Dynamic model of municipal solid waste management from households in Sukuta Nema, The Gambia

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Abstract. Improper waste management is a global concern, especially in developing countries where population growth is increasing. Improper waste management is increasingly becoming a global problem that requires a holistic approach to avert health consequences. This research aims to estimate the generation, reduction and disposal of solid waste from households in Sukuta Nema, The Gambia, in the next 25 years. An analytic observation with a cross-sectional design and a dynamic model approach and data from observations in the field were used—a sample size of 125 households was drawn using random sampling. The results showed that household waste generation in Sukuta Nema was 2.07 kg/house/day or 0.0083 m³/house/day. Household waste from Sukuta Nema is predominantly organic, with a proportion of 80.71%. Inorganic waste constitutes about 19.29%. Based on the model scenario for 25 years (2021-2046), the results show that the estimated average rate of waste reduction through waste banks is 5.84%, the rate of waste reduction through composting scenarios is 64.20%, and the rate of waste reduction through a combined scenario between a waste bank and composting is 70.04%. The best waste management tool to use ineffective waste reduction is the combination scenario.

1. Introduction
Solid waste, commonly known as trash or garbage in The Gambia according to [1], is a type of waste that consists of daily items that are discarded or intended to be discarded by the public. The problem of waste is a problem faced by all human beings, both as individuals, families and communities. The problem of waste is also a problem faced by an area, ranging from small scale to the level of hamlets, villages, sub-districts, districts /cities even in a country. Currently, more than 50% of the world's population resides in urban areas, and urbanization rates are rising rapidly. It will add to the challenge of waste management [2,3].

The region's growth, including districts/cities in several developing countries, has raised a range of concerns associated with proper waste management. Currently, urban areas in the West African Region spend about US$ 25 billion per year for the management of 760,000 tons of solid waste daily. Waste management is anticipated to continue to increase to US$ 50 billion by 2025, with a projected waste amount of 1.8 million tons per day [4,5]. The more advanced a country is, the characteristics and amount of waste produced will undoubtedly be more different from developing countries or countries that are still underdeveloped. Waste management in developing cities and large cities has become a relatively complex problem to be solved. Waste problems must be solved with a good management approach [2].
For example, centralized waste management, because it can reduce costs and greenhouse gas emissions produced [6].

Based on data obtained from the Environment Office of Kanifing Municipal Council (KMC), the incidence of waste in the Sukuta Nema sub-district in 2015 amounted to 10.14 tons/day. In 2016, the region produced 12.86 tons of waste/day. In 2017, there was 15.16 tons/day of waste. As for the amount of waste transported to a landfill in 2016, as much as 7.13 tons/day. In 2016 as much as 9.01 tons/day, and in 2017, waste was transported to the landfill as much as 12.14 tons/day [7]. Waste management services in Sukuta Nema start from waste collection activities, waste transportation and landfill. Waste management services at KMC serve households and non-households (markets, hospitals, hotels, shops, restaurants, schools and street sweeps). The waste collection facility consists of waste containers and temporary shelters in the form of plastic waste cans with a capacity of 0.1 m$^3$. Waste containers are used for waste collection sourced from markets, streets, garages and offices. Temporary collection containers in plastic waste bags with a volume of 0.1 m$^3$ are used for residential areas. This trash can is distributed in front of people's houses for public access and easy transportation to the temporary disposal sites. Waste collection activities are carried out by waste collection and transport officers under the Environment Office of Kanifing Municipal Council [8]. The KMC waste truck carries waste transportation and is transported to a landfill approximately 13 km from Sukuta Nema.

Dynamic modelling is one of the instruments to estimate the increase or the rise in waste in the city that is increasing every year. Dynamic modelling is used to describe complex system behaviours. A waste management system is a complex issue because everything involved in it is interconnected as a whole. Dynamic modelling also aims to explore, assess, and predict impacts holistically [9].

The waste management system in Sukuta Nema still uses the pattern of collecting, transporting and disposing of. It will cause an increasing amount of waste that will end up in landfills and will potentially affect the quality of the environment, including public health around the landfill site because landfill in Kanifing Municipal Council uses an open dumping system where waste is only disposed of at landfill openly which is later burnt openly [7,8,10,11]. The potential level of waste reduction can be established through dynamic modelling, which can be done with composting scenarios and waste banks. We can estimate the total volume of waste transported and disposed of at the landfill [12]. By knowing the estimated waste generation over the next few years, waste management planning will be more efficient and effective—waste management planning, among others, based on the collection and transportation of waste in Sukuta Nema. If organic waste in the household can be composted and inorganic waste can be managed in the waste bank, then the waste transported to the landfill becomes reduced, and the landfill's life will be longer.

Through dynamic modelling, waves of composting and waste banks are used as a form of model scenarios. With this model scenario, through dynamic modelling can estimate the level of waste reduction to know the number of temporary disposal sites needed and the needs of waste carriers in the next few years, including the life span of landfills.

1.1. Municipal waste

In The Gambian National Standards, it is stated that municipal waste is any waste that comes from a city. It consists of both organic and inorganic materials that are termed unusable and must be managed not to threaten or harm the environment and protect the development investments in an area [13]. The issue of urban waste is a problem faced by most cities in The Gambia, even in the world. Urban waste that is not handled correctly will impact social, economic and health aspects of the environment. The increasing production of waste that is not balanced with environmentally friendly waste management will cause damage and environmental pollution.

Furthermore, uncomprehensive waste handling will trigger an increasing incidence of social problems and health problems. Currently, most waste management in The Gambia ends up in landfills, and most of those waste is not segregated, which will increase the area demand of the landfill. In addition to the need for extensive land, it will also require costly environmental protection facilities. The
increasing amount of waste dumped into landfills over time is due to the lack of efforts to reduce waste in earnest since waste from the household as a source of waste is not segregated [14].

1.2. Types of Municipal waste

1.2.1. Household Waste. It is a waste that results from various activities carried out daily in the household, which do not include stool and other specific solid waste.

1.2.2. Household Related Municipal Waste. Household related waste is produced from business and other commercial areas, industrial estates, school areas, social facilities, public facilities or other facilities.

1.2.3. Factors that affect the amount of waste generated. Various activities and standards of living will significantly influence the amount of waste generated; therefore, the waste generated in an area/city will be strongly influenced by:

i. Population Density.
The population will affect the amount of waste produced. The more inhabitants in an area /city, the more potential for waste, which means the higher the population, the higher the waste produced in an area.

ii. Socioeconomic Activities.
The higher the socioeconomic state of the community in a region/city, the more per capita amount of waste is disposed of every day. The quantity of inorganic waste produced will be higher.

iii. Technological Advancements
Technological advances will affect the type and amount of waste generated. The more advanced technology available, the more diverse the amount and composition of waste generated.

1.3. The 4R waste management strategies
Reducing the amount of waste from the source can be made by improving the implementation of the 4R principle. 4R efforts are directed primarily to the community as the primary source of household waste. Sensitization is conducted to create awareness, clear the people's concerns, and encourage community participation in waste management activities. 4R principles as an effort to reduce waste at the source include:

Reduce: This is a way efforts are in place to reduce or minimize waste production in environmental sources and can be done well before the waste is produced. Households as the source of waste can make efforts to reduce waste by changing consumptive lifestyles. Changes can be made by changing wasteful habits (instead of buying materials that can be placed in different containers, using one container to keep all the raw materials used in the household for the day).

Reuse: This means to reuse materials without becoming waste (without going through any processing process). Implementation of the activity can use paper back and forth, reuse paper bags to store or buy stuff at the market and reuse used beverage bottles to place water. Thus reuse will extend the life of the use of goods through the treatment and reuse of goods.

Recycle means renewing the life of a material that is no longer useful (waste) into other materials or new goods after going through a unique process. Items such as iron, glass, tires and other materials require state-of-the-art technology, modern equipment, and third party interventions to be recycled. However, some types of waste can be recycled directly by the community using simple techniques and tools. People can process the rest of the patchwork into blankets, rags, and doormats. Sorting household waste and recycling activities can be considered other forms of informal practice that can generate additional income for economically disadvantaged communities.
Replacing: These are ways of reducing the production of waste done by replacing items that can only be used once into more durable goods—for example, replacing a plastic bag with a shopping cart.

2. Methodology
The dynamic modelling system is simple and powerful because simple ideas obtained from it can develop into complex system models and processes. In addition, dynamic modelling is helpful to make modelling integration simple. It is natural because the simple ideas behind the dynamic model systems correspond to human ideas and thoughts [15]. Dynamic model systems can help people to see the system holistically. Modelling can be applied in complex real-life situations related to modern science and can also be used for forecasting and designing wisdom. The dynamic model approach is deductive and can eliminate weaknesses in the assumptions made and draw conclusions based on assumptions. The process of changing from one condition or situation to another is the main idea emphasized in a dynamic model [9,16].

The involvement of dynamics modelling systems in system management should be used more often to facilitate the waste management process. It is done taking into account the variables used in modelling [17]. The software can be used in dynamic system modelling, among others: Vensim, Stella and Powersim. This software can help in understanding solid waste management practices by using a dynamics system.

2.1. Introduction of Stella 9.0.2 as the modelling tool.
Stella software is another form of pictorial programming language for system dynamics modelling introduced by Barry Richmond in 1985 [18]. The model is a simple motto for looking at a problem. Model is a representation (depiction) or formulation in an entire system's specific language (agreed upon). A natural system is a system that happens today in life. A natural system is a point that becomes the focus of attention or what is in question. A model is an actual system or event or an imitation of an object. The model contains only information that is considered essential to be studied [19]. A model will produce an overview of the overall process by using mathematical formulations of physical/chemical/biological processes of a natural phenomenon, so that if included supporting data, then calculated by a particular calculation method [4].

2.2. Advantages of Stella Modelling.
The advantages of Stella as a modelling tool, among others, is as follows: 1. It permits scientists to forecast or streamline complicated systems into one unit; 2. Inputs may be modified, and the results checked without waiting for events to occur in real life/ waiting for actual life events to occur; and 3. The results can be used in scientific research and the public decision making processes.

2.3. The disadvantages of Stella Modelling.
Its weaknesses may include 1. The results may not be completely accurate; 2. There may be very complex environmental factors that may hinder the final results; 3. The efficiency of the model relies on the skills of the individual using it; and 4. Different people may interpret the results in different ways.

2.4. Modelling stages.

2.4.1. Conceptualisation and identification. The conceptualization and identification process starts with preparing primary hypotheses of the theory involved and the formation and evaluation of the basis of the theory. Finally, the individual preparing the model can identify the structure of the model [20]. The articulation of the problem is the most critical stage in dynamic systems modelling. Problem articulation is the stage to discover what issues or problems want to know and observe and articulate emotional feedback problems (boundary selection). Emotional problems are expressed by patterns of behaviour that may be observed from the plotted data. Reduction methods from available qualitative information obtain these patterns of behaviour.
2.4.2. **Mathematical representation.** Usually in the form of differentials or algebraic equations, the importance of mathematical equations in modelling lies in writing down series of mathematical equations that mimic/resemble actual life situations in a model. The equations are set for the specific significance of the model parameters within the mathematical equation. It can use linguistic rules for an expert system.

2.4.3. **Numerical implementation.** Perform the preparation of numerical solution algorithms. Using Stella modelling is a commonly used dynamic modelling tool that aids in conceptualizing diagrams and converting them into numerical values. The platform performs calculations using a computer.

2.4.4. **Parameter estimation.** Parameter predictions and estimations of a dynamic model are performed through model calibration. This calibration minimizes the main difference between actual life events in the field and model predictions of waste composition, the availability of resources, waste bank systems, and composting environments and conditions. The settings on model parameters were done based on measurement data. In order for all measurement data and model parameters to be appropriate, calibration is performed.

2.4.5. **Hypothesis testing.** It tests the model's output against test conditions that have been specified for a particular hypothesis. The hypothesis for this modelling was "solid waste management usinig waste bank scenario is much more efficient than using composting scenario".

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**Figure 1.** Causal loop of the problem.

In figure 1, it can be seen that population size will affect the number of households, determining the amount of household waste. The household consists of family members. Household waste will be divided into 3 parts: waste for composting, waste banks, and disposal at a temporary dump site. The waste at the temporary dumpsite will be transported to the final disposal site (dumpsite), subject to the
car's capacity, the number of cars and the number of cars and trips. Garbage transported to the final disposal site (dumpsite) will also be scavenged by cleaning officers on the car while on the way to the final disposal site (dumpsite). Scavengers will scavenge garbage in the final disposal site at the final disposal site location, which is influenced by the number of scavengers in the landfill. Waste in the landfill is influenced by the area of the final disposal site, which is directly influenced by the capacity of the final disposal site and existing infrastructure in the final disposal site.

2.4.6. Data collection techniques. Data used in this research is mainly primary data and some secondary data. Primary data is derived from direct observation at the research location, which consists of data on the amount (weight and volume) of the waste generated and its composition of waste from households. The total weight and volume of waste are obtained through weighing the waste using a hanging scale, while to measure the weight based on the composition of the waste, a cake scale is used. The weight of waste is expressed in kilograms, while the volume of waste is expressed in units of m$^3$. The volume of waste is measured by putting the waste into a volume measuring box with dimensions of 30cm x 40cm x 50cm (60 litres) and marked with a height (limit) so that the volume of waste measured can be measured known.

In addition to data on the waste weight and volume from households, the number of family members of each household sampled, and the average monthly income of the household head. The household's data on waste management was also taken based on a questionnaire run the day before the household waste sampling. The composition of waste is divided into two: organic waste (kitchen waste and garden waste) and inorganic waste (plastic, rubber, metals, glass, and other undegradable wastes). Secondary data in population data for the last 5-10 years were obtained from the Gambia Bureau of Statistics (GBS) and the Office of Population and Civil Registry of Kanifing Municipal Council. Data on waste generation in the last few years was obtained from the Environmental Office of Kanifing Municipal Council (KMC).

![Stok flow diagram](image)

Figure 2. Stok flow diagram.

Based on figure 2, it is known that household waste will be influenced by the number of households and the population. Household waste will be divided into three components: the fraction of waste sent
waste bank, the waste fraction sent to composting, and household waste, which is supposed to be disposed of at the temporary landfill (dumpsite). Waste disposed of to the temporary dumpsite will be transported to the landfill (final dumpsite). Transportation to the dumpsite is influenced by the number of vehicles, capacity and number of rites. The garbage car officers will scavenge garbage brought to the landfill before finally taking it to the landfill. The scavengers will also scavenge the waste taken to the landfill at the final disposal site, so the amount of waste in the landfill will be reduced significantly. The volume of waste in the final disposal site will affect the land used and be determined by the existing infrastructure in the final disposal site.

3. Results and discussion

Table 1. Distribution of the research respondents.

| Type of house      | N  | %   |
|--------------------|----|-----|
| Permanent          | 81 | 70.4|
| Semi-Permanent     | 24 | 20.9|
| Non-Permanent      | 10 | 8.7 |

| Occupation         | N   | %   |
|--------------------|-----|-----|
| Civil servant      | 32  | 27.8|
| NGO Staff          | 10  | 8.7 |
| Business           | 40  | 34.8|
| Security           | 4   | 3.5 |
| Farmer             | 13  | 11.3|
| Fisherman          | 12  | 10.4|
| Unemployed         | 4   | 3.5 |

| Number of Family members | | |
|--------------------------|--|-----|
| 2 people                 | 5  | 4.3 |
| 3 people                 | 13 | 11.3|
| 4 people                 | 25 | 21.7|
| 5 people                 | 27 | 23.9|
| 6 people                 | 27 | 23.9|
| 7 people                 | 9  | 7.1 |
| 8 people                 | 4  | 3.5 |
| 9 people                 | 3  | 2.6 |
| 10 people                | 2  | 1.7 |

| Highest Education       | N  | %   |
|--------------------------|----|-----|
| No formal education      | 1  | 0.9 |
| Primary level            | 14 | 12.2|
| Secondary level          | 14 | 12.2|
| High School              | 52 | 45.2|
| Tertiary Institution     | 34 | 29.5|

| Average family income (D) | N  | %   |
|----------------------------|----|-----|
| < D5,000                   | 36 | 31.3|
| D5,000-D10,000             | 32 | 27.8|
| > D10,000                  | 47 | 40.9|

Table 1 shows the distribution of 115 respondents where most of the respondents, 70.4% (n=81), are living as permanent residents, which is their own houses; 27.8 (n=32) are civil servants; 34.8 (n=40) are businessmen. It was found that an average of 11.3-23.9% of the people have about 3-8 people as family members. Most of the respondents have either high school or tertiary education (45.2 and 29.5),
respectively. From the economic perspective, it was realized that the majority of the respondents have an average monthly income of more than D10,000 (>200).

It was also found that none of the respondents segregated (sort) their waste before being thrown into the trash cans or other temporary storage facilities, which are placed at various locations within the locality. All the waste from the household is piled and packed in one place, which is later transported to the permanent dumpsite (landfill) in Bakoteh.

Figure 3. Temporal household waste storage facilities in Sukuta Nema.

Figure 4. Waste transportation facilities in Sukuta Nema.

All the respondents have their wastes transported regularly by local government authorities or other private organizations using donkey carts. The local government authorities use compactor trucks to collect waste at designated locations with an area.

Table 2 shows that the average household waste production in Sukuta Nema is 2.07 kg/day or 0.0083 m³/day (8.3 litres/day). Waste production per person is 0.49 kg/person/day or in other words 0.002 m³/person/day (2 litres/person/day). It is also found that the average household waste generation is 2.73 kg (0.0083 m³). The composition of organic waste is 1.67 kg (0.0067 m³), while inorganic waste

| Waste Production         | Kg/day | m³/day |
|--------------------------|--------|--------|
| Total waste production   | 205.73 | 0.82   |
| Per Household            | 2.73   | 0.0083 |
| Per Person               | 0.49   | 0.002  |

| Waste Composition | Kg  | m³     |
|-------------------|-----|--------|
| Organic           | 1.67| 0.0067 |
| Inorganic         | 0.40| 0.0016 |
is 0.40 kg (0.0016 m³). The waste problem is a problem faced by all areas in both urban and rural, even in areas that are not densely populated [4]. It needs serious attention so that solid waste can be handled properly. The increase in a waste generation will increase along with the increase in population. Waste management is a must by any government so that waste does not become a problem that can cause various impacts, both economically, socially, let alone create some public health issues.

Waste production and generation are significant factors in household waste management. Increasing waste generation in an area will undoubtedly affect the waste management that will be carried out. The more waste generated, the higher the need for costs for waste management [21,22]. Therefore, waste reduction is significant so that waste management does not have the potential to cause problems in its implementation so that various negative impacts from waste can be prevented.

Figure 5. Model parameter test for household solid waste management for the total population against household waste generation.

The parameter test results show an identical graphic pattern, which increasing every year, which institutes that there will be a constant increase in the amount of waste as the population. The simulation test results indicate that the simulation parameters in the model are running according to the actual logic, which is that when the population increases, the amount of waste generation also increases, and vice versa. Therefore, as long as the model simulation is running according to the actual logic, the model is declared valid.

The model analysis uses four scenario simulations: simulation of existing conditions (without scenarios), simulation of waste bank scenarios, simulation of composting scenarios, and simulation of combined scenarios between composting and waste banks. The model simulation also uses three levels of simulations, which are pessimistic (with an inclination that the conditions are terrible or there is no proper infrastructure in place), moderate (with the inclination that facilities and infrastructure is available but not up to standard) and optimistic (with the inclination that all infrastructure and facilities are maximum and up to a standard that maximum outcome is expected). The pessimistic scenario is the result of the intervention with a low scale, the moderate scenario is the result of the intervention with a medium scale, and the optimistic scenario is the maximum outcome of the intervention.
Simulation I shows that household waste generation per day in the first year of the simulation is 38.44 m³ (organic) and 9.18 m³ (inorganic). In the existing condition, the waste reduction does not yet exist at the household level, so waste generated from households will be disposed of entirely to the temporary dumpsite or in the waste bin before being transported and dumped at the landfill. The waste generated in the 10th year was 51.90 m³ (organic) and 12.40 m³ (inorganic), while at the end of the simulation, the household waste generated was 74.34 m³ (organic) and 17.75 m³ (inorganic). The same condition occurs until the end of the simulation that all waste generated from households has not experienced a reduction at the household level.

Meanwhile, the waste generation at the landfill in the first year of the simulation was 16,385.62 m³ and 31,500.82 m³ at the end. Most household waste is expected to be collected temporarily, accumulated and dumped at the final dumpsite (landfill). Generation of household waste in Sukuta Nema will continue to increase from 47.63 m³ at the beginning of the simulation to 92.10 m³ in the 25th year. The waste generation will continuously accumulate and be collected in the landfill so that the total land area of the landfill is 18 ha. The increasing amount of waste generated will affect the service life of the landfill and the existence of this landfill, both on the environment and health.

Simulation II (waste bank scenario simulation) of household solid waste management in Sukuta Nema.
shows that at the beginning of the simulation year, the initial waste generation was reduced by 0.20 m³. The end of the 25th year simulation results stated that the household waste reduction rate was 1.11%.

The waste bank scenario is simulated under three conditions, which refer to the fraction or proportion of non-organic waste taken to the waste bank. Pessimistic (worst) conditions (0-10% inorganic waste), moderate (normal) conditions (11%-25% inorganic waste) and optimistic (best) conditions (26%-35% inorganic waste). Based on the simulation results, the ability to reduce waste through a waste bank (optimistic) is 5.84% of the total waste generated from households. It is because not all inorganic waste can be managed in a waste bank.

A waste bank can reduce the waste generation in Sukuta Nema before it is transported to the dumpsite (Bakoteh). The volume of waste dumped at the final dumpsite (landfill) will decrease significantly through the waste bank. In addition, the amount of inorganic waste that still has a selling value is still there before the model scenario is run. After the model scenario is carried out, the amount of non-organic waste that has some economic value will undoubtedly decrease, so that waste scavengers in the landfill no longer get inorganic waste sold to collectors. It will impact the number of scavengers in the landfill, which will increase, reduce, or even be eliminated. The scenario of the waste bank being carried out is that the landfill burden of inorganic waste that is difficult to decompose can undoubtedly be reduced so that the impact of waste on the environment can be minimized. According to the findings of the research conducted in the Gaza Strip, waste management carried out with waste banks with scenario simulations adding the number of waste banks can reduce the waste generation in Gaza by 25.67% [2].

Communities must leave the old ways of just throwing away waste by educating and familiarising people with sorting, selecting and appreciating waste while developing a people’s economy through waste banks [22,23]. The adaptation of waste banks in each community is determined mainly by citizen
participation which will also determine the sustainability of waste banks so that community-based management needs to be considered. Waste processing innovation with the waste bank program is an innovation at the grassroots level that can increase the income of urban communities [24]. The effectiveness of the waste bank in reducing inorganic waste is also proven from the research results of [2] conducted in Palestine. This research shows that the reduction rate of inorganic waste that enters this waste bank is 96.5%.

![Key Information](image1)

**Figure 10.** Simulation III; Simulation of household solid waste management in Sukuta Nema using the composting scenario of low standard condition.

In pessimistic conditions (low standard conditions), it is known that the average level of waste reduction in the composting scenario with pessimistic conditions is 17.69%. At the beginning of the simulation year, the reduced household waste was 5.11 m$^3$. The end of the 25th year of simulation shows a waste reduction rate of 18.71%. The generation of waste originating from households in the landfill in the 25th year was 25,602.21 m$^3$.

In moderate conditions, it was realized that in the reduction of waste in the composting scenario in moderate conditions at the beginning of the simulation year, household waste is reduced by 15.05 m$^3$. The end of the 25th year of simulation shows a waste reduction rate of 39.27%. Meanwhile, household waste generated in the landfill at the beginning of the simulation year was 11,530.30 m$^3$. In the 25th year, the waste generation in the landfill will be 16,900.66 m$^3$.

![Key Information](image2)

**Figure 11.** Simulation of household solid waste management in Sukuta Nema using moderate standard conditions.

Under favourable conditions (high standard conditions), the average rate of composting waste reduction is 64.20%. At the beginning of the simulation year, the waste reduction was 27.92 m to 59.87 m at the end of the simulation.

Efforts that can be made to reduce municipal waste are to make efforts to recycle waste through the composting process. The composting process is essential because 50-80% of household waste is organic
material used as compost [25,26]. Consider the simulation results through the composting scenario, and it was stated that the average waste reduction ability is 64.20%. It will have an impact on the amount of waste disposed of in the dumpsite. The amount of waste that ends up in the landfill will decrease so that the service life of the landfill can be prolonged. In addition, quite a lot of organic waste ended up in the landfill. The composting scenario can be reduced so that the impact of organic waste on the environment can also be reduced. Waste should not be treated as a useless item but a commodity that still has benefits if it is to be used. Waste must be able to be used as raw material or other valuable materials. Waste management must be carried out efficiently and effectively, starting at the household level or as close as possible to the source to reduce the amount of waste generated.

Composting is a natural recycling process, thus returning organic matter to its biological cycle. In addition, with composting, the pile of organic waste will be reduced so that the environment becomes clean, healthy and reduces pollution. From the social aspect, it creates jobs and becomes an object of learning for the community. Waste, if it accumulates and undergoes decay, produces methane gas (a greenhouse gas). Methane (CH₄) is a greenhouse gas that triggers global warming. Therefore, by making compost through waste, the release of methane gas from garbage disposal can be overcome, and global warming can be prevented [27,28]. In addition, through composting, the reclamation of degraded land ex-mining excavations can be carried out. Because the application of compost little by little can improve the existing critical land. A land whose soil is damaged due to chemicals, such as compost, restores previously existing nutrients and improves soil structure [29].

Compost will provide organic matter for the soil. Organic matter plays a vital role in the physical properties of the soil, which includes the stimulation of the soils ability to hold water. Organic matter also plays an essential role in the biological properties of the soil, which is the nitrogen fixation and transfer of nutrients in the soil by increasing the microorganisms that aids in the process. When assessed from the perspective of the chemical properties of the soil, it increases its capacity to exchange cations that plays a role in nutrient uptake by the plant [25].

3.1. The combination of both waste bank and composting scenarios

![Simulation of household solid waste management in Sukuta Nema using both waste bank and composting scenarios under low standard conditions.](image-url)
Waste, if not managed properly, will affect health and the environment. Improper waste management in most developing countries serves as the main threat source for public health problems, some environmental quality health issues and constitutes lower life qualities, especially for the poor in urban areas [4]. From a health aspect, the location and uncontrolled and open dumping will lead to situations that will lead to poorer waste management services that will be ideal for the growth of microorganisms and other higher animals that can serve as agents of the disease-causing organisms [30,31]. Potential diseases that can be caused are diarrhoea, cholera, typhoid and dengue fever [11].
Figure 15 above shows the trend in which the amount of household waste generation both in the existing condition and the application of the model scenario (waste bank, composting and a combination of waste bank and composting scenarios). It can be seen how the reduction in household waste generation occurs if the scenario runs well (favourable conditions). The waste bank scenario’s simulation results have the minor waste reduction capability compared to the reduction from the composting scenario simulation and the combined scenario simulation between the waste bank scenario and the composting scenario. It is because the proportion of inorganic waste from households is relatively smaller compared to organic waste. In addition, it was also realized that not all inorganic waste could be managed in a waste bank. They have specific types of inorganic wastes that are accepted.

4. Conclusion

The generation of waste originating from households in Sukuta Nema is 2.07 kg/house/day or equivalent to 0.0083 m³/house/day with a composition of 1.67 kg (0.0067 m³) organic waste and 0.40 kg (0.0016 m³) of inorganic waste. Based on existing conditions, the estimated household waste generation in Sukuta Nema in 2021-2046 is 47.63 m³/day in the first year of the simulation and continues to increase to 92.10 m³/day in the simulation 25th year of the simulation, and there is no waste reduction at the household level. The estimation of the average household waste reduction in Sukuta Nema based on the results of a dynamic model simulation for 25 years (2021-2046) with a waste bank scenario is 0.72 m³/day in a pessimistic (bad) condition simulation, 2.40 m³/day in a moderate (regular) and 4.09 m³/day in optimistic (standard) condition simulation. The estimation of the average household waste reduction in Sukuta Nema based on the results of a dynamic model simulation for 25 years (2021-2046) with a composting scenario is 12.49 m³/day in a pessimistic condition simulation, 26.87 m³/day in a pessimistic condition moderate and 44.95 m³/day in optimistic condition simulation. The estimation of household waste reduction in Sukuta Nema based on a dynamic model simulation for 25 years (2021-2046) with a combined scenario is 13.21 m³/day in a pessimistic condition simulation 29.27 m³/day in a moderate condition and 49.04 m³/day under simulated optimistic conditions.

The average household waste reduction rate based on the model scenario simulation results (favourable conditions) is 5.84% per year (waste bank scenario), 64.20% (composting scenario), and 70.04% (combined scenario).

4.1. Recommendations

For KMC, local government authorities or related independent agencies to carry out control and collaborative efforts to the degree to which household waste is generated in Sukuta Nema and the surrounding communities by increasing the number of waste banks in the Region.

The community is expected to actively reduce waste starting from the household level by practising waste sorting/segregation practices, making work easier for those transporting the waste to the final dumpsite.

The production of more compost sites will help reduce household waste in Sukuta Nema and the KMC in general, as the combination scenario of both composting and waste bank scenarios will drastically help reduce the amount of waste generated.

Further research should be carried, including and examining waste generation from non-households so that the total waste generation of Sukuta Nema can be known in real terms.

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