System dynamics modelling of waste management system

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Abstract: Waste management is the collection, transport or disposal and management of waste materials. Most waste management activities are decided upon and carried out in a public, semi-public area typically involving the waste management organization, one or more regulators and other stakeholders and members of the public. The management of waste is not only the responsibility of governments, but also an individual's duty. Waste management is an issue that has to be dealt with daily in order to control the huge amounts of waste currently passing through our towns and cities. It is main goal of this research to evaluate the performance of waste management activities. System dynamics methodology was use to study the waste management activities of a South Western State in Nigeria. Waste management system quantities were identified from waste generation and waste collection activities. Thirteen quantities were identified and a causal loop diagram was developed for the system. Thereafter a stock and flow diagram was developed for the system and this depicts the dynamic relationships among system quantities. The performance of waste management technique was determine in terms of waste collected and waste in stock. A system dynamic software; Vensim PLE was used to run the system dynamic model to simulate the activities of waste management system for a period of ten years. Amount of waste collected increases as the amount waste generated increases. At waste generation factors of 70% per year and 90% per year; the amount of waste collected was 302,137 tons and 617, 794 tons respectively at the end of ten years. If the amount of resources injected into waste management is increase; the amount of collected waste will definitely increase. The model developed will help the waste managers in decision making regarding waste management.

INTRODUCTION

In recent years, waste has been a problem to many environments whereby the use of different strategies has been put in place to solve the problem. The impacts of these wastes on the economy cannot be ignored and managing them has become a major problem. Waste management is the collection, transport or disposal, managing and monitoring of waste materials. Most waste management activities are decided upon and carried out in a public, semi-public area typically involving the waste management organization, one or more regulators and other stakeholders and members of the public. The environment has a limited capacity for waste assimilation therefore this assimilative capacity of the environment maybe exceeded or put under too much stress to handle the large quantity of waste and this may result in pollution and resource degradation and consequently economic damage.

As a society we manage to produce a vast amount of materials that are just thrown away, waste management is the collection of these materials in order to recycle them and as a result decrease their effects on our health, our surroundings and the environment. Practices in waste management are different the world over, dependent on certain issues such as how developed the nation is, if it is a city or rural area and so on. The management of waste is not only the responsibility of governments and the manufacturer, but also an individual's duty. Waste management is an issue that has to be dealt with daily in order to control the huge amounts of waste currently passing through our towns and cities.

There are several resource recovery systems in place and facilities that have been developed to deal with these issues. Natural recovery systems make use of food, organic and

green waste and are then dealt with in in-vessel compost systems, whilst materials collected for recycling include glass, plastic bags, metals and paper. Automated and manual methods are used to sort materials from construction sites, such as brick, tiles and concrete and after being sorted are re-used for road base and construction materials. E-waste (electronic waste) comes from items such as old computers which are taken apart in order to recover materials like cabling, aluminum, copper, glass and plastics. Bioreactor landfills are deployed to generate green energy through the capturing of biogas from municipal waste. There is also help provided for councils to award innovative technologies which can be used to recover recyclables (Sufian and Bala, 2007). We can all help out when it comes to waste management and recycling products. It may not seem effective to recycle products as a household, but put all those households together and you will produce a result. It is each person's responsibility to do what they can to conserve resources, reduce landfill volumes and produce new materials using less energy. Some cities in developed nations keep a record of their resource recovery systems in order to identify if they are working effectively, evaluate them and update them if necessary, this information can then be passed onto other areas or nations to help them in the recycle challenge. Deciding to recycle is a simple step and surprisingly easy to start. If you are unsure where to begin there are lots of resources, including the local environmental sector, who will be eager to teach you how to recycle your leftover waste and check on the internet too for information.

Waste management problem has increased at an alarming rate in Nigeria in direct response to rising population growth and industrialization. This has even worsened with option of the quick to use and quick to discard consumer habits which generate an endless stream of liquid and solid waste. Interestingly, in spite of this, waste generation in Nigeria is still lower compared to the developed countries of the world. Developed countries exercise the best management practices in waste handling and disposal, while the less developed countries including Nigeria, generally lack adequate means to handle and dispose off many wastes in an environmentally safe manner. In spite of the efforts of public agencies, waste management problem persists. The main reason for the pollution trading in the international market is poverty.

Until recently, Nigerians had not been concerned with solid waste disposal; their concern had not gone beyond physical removal of waste from the streets. It has been and still common practice to dispose of refuse by the most expedient method available. This submission has directed concerns towards the exploration of indigenous waste management practices for possible adoption by Nigerians.

System dynamics is a methodology to analyze situations that change over time. It is widely used to analyze a range of systems (Adebiyi and Charles-Owaba, 2006). The methodology focuses on the way one quantity can affect others through the flow of physical entities and information. Often such flows come back to the original quantity causing a feedback loop. The behaviour of the system is governed by these feedback loops. System dynamics was introduced by Jay Forrester in the 1960s at the Massachusetts Institute of Technology as a modeling and simulation methodology for the long term decision-making analysis of industrial management problems (*Chaerul et al., 2008*). System dynamics methodology provides a foundation for constructing computer models to do what the human mind cannot do i.e. to rationally analyze the structure, the interactions and mode of behavior of complex technological and environmental systems

System dynamics model has therefore been used in many areas including global environmental sustainability for pollution control/ abatement; waste management challenges and their solutions for safe living of human kind; and environmental management in developing countries. As a modeling method, system dynamics is particularly suited to the simulation of complex systems such as wastes/leachate generation and its management. The method is capable of dealing with assumptions about system structures in a stringent fashion, and particularly for monitoring the effects of changes in sub-systems and their relationships (Ojoawo, 2009, *Agbede et al 2012*).

There have been a variety of policy responses to the problem of waste management and generation of waste material is a consequence of everyday life and serious health and environmental problems have resulted from the improper management and accumulation of these amorphous substances (Ojoawo, 2009, *Agbede et al 2012*). Thus for us citizen to have a clean environments, we must put in place a proper and well managed waste management plans. Executing control of waste includes collections, hauling, disposal, recycling, reuse and reduction. The associated problem includes lack of institutional capability with technical expertise, financial resources, legal provisions and role designation, and lack of inadequate funds and services, and the inability of waste management authority to provides cost effectives services (Liu, (2004).

A more sustainable waste management system is a system that contributes to increasing efficiency in the use of natural resources, and to decreasing environmental burdens. To be sustainable, the waste management must also be affordable and widely accepted by the public as well as by key companies and organizations. The purpose of this research is to develop a system dynamics model for a waste management system and subsequently evaluate the performance of the system.

Waste management technique

Managing domestic, industrial and commercial waste has traditionally consisted of collection, followed by disposal. Depending upon the type of waste and the area, a level of processing may follow collection. This processing may be to reduce the hazard of the waste, recover material for recycling, produce energy from the waste, or reduce it in volume for more efficient disposal. Collection methods vary widely between different countries and regions, and it would be impossible to describe them all. For example, in Nigeria, garbage collected is usually transported to a regional landfill. Disposal methods also vary widely. In Nigeria, the most common method of disposal of solid waste is to landfills, because it is a large country with a high-density population. By contrast, in Japan it is more common for waste to be incinerated, because the country is smaller and land is scarce. The following are the method used in waste collection.

1. **Direct labour:** These are the only method used by the state in collection of their waste from the environment. The waste is collected from there designated places like the market, public places and also on the main road. They make sure that it is very effective and also monitor the operator in charge in other to achieve a clean environment. After picking up the waste; it is been taking to the dumpsite.

2. **Refuse truck:** The truck is used to pick waste along the main road; this is done with the help of the people who pack the garbage and drop it inside the truck. The truck move

after the people sweeping the road side and have cleaned up the drainage system. All the truck have their own area they operate and they move once in a day.

3. **Hook loader:** The hook loaders are placed in some designated places where they are been picked and exchange with another one. They make use of small hook loader with the capacity of 20 ton.

4. **Compactor:** The compactor is used to compact and compress waste and also break up large or fragile items of waste. This process is conspicuous in the feed at the back end of many garbage collection vehicles.

5. **Bulldozer:** The bulldozer is used to push waste into the pit after it has been dump at the site. The function of the bulldozer is to push the waste dump into the pit. This is done when ever waste is dump at the site.

Important element of waste management system and their dimension

1. **Waste generation:** This is the total amount of waste produced in an area per unit of time. In the model, it is the product of 'rate of generation' and 'population' and is expressed as ton/year. In the discussion, however, it is expressed as ton/year.

2. **Rate of generation:** This is the amount of waste produced by an individual in an area per day. It is mostly expressed in this paper as kg/year.

3. **Population:** This is refers to the population in an area in a given year. This is closely related to the waste generation factor.

4. **Waste:** This is refers to total waste stock existing in environment. It increases via 'waste Generation and is depleted through the recycling, waste collection, backyard burning and littering streams. This is expressed in tons.

5. **Waste collection:** This is refers to residual waste that is collected for final disposal.

6. **Waste management costs:** This is the total annual cost of waste management. This includes the cost of land filling or tipping fee, landfill maintenance, aftercare and wastewater treatment.

7. **Waste management budget:** This is the total annual allocation for Waste management. This includes the Waste management budget for the whole city.

Table 1: Specification of set of quantities and their dimensions

S/N	Symbol	Description	Dimension
1	B	WMS budget	₦
2	P1,P2,P3,P4,P5	Prop. Of WMS budget on direct labour, refuse truck, compactor, bulldozer, hook loader respectively.	Dimensionless
3	b1,b2,b3,b4,b5	Budget on direct labour, refuse truck, compactor, bulldozer and hook loader respectively.	₦
4	E1,E2,E3,E4,E5	Effectiveness on direct labour, refuse truck, compactor, bulldozer, hook loader respectively.	Tons/₦
5	t1,t2,t3,t4,t5	Target on direct labour, refuse truck, compactor, bulldozer, hook loader respectively.	Tons
6	R	WMS collection goal	Tons
7	WGF	Waste generation factor	1/Year
8	WCF	WASTE collection factor	1/Year
9	W	Waste	Tons
10	WG	Waste generation	Tons/Year
11	WC	Waste collection	Tons/Year
12	PB	Planned budget	Naira
13	PAB	Proportion of planned budget	dimensionless

Developing causal loop diagram (CLD) for waste management system

An unpublished work done by Akinyemi and Fasanya (2011) has developed a CLD for a waste management agency in south western Nigeria. This CLD has been modified with inputs from subject matter experts. All the quantities are identified in the Table 1 above. The CLD for the system is represented in Figure 1.

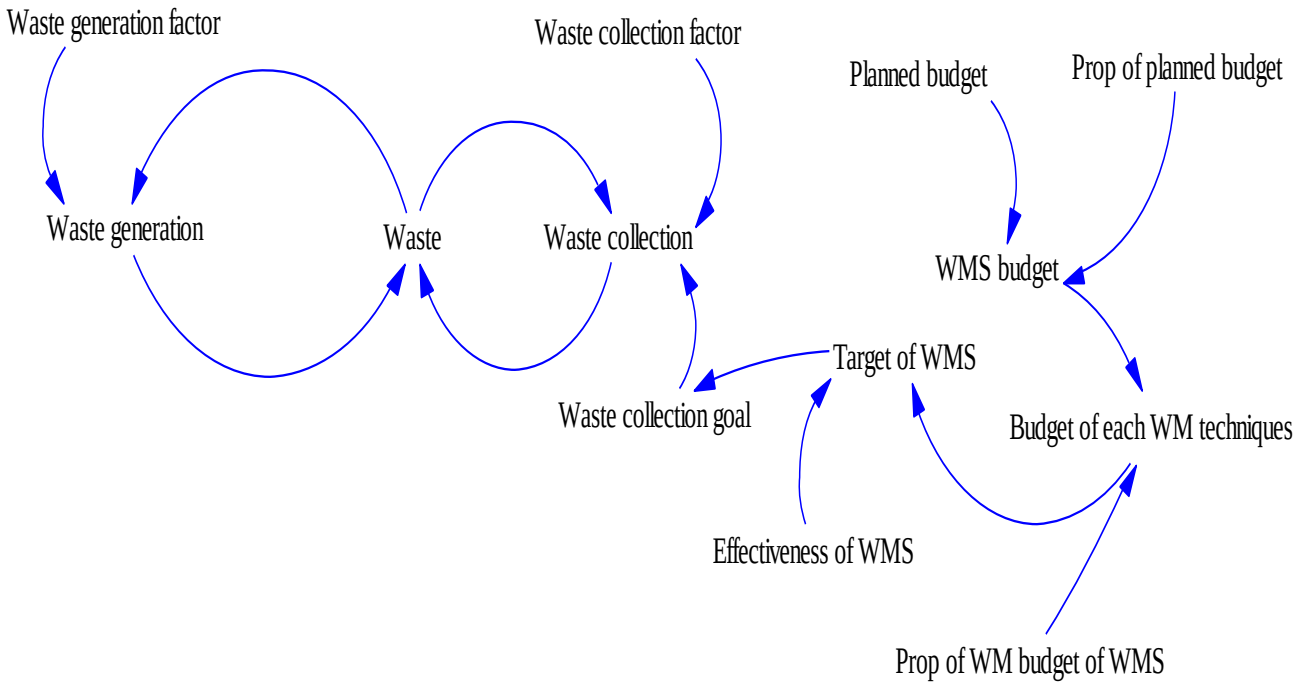

Figure 1: Causal loop diagram for waste management system.

The causal loop diagram above describes the major activities involved in waste management system i.e. waste generation and the process use in collection of waste. The outcome will show how waste could be managed as public utility. The waste as a matter of fact has elements that contribute to it and the ones that also reduce it.

Developing stock flow diagram for waste management system

After the CLD has been developed, Stock and Flow Diagram (SFD) was developed to establish the dynamic relationship between quantities of the waste management system i.e. tasks and attributes of human and organisational behaviours of waste management system was quantified in the SFD.

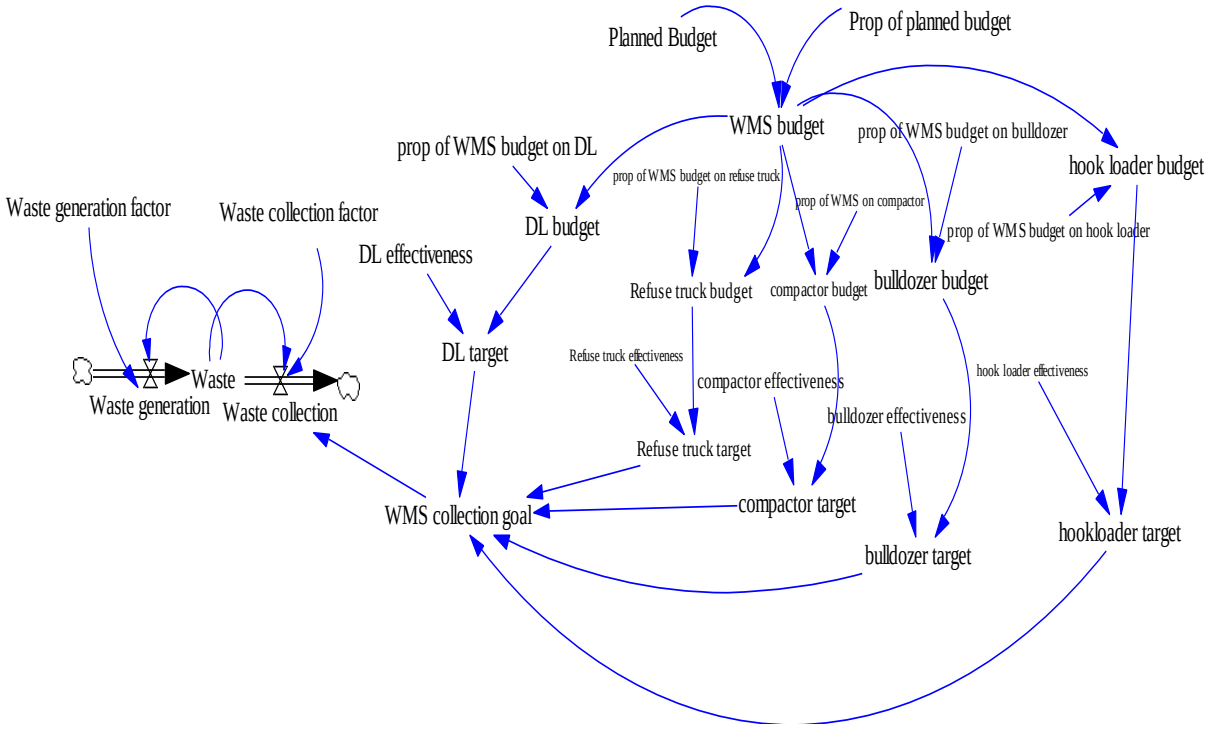

Fig 2: Stock and flow diagram for waste management system.

The stock and flow diagram above describe how waste is been generated, collected and the method used in the process of collecting the waste. The waste collection have different method of collecting the waste in other to make the environment clean. Each method has its own effectiveness factor that contributes to the waste management collection goal. Budget is planned and actualized on each technique employed.

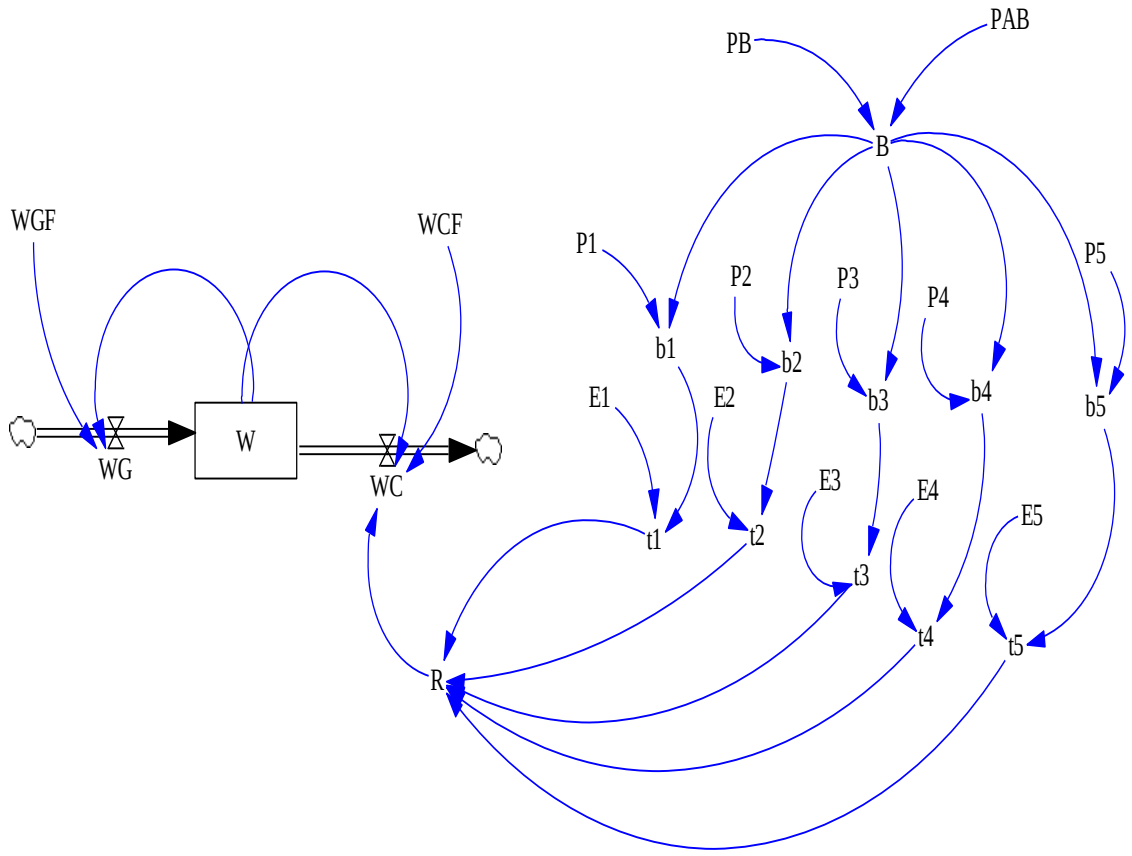

Figure 3: Annotated flow diagram of waste management system

Estimation of system parameters

1. **Planned Budget:** This is the amount budgeted for waste management. It was estimated as ₦180,090,000.
2. **Proportion of Planned Budget:** This was estimated as ratio of budget actually spent to amount of budget planned. This was estimated to 1.
3. **Proportion of actual Budget implemented on Waste Management activities (P):** This was estimated as ratio of actually spent on direct labour, refuse truck, compactor and bulldozer, hook loader activities respectively, to the budget actually spent as follows 0.15, 0.10, 0.20, 0.25 and 0.30 respectively.
4. **Waste Management Effectiveness Factor (E):** From the field study of the state in South Western of Nigeria, the amount of waste collected was divided by the actual budget implemented to estimate the effectiveness factor. For each waste management activity effectiveness factor was estimated as $1.02*10^{-6}$ tons/naira.
5. **Waste Collection Factor (WCF):** This is the proportion of waste collected by the waste management activities. It was estimated to be 70 percent/year.
6. **Waste Generation Factor (WGF):** This is the proportion of waste generated by the urban population (NPC, 2006). It was estimated to be 80 percent/year. Depending on the economic status and urban population, the estimated value can increase or decrease.

The model

The model is a system coupled with equations based on Forrester's model synthesis approach. This comprises two model dynamically linked systems; the waste generation and waste collection, such that the waste collection depends on waste collection goal and waste collection factor. The waste collection goal depends on the target of the method used in the collection of waste. The target depends on the effectiveness factor and the budget allocated to each method used in waste collection. The model was built to evaluate waste management strategies which will assist in decision making of the waste management system. The model was run on system dynamics software; Vensim PLE (version 5.0). Results of simulation runs were presented below.

Table 1: Amount of waste, waste generated and waste collected from the system

Time(Year)	W(Tons)	WG(Tons/Year)	WC(Tons/Year)
0	120	96	92
1	124	99	125
2	136	109	134
3	176	141	155
4	305	244	172
5	721	577	767
6	2065	1652	2687
7	6405	5124	8886
8	20415	16332	28900
9	65646	52517	93517
10	211680	169344	302137

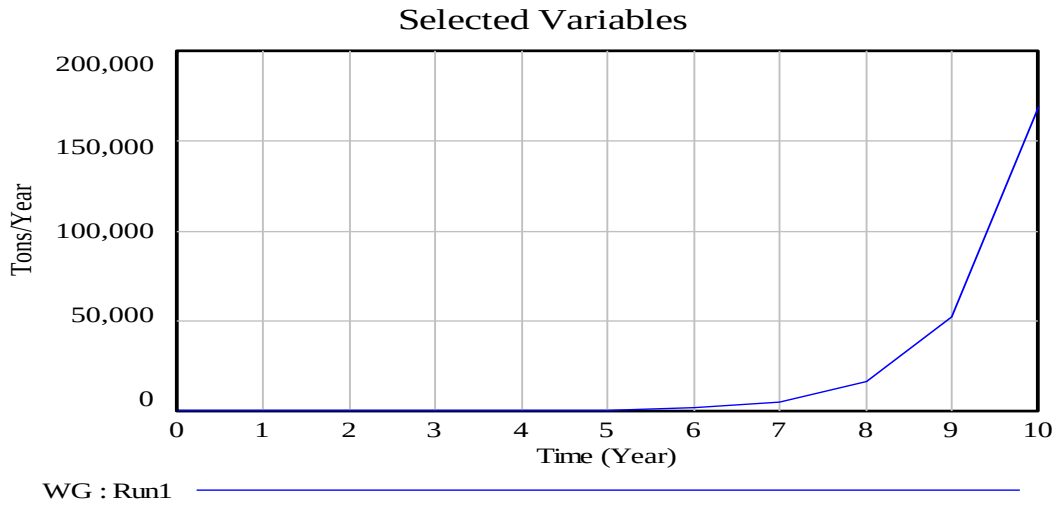

Figure 4: Result for validation run for waste generated

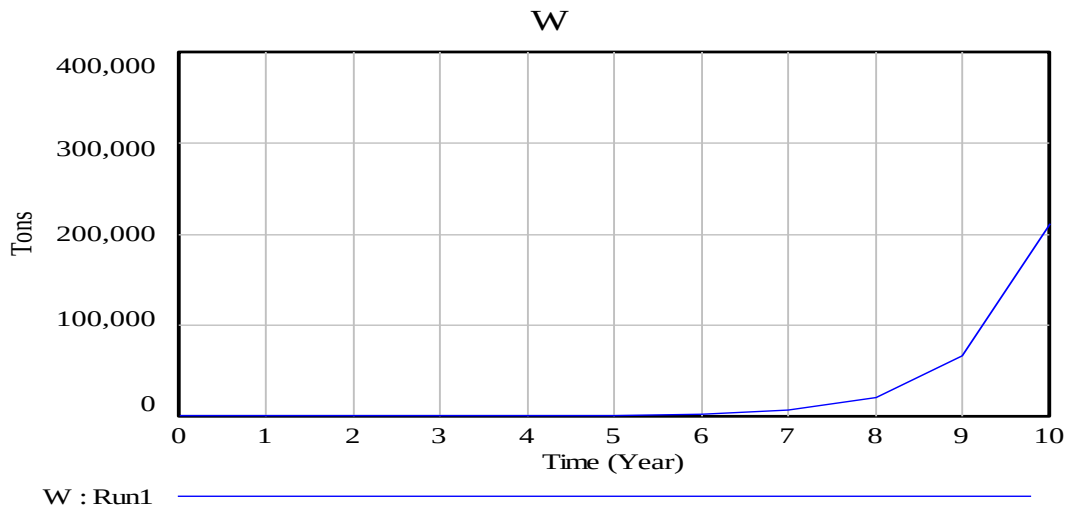

Figure 5: Result for validation run for waste

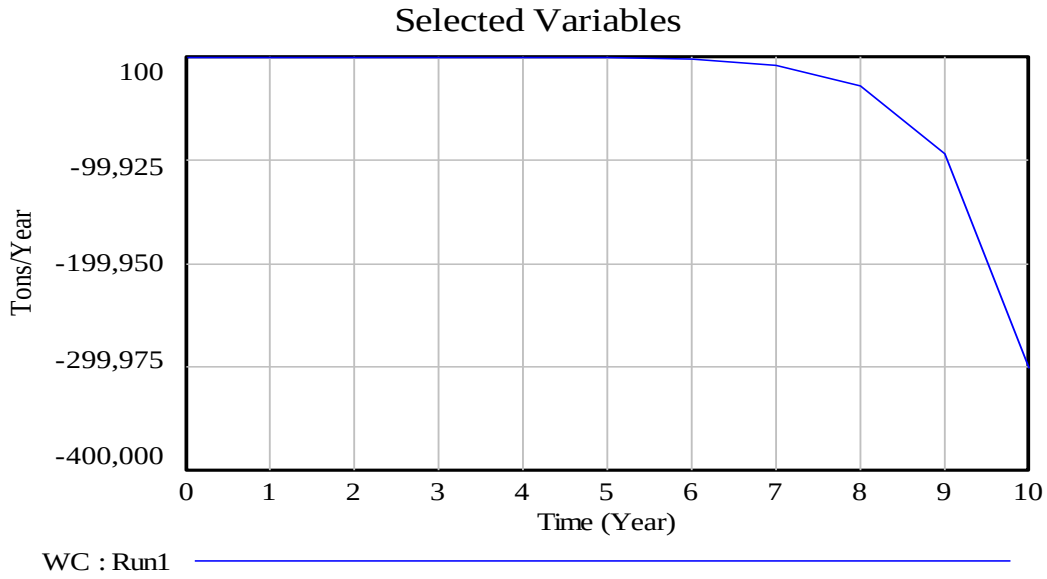

Figure 6: Result for validation run for waste collected

Table 2: Comparison between different WCF values.

Time (Year)	WCF=0.9 Run2	WCF=0.7 Run1
0	72	92
1	89	123
2	185	146
3	263	159
4	929	172
5	2870	766
6	8518	2687
7	24960	8886
8	72824	28900
9	212163	93516
10	617794	302137

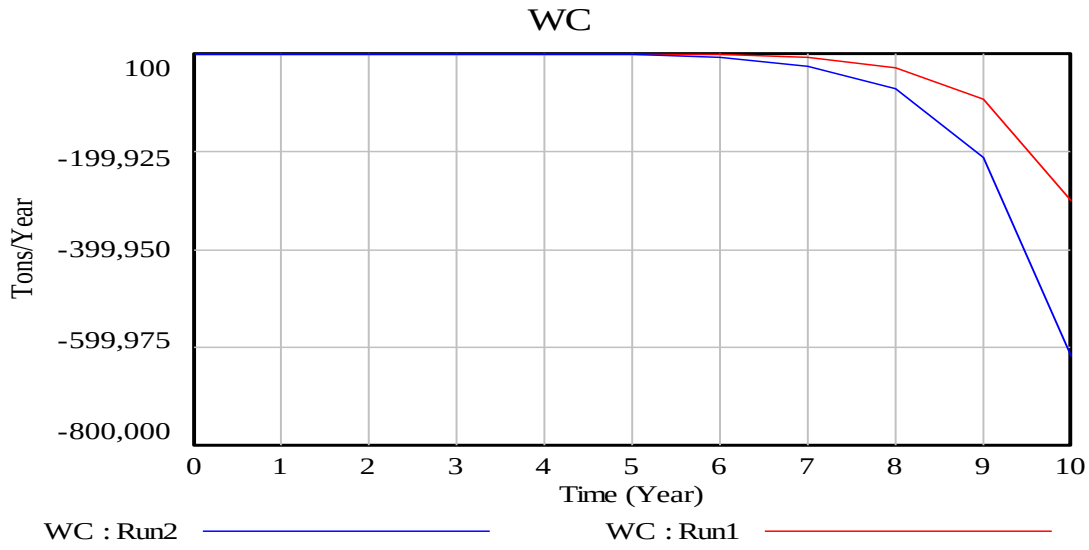

Figure 7: Result for comparing validation run for waste collected

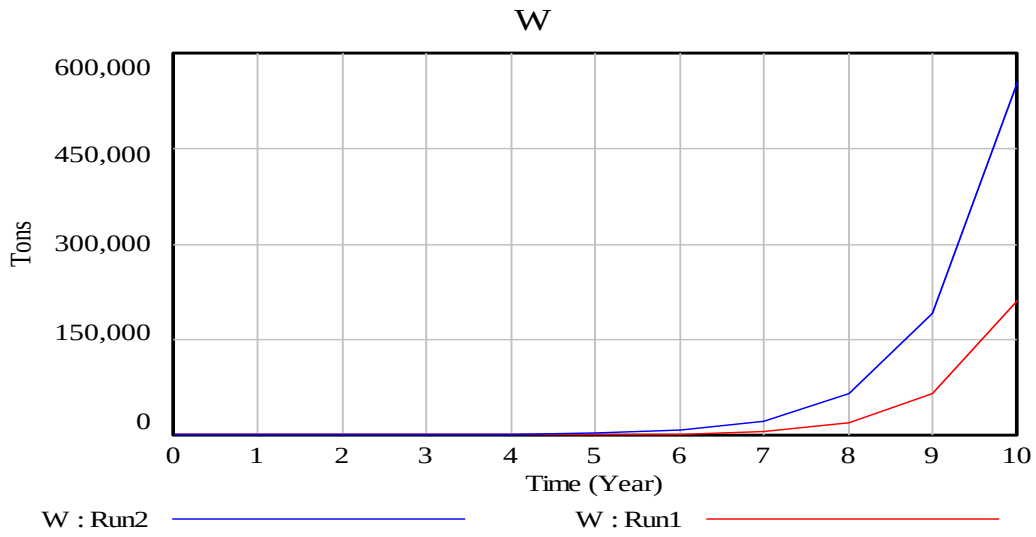

Figure 8: Result for comparing validation run for waste

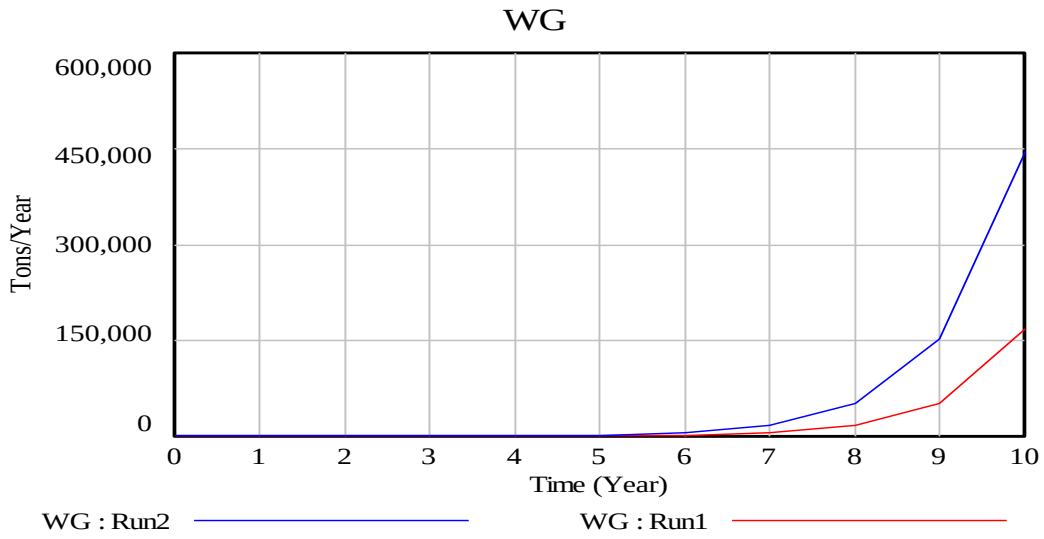

Figure 9: Result for comparing validation run for waste generated

DISCUSSION OF RESULTS

The flow diagram of the system was developed using Vensim PLE software and simulation package. The principle of system dynamics was applied to determine the interrelationships of waste, waste generation and waste collection. These were simulated to predict the results on how waste will be reduced and effectiveness of waste management technique. The data collected was fed into the model to determine the total amount of waste generated, waste collected and waste in the study area. As shown, Figures 4, 5 and 6 shows the simulation results for waste generated, waste and waste collected. It can be seen that the levels of generated waste and waste increase with time indicating that the equations are properly

constructed. Fig. 6 shows the waste collected also increase over the simulation period. On comparing the simulation results of waste collection whereby the WCF is been increase to 90 percent per year, it was found that the amount of waste collected increases as shown in Fig. 7. The waste in stock reduce due to increase in waste that is been collected as shown in Fig 8. The WCF is a function of time lag i.e. the amount of time required for us to start noticing a clean environment due to waste management activities. In the model formulation, it is assumed that the waste generated grows with the increase of population and the economic status which is reflected in the WGF. As shown in Fig 9 the simulation result shows that the assumption also matched.

The cost impact of waste management system will become a heavy burden on the government budget if proper planning is not put in place. The model has established the effectiveness of each waste management technique and its consequent target. The target is the amount of waste collected by the waste management techniques. The summation of target gave the waste collection goal which is total waste collected aimed to be collected. The model show that the percentage of budget allocated to waste management techniques will determine the waste management goal. The model has established a database for waste management.

Conclusion

Increasingly, waste is becoming an important environmental issue. The huge amount of waste generated caused by rapid urbanization, population growth and a changing life style. System dynamic methodology was used to model a waste management system. System quantities were identified from waste generation and waste collection activities. Waste management activities include the following: direct labour, refuse truck, compactor, hook loader and bulldozer. A causal loop diagram was developed to established the dynamic hypothesis for the system while a stock and flow diagram which established the dynamic relationship among system quantities was developed thereof. The SD model was run for a period of ten years using a SD software; Vensim PLE (version 5.0). The performance of waste management technique was determine in terms of waste collected and waste in stock. It was noted that the amount of waste collected increases as the target increases. The developed model is a useful predictive tool for decision making in waste management system.

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