Application of derived models for the prediction of municipal solid waste generation rates in developing countries

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Abstract— *Municipal Solid Waste Management (MSWM) is a complex process that requires a lot of information from various sources such as factors on waste generation and waste quantity forecasts. Waste generation rates are affected by socioeconomic development, degree of industrialisation, and climate. Generally, greater the economic prosperity and higher the percentage of urban population, greater is the amount of solid waste produced. It is essential to know the quantity of waste generated to plan a Municipal Solid Waste (MSW) management strategy for a given region. Various researchers have attempted to construct models to predict the MSW generation rates. In developed countries there are even models available to predict MSW generation rates, however very few researchers have developed models to predict MSW generation rates in developing countries. Therefore, it is a necessity to use MSW generation prediction models for urban and suburban municipalities in developing countries such as Sri Lanka. This study reviews previously tested models related to municipal solid waste generation and identifies possible factors which will help in identifying crucial design options. There are two different ways to classify models when it comes to analysis of MSW generation rates. They are: factor models that use factors describing the processes of waste generation (Consumption or Utilisation) and Input–output models based on the flow of material to or from waste generators (Removal). There are a number of independent and dependent variables that have been used to explain the overall quantity of partial or entire MSW streams. The study identifies that there is a need for an overall forecast model which identifies future growth in waste generated per capita. The major deficiencies of this study were the selection of few number of models and the use of qualitative approach rather than using statistical tools. Therefore, it is recommended to use a statistical analysis to facilitate better approach for the current models.*

Keywords— **Waste Generation, prediction, numerical modelling**

I. INTRODUCTION

Solid Waste Management (SWM) can be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing, and disposal of solid waste in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations and that is also responsive to public attitudes. The rapid economic growth and expanding urbanization in cities of Sri Lanka have caused the increase of waste generation and the diversification of waste composition. Residential, Commercial and Institutional solid waste accounted for high proportion of total Municipal Solid Waste (MSW), especially in urban and sub-urban cities. Therefore, the evaluation and understanding of waste generation rate from these sources are indispensable for the effective SWM planning.

Various research have shown that the amount of solid waste generated by a country is proportional to its population and the living conditions of the people (Wertz 1976; Grossmann et al. 1974). Waste generation rate is also proportional to income levels of people (Medina 1997). However, it has been shown that these are not the only governing factors. Amongst other socioeconomic factors that have been said to influence MSW generation are persons per dwelling, cultural patterns, level of education, and public attitudes (Al- Momani 1994; Grossmann et al. 1974). In addition, Bandara et al. (2007) said that some other factors, such as climate, living habits of the people, religious and social factors are also affecting the MSW generation rate.

Waste generation rates can be estimated using several methods. The different methods for estimating waste generation rate, include field studies (Purdy and Sabugal 1999), application of the survey sampling theory (King and Murphy 1996), conversion of economic sales data for a region into estimates of solid waste generation (Gay et al., 1993), classical method of direct waste analysis (Brunnr and Ernst 1986), and use of models (Daskapoulous et al., 1998). In developed countries there are even models available to predict MSW generation rates, however very few studies have developed models to predict MSW generation rates in developing countries. Models are available to predict the gross waste generation capacity of countries. But, these are not adequate for developing integrated waste management plans for municipalities or regions, since waste generation patterns are unique to regions. Therefore, there is a necessity for developing waste generation prediction models for suburban municipalities in developing countries. The main aim of this study is to review models previously arrived at and tested related to municipal solid waste generation and identify possible indications related to Solid Waste generation rate in Developing Countries

II. MATERIALS AND METHODS

2.1 Research methods

The research was done systematically using the previously published models regarding solid waste generation, especially in developing countries. The author searched the Science Direct, Sage, and Springer using the following topics and key wards: solid waste management, factors affecting the solid waste generation rate, modelling of solid waste generation rate, household waste management, and municipal solid waste generation. In addition, books and research reports on Municipal Solid Waste Management (MSWM) were also studied in finding corresponding information.

2.2 Competent Studies

The following criteria were considered in conducting systematic review of publications.

1) The research conducted on solid waste management.

2) The waste generation rate was observed using models.

3) The research constituted independent variables like solid waste generation, composition and utilization of solid waste.

4) Studies that carried out a review of SWM were excluded

In addition, the review of all publications was done based on some characteristic classification criteria when review of waste generation models and these include: the method used in the modelling, the waste stream that used for modelling, the place of study, and dependent and independent variables used in the model. The overall quantities of partial and entire MSW streams are analysed using a number of independent variables. Some of these variables are mentioned in studies those discussed in this paper. Forecasting of future solid waste generation is significant and solid waste management models are extensively used in this regard. There have been a number of studies that have dealt with various solid waste management models and their uses. These models are discussed below.

III. RESULTS AND DISCUSSION

3.1 Analysis of derived models

Chen & Chang (2000) said that solid waste management system requires accuracy in terms of knowing exact amount of solid waste being generated. However, the authors also contend that the manner in which the amount of solid waste generated is predicted is different in both developed and developing countries. This study focused on the city of Tainan in Taiwan. The study depicted that grey fuzzy dynamic modelling helps in reducing the inconsistency between the predicted values and the observed values. Authors found that different collection systems of solid waste affected the waste generation rate.

Dalemo et al., (1997) did a research on handling waste in urban areas. The research applied the ORWARE model to simulate various scenarios in solid waste management. This study describes a detailed view on the energy turn over, environmental effects and plant nutrient consumption in relation to solid waste management. Also, this is focused on different material streams identifying removal of waste. However, this study did not identify any parameters related to any socio economic features. Authors concluded that this model is affected by the input data such as amount and composition of waste, and transport distances.

Dyson and Chang (2005) used system dynamics modeling to predict solid waste generation rate which would greatly help in the management of the municipal solid waste. Authors used a case study based research and there were five planning models based on the various kinds of system dynamics models. The study included data on income and population density and it identified consumption and utilization patterns. The results of the model are directly useful in site selection and capacity planning of Material Recovery Facilities (MRFs).

Chang & Lin (1997) did a research on solid waste generation and found that the impact that time series intervention modeling has on it. The study concluded that recycling impacts to be important when it comes to forecasting the amount of solid waste generation. The study totally based on different collection systems of solid waste. The generation of solid waste was studied without identifying population density. In addition, authors identified that time series model will be a very useful tool in predicting solid waste generation rate.

Zhang et al., (2011) proposed an inexact reverse logistics model for municipal solid waste management systems. The inexact reverse logistics model was developed to facilitate the interactions between production and transport planning and inventory features in the system. Some of the factors that study avoided include the non inclusion of parameters such as resource conditions and differences in the legislation, economic and social conditions. This model could greatly benefit engineers and managers to develop a good solid waste management program. This study classifies waste collected based on the type of material and focuses only on removal of waste.

Navarro Esbri et al., (2002) identified some tools for time series analysis and forecasting MSW generation. This study uses the non linear dynamics which presented different performance measures by making use of a seasonal Autoregressive and Moving Average (SARIMA) methodology. The model presented a forecast model which clearly identified a possible practical implementation for

an effective MSW management. In this study a community based waste collection approach, waste classified across different waste streams and identifying consumption patterns were identified as major factors affecting waste generation rate.

Skovgaard et al. (2005) presented a model for all required predictors and MSW forecasts for predicting solid waste generation rate. The study identified consumption types and size of household and income in relation to population as major factors on solid waste generation rate.

Bandara et al., (2007) identified the relation of waste generation to socio-economic factors. Some of the socio economic variables that could be affected include the population density and average income of the individuals. In addition to these variables, level of education, climate, religious and cultural beliefs, living habits and social and public attitudes are also affected on waste generation rate.

3.2 Appropriate model for Developing Countries

The factors those affected on waste generation rate were varied for different types of models. However, there were some common factors also for different types of models. From the discussions on the concept in previous studies and paper the following aspects can be proposed. Three factors were identified as most appropriate for solid waste generation rate in developing countries. These factors include population density (X_1), average income of the individuals (X_2), and social and public attitudes (literacy) (X_3). The easiest method of correlation is a linear model, which assumes a linear relationship between the amount of municipal solid waste generation and their contributing factors. The following model was derived in order to predict the solid waste generation rate in developing countries.

$$\text{Waste Generation} = a + \ X_1 + \ X_2 + \ X_3$$

Where a, α, β and γ are the coefficient of correlation variables.

3.3 Relationships between waste generation rate and selected factors

The relationship between waste generation rate and population density is linear in most of the developing countries. Developing countries produce municipal solid waste at very high rate. The amount of municipal solid waste has been increasing rapidly in the last two decades. This is particularly due to the rapid growth of urban areas and migration of population from rural to urban areas. Fig 1 shows the relationship between urban population and waste generation of some developing countries from 2001 to 2007. Fig 1 depicted that solid waste generation rate is linearly proportional to the population or population density.

The relationship between waste generation rate and GDP per capita is also a linear. The living standard and the rate of consumption of materials are changed by improved economic conditions in most of the developing countries. As a result, a large amount of solid waste are been generated in these countries. Fig 2 shows the relationship between GDP per capita and waste generation of some developing countries from 2001 to 2007. Fig 2 depicted that solid waste generation rate is linearly proportional to the GDP per capita in most of the developing countries. Therefore, it is clear that the waste generation rate is linearly proportional to the selected factors.

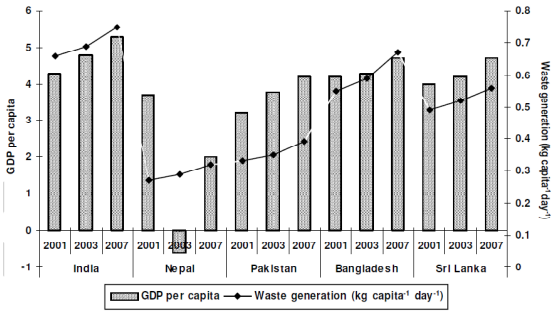

Fig 1. Relationship between urban population and waste generation of studied countries in 2001-2007.
Source: (Anupam et al, 2010)

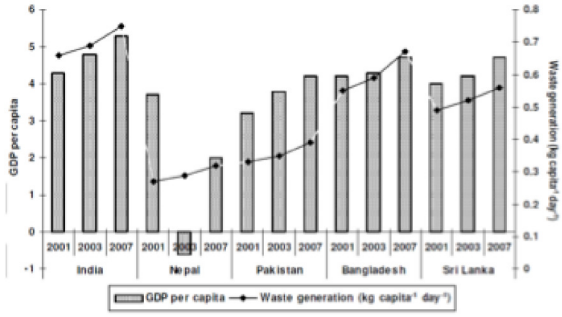

Fig 2. Relationship between GDP per capita and waste generation of studied countries in 2001-2007.
Source: (Anupam et al, 2010)

CONCLUSIONS

There are a number of independent variables that have been used to explain the overall quantity of partial or entire MSW generation in Developing Countries. Population density, average income of the individuals and social and public attitudes are major variables especially for developing countries. A linear model was developed, which assumes a linear relationship between the amount of municipal solid waste generation and their contributing factors. However, the validation of developed model with real solid waste generation data is important before using the model.

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