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Solid Waste Handling Using Ships as a Land Replacement in Small Islands (Case Study: Raas and Sapudi Islands)

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ABSTRACT: Indonesia is an archipelagic state with a very large number of islands including large islands and small islands, such as small islands in Sumenep Regency, East Java. The existence of small islands that have limited human resources, transportation and communication access, weak surveillance, and procurement of budget and infrastructure can cause the solid waste management system does not work properly. Solid waste that has not been managed properly can affect human health and the environment directly or indirectly. Therefore, it is necessary to study the solid waste management system in small islands of Indonesia. The aim of the study is to discover the solid waste handling practices in Raas and Sapudi Islands. The methods used in this study are primary and secondary data collection. Primary datas are obtained through direct observation, questionnaire, and documentation. Secondary datas are obtained through textbooks, scientific articles from national and international journals, papers, final assignments, thesis, dissertations, other scientific works, and document from government or world organization related to the topic of this study. Search for scientific articles is conducted through Google Scholar, Science Direct, and Researchgate. Practice of solid waste handling is by using ships. The estimated total cargo weight on the ship is 42,14 tons/day and the required solid waste handling area is 667,92 m^2 in 2034. The type and size of ship that can be used is a roll on-roll off ferry with maximum specifications of 525 GT, DWT 336 tons, Loa 51 m, beam 14 m, and speed 4,3 knots.

KEYWORDS: Source of solid waste, impact of solid waste, small islands, solid waste, solid waste handling.

I. INTRODUCTION

Indonesia is the largest archipelagic country in the world based on the number of its islands (Wattimena, 2022). There is a term that refers to areas or islands located on the borders of Indonesia's territory that are farthest from the center of government, have limited accessibility, and are located in geopolitically strategic areas, namely outermost, frontier, and underdeveloped (3T). Development challenges on small islands and 3T islands include limited human resources, access to transportation and communication, weak supervision in these areas, budget and infrastructure procurement, vulnerability to disasters, and environmental degradation (Situmorang and Ayustia, 2019).

Environmental degradation is one of the main problem underlying the interest in improving the environmental management system. Environmental degradation can be caused by land use and the entry of polluting materials in the form of solid, liquid or gas into the environment where these materials are not part of the original components of the environment. Solid waste is one of the causes of environmental degradation. In 2020, Indonesia was ranked as the second largest producer of marine debris in the world after China. According to data from the Ministry of Environment and Forestry in 2020, Indonesia's ocean areas were polluted by around 1.772,7 g/m^2 of marine debris. Of all the solid waste that is not properly managed, some is thrown into river and end up in the ocean. The most common type of solid waste found was plastic waste weighing 627,8 g/m^2. This amount accounts for 35,4% of the total waste in Indonesian seas. Apart from plastic waste, glass and ceramic waste is also quite large, reaching 226,29 g/m^2 or 12,76% of the total solid waste in the sea. Then as much as 224,76 g/m^2 of waste in Indonesia's seas is in the form of metal. Followed by waste in the form of wood 202,36 g/m^2 and other solid waste 173,73 g/m^2. There was also rubber waste amounting to 110,64 g/m^2, plastic foam waste 56,68 g/m^2, paper and cardboard waste amounting to 21,86 g/m^2. However, in 2021 Indonesia was ranked fifth as the largest country that produce marine debris in the world, namely 56,333 tons. The large amount of waste generation, especially plastic waste, is caused by various activities or public activities carried out by people living on large islands and small islands (Subagiyo et al., 2017).

Small islands are islands and their ecosystem unit with an area smaller than or equal to 2.000 km^2. One area that has several small islands is Madura Island which is part of Java Island. Some of these small islands include Raas Islands and the Sapudi Islands. The Raas Islands and Sapudi Islands are administratively located in Sumenep Regency, East Java. The Raas Islands have an area of 38,9 km^2, while the Sapudi Islands have an area of 128,48 km^2 (Sumenep dalam Angka, 2022). People around these islands have their livelihoods originating from the agriculture, livestock, fisheries, trade and tourism sectors.

Negative impacts that can arise include increasing the amount of waste generated, environmental pollution, ecosystem disruption, human health problems, and so on. One of the waste problems that occurs in small island areas is trash that is thrown carelessly in the Gayam Market beach area, Sapudi Islands. This waste generation causes unpleasant odors and pollutes the beach area. These things must be handled appropriately in order to preserve the environment, balance the ecosystem, and prevent the emergence of health problems in human. According to UU No. 18 (2008), efforts that can be made to improve the solid waste management system are by reducing and treating solid waste. Solid waste treatment consists of waste sorting, waste collection, waste transportation, waste processing and final waste processing. In several small island areas in Indonesia, solid waste management systems have been developed through several previous studies.

One of the previous studies regarding solid waste management on small islands was on Kangean Island, Sumenep Regency. The results of this research showed that the composition of solid swaste produced by the community in this area is dominated by food waste and plantation waste at 62,70%. In this area, a solid waste management system had never previously been implemented, people were accustomed to illegal dumping and burning. The recommended solid waste management system is to provide special bins for organic and inorganic waste, collect waste from the source, process waste by sorting and processing using open windrow composting, and waste residues are processed using thermal technology and disposed of in a mini backfill area (Rahman and Bagastyo, 2021). Due to limited human resources, land and infrastructure in small island areas, the provision of solid waste treatment facilities will tend to be difficult to be done.

II. METHODOLOGY

Data collection consists of secondary data. Secondary data comes from solid waste generation and composition of Sumenep Regency. Another datas are obtained through various library sources such as textbook, scientific articles from national and international journal, paper, thesis, dissertation, other scientific works, and government or world intitutional document related to the topic.

Based on SIPSN KLHK datas regarding solid waste generation in Sumenep Regency (2023), it is known that the amount of solid waste generated in Sumenep Regency in 2023 is 367,44 tons/day or around 367.440 kg/day. Solid waste composition based on solid waste type in Sumenep Regency in 2023 consists of 58,62% food waste, rubbish paper/cardboard 20,83%, plastic waste 17,33%, wood/twig waste 1,08%, cloth waste 0,91%, glass waste 0,51%, other waste 0,4%, and rubber/leather waste 0,26%.

III. RESULTS AND DISCUSSION

A. Population, Solid Waste Generation, and Reduction Potential in Study Area

By projection in 10 years ahead particularly in 2034, it is known that population projection is 92.555 people, solid waste generation projection is 29.758 tons/day. As for the reduction potential in study area for 2023, it can be known that the amount of waste that can be reduced is 17,79 tons/day or 63,42% of the total waste generated amounting to 28,05 tons/day and producing residue of 10,26 tons/day. With recovery factor of 75% wet waste which can be reused is 12,33 tons/day with a residue of 4,11 tons/day. A total of 2,92 tons/day. Paper/cardboard waste can be reused with a recovery factor of 50%, resulting in a residue of 2,92 tons/day. 2,43 tons/day of waste. Plastic can be reused with a recovery factor of 50% so produces residue of 2,43 tons/day. 0,10 tons/day of glass waste can be obtained reused with a recovery factor of 65% to produce residue of 0,06 tons/day. After determining the reduction potential calculation waste, then the next step is to carry out a mass balance analysis. The mass balance analysis can be seen in Figure 1.

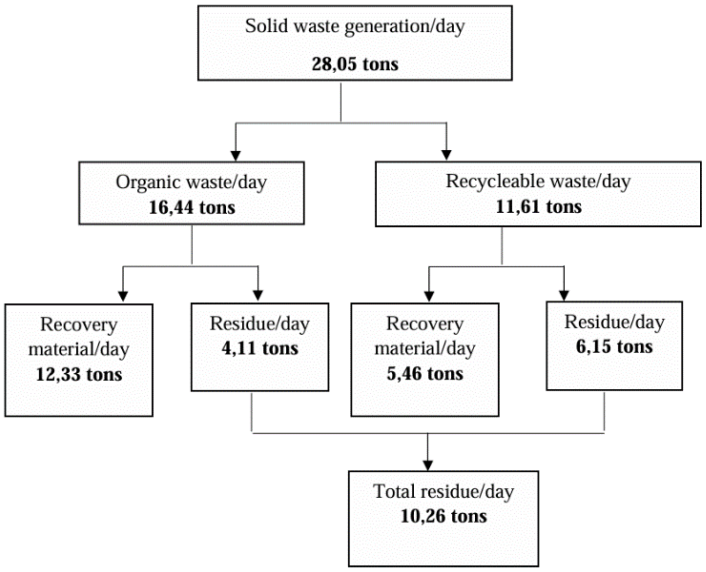

Figure 1. Mass Balance Analysis in 2023

B. Receiving and Sorting Area

Solid waste that still has a selling value being collected and separated during the solid waste sorting process on the ship. The recycled waste then collected to a certain amount, then it can be resold to garbage collectors. Recycled waste that still has a selling value includes plastic, glass, iron, paper, cardboard, and so on. Sorting is carried out by sorting officers when garbage leaves the port transferred onto the ship. The reception and sorting area is needed. The need for the area of reception and sorting area is calculated based on the daily volume of solid waste divided by the height of the landfill plan garbage in the receiving area. Total solid waste generation from the Raas and Sapudi Islands in 2034 will be 29,758 tons/day or 29.758 kg/day. If the height of the garbage pile is 1 m, and the density of loose waste is 139 kg/m^3 (Purnama, 2003), then the area of reception and sorting is 214,1 m^2.

C. Storage Area

The solid waste that has been sorted by its type then will be processed. Organic waste will be processed using the anaerobic composting method with the addition of microorganisms that will speed up the maturation process. Compost and recyclable waste that has been sorted will be stored in the recycled waste storage will subsequently be sold to collectors. Based on the results of the calculation of solid waste recycling potential in Raas and Sapudi Islands in 2023, solid waste that has the potential to be recovered is plastic waste, paper/cardboard waste, and glass waste. To determine the volume of each component of stall waste, required datas are the weight of the garbage and the specific weight of the garbage. The calculation of the volume of each component of stall waste is by dividing the weight of the waste (kg/day) with the specific weight of the waste (kg/m^3). By projection in 2034, the volume of recycled waste or stall waste is 74,93 m^3/day, if the height of the stall garbage pile is 1 m, so the area of the garbage storage area needed per day are 74,93 m^3.

D. Shredding Area

Total potential of organic waste that can be processed into compost reaching 13,08 tons/day or 13.080 kg/day. Early stages of the composting process is enumeration. Shredding is carried out to make solid waste easier to decompose or degraded. The area of the shredding area is greatly influenced by the capacity and quantity of choppers, working time, and the number of chopping. If the number of choppers needed is 3 pieces, so the area of organic waste shredding is 10,2 m^2.

E. Composting Area

The area of the composting area is calculated using an anaerobic system. Based on the composition of solid waste and the value of the recovery factor, the volume of compostable solid waste is 13.080 kg/day or 45 m^3/day based on the specific weight of food waste was 290,72 kg/m^3 (Tchobanoglous et al., 1993). The total area of the composting area is as large as 215,35 m^2.

F. Sifting Area

During the compost maturation process, there is a shrinkage of weight and volume of compost. If the weight of composted solid waste is 13.080 kg/day, with the weight of solid waste after shrinkage of 5.140,44 kg/day and there are 2 compost sieving devices, then the area needed for compost sifting is 20 m^2.

G. Packing and Compost Warehouse Area

At a compost density of 326,32 kg/m^3 (Tchobanoglous et al., 1993) and the weight of compost that has shrunk by 5.140,44 kg/day, then the volume of compost is 15,75 m^3/day. So that for packing and compost storage warehouses requires an area of 10,5 m^2.

H. Residual Area

The area of the residue area is closely related to the number of available containers. Based on mass balance analysis, the amount of residue in Raas and Sapudi Islands reached 10,89 tons/day or 10.890 kg/day. If the density of solid waste in the container is assumed to be 350 kg/m^3, so the volume of residual waste is 31,1 m^3. If the residue container has a capacity of 10 m^3 with dimensions 3,6 m x 2,3 m and 1,55 m high, then the number of containers required is 4 containers for residual waste. The area required if the circumference 0,5 m is 45,92 m^2.

I. Leachate Reservoir Pond Area

Some of the organic waste from sorting step is processed into compost. The organic waste processing process will produce leachate, so that a leachate reservoir is needed. When the water content in food waste is 74% (Cerda et al., 2018), the moisture content in the compost is 50% (Ameen et al., 2016), leachate specific gravity of 1.000 kg/m^3 (Tchobanoglous et al., 1993), and the weight of compostable solid waste is 13.080 kg/day, so the volume of the leachate reservoir pond is 3,14 m^3/day. The detention time for leachate reservoirs is 7 days and pool height is 1 m, so the volume of the leachate reservoir is 21,97 m^3. So that to accommodate leachate requires an area of the leachate reservoir pond of 21,97 m^2.

J. Supporting Facilities Area

Supporting facilities are quite important to support activities or solid waste handling activities on board. The supporting facilities needed include crew room, place of worship, and toilet. Assuming the area for the crew room is 30 m^2, toilets are 16 m^2, and places of worship are 9 m^2.

K. Estimated Total Area and Weight Required

Based on the results of the calculation needs for the area of solid waste handling facility on a solid waste treatment ship, it can be known that the total needs of the area of solid waste handling facilities needed in 2034 is as large as 667,97 m^2. Based on the calculation results of the estimated weight of the cargo on the ship at 2034 per day, it can be seen that the total load is around 42.142,8 kg or 42,14 tons.

L. Ship's Type Option

Based on the estimated cargo weight in 2034 which is 42,14 tons and the total area required for solid waste handling facilities in Raas and Sapudi Islands amounting to 667,97 m^2, the type of ship that can be used as a ship that facilitates daily solid waste handling is Ro-Ro (roll on-roll off) ferry type with maximum tonnage specifications of 525 GT, DWT of 336 tons, size 51 m x 14 m, and ship speed of 4,3 knots (7,9636 km/hour) or it can also use another types of ships with similar specifications.

M. Operational Scenario

The solid waste processing vessel's route begins when the vessel docks in Raas Port departs from Raas Port, Raas District. The second island destination is Sapudi Island where the ship will go to Sapudi Port, Gayam District. Distance from Raas Port to Sapudi Port is about 36 km. In the ship there will be solid waste processing process while the ship carries rubbish from one other island. After leaving the Sapudi Port, the ship will be ahead to Tanjung Perak Port, Surabaya. Distance from Sapudi Port, Gayam District to Tanjung Perak Port, Surabaya is about 191 km. After that, the ship will return to Raas Port, Raas District, distance from Tanjung Perak Port, Surabaya to Raas Port is 223 km. In one shipping route from Raas Port to Sapudi Port - Tanjung Perak Port required a distance of around 227 km.

So that solid waste handling from each island is to be done properly, a pattern needs to be created for solid waste handling operations of the two islands. If the speed of the ship used is 4,3 knots (7,9636 km/hour) with a distance between Raas Port – Sapudi Port is 36 km, so the sailing time required is 5 hours. If the distance between Sapudi Port - Tanjung Perak Port is 191 km, so the shipping time required is 24 hours. Garbage from each resident's house will be collected by officers who pick up the solid waste and then take it to the port. At this port, the process of solid waste loading onto the ship takes place. Loading process of solid waste can be using a dump truck or other type of transportation equipment. After the solid waste is on board of the ship, the sorting process will then be carried out, shredding, composting, and other processes. Operational activities begin on day one with the solid waste loading process in Raas Island at 07.00 – 10.00 WIB. Continue with a trip to the Sapudi Island at 10.00 – 15.00 WIB. During this journey, a solid waste sorting process is carried out enumeration of solid waste from Raas Island. After arriving at Sapudi Port, the ship's crew including workers rest for 1 hour at 15.00 – 16.00 WIB. Then, the process of solid waste loading

from the Sapudi Island is carried out at 16.00 – 19.00 WIB. At 19.00 – 22.00 WIB, the process is carried out solid waste sorting from the Sapudi Island. Next, crew and including another workers rest for 8 hours from 22.00 – 06.00 WIB.

On the second day, the process of enumerating solid waste from the Islands was carried out in Sapudi Island at 06.00 – 07.30 WIB. At 07.30 – 09.00 WIB, it is carried out the preparation process for composting organic waste, then starts from 09.00 WIB the composting process was carried out. Assumed composting time until the solid waste ready is 4 days, because it takes several days then the ship will dock for 3 days at Sapudi Port onwards the remaining 1 day the composting process will continue while the ship travels heading to the port in Surabaya on the sixth day precisely at 09.00 WIB. During the trip to Surabaya, while waiting for the compost to ripen, the process of recycled waste packing will be carried out. After the ship arrives and docks at the Port of Surabaya, the mature compost will be sieved. The sieving process is carried out at 09.00 – 10.00 WIB. At 10.00 – 13.00 WIB, the compost packing process is carried out. Then at 13.00 – 15.00 WIB, the process of unloading compost, recycled waste, and solid waste residue. Compost and recycled waste can be sold to collectors directly or through distributors, while solid waste residues can be processed back at another landfill.

Operational process for handling solid waste in Raas and Sapudi Islands in 1 route takes time until 6 days. So, the ship will go to Raas Island and Sapudi Island every 6 days. For optimizing the solid waste handling process on the islands, 6 ships are needed so that after ship A has arrived at the port of Surabaya, the B-F ships can be immediately operate to each of the island the next following days. So there is no need to wait for another ship to return to Raas Island where the sailing time takes about 1 day. If there are 6 units ships that take turns start to sail, then within 1 day there are maximum of 3 ships dock at Sapudi Port. As another alternative, it can be considered to choose other types of ship that have a load capacity and larger area so it can accommodate 6 times of the load capacity. For example KMP. Dharma Rucitra 8 Ro-Ro Cargo Ship with specification of maximum tonnage of 7.756 GT, DWT of 4.987 tons, size 145 m x 25 m and ship speed 15,9 knots.

IV. CONCLUSIONS

Solid waste handling practices that can be applied in the Raas and Sapudi Islands is by using solid waste carrier and processing vessels where inside the ship the process of sorting, chopping, composting, sieving, and packing included. The estimated total cargo weight on the ship is 42,14 tons/day and the area requirement is 667.97 m^2 based on calculation projection until 2034. So there are options for the type and size of ships that can be used such as a roll on-roll off ferry type with maximum specifications of 525 GT, DWT 336 tons, Loa 51 m, beam 14 m, and 4.3 knots speed.

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