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Sensitivity Analysis of Population in The Generation of Hazardous and Non-Harzardous Wastes, and Gas from Dumpsites of Ogbomosoland in Nigeria

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Abstract

This paper applies the principles of system dynamics modeling in studying the pattern of population changes and the corresponding non-hazardous wastes and gas being generated from the dumpsites of Ogbomosoland, Nigeria. The five (5) Local government Areas (LGAs) of Ogbomosoland were categorized as Urban (Ogbomoso North and Ogbomoso South) and Rural (Oriire, Ogo Oluwa and Suurulere) based on the size, population of residents, consumption pattern and socio-economic activities of the area. A sensitivity analysis of the simulated variables i.e the population, wastes and gas, was performed by employing the developed model results. Findings showed that the wastes and gas increased with the increased population in the 1000 years period. Also, gas production exceeds wastes generation rates for the rural LGAs in all cases. After a 25 years benchmark, when the simulated population of the urban and rural LGAs are respectively 303,411 and 344,735, the rates of waste generation are $3.33x10^6$ and $6.22\ x10^6$ m^3, while the corresponding rates of gas production is $2.44x10^3$ and $6.47x10^3$ m^3 in same order. The study concludes that wastes and gas generation from dumpsites are highly sensitive to population growth. It also concluded that the rate of gas generation is higher in organic wastes of the rural LGAs. The maximum population permissible in the model is 300,000 thus design of full-fledge landfills is recommended to replace the existing dumpsites in the study area.

Keywords: system dynamics, sensitivity analysis, population, non-hazardous wastes

1. Introduction

Non-hazardous wastes are composed of different materials or commodities and constitute a major portion of the Municipal solid wastes (MSW). They are not simply trash; however, they cover components of the MSW with valuable commodities such as paper, cardboard, aluminum, steel, and energy [1]. An integrated waste management system considers fluctuating recycling markets, energy potential, and long-term landfill cost and capacity to make a waste management strategy that is sustainable. Waste generation increases with population expansion and economic development [2]. Improperly managed solid waste poses a risk to human health and the environment. Uncontrolled dumping and improper waste handling causes a variety of problems, including contaminating water, attracting insects and rodents, and increasing flooding due to blocked drainage canals or gullies. The amount of wastes produced is influenced by economic activity, consumption, and population

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growth. Affluent and populous societies, such as the United States generally produce large amounts of municipal solid wastes. Among industrialized nations, the United States generates the highest amount of wastes per capita [3].

As wastes could not have been largely generated without residents in a given area, population has been considered as one of the factors which is responsible for waste generation. Historically, the quantity of waste generated by humans was insignificant due to low population density but with the advent of industrial revolution, waste management became a critical issue. This was due to continuous population increase and rural-urban migration. It has been reported that population growth has a causal relationship with waste management in urban centres. Nigeria's urban population has been growing in an alarming rate, as problem of waste collection; disposal and transportation are among the main causes of unsightly heaps of garbage all round the cities [4]. According to the United Nation's Food and Agricultural Organization, 30% of all food produced in the world each year is wasted or lost, constituting about 1.3 billion tons. The per capita, Europeans and North Americans waste between 95 and 115 kg of food. Sub-Saharan Africa, South Asia and Southeast Asia waste much, much less- between 6 and 11 kg per person. The developed world wastes 10 times more food than the developing one. Also, all the food that the world's richest countries waste is about equal to all food that sub-Saharan Africa produces [5]. According to [6], the current global MSW generation levels are approximately 1.3 billion tonnes per year and are expected to increase to approximately 2.2 billion tonnes per year by 2025. This represents a significant increase in per capita waste generation rates, from 1.2 to 1.42 kg per person per day in the next fifteen years. OECD countries produce almost half of the world's wastes, while Africa and South Asia regions produce the least wastes.

So far, landfill is the most widely employed for MSW disposal worldwide. Landfill can be in the form of an uncontrolled open dump or of a full containment site engineered to protect aquatic environment. Unlike engineered landfills, open dumps do not have bottom liners to prevent the seepage of leachate. Nor do these traditional landfills have a top cover or other preventive measures to reduce methane emission into the atmosphere. In developing countries, dumpsites are rampant where uncontrolled wastes are being dumped and in an indiscriminate manner.

Methane and carbondioxide are two major gases produced from the decomposition of the organic fraction of solid waste in the landfill. Therefore, landfills have been implicated as the largest source of atmospheric methane in the world, leading to a natural phenomenon called *"global warming"* [7]. Due to global warming, changing temperature and rainfall patterns will bring a variety of pressure upon plant and animal life. If temperature rises as projected, one-third of species will be lost from their habitat, either by moving elsewhere or by becoming extinct [8].

Apart from global warming, traditional landfills like open dumps pose serious threats to aquatic environment. One of the greatest environmental concerns associated with MSW landfilling is the generation of leachate. During degradation process, one tonne of landfilled solid waste generates about 0.2 m^3 of leachate, depending on the type of waste and seasonal climate. This wastewater primarily results from the degradation of the organic portion of the waste in combination with percolating rainwater and moisture that leaches out organic and inorganic constituents through the waste layer in the landfill depending on rainfall conditions, the color of leachate varies from black to brown [9].

A landfill site may still produce leachate with a high concentration of NH_3-N for over 50 years after filling operations have ceased. If not properly treated, leachate seeping from a landfill can enter the underlying groundwater, posing potentially serious hazards to the environment and to public health. For this reason, the generation of leachate has become a worldwide environmental concern in recent years. The overall goal of urban solid waste management is to collect, treat and dispose of solid wastes generated by all urban population groups in an environmentally and socially satisfactory manner using the most economical means available. Local governments are usually authorized to have responsibility for providing solid waste management services, and most local government laws give them exclusive ownership over waste once it has been placed outside a home or establishment for collection. As cities grow socially and economically, business activity and consumption patterns drive up solid waste quantities. Hence, the need for a study on the direct effects of population on the wastes and gas being generated in our communities.

Waste generation in sub-Saharan Africa where the case study falls is approximately 62 million tonnes per year. Per capita waste generation is generally low in this region, but spans a wide range from 0.09 to 3.0 kg per person per day, with an average of 0.65 kg/capita/day [10]. The current study aim at taking an indepth look into the role of population factor in both the hazardous and non-hazardous wastes and gas being generated from dumpsites in Ogbomosoland, Nigeria. This study area consists of five (5) Local Government Areas (LGAs) viz: Ogbomoso North and Ogbomoso South (located within the city and categorized as the rural LGAs; and the rest three rural LGAs (Oriire, Ogo Oluwa and Suurulere). Ogbomosoland is located approximately on Longitude 4^0 15’ East, Latitude 8^0 07’ North and situated in the transitional zone between rain forest and savannah region [11]. The objectives are to study the population growth pattern of the study area and to relate this with the rates of non-hazardous solid wastes and gas being generated from the dumpsites in the area.

2. Methodology

The consumption pattern and socio-economic activities of the residents were assumed to have negligible effects on the waste generation of the residents compared to the influence of population. Therefore, a dynamic model was developed from the mathematical equations for the population, wastes generation and gas production.

(a) Governing equations

(i) Population estimation

$$G_n = j^{\alpha} k^{\beta} P_n (t) \tag{1}$$

where Gn = Total wastes generated; α and β = Boolean notations for j and k respectively, having only 0 and 1 values in a mutually exclusive manner; j = Average waste generated by urban community; k = Average waste generated by rural community; $Pn\ (t)$= Population

The generation of wastes is a function of two main factors [13]; [14]:

(1) Population size per time

(2) Social status of the people (classified as urban/rural centre or high/low income)

The relationship between the Birth rate (B), Death rate (D) and Population are given by the model equations 2 and 3 [15].

$$B = B' . P_n (t)\, l_n\, [P_n (t) / P_n\, max (t)] \tag{2}$$

$$D = D' . P_n (t)\, l_n\, [P_n (t) / P_n\, max (t)] \tag{3}$$

where B = Birth rate at present; B' = Initial Birth rate; D = Death rate at present; D' = Initial Death rate; $P_n\ (t)$ = Population and $P_n\ max(t)$ = Maximum population

Therefore, the Population at a given time, t is $dP_n(t)/dt = [B - D + I - E] P_n(t)$ and the estimated Population at the time $t + 1$ is thus given as:

$$P_n(t+1) = P_n(t)\, e^{(B - D + I - E)\, t} \tag{4}$$

where I and E represents Immigration and Emigration respectively

The amount and composition of wastes generated comprise the basic information needed for the planning, operation and optimization of waste management systems [16]. Waste generation has been predicted on a per capita basis [17], [18]. If the average waste generated by an urban community is j ton/yr and that of a rural community is k ton/yr. Also, if α and β are Boolean variables of either 0 or 1 at any given period. Population data for the study area is as given in Table 1. Then, the total waste generated, G_n

$$G_n = j^{\alpha} k^{\beta} P_n(t) \tag{5}$$

(ii) Decomposition gas production equations:

According to Ref. 19, the total amount of gas expected to be produced is

$$Gp = 1.868\, C\, (0.0141\, T + 0.28) \tag{6}$$

Gp = gas produced (m^3/ton of MSW); C = the total organic content (TOC) kg/ton of MSW. C is taken as 60-90% of G_n for rural and 30-59% for urban communities [20]; T = Temperature in Centigrade

According to [20], the model for gas generation rate increases and then decreases as formulated below:

$$G_1 = (Gp/2) \exp[-k_1(t_{1/2} - t)] \tag{7}$$

$$G_2 = (Gp/2) \exp[-k_2(t - t_{1/2})] \tag{8}$$

where G_1 and G_2 are volumes of gas produced prior to time $t_{1/2}$ and after $t_{1/2}$ respectively; k_1 and k_2 are decay constants and $t_{1/2}$ is the time taken for half of total gas

Table 1 Population data for the study area

Local Government Area	***Population (1991)***	***Population (2006)***	***100 years Simulated***
Ogbomoso North	101,800	198,720	468,631
Ogbomoso South	64,234	100,815	463,068
Oriire	93,438	150,625	468,389
Ogo Oluwa	36,255	65,184	303,063
Suurulere	67,709	142,070	464,948

(b) Computer programming and Simulation

The Visual Basic language was employed in coding the equations. The key elements of the Model were defined and quantified as variables. These variables include population, precipitation, moisture content and temperature. Their relationships were formulated mathematically and the system dynamics structures applied in developing the source codes. Once the parameters and the initial values for the State Variables (Stocks) were specified, the model became definitively determined through the program. The stock flow diagram of the system was designed by using STELLA 9.1.4 software and simulation package. The principles of system dynamics were applied to determine the interrelationships of population, wastes and gas generation. These were simulated to predict the results for the next 100 years using year 1991 data as initial values in the stocks of the flow diagram. Causal loops indicating the linkage of population and other variable were developed. The STELLA flow diagram of the model is shown in Fig 1.

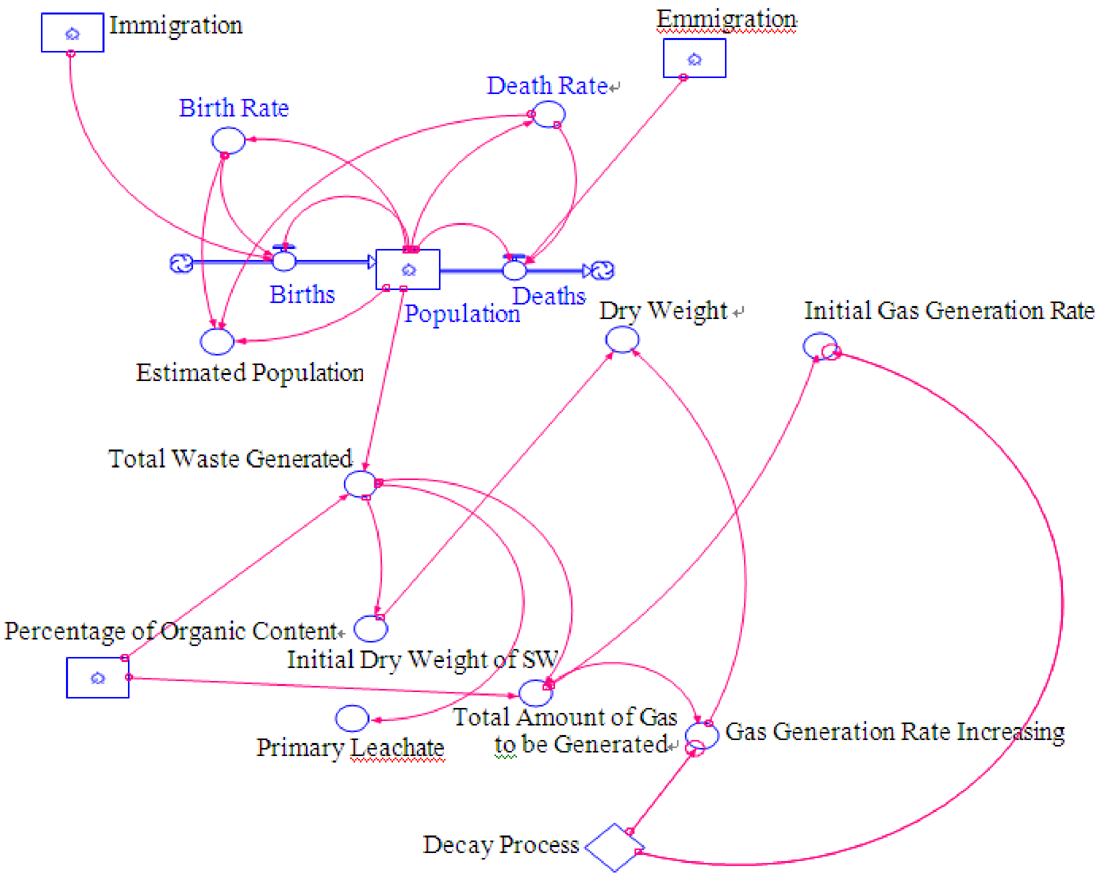

Fig. 1 Stella flow diagram of the model

(c) Validation of the model

To compare the model results with historical data and to check whether the model generates plausible behavior there is need for its validation. The developed model was validated by applying it in the assessment of practical challenges of population increase and corresponding wastes and gas generated in the study area.

3. Results and Discussion

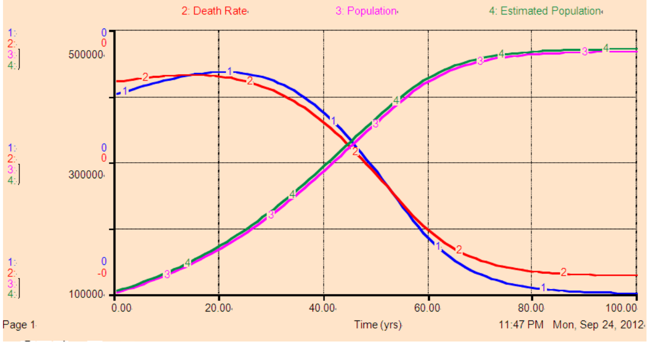

Fig. 2 Population related factors in the 1991 data for

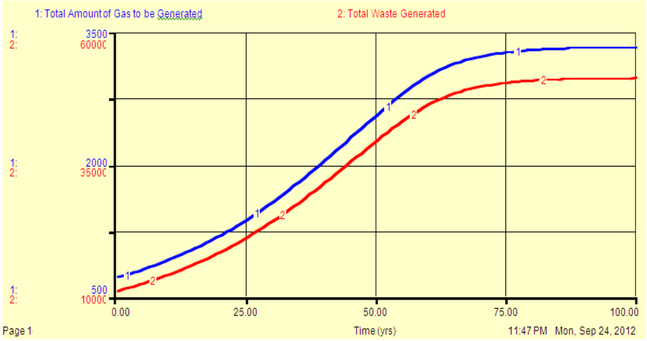

Fig. 3 Wastes and gas generation based on 1991 data in

Ogbomoso North LGA

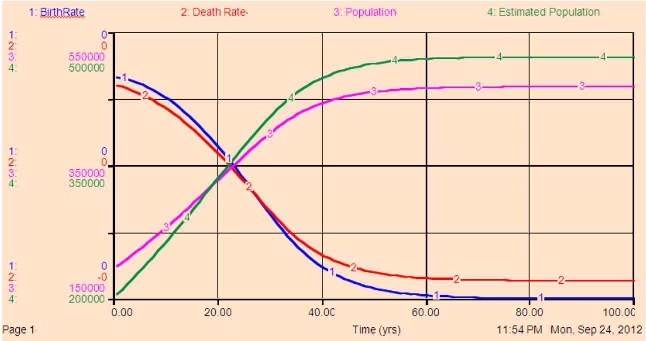

Fig. 4 Population related factors in the 2006 data for Ogbomoso North LGA

Ogbomoso North LGA

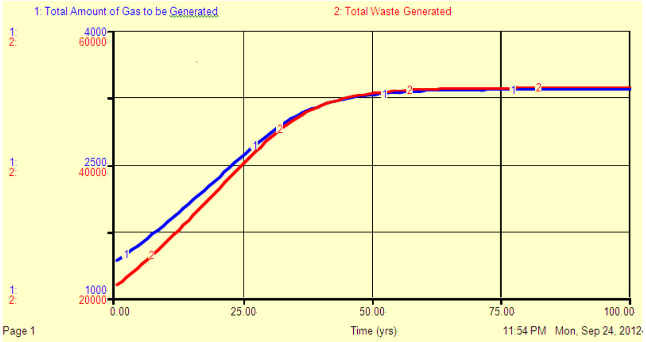

Fig. 5 Wastes and gas generation based on 2006 data in Ogbomoso North LGA

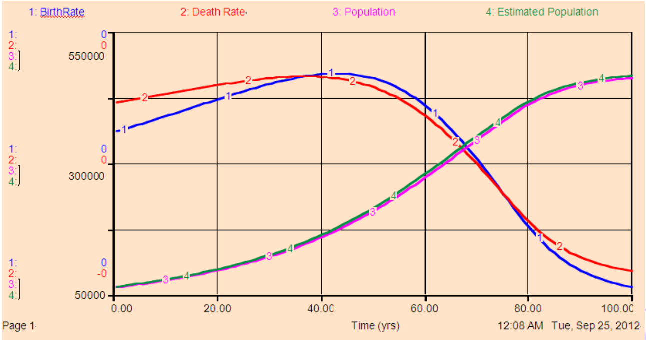

Fig. 6 Population related factors in the 1991 data for Ogbomoso South LGA

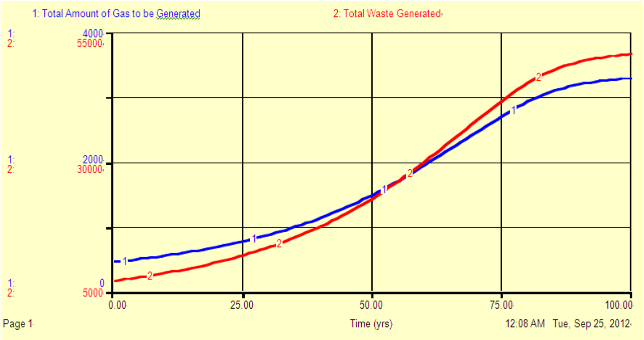

Fig. 7 Wastes and gas generation based on 1991 data in Ogbomoso South LGA

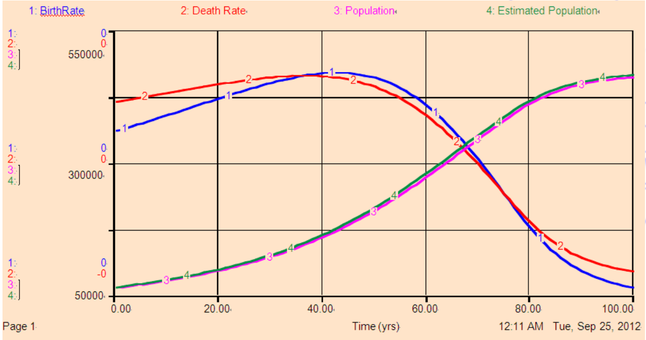

Fig. 8 Population related factors in the 2006 data for Ogbomoso South LGA

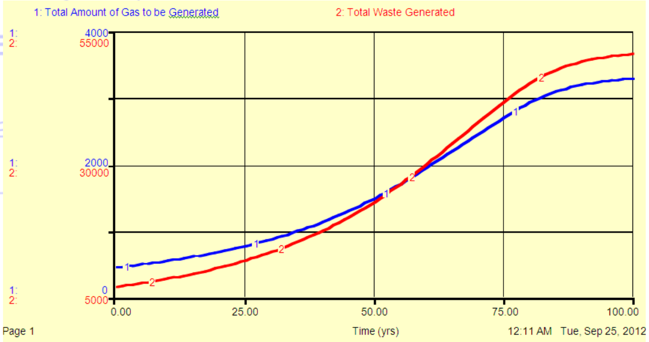

Fig. 9 Wastes and gas generation based on 2006 data in Ogbomoso South LGA

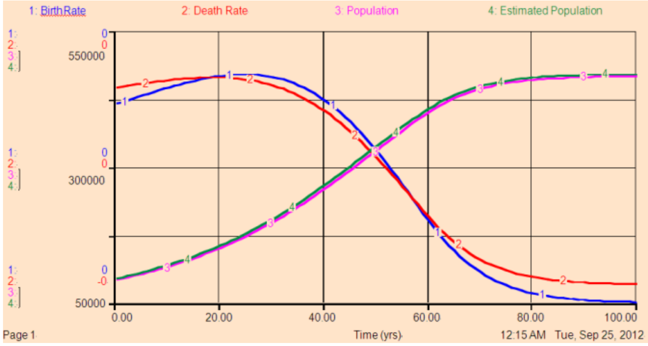

Fig. 10 Population related factors in the 1991 data for Oriire LGA

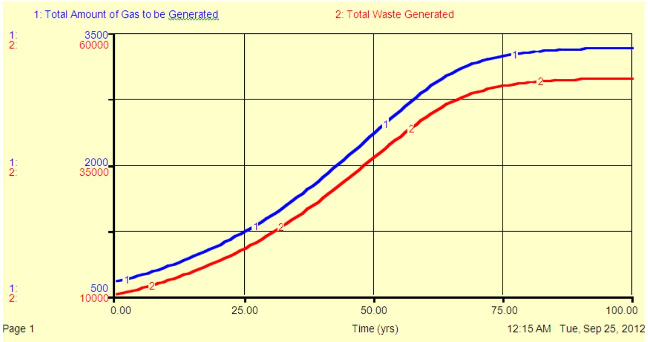

Fig. 11 Wastes and gas generation based on 1991 data in Oriire LGA

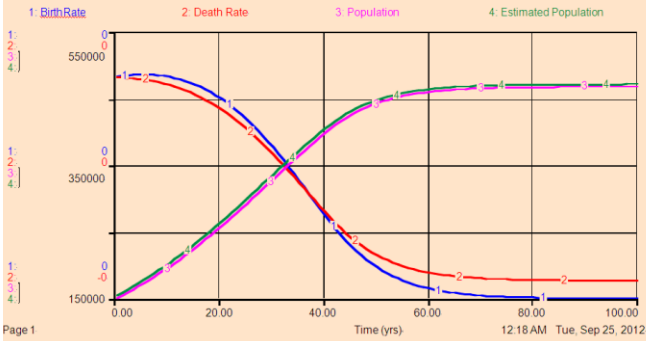

Fig. 12 Population related factors in the 2006 data for Oriire LGA

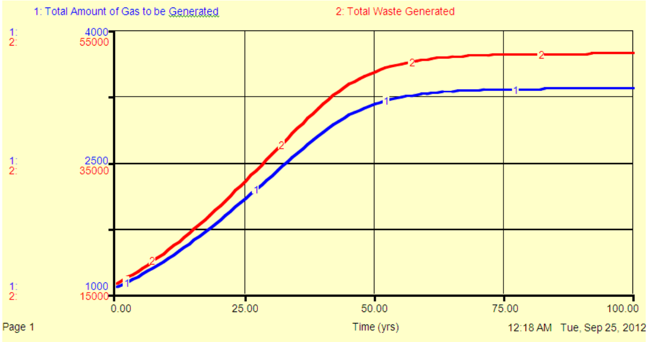

Fig. 13 Wastes and gas generation based on 2006 data in Oriire LGA

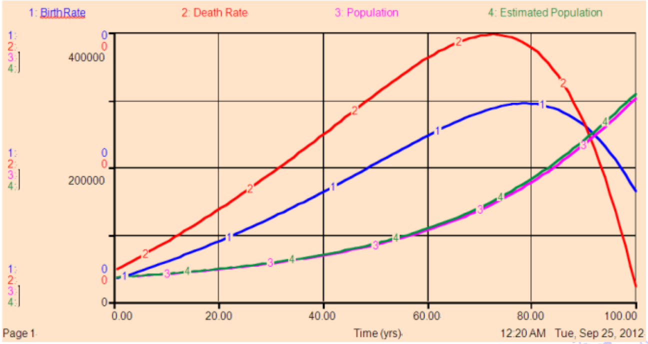

Fig. 14 Population related factors in the 1991 data for Ogo Oluwa LGA

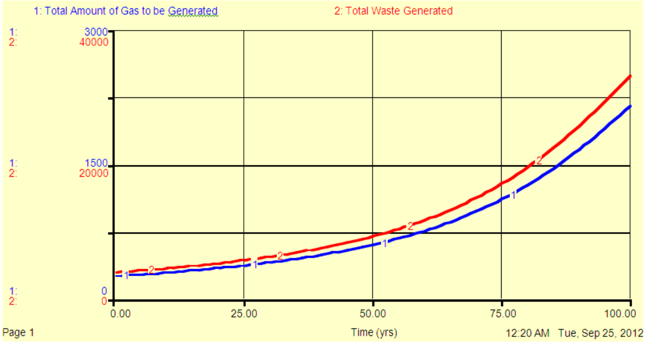

Fig. 15 Wastes and gas generation based on 1991 data in Ogo Oluwa LGA

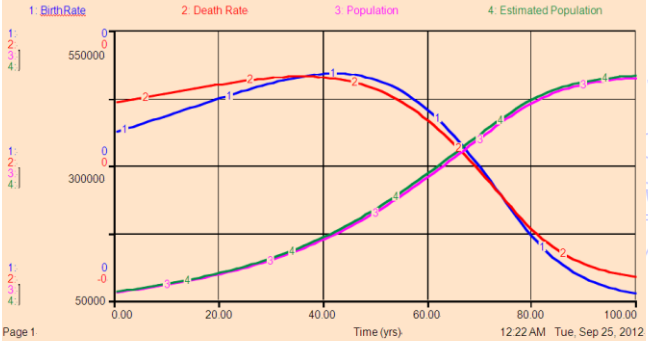

Fig. 16 Population related factors in the 2006 data for Ogo Oluwa LGA

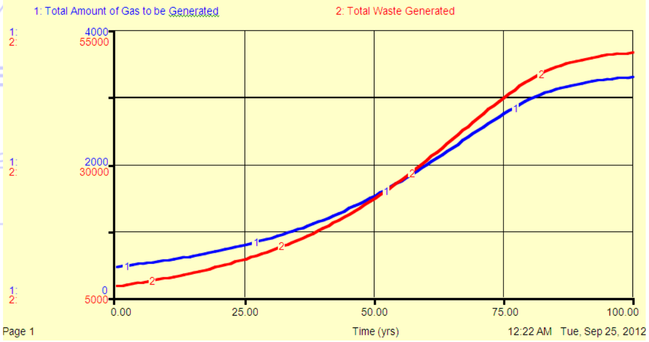

Fig. 17 Wastes and gas generation based on 2006 data in Ogo Oluwa LGA

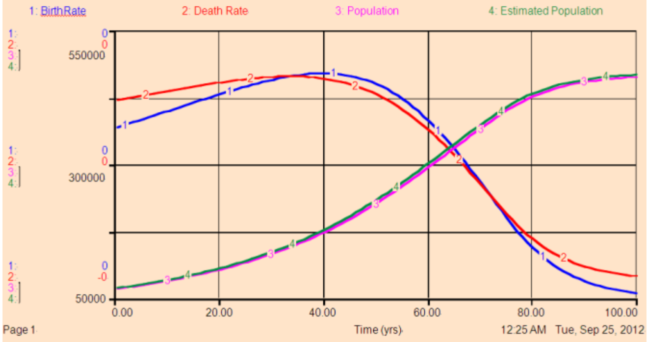

Fig. 18 Population related factors in the 1991 data for Suurulere LGA

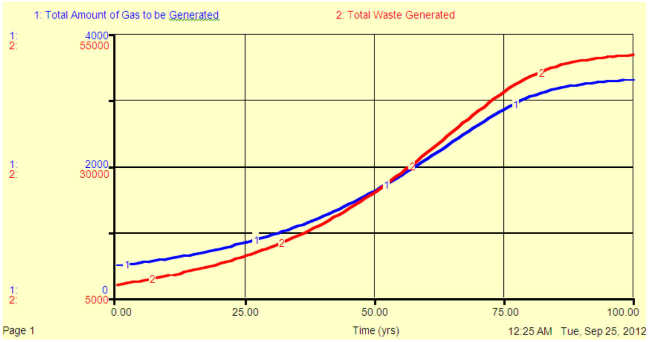

Fig. 19 Wastes and gas generation based on 1991 data in Suurulere LGA

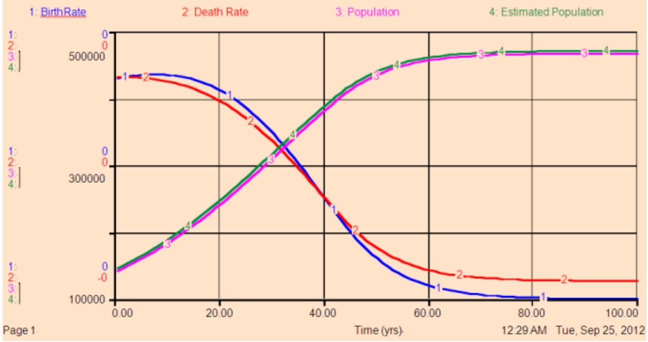

Fig. 20 Population related factors in the 2006 data for Suurulere LG**A**

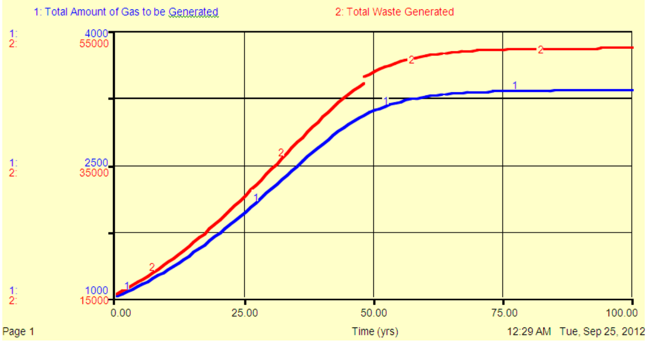

Fig. 21 Wastes and gas generation based on 2006 data in Suurulere LGA

Table 2 Simulated population and quantities of wastes and gas generated after 25 years

Local Government Area	***Population***	***Generated Wastes (x 106m3)***	***Generated Gas (x 103m3)***
Ogbomoso North	194,083	2.13	1.192.0
Ogbomoso South	109,328	1.21	1,250.7
Oriire	174,029	3.15	3,133.3
Ogo Oluwa	52,628	0.96	1,060.2
Suurulere	118,078	2.11	2,279.4

From the results, it was observed that as the population increases all the LGAs witnessed continuous increase in solid wastes and gas over the first 50-year projection. Population increase translates to more wastes being generated and by extension more gas production. This was confirmed by the trends in the graphs of the population, wastes and gas generation (Figures 2 to 21). The behavior of the wastes and gas generation beyond the first 25 year however varies with the nature of wastes. It was noted that gas production generally exceeds wastes quantities in the rural LGAs. This could probably be explained by the fact that organic wastes being generated in the rural areas evolve more gas than the non-biodegradable waste components of the urban LGAs.

As shown in Table 2, after 25 years, the rates of waste generation from the urban LGAs (Ogbomoso North and Ogbomoso South) and the rural LGAs (the rest three) are $3.33\text{x}10^6$ and $6.22\ \text{x}10^6\ \text{m}^3$ respectively. The corresponding rates of gas production are $2.44\text{x}10^3$ and $6.47\text{x}10^3\ \text{m}^3$. These findings corroborate the fact that more gas is produced from organic-related wastes which are predominant in the rural LGAs than from the refuse from the urban LGAs.

It has been reported that gas generation begins months after wastes deposition [23]. It was observed that the rate of gas generation in all the LGAs exceeded that of wastes at any given time in the system. This may be linked to high proportion of organic/putrescible components of the total wastes in Ogbomosoland which is about 70% [20]. This category of waste decomposes and degenerates with time, thereby reducing the quantity of available wastes.

The highest amount of gas generation was recorded in Oriire LGA, a rural area; thus, attesting to the fact that biodegradable wastes of rural areas generate more gas than the inorganic waste components of urban areas. The trend was similar for quantities of wastes generated. From the simulation results (Figures 2 to 21), the total simulated waste volume after 25years period was about 96,000 tonnes whereas after 50years, the average waste volume remained at 150,000 tonnes this being 1 ½ times the 25year value. Waste degeneration process could be held accountable for this indirect relationship.

4. Conclusions

Population remains an indispensable factor as regards the wastes and gas generation from dumpsites. It has a direct relationship with both the rates and the quantities of wastes and gas being generated at any given time. System dynamics modeling approach is a versatile tool in analyzing complex non-hazardous solid wastes and gas generation issues. More gas is produced from organic wastes components in rural areas when compared with those of urban centres. The main limitation of this model is its inability to handle a population size exceeding 300,000. As such, the sensitivity on population of urban centres is reasonably high. The study thus recommend that full-fledge landfills should replace the open dumpsites rampant in the study area.

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