Impact Analysis of Integrated Waste Management Program on Reducing Sedimentation of Saguling Reservoir by PT. PLN Indonesia Power UBP Saguling

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Abstract

Saguling Reservoir, located in West Bandung Regency, West Java Province, is one of the assets for energy sources for hydroelectric power generators (PLTA). The sustainability of the reservoir is one of the important aspects that needs to be considered to maintain its role and benefits. Sedimentation is a crucial issue in determining the sustainability of a reservoir. Increased waste production in the Bandung Raya area is one of the contributing materials to sedimentation if left uncontrolled. PT. PLN Indonesia Power UBP Saguling initiated an integrated waste management program, addressing waste from upstream areas to those that flow into the Saguling reservoir, as part of their efforts in supporting reservoir conservation. This study aims to determine the impact of implementing an integrated waste management, a community empowerment program, on reducing sedimentation. The secondary data analysis was utilized in the current research. The decrease in reservoir sedimentation was analyzed using data on the amount of waste absorption managed by community groups fostered by PT. PLN Indonesia Power UBP Saguling. The integrated waste management program reviewed from 2020 to 2024 was able to reduce sedimentation by 5,843 m3 with a percentage of sedimentation reduction of 0.36%.

***Keywords**: Saguling Reservoir, Sedimentation, Waste Management.*

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A. INTRODUCTION

Saguling Reservoir is located in West Bandung Regency, West Java Province and is one of the assets of PT. PLN Indonesia Power UBP Saguling as a place to store water for power generation. Saguling Reservoir is one of the three large reservoirs located in the Citarum Watershed (DAS). This reservoir has a relatively high-water discharge of 90.2 - 108 million m3/year (Ferdiansyah et al. 2020). The high discharge flow is one of the factors that affect the reservoir sedimentation process (Setiyadi et al. 2013). Dharmananta (2019) also noted a positive correlation between water flow discharge and the reservoir sedimentation produced. An increase in water flow discharge will lead to higher sedimentation and greater reservoir siltation. Tatipata et al (2015) also emphasized that the influx of sedimentation into the reservoir will result in deposition and siltation of the reservoir. Increased sedimentation will have a major impact on the safety and benefits of the reservoir (Krisnayanti et al. 2018).

The role of Saguling reservoir as a hydroelectric power generator is very crucial, so the reservoir service life is an important thing that must be considered to support the sustainability of its role. Manalu (2013) revealed in his research that the reservoir's service life, based on the dead storage capacity, is projected to last only until 2042; however, if land conservation management can achieve a 75% success rate, the reservoir's service life will increase by 11 years, until 2053. Sedimentation is the main factor in determining the service life of the reservoir. Nasution and Wulandari (2021) explained that the sedimentation rate that occurs will affect changes in reservoir storage capacity and the technical service life of the reservoir. High sedimentation rates will reduce the service life of the reservoir. Sedimentation which is not managed and supported by land conservation will accelerate the reservoir's service life and reduce the benefits of Saguling reservoir.

Saguling Reservoir is located in the upstream catchment area of the Citarum River, encompassing the area of Bandung Raya. Problems that occur in the upstream area, if not handled properly, will affect the downstream area. Currently, waste from Bandung Raya and its surroundings is one of the issues faced by the Saguling reservoir management. The waste produced by people in Bandung Raya reaches 2000 tons/day (DLH Bandung in Kompas.com 2023). These waste, including both organic and plastic materials, flow downstream and ultimately ends up in the Saguling reservoir. The increasing flow of waste into the reservoir will accelerate sedimentation, shortening its service life. On the other hand, the Saguling reservoir provides enormous benefits, one of which is as a source of hydroelectric power.

PT. PLN Indonesia Power UBP Saguling initiated a community program to prevent the acceleration of reservoir sedimentation through an integrated waste management program that spans from upstream to downstream areas (reservoirs). This program is carried out by five groups, including Sukamaju Sejahtera Waste Bank and several waste banks in Bandung Raya, Bening Saguling Foundation, Jurig Runtah, Kelompok Pengelola Eceng Biomass, and Reservoir Waste Scavenger (Pemulung Sampah Waduk [PSW]). The five groups have operational areas that extend from the upstream to downstream regions close to the Saguling reservoir. The purpose of this study is to analyze the impact of the integrated waste management program developed by PT. PLN Indonesia Power UBP Saguling on ecological functions, specifically focusing on reducing sedimentation of the Saguling reservoir.

B. LITERATURE REVIEW

1. Reservoir sedimentation

Sediments have an important role in environmental pollution, especially in water environments. Sedimentation in reservoirs or dams will affect their safety and reduce their energy production, storage, discharge capacity, and flood attenuation capabilities. There are several factors that affect the sedimentation process, including the speed of particles carried by the water flow discharge (Setiyadi et al. 2013; Rosyadewi and Hidayah, 2020), as well as the size and shape of the particles (Roessiana et al. 2014), run off (Tribiyono et al. 2018), the density of particles, and environmental effects. The amount and distribution of bottom sediments in waters that are usually dominated by sand and silt are influenced by current speed and current patterns (Pawita et al. 2022; Purnawan et al. 2012; Suciaty et al. 2019). Settled bottom sediments will accelerate the sedimentation process. Human behavior that intentionally dumps their waste in the river is one example of environmental effects. One of the most significant problems from sedimentation is loss of storage capacity of dams or reservoirs. Accumulation of sediment in reservoirs is affecting how much reservoir water can be utilized for irrigation sources, hydroelectric power generators, and flood control.

One of the causes of sedimentation in reservoirs is the low level of public awareness of waste management. There are various particles that are transported and accumulated in reservoir sediments. Tiwow et al (2019) mentioned that the concentration of certain heavy metals in sediments is an indicator of heavy metal pollution in rivers. Several studies reported that Saguling Reservoir sediments contain heavy metals such as cadmium (Wardhani et al. 2016), chromium (Paramita et al. 2017), copper (Sudarso et al. 2005), zinc (Adani et al. 2018) and lead (Arindra and Wardani, 2018), while heavy metals such as copper, mercury, and lead are present in the sediments of Cirata Reservoir (Priyanto et al. 2008).

Sedimentation can be managed with several specific strategies. Sumi and Kantoush (2022) revealed that sediment management techniques, which are widely developed around the world, in principle consist of three basic strategies, including (a) sediment yield reduction, (b) sediment flow, and (c) sediment removal. The International Hydropower Association [IHA] (2022) also explained that there are sediment management strategies that can be applied to reduce sediment accumulation. Management activities to address reservoir sedimentation can be classified into four types of methodologies:

a. Reducing sediment yield from upstream;
b. Managing water flows during periods of high sediment yield to minimize sediment trap in the reservoir, particularly by trapping it upstream;
c. Removing sediment already trapped in reservoir; and
d. Implementing adaptive structural and functional measures.

2. Plastic waste in sedimentation

Currently, plastics are present in almost all ecosystems, and are even found most abundantly in densely populated residential areas such as Bandung Raya. Plastics have been entering the environment through various pathways, including incorrect disposal, direct dumping of untreated waste, leakage from sewage or industrial infrastructure, waste disposal, hydrometeorological variables such as wind and surface runoff, and disasters such as floods, storms, or landslides (Lechthaler et al. 2020).

Macroplastics have been found floating on the surface of lake water (Faure et al., 2015), buried in lake bottom sediments (Egessa et al., 2020), and deposited on lake coastlines (Faure et al., 2015; Egessa et al., 2020). These plastics are derived from local activities (e.g., littering, fishing gears, direct wastewater discharge from nearby urban areas, or direct surface runoff) or carried by rivers that lead to the lake. As rivers from upstream areas flow into the lake, plastics are carried by lake surface currents and can concentrate in the lake (Faure et al., 2015).

Large-sized plastic can be degraded into small-size through mechanical abrasion, UV radiation, and biological processes (Hernandez et al. 2017). The small-size of plastic pollution will be easily carried by water flow and become sediment. The amount of microplastics in sediments is influenced by environmental factors (Azizah et al. 2020). Oktavia et al. (2020) mentioned that the dynamic movement of currents, waves, and wind are environmental factors that can carry microplastics that precipitate into sediments. Microplastics in marine sediments are harmful to aquatic organisms including fish, shellfish, and others. Studies on the distribution and amount of microplastics in reservoir, river, and coastal sediments in Indonesia have been widely reported. Sediments in the Ogan River (Meiwinda et al. 2023), coastal areas in West Kalimantan (Sulastri et al. 2023) and in the waters of Bandengan Kendal Regency (Laksono et al. 2021) have varying abundances and types of microplastics. The type of microplastics in sediments depends on the source of pollution or the type of plastic that is dominant around the waters (Azizah et al. 2020). The rise in plastic waste (macro and micro plastic) from human activities will contribute to sedimentation. Chanez et al (2014) reported that the lockdown regulation implemented in 2020 due to COVID-19 led to a significant decrease in the percentage of plastic pollution sediment.

3. Plastic waste management

Nowadays, plastics have made significant contributions in almost all areas of human activity, whether in agriculture, medical, transportation, engineering, electrical and thermal installations, packaging, manufacturing of household and electronic products, furniture, and other items of daily use or special use (Siddiqui and Pandey, 2013). Plastics can be transported into the environment by wind from landfills or from carelessly discarded plastic items; thus, those plastic waste, which are carried out by wind and water flow, can end up in reservoirs and oceans (Thompson et al., 2005).

The use of plastic in all areas of life leads to an increasing waste production. The high production of plastic waste was influenced by human activities. Borelle et al. (2020) stated that plastic production has now exceeded the capacity of the global community to manage the plastic waste they produce. In other words, waste production is greater than the efforts to manage plastic waste. The amount of plastic waste production will continue to increase. If it is not balanced with effective use of plastic and waste management, plastic pollution in the environment will increase. Syakti el al. (2017) mentioned that ineffective solid waste management, especially plastic waste in developing countries with large populations such as Indonesia, needs special attention.

In Indonesia, a significant amount of waste remains uncollected or inadequately managed, resulting in large piles at landfills; this can lead to various health issues, social problems, environmental quality degradation, and a decrease in aesthetic value

(Aisha, 2023). Waste is categorized into organic and inorganic waste. Organic waste includes food waste, while inorganic waste consists of paper, plastic, wood, metal, cloth, glass, leather and others. Plastic waste becomes a main problem because it is difficult to decompose naturally due to its complex carbon chains.

Plastic waste is a major environmental issue, especially in Indonesia. This problem arises because the population density in each region is not accompanied by a good waste management mechanism; additionally, the lack of public awareness and understanding regarding the grouping and disposal of waste according to type and location (Aisha, 2023) contribute to higher plastic waste production and, as a result, increased plastic pollution. Plastic pollution is an emerging environmental risk due to its negative impact on ecosystem health and human livelihoods. Aisha (2023) revealed that Indonesia is the second country after China to pollute the world's marine waters with its plastic waste. 83% of plastic waste in Indonesian waters, amounting to 3.22 million tons/year, remains unmanaged, affecting 10.1% of the world's marine pollution every year.

The high number of waste production must be balanced with effective waste management efforts. In recent years, waste management with the 3R (Reuse, Reduce, Recycle) concept has been widely developed in several places. However, this approach has not been effective due to the lack of public awareness about the impact of waste. Siddiqui and Pandey (2013) stated that the solution to waste management problems lies in separating dry and wet solid waste at the source; therefore, effective mass awareness campaigns are essential in supporting waste management efforts. Currently, plastic waste management has been widely processed and recycled into appropriate and valuable technology. The rapid development of technology can be a great opportunity for effective, efficient, and valuable plastic waste management. Some countries have started to implement plastic waste management with schemes that are tailored to the targets in each country. For example, plastic waste management in Indonesia focuses more on regulations to reduce, recycle, and reuse plastic, whereas Malaysia emphasizes on strict monitoring and regulatory reforms, as well as implementing a circular economy in managing plastic waste (Nurratri et al. 2024).

Plastic waste management is categorized according to the technology used. Siddiqui and Pandey (2013) explained that there are many plastic waste management techniques that can produce useful and valuable products, such as asphalt roads with polymer mixtures, conversion of plastic waste into liquid fuels, etc. (Figure 1). In Indonesia, technology-based waste management has been widely practiced, including plastic waste that is processed into a substitute aggregate in asphalt concrete pavement mixtures (Aschuri et al. 2016).

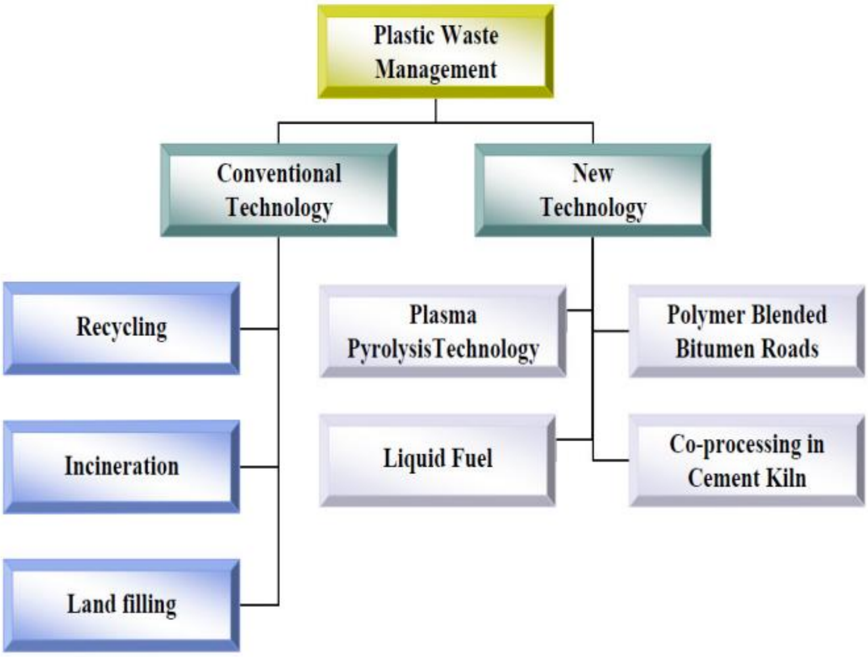

Figure 1. Diagram of Plastic Waste Management that Can be Developed
Source: Siddiqui & Pandey (2013)

C. METHOD

1. Data Collection

Secondary data were utilized in the current study. They were obtained from interviews with members of several community groups of waste management programs, including Sukamaju Sejahtera Waste Bank, Bening Saguling Foundation (BSF), unit waste banks (West Bandung Regency, Cimahi City, Bandung City and Bandung Regency), Jurig Runtah, Kelompok Pengelola Eceng Biomass and Reservoir Waste Scavenger (Pemulung Sampah Waduk [PSW]).

2. Waste Classification

The waste managed by the community groups consists of 3 types: low-value plastic waste, high-value plastic waste, and organic waste. The plastic waste managed by the groups is then sold to plastic companies. According to the plastic company's acceptability criteria, plastic waste is categorized into low-value and high-value plastic waste. Low-value plastics are those whose collection and processing costs are higher than the revenue generated from the sale of recovered plastics. They are usually plastic waste that is difficult to recycle. Whereas high-value plastics are those that can generate a fairly high income when recycled.

3. Rate of Sedimentation

The sedimentation rate of a reservoir was calculated by measuring sediment transport at the estuary of a river flowing into the reservoir. The total sediment entering the reservoir is the sum of the suspended loads measured at the river estuary. In this case, the suspended load calculated is the amount of plastic waste and organic waste entering the reservoir. To calculate the sedimentation rate, it can be approached by knowing the amount of waste carried and the specific gravity of the waste. Based on the SNI 3242-2008 standard, the specific gravity of waste is assumed to be 200-300 kg/m3 (0.2 - 0.3 kg/liter). The equation used to calculate the sedimentation rate is as follows:

$$Sedimentation\ rate\ (m3/year) = \frac{Total\ of\ waste\ entering\ to\ the\ reservoir\ (kg)}{Bulk\ density\ of\ waste\ (kg/m3)}$$

The equation for the reservoir's sedimentation rate by plastic waste can be used to calculate the rate of sedimentation reduction that can be controlled through the program, particularly by using the data of the amount of waste managed from the program.

D. RESULTS AND DISCUSSION

1. Integrated Waste Management Program by PT. PLN Indonesia Power UBP Saguling

The integrated waste management program developed by PT. PLN Indonesia Power UBP Saguling is intended to overcome waste problems that can impact the Saguling reservoir. The downstreaming of waste from the Bandung Raya area will accelerate sedimentation in the reservoir. The integrated waste management program has a concept that combines preventive, repressive (impact reduction), and curative (control actions) measures.

The preventive action starts from reducing waste entering the river through the waste bank program in the upstream waste area as an initial prevention effort for reservoir sedimentation. Impact reduction is carried out by picking up waste carried by the flow in the downstream area, while control action is carried out by picking up waste in the reservoir. The integrated waste management program consists of several community-based waste management groups, namely Sukamaju Sejahtera Waste Bank, several unit waste banks (West Bandung Regency, Cimahi City, Bandung City, and Bandung Regency), Bening Saguling Foundation, Jurig Runtah, Kelompok Pengelola Eceng Biomass, and Pemulung Sampah Waduk (PSW), which are spread from the upstream waste area (closed to Bandung Raya area), downstream areas, to the Saguling reservoir (Figure 2).

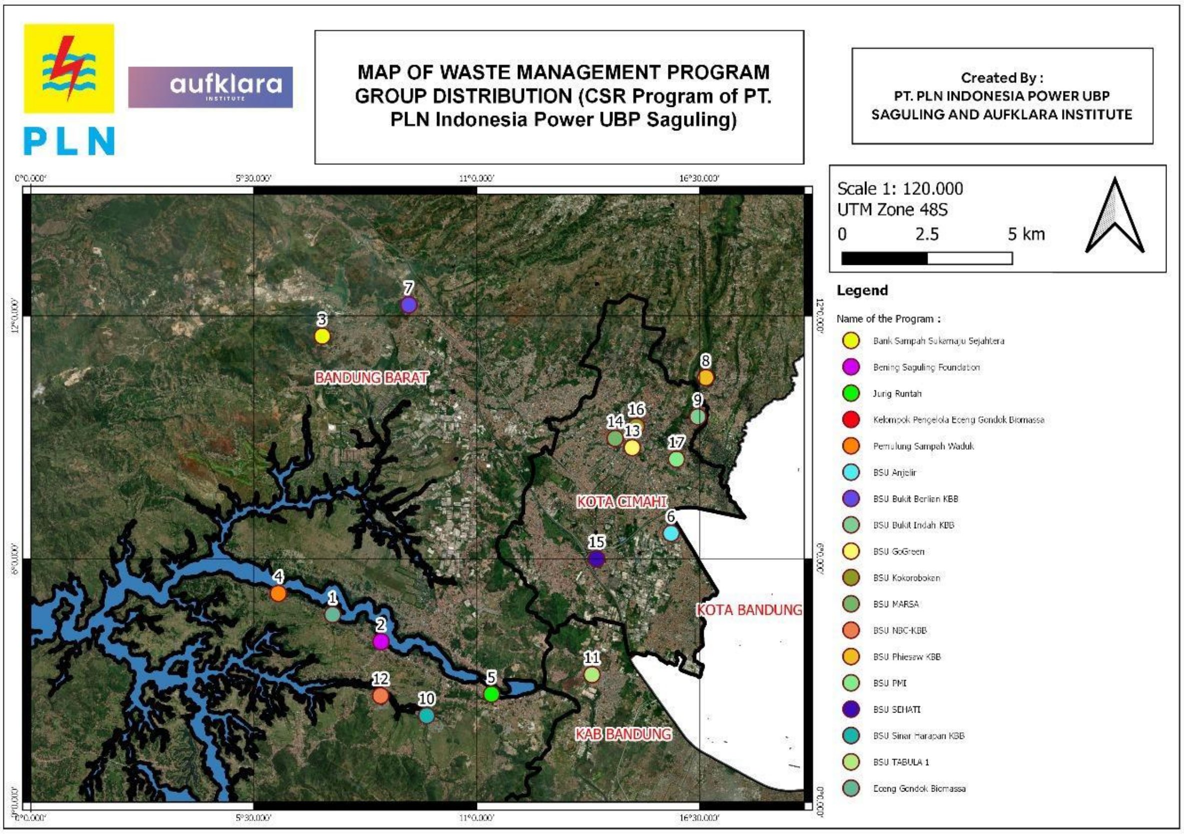

Figure 2. Distribution Map of Waste Management Program Group Locations

The integrated waste management program groups developed by PT PLN Indonesia Power UBP Saguling have their operational areas with specifications on the types of waste managed. In the upstream area (close to the Bandung Raya area), the Sukamaju Sejahtera waste bank group and several waste bank units spread across several areas (West Bandung Regency, Cimahi City, Bandung City, and Bandung Regency), focusing on waste sorting. These waste banks aim to reduce the total of community waste dumped into the river. Sukamaju Sejahtera waste bank (BS3) manages 3 types of waste (low-value plastic waste, high-value plastic waste, and organic waste). Sukamaju Sejahtera Waste Bank operates in the Padalarang sub-district, sorting and managing waste from Bandung Raya. The collection of inorganic waste from the community is conducted using two methods: (a) customers come to the waste bank and deposit the waste as waste savings, or (b) the waste is collected from the customer's houses by *cator* (three-wheeler dumper) twice a week. Meanwhile, organic waste collection is carried out by BS3's partner, the youth organization, using garbage carts every 2 days. The Sukamaju Sejahtera waste bank group has managed 38,573 kg of waste, including both plastic and organic waste, from 2022 to 2024 (Table 1).

Table 1. Total Waste Managed by 5 Program Groups from 2020 to 2024

Name of Program Group	Type of Waste Managed Per Category (kg)			Total of Waste Managed Per Groups (kg)
	Low Value Plastic Waste	High Value Plastic Waste	Organic Waste	
Kelompok Pengelola Eceng Biomass	30,000	-	-	30,000
PSW (Pemulung Sampah Waduk)	279,760	69,770	-	349,530
BSF (Bening Saguling Foundation)	39,892	66,303	637,720	743,915
Jurig Runtah	3,618.7	1,784.9	1,221	6,625
BS3 (Bank Sampah Sukamaju Sejahtera)	3,056	30,807	4,710	38,573
Total waste managed	356,326.7	168,664.9	643,651	1,168,643

Waste management does not stop at the upstream area (near Bandung Raya area), but it continues to the downstream area (river flow). Waste management in this downstream area is carried out by 2 groups, namely Bening Saguling Foundation (BSF) and Jurig Runtah. The Bening Saguling Foundation operates in the Cihampelas and West Batujajar sub-districts, collecting waste along the river using boats and conveyors for 5 working days (Monday-Friday). Meanwhile, the Jurig Runtah group is a waste volunteer group that operates in the riverbank area of Bandung Regency covering the sub-districts of Margaasih, Katapang, Soreang, Cangkuang, Banjaran, Pamengkeuk, Bojongsoang, and Baleendah with the same working days. Waste management activities by BSF and Jurig Runtah have been carried out since 2023. BSF and Jurig Runtah have managed waste from low-value plastic waste, high-value plastic waste and organic waste of 743,915 kg and 6,625 kg for each program group (Table 1).

The waste management program in the Saguling reservoir area as the estuary of the rivers in the Bandung Raya area is carried out by 2 groups, namely the Kelompok Pengelola Eceng Biomass and the Reservoir Waste Scavenger (PSW). The Kelompok Pengelola Eceng Biomass operated in Saguling reservoir area in 2020, utilizing water hyacinth and waste management as fuel for the Steam Power Plant (PLTU). This group managed 30,000 kg of low-value plastic waste (Table 1); however, the activity was not sustained.

The PSW group operates in the Saguling reservoir area, precisely in Batujajar and Cihampelas sub-districts by using boats to collect waste in the Saguling reservoir. A total of 40 boats operate five days a week (Monday-Friday) from 07.00 -16.00. This group began operating in 2024 by taking low-value and high-value plastic waste. The total of plastic waste managed by the PSW was 349,530 kg for 6 months (Table 1).

The distribution of the total of plastic waste and organic waste managed by each group can be seen in Figure 3 below:

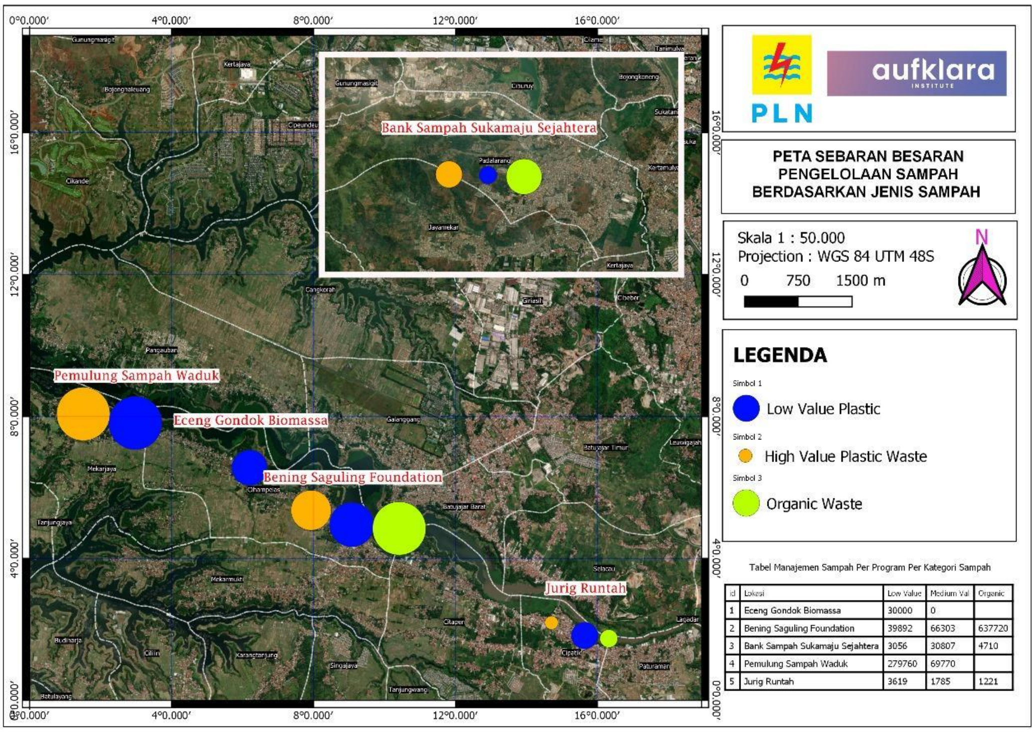

Figure 3. Distribution of the total of waste managed by the 5 program groups

Community-based waste management not only provides direct benefits by reducing waste, but also economic benefits in the form of additional income from waste savings managed (Aasteria and Heruman, 2016). Community activities such as MSME (Micro, Small and Medium Enterprises) and women's empowerment that convert waste into creative products can increase the community's economic income (Mikaresti et al. 2024; Ismail and Wolok, 2019). The managed plastic waste is then sold to plastic companies for recycling. The proceeds from the sale of the waste become the income earned by the group members. In addition to the Jurig Runtah group, the four program groups earn their income from the managed waste. The monthly income of each group varies depending on the type and total of waste managed. The average income received ranges from 1,000,000 to 2,100,000 per month.

2. Impact of integrated waste management program on reducing reservoir sedimentation

The integrated waste management program developed by PT PLN Indonesia Power UBP Saguling has been in operation since 2020 with 5 program groups. However, several program groups such as the Eceng Biomass Management Group, only operated in 2020 and did not continue.

One of the most significant factors determining reservoir storage quality and reservoir service life is sedimentation. The sedimentation process will occur quickly, if the suspension carried by the river flow into the reservoir is in large quantities. Both plastic waste and organic waste carried by river flow can accelerate reservoir sedimentation. The integrated waste management program aims to reduce the amount of waste carried by the river with several activities. The amount of waste managed by the program groups from 2020 to 2024 is presented in Table 2 below:

Table 2. Total of waste managed by program groups from 2020-2024

Year	Type of waste managed per category (kg)			Total of waste managed per year (kg)	Reduction of sedimentation (m3/year)	Percentage of sedimentation reduction (%)
	low value plastic waste	high value plastic waste	organic waste			
2020	30,000	-	-	30,000	150	0.01
2022	2,400	13,280	147,370	163,050	815	0.05
2023	2,528	15,748	294,781	313,057	1,565	0.1
2024	321,399	139,637	201,500	662,536	3,313	0.2
Total waste per category	**356,327**	**168,665**	**643,651**	**1,168,643**	**5,843**	**0.36**

The amount of waste managed increased from 2020 to 2024 (Table 2). This indicates that the integrated waste management program is successful. Based on the type of waste, the total amount of organic waste managed was the highest, compared to low-value and high-value plastic waste. This condition shows that public awareness to process organic waste independently is still low. There are still many people who throw garbage in the river.

Managing waste by taking them from waste banks, riverbanks, and Saguling reservoirs reduced the amount of waste entering the reservoir, thereby reducing the sedimentation rate. From Table 2, it can be concluded that the rate of sedimentation reduction from 2020 to 2024 has also increased. The rate of sedimentation reduction in 2020 was 150 m3 and increased to 3.313 m3 in 2024. Based on the Saguling Hydroelectric Reservoir Inspection report by PT Indra Karya in 2022, the actual sedimentation rate of the Saguling Reservoir at the base is estimated at 1,616,740.27 m3/year. Thus, the percentage impact of integrated waste management on sedimentation reduction can be approached by comparing the sedimentation reduction rate of the waste program with the actual sedimentation rate. The analysis of the waste management program's impact on sedimentation reduction from 2020 to 2024 shows a percentage of 0.36% (Table 2).

Table 3. Total of Waste Managed by Each Group and its Contribution to Reduce Reservoir Sedimentation

Name of Program Group	Type of waste managed per category (kg)			Total of waste managed per groups (kg)	Reduction of sedimentation (m3/year)	Percentage of sedimentation reduction (%) (%)
	Low Value Plastic Waste	High Value Plastic Waste	Organic Waste			
Kelompok Pengelola Eceng Biomassa	30,000	-	-	30,000	150	0.01 %
PSW (Pemulung Sampah Waduk)	279,760	69,770	-	349,530	1,748	0.11 %

BSF (Bening Saguling Foundation)	39,892	66,303	637,720	743,915	3,720	0.23 %
Jurig Runtah	3,618.7	1,784.9	1,221	6,625	33	0.002 %
BS3 (Bank Sampah Sukamaju Sejahtera)	3,056	30,807	4,710	38,573	193	0.01 %
Total waste managed	356,326.7	168,664.9	64,3651	1,168,643	5,843	0.36 %

The five groups involved in the integrated waste management program also have a role in reducing sedimentation in Saguling reservoir. The contribution of each group to sedimentation reduction and the percentage of its contribution is presented in Table 3. Among the five groups, the Bening Saguling Foundation provided the highest contribution in reducing sedimentation, achieving approximately 3720 m3/year, with a contribution percentage of 0.23%. This was followed by Reservoir Waste Scavengers (Pemulung Sampah Waduk [PSW]), Sukamaju Sejahtera Waste Bank, Kelompok Pengelola Eceng Biomass and Jurig Runtah. The waste managed by Jurig Runtah provided the lowest contribution to sedimentation reduction, with a percentage of 0.002%. This is considered as 'good' because Jurig Runtah is a non-profitable activist group that consciously supports the waste management program in an effort to support the conservation of Saguling reservoir.

E. CONCLUSION

The integrated waste management program initiated and developed by PT. PLN Indonesia Power UBP Saguling which consists of 5 program groups including (Sukamaju Sejahtera Waste Bank, Bening Saguling Foundation, Jurig Runtah, Kelompok Pengelola Eceng Biomass, and Pemulung Sampah Waduk (PSW) is successful, as indicated by the increase in the amount of waste managed from 2020 to 2024. The total amount of waste managed increased from 30,000 kg in 2020 and 662,536 kg in 2024. The integrated waste management program also plays a role in supporting reservoir conservation efforts by reducing sedimentation up to 5,843 m^3 and reducing sedimentation percentage by 0.36% for 4 years (2020-2024).

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