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Study of Rainwater Harvesting Implementation

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ABSTRACT

In recent years, because of the changes in the environment and an increase in the global population, there is an increase in the threat of water scarcity. Therefore, there a need for developing water supply systems that is sustainable and resilient. Rainwater harvesting (RWH) systems are a decentralized sustainable water supply system that has the potential to be implemented. Industries, as one of the sectors that will be affected, could potentially gain many benefits through the implementation of RWH systems. This paper is a literature review that has the objective of explaining the general concept of RWH systems and understanding several aspects that go into planning a rainwater harvesting system. RWH system is an old concept that has benefits and disadvantages. In planning an RWH system, there are many considerations and calculations. The catchment area, water storage, treatment train needs to be carefully chosen. In some cases of implementation, it has been observed that RWH systems have resulted in water and financial savings. There is much potential for further study of the implementation of RWH systems in industrial settings.

Keywords: *Rainwater Harvesting, Industrial, Sustainable Water Supply.*

ABSTRACT

Dalam beberapa tahun terakhir, karena perubahan lingkungan dan peningkatan populasi global, ada peningkatan ancaman kelangkaan air. Oleh karena itu, ada kebutuhan untuk mengembangkan sistem pasokan air yang berkelanjutan dan tangguh. Sistem pemanenan air hujan (RWH) adalah sistem pasokan air berkelanjutan terdesentralisasi yang berpotensi untuk diimplementasikan. Industri, sebagai salah satu sektor yang akan terpengaruh, berpotensi mendapatkan banyak manfaat melalui penerapan sistem RWH. Makalah ini adalah tinjauan literatur yang memiliki tujuan untuk menjelaskan konsep umum sistem RWH dan memahami beberapa aspek yang masuk ke dalam perencanaan sistem pemanenan air hujan. Sistem RWH adalah konsep lama yang memiliki kelebihan dan kekurangan. Dalam merencanakan sistem RWH, ada banyak pertimbangan dan perhitungan. Area tangkapan air, penyimpanan air, kereta perawatan harus dipilih dengan cermat. Dalam beberapa kasus implementasi, telah diamati bahwa sistem RWH telah menghasilkan penghematan air dan finansial. Ada banyak potensi untuk studi lebih lanjut tentang implementasi sistem RWH di pengaturan industri.

Kata Kunci: *Pemanenan Air Hujan, Industri, Pasokan Air Berkelanjutan.*

1. Introduction

Water is an essential resource that is consumed every day by human beings. Also, water is utilized regularly for various activities. Such activities include industrial activities and day to day activities. UNESCO projected that the earth has a total of 1.4 billion km3 of water. With a substantial portion being in the ocean. From the total amount of water worldwide, 70% of which used for agricultural purposes, 22% for domestic use, and 8% for industrial uses. (Dharminder, R. K. S., Kumar, V., Devedee, A. K., Mruthyunjaya, M., & Bhardwaj, 2019) The increase of population and human interference in the water supply raises the threat of severe water scarcity. In fact, 80% of the total global population has to encounter water scarcity (Abbott et al., 2019).

By 2045, it is predicted in a statement made by the Ministry of National Development Planning of the Republic of Indonesia in 2019 that Java island will have a clean water crisis. Despite having sufficient natural resources, such as adequate rainfall and rivers, these resources cannot meet the projected demand if no treatment is provided. (Ali et al., 2019) Because of water scarcity, policies that give higher priority to domestic water usage above other water usage are made by many national governments worldwide. This fact urges industries to find alternative water sources to address this issue (Rahmani, 2015). Because of the rise in urbanization and growth of population, there is high importance on developing water supply systems that adopt the concept of sustainability (Lee et al., 2018). This can be done through two ways, first finding an alternative water source and second, using water resources in a more efficient way (Yannopoulos et al., 2019).

The principle of sustainable water management (sustainable water) can be achieved by using alternative water sources that can be supplied to meet water demand. (Ali et al., 2019) The central concept of sustainable water management is using integrated and decentralized systems that increase the sustainability and resiliency of the water supply system. Common examples of these systems are rainwater harvesting, greywater reuse, and water reclamation. (Leigh & Lee, 2019). Therefore, conservation measures that reduce water consumption and reduces dependency on conventional water supply system needs to be implemented moving forward.

Rainwater harvesting system comprises of “concentration, collection, storage and treatment of rainwater from rooftops, terraces, courtyards, and other impervious building surfaces for on-site use” (Campisano et al., 2017). From the total rainfall that comes in contact with urban rooftops, 80% of it is available to be harvested. Without a rainwater capturing system, the water will contribute as a source of surface water pollution (Lee et al., 2018). The practice of rainwater harvesting itself dates back to ancient times more than 9000 years ago (Yannopoulos et al., 2019). Rainwater harvesting systems have many benefits, including water usage savings. A research found that the system can supply about 90% of domestic non-potable water usage and 43% for commercial non-potable water usage (Leong et al., 2018).

For this reason, rainwater harvesting systems are worth to be explored as a potential solution to mitigating the water scarcity issue worldwide. This literature review has the objective of explaining the general concept of RWH systems, understanding several aspects that go into planning and design a rainwater harvesting system, and observing the current implementation of rainwater harvesting systems around the world.

2. Methods

This study used the method of literature review to understand the basics of planning and implementation of rainwater harvesting systems. The result and discussion section discussed the water demand in industries, basics of sustainable water management, the regulation and potential of rainwater harvesting system in Indonesia, the principles of rainwater harvesting, benefits, disadvantages, and the calculation that is used in the planning of a rainwater harvesting system. Next, the common practices for rainwater quality analysis and the common practices of rainwater treatment is observed. Lastly, several case studies will be studied in order to understand the current implementation and economic viability of rainwater harvesting systems.

3. Result and Discussion

3.1 Sustainable Water Management

Industries are an integral part of an area's economy and development. In an industrial process, water is a primary resource that serves many purposes. There are three uses for water in an industrial area. First, process water used to treat or process raw materials. Second, utility water, which is used to support the production process. Cooling water and boiler water are an example of utility water. Lastly, domestic water is used for the daily activities of the workers, such as toilet flushing or other activities (Fauzi et al., 2018). A research in Tangerang city found that 21% of the available surface water from the Cisadane river and 20% from the local groundwater is estimated to be allocated for industrial water demand (Fauzi et al., 2018). The water usage may differ with different types of industries and type of products that are produced. With regard to water consumption, the chemical industry has the highest demand. Other industries with high water demand include paper, food, metal, and textile industries (Sievers, 2017).

Water demand for industrial purposes is predicted to increase, especially in developing countries. From 1995 to 2025, it is estimated that water demand for industrial and domestic purposes will increase by 62 percent. Currently, industrial water demand needs to compete with other vital activities such as agricultural and domestic water use (Rosegrant et al., 2020). Utilizing decentralized supplies, wastewater reuse, and wastewater treatment on an industrial scale can help with addressing the issue of rising water demand and worsening quality of water (Pham et al., 2016).

Sustainability can be defined as "the degree to which the system maintains levels of service in the long-term while maximizing social, economic and environmental goals" (Butler et al., 2017). In terms of urban water systems, sustainability means seeking a balance between these three priorities, which is described in Figure 1.

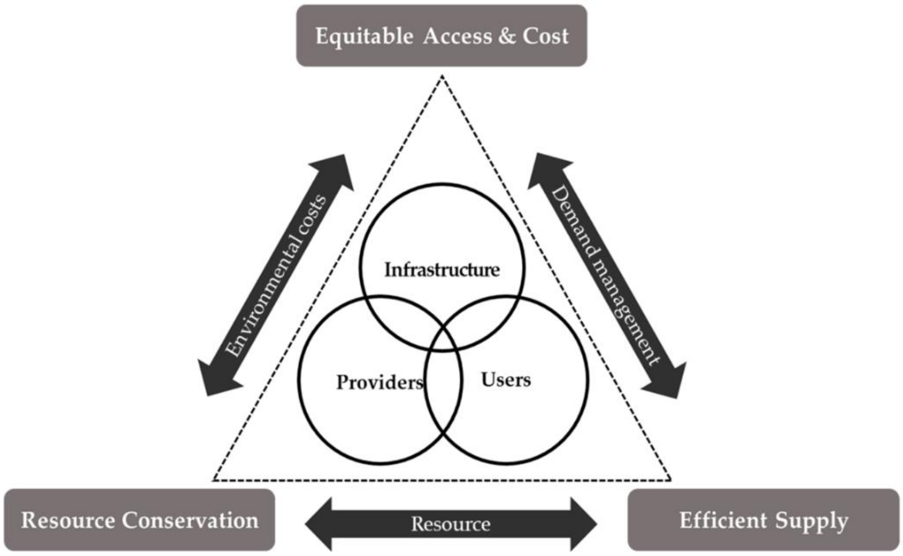

Figure 1. Model of sustainability
Source: (Leigh & Lee, 2019)

In addition to being sustainable, the resiliency of the urban water system is another important aspect to be considered. To have a resilient system, spatial diversity and functional diversity is required (Leigh & Lee, 2019).

3.2 Concept of Rainwater Harvesting

In Indonesia, matters regarding rainwater harvesting are regulated in Minister of the Environment Regulation Number 12 of 2009 about Rainwater Utilization and Minister of Public Works Regulation No. 11 of 2014 concerning Management of Rainwater in Buildings and Plots (Rofil, 2017).

According to Environment Regulation Number 12 of 2009, rainwater utilization is defined as a series of activities collecting, using, and/or absorbing rainwater into the ground. Rainwater utilization can be done through building rainwater collection ponds, infiltration wells, and /or biopore infiltration holes. This regulation only regulates the rainwater utilization with the function of reducing standing water or flooding and maintaining the quality and increase the quantity of groundwater. Collection of rainwater to be treated or reused as a clean water source is however not mentioned in this regulation (Permen KLHK, 2012)

While according to Minister of Public Works Regulation No. 11 of 2014 concerning Management of Rainwater in Buildings and Plots, Rainwater Management is an effort and activity to improve natural hydrological conditions, by maximizing the use of rainwater, infiltration of rainwater, and temporarily storing rainwater to increase flood discharge, to use the application of transfer of natural elements and the work of artificial elements. Rainwater management has the purpose of:

a. Maximize the use of rainwater in buildings and plots

b. Maximize Rainwater infiltration; and
c. Hold rainwater temporarily to reduce rainwater runoff. (Peraturan Menteri Pekerjaan Umum Republik Indonesia tentang Pengelolaan Air Hujan pada Bangunan Gedung dan Persilnya, 2014)

The high rainfall of intensity in Indonesia that ranges from 2,000 – 4,000 mm/year makes Indonesia have the potential to implement rainwater harvesting. Worldwide, Indonesia is part of the five countries with the most potential for freshwater. However, the potential for abundant rainwater is often a problem in many places. The high rainfall causes flooding, landslides, and puddles due to inadequate drainage system. (Indriatmoko & Rahardjo, 2018)

In analyzing the potential of a rainwater harvesting system, several stages are done, such as rainfall analysis, analysis of rainwater harvesting potential for each building and open space, analysis of water demand, and analysis of the capacity of rainwater harvesting facilities. (Kharisma et al., 2016)

The amount of rainfall intensity varies due to the length of rainfall or the frequency of occurrence. Furthermore, if no data is found for each rain duration, then an empirical approach is needed by referring to the duration of 60 minutes and the maximum daily rainfall that occurs each year (Kharisma et al., 2016) The intensity is calculated using the following equation.

$$I = \frac{90\% \times R24}{4} \quad (1)$$

Where:
I = Rainfall Intensity
R24 = Maximum daily rainfall (mm/24h)

The rainwater harvesting yield potential can be calculated using the following equation, where “RH is the yearly amount of harvestable rainwater from the building’s rooftops (m^3), P tot is the total annual precipitation (m), A roof is the rooftop area (m^2), and C is the harvesting efficiency of the system (dimensionless)” (Lupia et al., 2017)

$$RH = P_{tot} \times A_{roof} \times C \quad (2)$$

Where:
RH = Annual amount of harvestable rainwater (m^3)
P_{tot} = Total annual precipitation (m)
A_{roof} = Rooftop area (m^2)
C = Harvesting efficiency

The C value considers various factors, such as leaks and wind. Some literature takes a value of 60%, while others have a range of 70% to 95%, with 95% being achieved in perfect condition. (Lupia et al., 2017)

Rainwater harvesting storage capacity analysis is used to determine the ability or capacity of the storage that needs to be available to collect rainwater captured by the roof per building. The formula is as follows (Kharisma et al., 2016)

$$V = S - B \quad (3)$$

Where:
V = Volume of the storage basin at the end of the month (m^3)
S = The ability of the basin to collect rainwater in one month
B = Water demand in one month

Where V is the volume of the storage basin at the end of the month (m3), S is the ability of the basin to collect rainwater in one month, and B is the water demand in one month (Kharisma et al., 2016).

An important concept in rainwater harvesting is the "first flush concept". Because of the contaminants that aggregate in catchment surfaces, the first volume of rainwater often contains higher levels of contaminants. This phenomenon can be corrected by installing a device that will segregate the first-flush water from the subsequent volumes of rainwater. (Atsali et al., n.d.)

According to Rofil (Rofil, 2017), the benefits of rainwater harvesting systems can be classified into two categories, benefit for water resources and benefit for the environment and society. RWH also have economic benefit in the form of reduction of the water bill. (Matos et al., 2015) According to a literature review by Lani (Lani et al., 2018), RWH systems has the environmental benefit of reducing flooding, increasing water storage, reducing dependency on conventional distribution systems, and reducing peak flow.

On the other side, RWH has the disadvantage of being dependent on the quantity of rainfall and catchment area. Moreover, the large storage requirement for a long dry period may be costly, and even then other water sources may still be needed.

The rainwater quality that is harvested is affected by many different factors, such as air pollution, the land use of the surroundings, roofing material, and type of catchment. Consequently, it is found that the most polluted rainwater is in urban areas. (Friedler et al., 2017) Therefore, it is essential to analyze the rainwater quality in order to determine the required treatment train. Generally, there is high variability in the type and number of parameters that are analyzed because there is no universal or national standard.

Generally, pH and turbidity are the most common parameters of rainwater quality. (Zdeb, Papciak, et al., 2018) Research by Hasan et al. (Hasan et al., 2019) analyzed the rainwater quality in Bandung area by analyzing pH with the use of pH meter, and nitrate, sulfate, chloride, heavy metals (As, Cd, Cr, Pb, and Zn) using Ion chromatography. Zdeb et al., (Zdeb, Papciak, et al., 2018) analyzed the difference of rainwater quality in relation to different roof materials. The parameters analyzed were: 1) pH 2) Turbidity 3) biogenic compound 4) TOC 5) Permanganate Index

Unlike surface water sampling, that has a national standard (SNI 6869.57:2008). Currently, there is no national standard for rainwater sampling. However, there is an international standard for sampling and analysis of rainwater that is stated in ASTM STP 823.

In Indonesia, non-potable water and drinking water output may comply with Regulation of the Minister of Health About Water Quality Requirements and Monitoring. (*Regulation of the Minister of Health About Water Quality Requirements and Monitoring*, 1990) The standards for each parameter are summarized in Appendix 1

The conventional method of treating harvested rainwater is using filtration systems. Generally, there is two common types of filtration, granular filtration, and membrane filtration. A "granular filtration system" (GFS) has the function of removing suspended solids, particulates, and bacteria. This system applies biological, chemical, and physical processes (Albalawneh et al., 2017) A membrane is a filter that eliminates compounds based on the molecular weight. There are four types of membrane filtration: RO, UF, MF, NF (Teixeira & Ghisi, 2019). Due to the microbiological content of rainwater, for drinking water, there is an additional option of adding disinfection treatment by using UV, ozonation, chlorination, or other disinfection methods. (Zdeb, Zamorska, et al., 2018) Although research by Zdeb found that chlorination is more effective compared to ozonation. (Zdeb, Zamorska, et al., 2018) Teixeira and Ghisi (Teixeira & Ghisi, 2019) Compared the use of membrane filtration and granular filtration, the conclusion found that because of the already great quality of rainwater. There is no significant difference in efficiency between the two filters, although this might not be the case in an area with more inferior quality of rainwater. In filtration, there are many media configuration options. Yulistyorini found that a combination of zeolite and activated carbon results in a 37% reduction in TDS and a 36% reduction of coliform, while pure zeolite only reduces $KMnO_4$ by 35%. (Yulistyorini et al., 2018) Research by Shaheed tried to implement an adsorption-filtration system for rainwater that have high levels of NH_3-N and E.coli. As a result, both parameter concentration was able to meet the clean water standard but not the drinking water standard. (Shaheed et al., 2017)

3.3 Implementation of Rainwater Harvesting

Currently, there are many implementations of rainwater harvesting systems in Indonesia and around the world. A study that analyzed the economics of rainwater harvesting systems in a commercial area found that the payback period ranges from 2-6 years and 23-76 % internal rate of return. There are many types of rainwater harvesting that each has its own benefits. The case study and the benefits of each system are summarized in Table 1

Table 1. RWH Implementation

Case Study	RWH Application	Findings	Economic Viability
FT-UH Education Center (Kharisma, et al., (Kharisma et al., 2016))	-After Collection, the rainwater was stored in a man-made lake -Treated using slow sand filtration	The volume of rainwater harvested was 18,198.63 m3 / year, which can reduce water supply from groundwater sources by 10.55%	No information
Industrial Facility in North Jakarta (Murdiana, et al. (Murdiana et al., 2019))	- Ground Collection system using a rainwater collection pool - Treatment consists of lamella clarifier, filtration, and chlorination.	Amount of rainwater harvested reduce PDAM water consumption by 20%	No information
Petrochemical Company (Thome, et al., (Thomé et al., 2019))	- Rainwater for cooling towers - Collected using open channels - Treated using chlorination and filtration	24,000 m3 rainwater harvested, resulting in an energy reduction of 12,000 kWh/ year.	Payback period of 2 years
Textile Mil (Madara, et al,. (Madara & Namango, 2016))	- Roof catchment with an area of 34, 676, 6 m2 - Use "first flush off system and filtration to treat high levels of TSS	Recommend tank design capacity of 550 m3	Payback Period 5.6 Years

From the case studies above, it is observed that there are many different combinations of collection method and treatment method for each rainwater harvesting system. The different quality of rainwater also affects the type of treatment train that is chosen. Although from the four case studies mentioned above all of them applied the filtration process. Meaning that the observation matched with the literature previously mentioned above that the most conventional method of treatment for rainwater harvesting systems are filtration. Some of the case study also showed that there is a reduction of water consumption from conventional sources.

4. Conclusion

Rainwater harvesting (RWH) systems are a possible solution to cope with the alarming issue of water scarcity. Moving forward, water supply systems needs to be sustainable and resilient to deal with challenges that may arise due to climate change, especially with the increasing competition that industries will have with other sectors such as domestic and agriculture. Implementing decentralized systems such as RWH systems may help alleviate the load on conventional water supply systems.

In planning an RWH system, there are many considerations and calculations. The catchment area, water storage, treatment train needs to be carefully chosen. There are many treatment options that is available, and it will depend on the rainwater quality of the area and other factors. Although many RWH systems have been implemented around the world, there are still few that are implemented in Indonesia. Moreover, the majority of the current implementation is in residential, domestic buildings. Therefore there is much potential for further study about the implementation of RWH systems in industrial settings.

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Appendix. Water Quality Parameters

Drinking Water	Clean Water
Non-Potable Water	(see table below)

No.	PARAMETER	Satuan	Kadar Maksimum yang diperbolehkan	Keterangan
1	2	3	4	5
A.	FISIKA			
1.	Bau	-	-	Tidak berbau
2.	Jumlah zat padat terlarut (TDS)	mg/L	1.500	-
3.	Kekeruhan	Skala NTU	25	-
4.	Rasa	-	-	Tidak berasa
5.	Suhu	°C	Suhu udara ± 3°C	-
6.	Warna	Skala TCU	50	
B.	KIMIA			
1.	Air raksa	mg/L	0,001	
2.	Arsen	mg/L	0,05	
3.	Besi	mg/L	1,0	
4.	Fluorida	mg/L	1,5	
5.	Kadnium	mg/L	0,005	
6.	Kesadahan (CaCO3)	mg/L	500	
7.	Klorida	mg/L	600	
8.	Kromium, Valensi 6	mg/L	0,05	
9.	Mangan	mg/L	0,5	
10.	Nitrat, sebagai N	mg/L	10	
11.	Nitrit, sebagai N	mg/L	1,0	
12.	pH	-	6,5 – 9,0	Merupakan batas minimum dan maksimum, khusus air hujan pH minimum 5,5
13.	Selenium	mg/L	0,01	
14.	Seng	mg/L	15	
15.	Sianida	mg/L	0,1	
16.	Sulfat	mg/L	400	
17.	Timbal	mg/L	0,05	
	Kimia Organik			
1.	Aldrin dan Dieldrin	mg/L	0,0007	
2.	Benzena	mg/L	0,01	
3.	Benzo (a) pyrene	mg/L	0,00001	
4.	Chlordane (total isomer)	mg/L	0,007	
5.	Coloroform	mg/L	0,03	
6.	2,4 D	mg/L	0,10	
7.	DDT	mg/L	0,03	
8.	Detergen	mg/L	0,5	
9.	1,2 Discloroethane	mg/L	0,01	
10.	1,1 Discloroethene	mg/L	0,0003	
11.	Heptaclor dan heptaclor epoxide	mg/L	0,003	
12.	Hexachlorobenzene	mg/L	0,00001	
13.	Gamma-HCH (Lindane)	mg/L	0,004	
14.	Methoxychlor	mg/L	0,10	
15.	Pentachlorophanol	mg/L	0,01	
16.	Pestisida Total	mg/L	0,10	
17.	2,4,6 urichlorophenol	mg/L	0,01	
18.	Zat organik (KMnO4)	mg/L	10	

No.	PARAMETER	Satuan	Kadar Maksimum yang diperbolehkan	Keterangan
1	2	3	4	5
C.	Mikro biologik			
	Total koliform (MPN)	Jumlah per 100 ml	50	Bukan air perpipaan
		Jumlah per 100 ml	10	Air perpipaan
D.	Radio Aktivitas			
1.	Aktivitas Alpha (Gross Alpha Activity)	Bq/L	0,1	
2.	Aktivitas Beta (Gross Beta Activity)	Bq/L	1,0	

Drinking Water Standard

No.	PARAMETER	Satuan	Kadar Maksimum yang diperbolehkan	Keterangan
1	2	3	4	5
A.	FISIKA			
1.	Bau	-	-	Tidak berbau
2.	Jumlah zat padat terlarut (TDS)	mg/L	1.000	-
3.	Kekeruhan	Skala NTU	5	-
4.	Rasa	-	-	Tidak berasa
5.	Suhu	°C	Suhu udara ± 3°C	-
6.	Warna	Skala TCU	15	
B.	KIMIA			
a.	Kimia Anorganik			
1.	Air raksa	mg/L	0,001	
2.	Alumunium	mg/L	0,2	
3.	Arsen	mg/L	0,05	
4.	Barium	mg/L	1,0	
5.	Besi	mg/L	0,3	
6.	Fluorida	mg/L	1,5	
7.	Kadnium	mg/L	0,005	
8.	Kesadahan (CaCO3)	mg/L	500	
9.	Klorida	mg/L	250	
10.	Kromium, Valensi 6	mg/L	0,05	
11.	Mangan	mg/L	0,1	
12.	Natrium	mg/L	200	
13.	Nitrat, sebagai N	mg/L	10	
14.	Nitrit, sebagai N	mg/L	1,0	
15.	Perak	mg/L	0,05	
16.	pH	-	6,5 – 8,5	Merupakan batas minimum dan maksimum
17.	Selenium	mg/L	0,01	
18.	Seng	mg/L	5,0	
19.	Sianida	mg/L	0,1	
20.	Sulfat	mg/L	400	
21.	Sulfida (sebagai H2S)	mg/L	0,05	
22.	Tembaga	mg/L	1,0	
23.	Timbal	mg/L	0,05	
b.	Kimia Organik			
1.	Aldrin dan Dieldrin	mg/L	0,0007	
2.	Benzena	mg/L	0,01	
3.	Benzo (a) pyrene	mg/L	0,00001	
4.	Chlordane (total isomer)	mg/L	0,0003	
5.	Coloroform	mg/L	0,03	
6.	2,4 D	mg/L	0,10	
7.	DDT	mg/L	0,03	
8.	Detergen	mg/L	0,05	
9.	1,2 Discloroethane	mg/L	0,01	
10.	1,1 Discloroethene	mg/L	0,0003	
11.	Heptaclor dan heptaclor epoxide	mg/L	0,003	
12.	Hexachlorobenzene	mg/L	0,00001	
13.	Gamma-HCH (Lindane)	mg/L	0,004	
14.	Methoxychlor	mg/L	0,03	
15.	Pentachlorophanol	mg/L	0,01	

No.	PARAMETER	Satuan	Kadar Maksimum yang diperbolehkan	Keterangan
1	2	3	4	5
16.	Pestisida Total	mg/L	0,10	
17.	2,4,6 urichlorophenol	mg/L	0,01	
18.	Zat organik (KMnO4)	mg/L	10	
C.	Mikro biologik			
1.	Koliform Tinja	Jumlah per 100 ml	0	
2.	Total koliform	Jumlah per 100 ml	0	95% dari sampel yang diperiksa selama setahun. Kadang-kadang boleh ada 3 per 100 ml sampel air, tetapi tidak berturut-turut
D.	Radio Aktivitas			
1.	Aktivitas Alpha (Gross Alpha Activity)	Bq/L	0,1	
2.	Aktivitas Beta (Gross Beta Activity)	Bq/L	1,0	