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A Review on Factors affecting Municipal Solid Waste Generation

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ABSTRACT

Municipal solid waste (MSW) management is not a one-off planning, it is a dynamic evolution and planning has to cater for it. The quantity of MSW generated and composition form the basis for planning and management of MSW. However, for an effective MSW reduction policy to be implemented, generated quantity of MSW is not sufficient alone for policy implementation but more of the variables affecting the generation rate and composition are critical. Without an in-depth understanding of these variables, waste reduction policies may be ineffective and unsuccessful. In this study, we reviewed the impact of these factors on MSW. A case of the City of Johannesburg (CoJ) was studied. Population and gross domestic product (GDP) are the two compelling factors affecting MSW generation. The waste generation per capita is influenced by income level. High income group generate on average 1.91 kg/capita/day, middle income group generates 1.01 kg/capita/day and low income group 0.92 kg/capita/day. This put the CoJ total waste generated at an average of 1.83 million ton/year.

Keywords: *Municipal Solid Waste; Waste Quantity; Waste Generation Factors; Generation per capita.*

1 INTRODUCTION

The knowledge of important environmentally related outputs, both in quantity and quality, from human and industrial processes and the correlating regional characteristics, are the pre-requisite for effective planning and implementation of sustainable strategies (Beigl, Wassermann et al. 2004). Aside the related process parameters, the trends of the socio-economic related factors are important for environmental and ecological impact assessment. One of such impact is the regional ecosystem sensitivity to MSW disposal driven by the regional activities, expansion and income-driven level of consumption with development that gives rise to MSW generation and heterogeneity (Yi, Hartloff et al. 1999, Beigl, Wassermann et al. 2004). Understanding the relationship between human and socio-economic factors and MSW generation rate is important for predicting future trends and designing MSW management system required. For a realistic and yet sustainable outcome in MSW management, both system engineering models and system assessment tools must be integrated. System engineering models are mathematically structured models which are capable of studying the interaction between MSW generation and other factors of technical, social and economic importance (Kadafa, Manaf et al. 2014). System engineering models include cost benefit analysis, forecasting, simulation and optimisation models. On the other hand, system modelling tools are data driven models which are used to assess the MSW management system and resource flows to identify performance gaps, system deficiency and recommend improvement (Gavrilita 2006). The tools include material flow analysis (MFA), substance flow analysis (SFA), life cycle assessment (LCA), risk assessment, management information systems, decision support system, expert system, and scenario development. Kadafa, Manaf et al. (2014) reviewed both system engineering and assessment models and concluded that the integration of both approaches is more appropriate for obtaining a holistic assessment on the management of MSW.

2 FACTORS AFFECTING MSW GENERATION

Garrod and Willis (1998) identified 6 functional unit of MSW management activities, which are MSW generation, storage, collection, transfer, processing and disposal. MSW generation rate has been linked to population growth, income level, migration, economic and industrial development. Generally, factors affecting MSW generation can be classified into seven global variables as presented in Table 1 (Ordonez-Ponce 2004, Patel and Meka 2013, Intharathirat, Abdul Salam et al. 2015, Sukholthaman, Chanvarasuth et al. 2015). Divergent research results considering these variables have often been reported due to different factors mainly due to the quality of data available and location of research, however, population and income are the most hypothesised and investigated (Adamovic, Antanasijevic et al. 2016).

(Hockett, Lober et al. 1995, EPA 1997, Hamburg, Haque et al. 1997, Patel and Meka 2013) found population as the most critical variable affecting MSW generation. EPA (1997) further highlighted income and tax as other factors. On the contrary, Rachdawong, Khaodhiar et al. (2000) found electricity consumption a more compelling variable than population in Bangkok. More recently, Sukholthaman and Chanvarasuth (2013) and Sukholthaman, Chanvarasuth et al. (2015) presented income and macroeconomic factors of gross domestic product growth and consumer purchase index to have a positive correlation with MSW generation rate in Bangkok.

Similarly, in Morelia Mexico, monetary income was the over-ridding variable compared to population density, education level and age (Buenrostro, Bocco et al. 2001). Also, Bandara, Hettiaratchi et al. (2007) highlighted income as an influencing factor for MSW generation in Sri Lanka. Beigl, Wassermann et al. (2004) showed that gross domestic product, infant mortality rate, life expectancy, age group and household size correlated positively with MSW generation. Dyson and Chang (2005) concluded that both economic activity and population growth strongly correlate with household income. Higher household income affects per capita waste generation with a tendency of increased MSW generation. Saltzman, Duggal et al. (1993) argued otherwise that, the household with higher income tend to participate more in recycling activities, thus reducing the generated MSW. Bruvoll (2001) and Hockett, Lober et al. (1995) claimed that overall quantity of MSW is most influenced by landfill fee charges and not income.

Table 1 Factors affecting MSW generation rate

Global Variable	Sub-variables
Demographic	Population and population density, household count and household density, house hold type and household size, age, gender, occupation, expenditure on groceries, electric energy consumption and income level
Economic	Economic growth, gross domestic product, consumer price index, employment, unemployment and waste budget
Geographic	Climate and geographic conditions, natural resource
Technical/technology	Lack of manufacturing standards, engineering problems, inefficient facilities and equipment
Social	Awareness, level of literacy, public cooperation, religion and cultural practice, urbanisation, tourist attraction, political stability
Consumer behaviour	Consumption pattern, cooking activity, lifestyle, disposal pattern
Legislative and Administrative	Strategies, policies, laws, enforcement level and management institution efficiency. E.g. disposal fees, existence of recycling programmes and quantities recycled

MSW management in developing countries around the world has been reported on by several researchers (Dyson and Chang 2005, Antanasijevic, Pocajt et al. 2013). Population and income have been highlighted as the main variable affecting MSW generation rate (Bandara, Hettiaratchi et al. 2007). In Dar-es-Salam Tanzania, Senzige (2014), concluded that population size and GDP growth correlated with higher MSW generation while decreasing economic status resulted in a decline. Bureecam and Chaisomphob (2015) emphasised that population density, the household size and size of municipality are the significant factors that determine the MSW generation rate in Thailand. Thanh, Matsui et al. (2010) analysed socio-economic factors that influence MSW generation in Can Tho city, Southern Vietnam. MSW generation correlated positively to population density and urbanisation level. Dangi, Pretz et al. (2011) found a strong correlation, 0.94, between waste generated in Kathmandu, Nepal and number of people. Afroz, Hanaki et al. (2011) presented the correlation between socio-economic factors and waste generation in Dhaka City of Bangladesh. The MSW generation rate was reported to correlate positively with income and household size. Monavari, Omrani et al. (2012) in their study in Ahvaz, Iran argued otherwise to the correlation between income and MSW generation. They found a negative correlation between income and MSW generation. Their result was substantiated by the argument of ambiguity in associating MSW quantity with income and social status. But they found a positive correlation between family employment, number of rooms and MSW generation. Sankoh, Yan et al. (2012) investigated socio-economic factors affecting waste generation in Freetown Sierra Leone through questionnaire administration. The study showed that increasing age, level of education and family size increases the composition of plastic, wood and paper waste but reduced garbage waste. Aside from population density, Beigl, Lebersorger et al. (2008) stated that age distribution is an important factor affecting waste generation at household level. A city with a large population of children and young adult will produce more MSW than city with elderly couples and singles (Beigl, Lebersorger et al. 2008). Grazhdani (2016) developed a model that investigated the impact of economics, demography, housing structure, education level and waste management policy on MSW generation in Prespa Park Villages. The model showed that a 1% increase in education level reduces waste generated by 3 kg/annum/capita while old occupied houses increased waste generation by 12 kg/annum. From a policy perspective, implementation of pay-as-you-throw encouraged recycling rate by 1.87%. The study concluded that population growth did not necessarily result in an increase in waste generation. Contrarily to increase in literacy level as presented by Grazhdani (2016) to reduced

waste generation, Yi, Hartloff et al. (1999) analysed data from Great Britain, Italy and Netherlands on the impact of higher education level and increased income in willingness to recycle. These two factors which lead to better informed and concerned population correlated albeit weakly 0.144 and 0.174 respectively to willingness to recycle. Monavari, Omrani et al. (2012) also found a poor correlation between education level and MSW generation rate. Jadoon, Batool et al. (2014) investigated the effect of seasonal and socio-economic factors on MSW generation rates. The study found out that the generated MSW across weekdays is higher on Monday but concluded that the difference among weekdays is not significant. Seasonal variation (Winter and summer) were slightly found to influence the quantity of waste due to reduced human activities while socio-economic factor affects the fractional composition distribution among the different income levels. Other seasonal factors also reported in literature are holiday activities, tourism, special event and student population within a city (Denafas, Ruzgas et al. 2014, Sukholthaman, Chanvarasuth et al. 2015).

Aside from the main objective variables, other subjective variables impact MSW generation rate. Gu, Jiang et al. (2016), presented cultural, policy and behavioural changes affecting both composition and quantities of waste generated in China. Cultural diet preference for unprocessed and unpackaged food resulted in a high percentage of food waste. Gu, Jiang et al. (2016) concluded that the composition of organics may not reduce irrespective of wealth or improved standard of living due to cultural preference. On policy approach, implementation of user fee policy leads to a reduction in paper and plastic waste which increased prior to 2008. The behavioural shift from using coal for cooking to natural gas reduced ash waste from 27.2% in 1989 to 2.5% in 2014. In another study, Sukholthaman, Chanvarasuth et al. (2015) considered the role of public attitude and stakeholders participation on MSW generation. Lack of education and stakeholders involvement are some of the highlighted problems. Miezah, Obiri-Danso et al. (2015) emphasized the need for involvement and education if MSW generation rate is to be controlled. Afroz, Hanaki et al. (2011) also emphasized environmental awareness and social behavioural change can control MSW generation rate. Yi, Hartloff et al. (1999) concluded that the opportunity cost and reward perception that shape MSW management policy and household decision about material demand are pivotal to MSW minimisation.

The trend generally from reviewed literature for developing countries is population and income level strongly affect the quantity and composition MSW. These two factors can serve as the base case for forecasting waste generation based on their historical data and trends. The subjective variables suggest that household and individual moral obligation alongside policies implemented can improve the intention of recycling and waste reduction.

3 CASE STUDY

The City of Johannesburg is the case study chosen for this study. An annual average of 1.4 million ton of MSW is managed by the City's waste management company, Pikitup. The waste distribution to four operational landfills is as presented in Figure 1. Recent studies indicated that the waste generated within the City range between 1.3 and 2.6 million ton/year (Aurecon South Africa (Pty) Ltd 2015). Traditional approach has been applied in forecasting MSW generation for the CoJ up to 2040. According to a report by Jeffares & Green, as cited in (City of Johannesburg 2014), the City's MSW is projected to reach 1.99 million tons by 2020 and 3.6 million tons by 2040. It is expected that by 2040 approximately 9.2 million people will be residing in the CoJ.

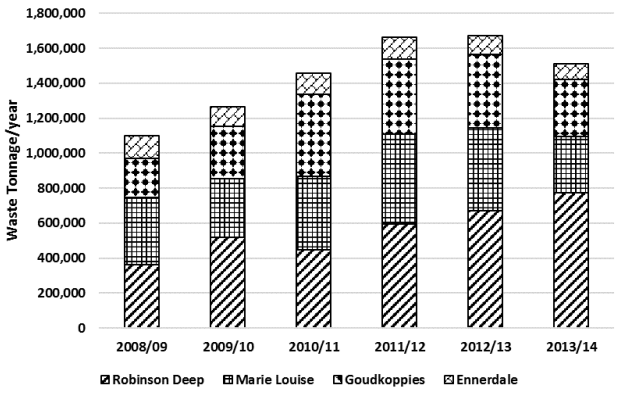

Figure 1 Annual tonnages of waste disposed to landfills

3.1 DATA COLLECTION ON FACTORS AFFECTING MSW

From the literature reviewed in section 2, no firm conclusion can be made on variables affecting MSW generation though population and income are the base factors to consider in the absence of other variables. However, some set of variables were identified as potential indicators beside population and income. They are age, education level, electricity consumption that indicate the extent of manufacturing, employment, gross domestic product, household size, dwelling types, employment, unemployment and income.

In this study, the waste generation factors considered are population, number of households, gross domestic product, employment and unemployment. The considerations were limited to these variables due to the availability of data. The dataset retrieved were from 1997 to 2015. Complete dataset for this period was available for GDP, employment and unemployment. Population data and number of household for 2001 and 2011 were retrieved from the purchased census data from Statistic South Africa. Linear interpolation and published CoJ annual reports were

used to provide data for the missing interval. The annual waste reported by the City waste management company, Pikitup, from 2002 to 2015 was retrieved from online published articles. It is worth mentioning that the values reported in the annual reports of Pikitup are not the waste generated but the waste disposed at their landfills. The actual data for the quantity of waste generated is not readily available. Efforts are being made to improve the generation data quality as weighing bridges are been installed at landfill site across the City and measurement of waste collected by informal recyclers is also being considered.

4 RESULTS AND DISCUSSION

4.1 WASTE GENERATION FACTOR CORRELATION

Due to the limitation of historical data, factors considered as candidates for forecasting MSW were population, GDP, number of employed people in formal sector, number of unemployed persons and number of household. The correlation result shows that all factors are positively correlated to MSW generation. GDP and population are the two compelling factors as presented in Table 2. It can be observed that these factors are also inter-correlated, indicating that any one of the factors can be used to predict waste generation in the absence of others.

Table 2 Waste generation factor correlation coefficient

	Population	GDP	Employed formal	Unemployed	dwellings	MSW
Population	1					
GDP	0.97	1				
Employed formal	0.98	0.99	1			
No. of household	0.83	0.84	0.86	1		
Dwellings	0.98	0.97	0.99	0.88	1	
MSW	0.60	0.61	0.57	0.58	0.51	1

4.2 WASTE GENERATION PER CAPITA PER DAY

Due to lack of data on the quantity of waste generated as informal recyclers picks up recyclables from waste bin just before the arrival of the Pikitup truck as shown in Figure 2, there was a need to conduct a waste weighing exercise. The waste quantification was conducted for three selected areas. The three selected areas were chosen based on the researcher's knowledge on the affluence of the people living within that region. Only 10 sampling was conducted in each selected area, a total of 30 data points, due to limitation of resources. The limited data points are insufficient to generalise; however, it provides an insight into the generation per capita. The waste generation per capita is calculated according to Equation 1. In the study for each location, an accumulation days of 7-days was used as waste bins are emptied once a week for 98% of the coverage areas of Pikitup. The authors clarified with the residents that the waste bin has been emptied a week prior to the weighing activity. This was needed to ensure sufficiently accurate results as it is possible for residents not to place their bins at locations where the waste collection truck can assess and empty such bins. The result obtained, presented in Table 3, was within confidence margins of recently reported results for studies commission by the CoJ (Aurecon South Africa (Pty) Ltd 2015)

Figure 2 Informal recyclers collecting recyclables before waste truck arrives

$$Generation\ per\ capita = \frac{weighed\ waste}{(accumulation\ days * household\ size)} \quad (1)$$

Table 3 Generation per capita for the CoJ

Income group	Min	Max	Avg.	Recent studies
High income	1.01	2.78	1.91	1.03-2.20
Middle income	0.67	1.48	1.01	0.83-1.04
Low Income	0.52	1.39	0.92	0.75-0.99

Based on the generation per capita and 2011 census data, it is estimated that the waste generated within CoJ will be between 1.06 million ton/year and 2.7 million ton. The average generated is 1.83 million ton/year presented in Table 4.

Table 4 Estimated quantity of waste generated within the CoJ

Income group	Minimum	Maximum	Average
High income	299,443	824,263	566,826
Middle income	306,840	681,305	463,445
Low income	451,509	1,197,033	795,209
Ton/year	1,057,792	2,702,601	1,825,480

5 CONCLUSION

Factors affecting MSW generation rate has been presented. Though population has been highlighted as the base factor to consider in the absence of other variables, however, in some cases, population is less an important factor. A case study of the CoJ showed that GDP correlated slightly more strongly than population among other variables on MSW generation. The study also showed that income level affects waste generation. From the study, a median 1.83 million ton of MSW is generated within the CoJ. The results obtained can be used as a base case for developing the waste management plan of the CoJ.

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