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Modeling of Electrical Energy Generation and Production of Compost from Solid Waste in Dhaka City

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Abstract

Present solid waste management system in Dhaka city is reviewed and the constraints and shortfalls are discussed. A system dynamics computer model is presented to predict population, solid waste generation and composite index, electricity generation from solid waste and composting. Simulated results show that population, solid waste generation, public concern and composite index increase with time. The model was also simulated to assess the potentials of electricity generation from solid waste for Dhaka city and production of compost. Electricity from solid waste could supply a significant portion of the electricity demand of Dhaka city. Composting is a less costly proposition with a composite index much higher than that of electricity generation from solid waste. This higher value of the composite index for composting is due to the fact that 50% of non-recyclable solid waste by weight is converted into compost and the rest of the material is dumped as untreated. The composts are good quality organic fertilizers for vegetables and other crops. Finally, this model can be used as a computer laboratory for urban solid waste management policy analysis of electricity generation and composting.

Keywords : Modeling, Solid waste, Composite index, Electrical energy generation, Composting

1. Introduction

Dhaka is the capital city of Bangladesh and its present population is estimated at 6.14 million. Annual solid waste generation is estimated as 2.4 million tons and it depends on population growth and GNP (Sufian and Bala, 2005). The major sources of solid waste in Dhaka city are residences, streets, market places, commercial establishment, and hospitals. The sources and their contributions are shown in Table 1.

The density of solid waste depends on its organic and inorganic contents and the density value of solid waste in the Dhaka city is 600 kg/m^3. Dhaka City Corporation is responsible for collecting and disposal of solid wastes in Dhaka city. Solid wastes are collected from street corners, dumping grounds, concrete and steel bins while some recyclable solids are collected on payment from the houses.

There exists three types of solid waste management systems and these are (i) formal system, (ii) community initiative and (iii) informal system. In the formal system solid wastes are collected and dumped outskirts of the city. In the community initiative solid wastes are collected from the houses and subjected to composting while in informal system recycling solids are collected by informal labour forces (Department of environment, 2004).

Traditional labour intensive methods are used for solid waste management in Dhaka city. Waste is simply collected from the designated communal dustbins and demountable containers, transported by open 1.5-5 ton capacity trucks, demountable containers, tractors and trailers and disposed in a crude unsanitary way in nearby low-lying areas of the city. Collection system is inadequate and involves 4 or 5 times of handling of a particular waste before it is finally disposed at an open dumping site. The waste collection system relies on communal containers located along the road sides. Collection coverage of waste is inefficient and as a result 35 to 50 % of waste remains uncollected in the city. Approximately 120,000 people are involved in recycling and almost 50 % inorganic fraction is recycled (Department of environment, 2004).

The major constraints of solid waste management in Bangladesh are (i) lack of finance and insufficient tax collection, (ii) lack of manpower and infrastructure, (iii) lack of access to municipal solid waste service, (iv) shortage of suitable land for final disposal of solid waste, (v) lack of proper institutional setup, (vi) lack of awareness, (vii) lack of partnership, (viii) incomplete and insufficient waste collection, (ix) lack of proper handling rules and standard, (x) absence of national policy to encourage recycling (Department of environment, 2004).

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Table 1. Sources and contributions of solid waste from different sources

Types of solid waste	Quantity, %
Domestic	40-60
Commercial	5-20
Street sweeping	20-30
Combustible	20-30
Noncombustible	30-40
Moisture	45-50

In order to improve solid waste management system in Dhaka city the following issues should be addressed (i) promotion of recycling/ composting/ electricity from solid waste, (ii) promotion of participatory action, (iii) promotion of source separation of waste. (iv) tax incentive for use and production of recycled product and (v) promotion of more waste related projects (Department of environment, 2004).

Here two important alternatives are (i) electricity generation from solid waste and (ii) production of compost from composting of the solid waste and these are summarized below:

The solid waste has a heating value of 6.0 MJ/kg, about one-third the heating value of coal, but unlike coal it has a very low sulphur content. The electrical energy from heat energy recovery from an incineration plant involves the burning of solid wastes at high (815 °C – 980 °C) temperatures (Walter, 1987). If incineration is to become an economical method for solid waste disposal, useful material and energy must be recovered by the process. Heat can be recovered by putting a waste heat boiler or some other heat recovery device on an existing solid waste incinerator. The heat so recovered can be utilized for generating electricity or for space heating purpose.

Organic wastes can be converted into compost using labor intensive and a simple thermophile composting procedure (Zurbrugg et al. 2002). Fig.1 shows flow chart of the composting process. The pre-stored organic waste is mixed with additives and piled around a triangular aerator/rack made of bamboo, which allows a better air circulation inside pile. The total composting process lasts for 53 days, which can be described by a thermophilic phase (27 days, 40-70°C) and a mesophilic phase (26 days, 20-40°C). During the first phase the compost piles are turned frequently to regulate their temperature and ensure an equal decomposition level throughout the pile. The turning process, together with the observed temperature curve indicates that the pile is well hygienised and pathogenic organisms and weed seeds do not survive. As the pile temperature drops to ambient temperature the material is left to mature without turning or watering. The material changes its colour into dark-brown, which is a sign of mature compost. The mature compost is then screened and packed into bags.

In Bangladesh analysis of the compositions of the urban solid waste is not generally carried out on a regular basis by the municipalities. The typical compositions of solid waste by weight of Dhaka city analyzed by several sources are shown in Table 2. On average, constituents are 18% inorganic matter and 82% organic matter (Khan, 1999).

Many studies have been reported on strategies to achieve municipal solid waste management (Pawan et. al. 1997, Salvato 1992, and Kum et al. 2005). Linear programming, mixed integer programming, input-output analysis, expert system and system dynamics have been applied to aid decision makers in planning and management of solid waste management systems (Everett and Modak 1996, Badran and El-Haggar, 2005, Clayton and McCarl 1979, Basri 2000, Ming et. al. 2000, Heikki 2000, Mashayekhi 1992 and Sudhir et. al. 1997). Waste analysis software tool is also becoming available (Diaz and Warith, 2005). More recently Dyson and Chang (2005) emphasized the capability of system dynamics for prediction of solid waste generation.

Alam and Bole (2001) analyzed the electrical energy recovery potential from urban solid waste of Dhaka city and its economic feasibility and emphasized that 1.28 million tons of municipal waste generated in the Dhaka city could be used to produce about 72 MW of electricity. If it is not economically viable in the context of only electricity production, considering the optimum energy utilization and environmental implications it has importance. Recently Sufian and Bala (2005) applied system dynamics for modeling electrical energy recovery from urban solid waste. Also more recently Sufian and Bala (2006) applied system dynamics for modeling of urban solid waste management system and to assess different policy options for solid waste management.

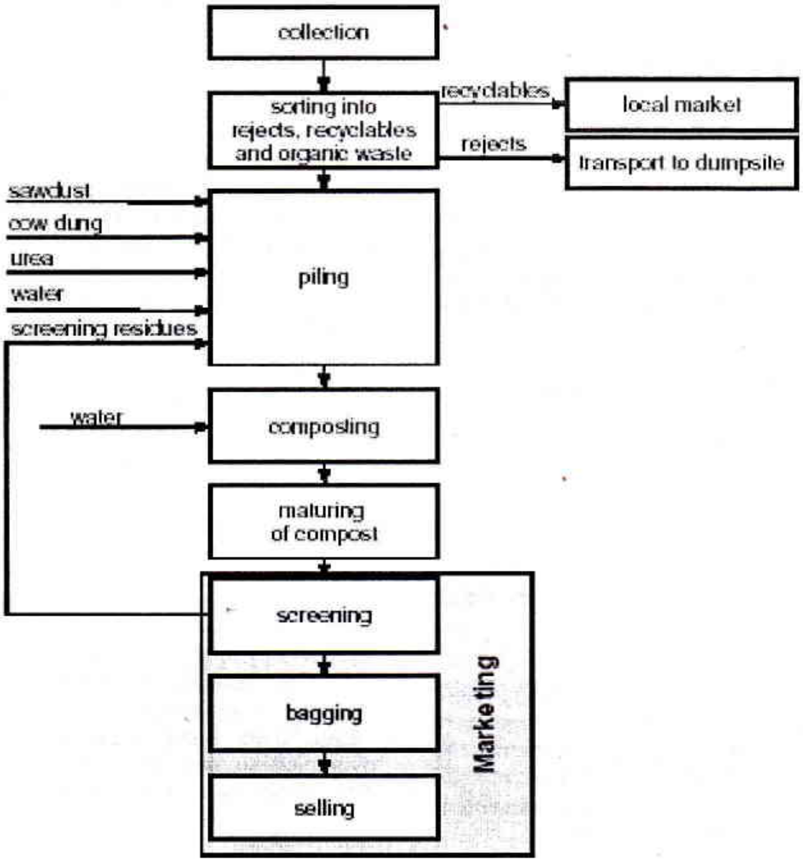

Fig.1. Flow chart of composting process

Table 2. Compositions of solid waste of Dhaka

Constituent	Reported by (Khan, 1999)		Reported by (Alam, 2001)
	Residential (weight %)	Industrial (weight %)	(weight %)
Plastic	1.74	1.48	2.3
Paper	5.68	7.22	10.0
Glass	6.38 (Glass + Metal)	10.22 (Glass + Metal)	1.4
Metal			0.5
Textile	1.83	1.59	--
Food stuff & kitchen	84.37	79.49	--
Food waste	--	--	18.0
Wood/grass	--	--	2.1
Ash/soil	--	--	40.0
Other	--	--	25.0
Total	100.00	100.00	99.3

Zubrugg et al. (2002) reported a study based on **the experiences** of *Waste Concem*, a NGO with a community based decentralized composting project in Mirpur, Dhaka, Bangladesh. Organic waste was converted into waste using a labor intensive aerobic and mesophilic composting procedure. This case study is a success story of decentralized collection and composting scheme. The case of Mirpur shows that composting can be a good alternative to conventional solid waste management options, reducing the amount of waste to be transported and dumped by producing a valuable raw material for fertilizers.

The purpose of this study is to develop a system dynamics model to predict solid waste generation, address the issues of electrical energy recovery from the solid waste of the Dhaka city and compost from composting of solid waste.

2. System dynamics modeling of urban solid waste management system

Planning of Urban Solid Waste Management (USWM) has to address several interdependent issues such as public health environment, the electricity generation potential from the urban solid waste generated, compost from the composting of solid waste and present and future costs to society. The urban solid waste management system is a complex, dynamic and multi-faceted problem depending not only on available technology but also upon economic and social factors. Experimentation with an actually existing urban solid waste management system containing economic, social, technological, environmental and political elements may be costly and time consuming or totally unrealistic. Substituting urban solid waste management system by a computer model one can conduct a series of experiments. The computer models clearly are of great value to understand the dynamics of such complex systems (Bala, 1999). Owing to the intrinsically complex nature of urban solid waste management problems, it is necessary to implement urban solid waste management policy options only after careful modeling analyses. The analysis involves use of different modeling techniques such as optimization, econometrics, input-output analysis, multi-objective analysis and system dynamics simulation. Forrester's system dynamics methodology provides a foundation for constructing computer models to do what human mind can not do – rationally analyze the structure, the interactions and mode of behavior of complex socio-economic, technological, and environmental systems and hence system dynamics approach is the most appropriate technique to handle this type of complex problems.

The methodology used in the development of the solid waste management model is *system dynamics*. A detailed description of the methodology is given in Forrester (1968) and Bala (1998 and 1999). It has been used in many areas including global environmental sustainability (Forrester, 1971, Meadows *et al.*, 1992), environmental sustainability in agricultural development project (Saysel et al. 2002), modeling strategies for promoting agricultural development (Drew, 1990), regional sustainable development issues (Saeed, 1994, Bach and Saeed, 1992), environmental management (Mashayekhi, 1990 and Sudhir *et al*, 1997) and ecological modeling (Saysel and Barlas, 2001) and modeling of electricity generation from solid waste and modeling of solid waste management system and policy analysis (Sufian and Bala, 2005 & 2006).

System dynamics methodology is based on feedback concept of control theory and the feedback loops simulate dynamic behaviour (Bala, 1999). Two basic building blocks in system dynamics studies are stock or level and flow or rate. Stock variables (symbolized by rectangles) are state variables and stocks represent accumulation in the system. Flow variables (symbolized by valves) are the rate of change in the stock variables and flows represent the activities and decision function in the system. Converters (represented by circles) are intermediate variables used for miscellaneous calculations. Finally, the connectors (represented by simple arrows) represent cause and effect links within the model structure (Bala, 1999). The flow diagram of the urban solid waste management system is shown in Fig. 2. The original computer model was developed as a part of thesis and it was constructed using STELLA Research software (HPS, 1996) designed for dynamic feedback modeling of complex systems. Full details are available in Sufian (2001).

The model described here is a theoretical framework for examining urban solid waste generation and its management system in Dhaka city and also to address the issues of electrical energy generation potential to meet the electrical energy consumption requirement of Dhaka city and production potential of organic fertilizers from compost from composting of solid waste. There is a

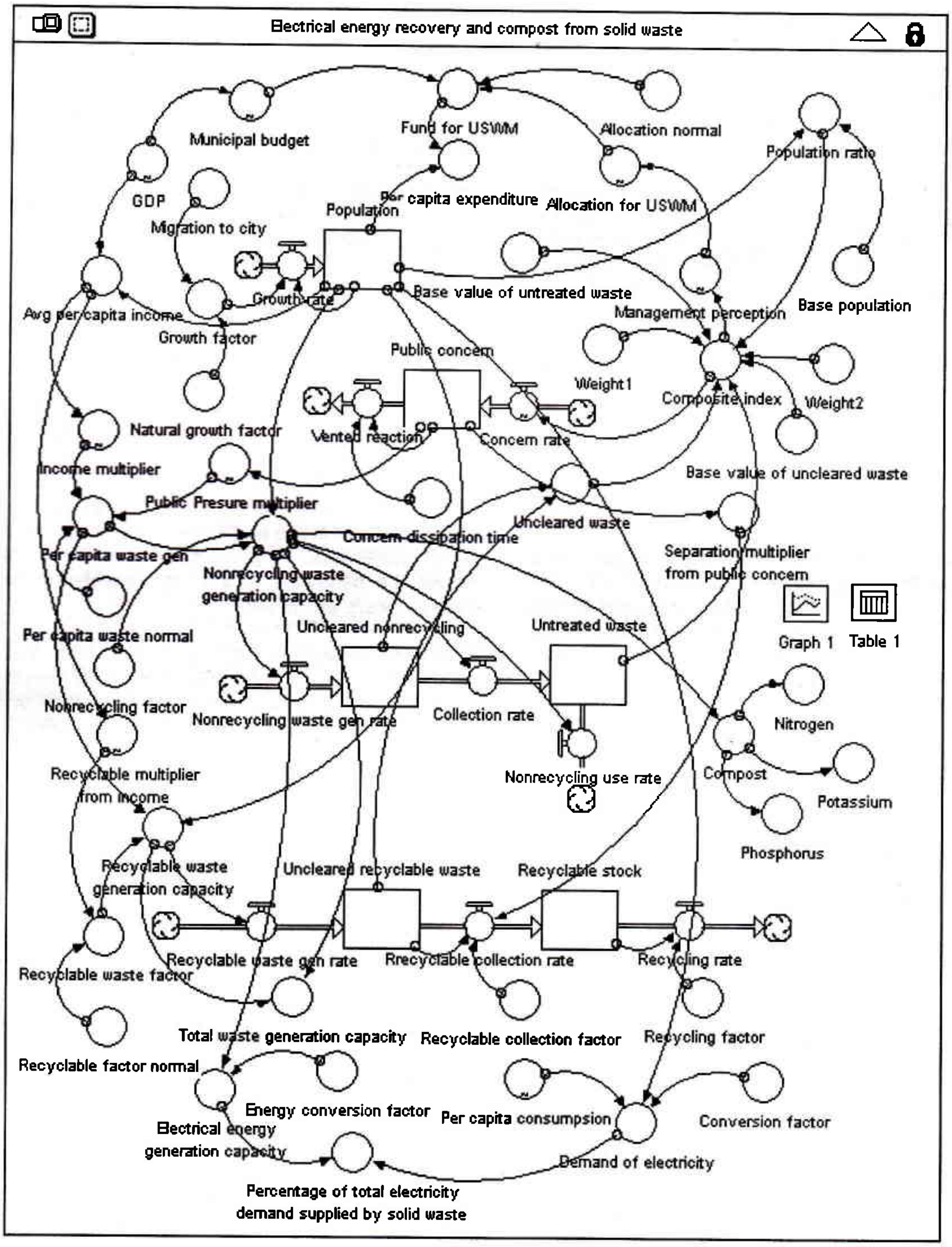

Fig. 2. STELLA flow diagram of the system dynamics model of electrical energy recovery and compost from solid waste

large gap between the waste generation and management system which results in environmental pollution. Both the uncollected waste and unhygienic disposal of waste create environmental pollution, which cause to increase public annoyance and anger and hence public concern develops to reduce waste generation and source separation of recyclable waste. But, waste generation increase with increase of population and GDP as well as per-capita income. Hence the electrical energy generation potential from the urban solid waste increases and also the organic fertilizers from compost increase from solid waste. On the other side, composite index shows the lack of waste collection (uncleared waste). Higher composite index increases management perception which increases fund allocation for solid waste management.

In the Dhaka city, normal practice is that, the householders put their solid wastes at different collecting points at street. The Dhaka City corporation's personnel collect the wastes at a particular time and transport to disposal site. The disposal method is only open dumping in an unhygienic manner. The Dhaka City Corporation does not do any have sanitary landfill, incineration, composting or recycling process. A portion of recyclable solid waste of Dhaka city is used in recycling industries (plastics, paper, glass, metals etc.), but this amount is very small and done by fully informally.

Although the Dhaka City Corporation does neither have any electricity generation plant from urban solid waste nor facility for production of composts from composting of solid waste, a model to project electrical energy generation potential from solid waste and also organic fertilizers from compost from composting of solid waste are included. Fig. 2 shows the STELLA flow diagram of a system dynamics model used to predict electrical energy generation and production of compost from urban solid waste in the Dhaka City.

3. Results and discussions

Various ways of validating a system dynamics model have been considered such as comparing the model results with historical data, checking whether the model generates plausible behavior and checking the quality of parameter values. Some of the parameters have been derived from studies in other areas and some were the results of expert guesswork. To judge the plausibility of the model, the behaviors of the key variables in the base run were examined.

Computer projections of population, total solid waste generation, non-recycling solid waste generation, recyclable solid waste generation and composite index for Dhaka city are shown Fig. 3.

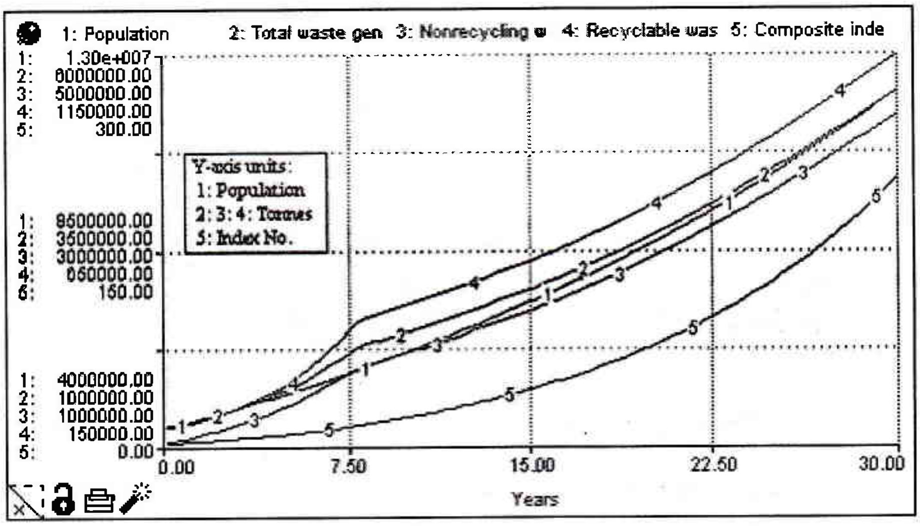

Fig. 3. Simulated population, total solid waste generation, nonrecycling solid waste generation, recyclable solid waste generation and composite index in Dhaka city over a time horizon of 30 years.

Dhaka city had a population of 4.375 million in 1995 and it approaches to 12.082 million in 2025. The population growth rate of the city is higher than the average value of the whole country. This might be due to the fact that for job opportunities or other attractive factors there is a rapid population inflow into the city. More population means more waste. The waste generation increases from 1.027 million tons in 1995 to 4.257 million tons in 2025. The composite index is high and it increases from 0.86 in 1995 to 202.70 in 2025. This is due to both higher uncleared and untreated wastes. Higher composite index means higher environmental deterioration.

It is interesting to note that the electrical energy generation potential increases from 456900 MWh in 1995 to 1733400 MWh in 2025 and the percentage of total electricity demand supplied by solid waste decreased from 146% in 1995 to 72% in 2025 (Fig. 4). Thus, electrical energy recovery from urban solid waste generation of the Dhaka city can supply a significant portion of the consumption requirement of electrical energy of the city. The composite index increases from 0.06 in 1995 to 5.00 in 2025 and here all non-recyclable is used. That is why electricity generation from solid waste has resulted considerable improvement in the quality of environment from the base scenario. However, adoption of the policy for electricity from urban solid waste of Dhaka city should be dictated by the economy of adoption of the technology of electricity generation from the solid waste and environmental implications.

Fig. 5 shows simulated composts i.e. nitrogen, potassium and phosphorus, and composite index. Composts available from solid waste increases from 5,13,400 tons in 1995 to 21,232,200 tons in 2025. Nitrogen, potassium and phosphorus from compost increase from 12,300 tons in 1995 to 50,900 tons in 2025 and from 8,700 tons in 1995 to 36,000 tons in 2025 and from 6,100 tons in 1995 to 25,400 tons in 2025 respectively. Thus, there is a significant contributions of organic fertilizers from the compost from composting of solid waste. This compost is a good quality organic fertilizer for garden vegetables and other crops and it is approved by Bangladesh Agricultural Council (BARC). Composite index increases from 0.03 in 1995 to 113.16 in 2025. From the non-recyclable solid waste 50% of its weight is converted into compost and the rest of the material is dumped as untreated. That is why the composite index is higher than that of electricity generation where all the non-recyclable solid wastes are used for electricity generation. Although composting significantly improves the quality of environment from the base scenario, it is still poorer than the scenario for electricity generation from solid waste. But it is less costly proposition in comparison to electricity generation from solid waste and can be adopted for poverty alleviation through employment generation.

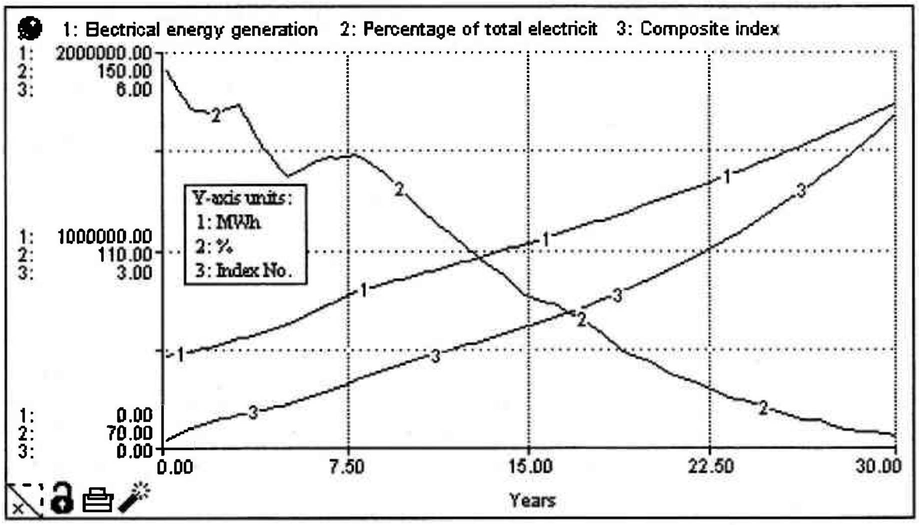

Fig. 4. Simulated electrical energy generation capacity, percentage of total electricity demand supplied by solid waste and composite index in Dhaka city over a time horizon of 30 years.

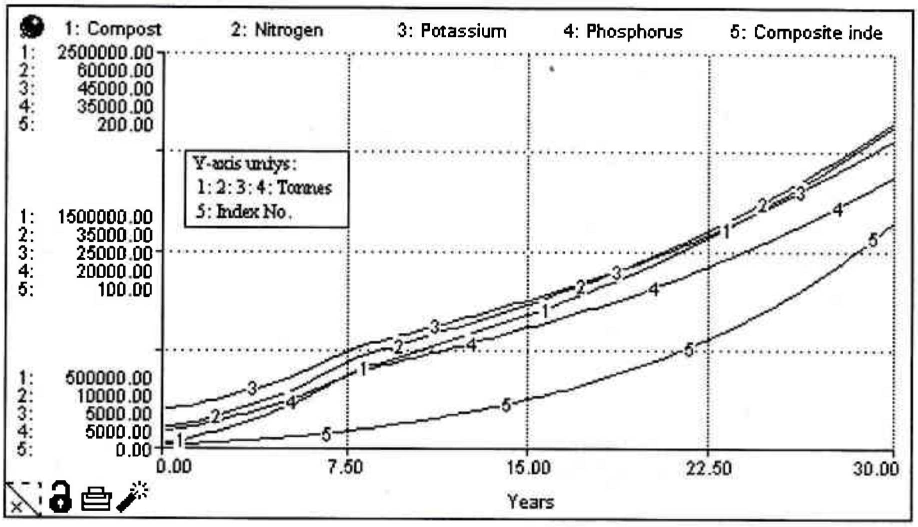

Fig. 5. Simulated compost, nitrogen, potassium, phosphorus generation potential from solid waste and composite index in Dhaka city over a time horizon of 30 years.

4. Conclusions

Solid waste generation increases with the increase of population and thus increases with time. Electrical energy generation potential from the solid waste for Dhaka city increases with time. Adoption of the policy for electricity from urban solid waste of Dhaka city should be dictated by the economy of adoption of the technology of electricity generation from the waste and environmental implications. There exists a great potential for organic fertilizers from composting of solid waste and it also increases with time. The organic fertilizers from the composts are good for vegetables and other crops. Finally, this model can be used as a computer laboratory to predict electricity generation and production for compost from urban solid waste.

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