofilm, cross connection, backflow, rusty and aged, contamination during service and nitrification [21].

Our study did not assess bacteriological quality at distribution system. We cannot take water sample due to absence of faucets or tub pressure release on distribution pipes. Previous study showed the existence of biological contaminants (total coliform) at distribution points [16]. Most microorganisms that multiply in the distribution system are not dangerous, except *Legionella* and *Mycobacterium avium* complex [22]. After 12 to 18 months, a plateau phase of biofilm development was reached. Surface colonization on the materials ranged between 4×10^6 and 3×10^7 cells / cm², with heterotrophic plate count (HPC) bacteria between 9×10^3 and 7×10^5 colony-forming units (cfu) / cm². Investigated the biofilms were established in 18 pipe sections (2 to 99 years old) cut out from distribution pipelines [24].

At distribution system, the physicochemical quality (pH, turbidity, total dissolved solids and hardness) of water was satisfactory, while 50 to 62.5% of the samples contained bacteriological contamination (total coliforms and faecal coliforms) before monsoon. This percentage rose to 75% after the monsoon. Possible causes of contamination were leaking water mains and cross connections between water mains and sewers due to the close proximity [25].

At costumer/household system, we observed connection pipes, water-meters and faucets in the houses, and obtained a very high risk (value 25). The result showed 9 water-meters are submerged, either by tidal inundation or soil. Thus, several connection pipes leaked or seeped, which may cause water contamination. Our results also showed 34 of the 40 samples (85%) have bacterial contamination. Other study found existence of bacterial contaminants (total coliform) from 171 of 226 samples (75.7%) in the drinking reservoir in the house [16].

A previous study in Bermuda found 90% of 102 reservoir samples were contaminated by coliform, which exceeds the standard 10 colony forming unit (CFU)/100 mL. The study also showed 66% of the 102 samples were contaminated with *E. coli* [26]. Besides, we observed visually dirty water at customer system. It might happen because sediment from source and distribution pipes is carried to the customers. The owner of artesian well never drain reservoir at source system, or flushing the pipelines.

4. Conclusion

The contamination risk water supply system in sources, distribution and costumer are low to very high respectively. Several priorities for improvement are build a concrete cover for water-tank, regular drainage, disinfection at source system; regular water flushing at distribution pipelines; and immediate elevation of pipes and water-meter, minor repair in household connection and faucets at customer system.

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