MULTIDISCIPLINARY SCIENCE JOURNAL

RESEARCH ARTICLE
Published Online: April 8, 2023
https://doi.org/10.31893/multiscience.2023019

Forecasting municipal solid waste generation using linear regression analysis: A case of Kathmandu Metropolitan City, Nepal

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Abstract There is lack of study predicting the Municipal Solid Waste (MSW) output scientifically and accurately for least developed countries like Nepal. Previous studies have primarily relied on the tentative amount of waste generation linked with the number of vehicles involved in waste collection and transfer to the landfill site. This study used linear regression analysis to forecast the solid waste generation of Kathmandu Metropolitan City (KMC) by undertaking past population data and solid waste generation. The SPSS analysis resulted in a strong relationship between population and solid waste generation with a coefficient of 0.956. A linear regression validation was performed to ensure that the derived formula is statistically significant. The finding indicates the r squared (R^2) value to be 0.913, leading the waste prediction model to be very strong. The prediction equation of 0.659X - 204222.952 resulted in an average waste generation of KMC as 1006 t/d on average till 2035 with an average per capita/d waste generation of 0.54 kg. The current MSW generation of KMC is found to be 766 t/d and predicted to reach 1259 t by 2035. The information can be helpful for the municipality and urban planning authorities to make strategies for effective management of waste generated in KMC, creating less burden at the Banchare Danda landfill site.

Keywords: Dumpsite, Landfill, Kathmandu, prediction, waste management

1. Introduction

Solid waste management is a major issue faced by urban areas of the globe. Though the cities have made advancements in introducing proper systems and technologies, the amount of solid waste has been increasing trend. There is a lack of integrated solid waste management systems and green technology (Saxena and Srivastava 2022), which has caused severe risks to human health and the environment (Gumel 2022). The consumption pattern of a commodity varies from one individual to another. It is necessary that an individual identifies their role towards sustainable consumption patterns (Khanal 2021b) so that it wouldn't cause any negative impact on the environment. In order to achieve sustainable municipal solid waste management, it is necessary to understand the mechanism related to solid waste generation.

The world generates around 2.01 Bt of municipal solid waste annually with 0.74 kg/capita/d, and this is expected to reach 3.40 Bt by 2050 (Kaza et al 2018). The amount of municipal solid waste (MSW) generation is in increasing trend every year due to rapid urbanization and population growth (Sharma, Ganguly, and Gupta 2018; Khanal 2021b). Not only population, there is also a correlation between income and waste generation (Reno 2015). The amount of waste generation will increase as the year passes by. The average waste generation in Asia was 0.52 kg/capita/d, which was lower than the global of 0.74 kg/capita/d in 2016 (Kaza et al 2018) but predicted to increase by an average of 40% in the countries like Bangladesh, Sri lanka, Pakistan, Afghanistan, Bhutan, and India by 2050.

The total municipal solid waste generation of Nepal is about 1,435 t/d with 317 gram/capita/d (ADB 2013). Kathmandu Valley generates the highest amount of solid waste in Nepal (Khanal Giri and Mainali 2023), with the maximum waste transferred to the Sisdol landfill site (Khanal Sondhi and Giri 2021). Kathmandu is facing urban environmental crises with labor-intensive waste handling practices and a poor disposal system (Pandey 2004; Khanal and Giri 2016). There is a lack of a proper solid waste management system in Kathmandu, with ineffective waste collection, transfer, treatment, and disposal resulting in a spike in solid waste generation in recent decades (Khanal 2021a; Khanal 2023).

This study has used the past data of MSW generated in Kathmandu Metropolitan City (KMC) and made a prediction for the future's solid waste generation. Municipal solid waste includes both household and commercial waste (World Bank 2018). Household waste is also called domestic or residential waste, which is generated from houses, including kitchen waste, paper, bottles, cans, cloths, green waste and others. While commercial waste is generated from corporate houses, institutions and

 Received: December 25, 2022 | Accepted: March 13, 2023

organizations, mostly including dry materials. Assigned waste collectors collect the generated waste. There is no fixed route of transportation of collected solid waste to the transfer station and landfill site as it solely depends on drivers (Alam et al 2008). Though the waste collection timetable has been shared with households and institutions, the service is irregular. In KMC, private companies are very active (Khanal 2021a) and play an important role by collecting waste from 25 different wards (Figure 1). Both public and private companies have important roles in solid waste management (Guerrero et al 2013). There were 18 private organisations in 2014 involved in the waste management of KMC (Singh et al 2014) which has currently increased to 31 by 2021. KMC has now identified two companies, Nepwaste and Clean Valley Pvt. Ltd., for managing the overall solid waste of Kathmandu Valley (World Bank 2016). The appointed companies have submitted plans for integrated solid waste management (ISWM) of Kathmandu Valley with the usage of modern technologies. The environment friendly waste recovery machinery will increase work efficiency with less burden on human resources. On the other hand, it is equally challenging to integrate the current waste management service provider.

In the past, the organic waste was managed at the household level in Kathmandu using home compost bins called "*saagas*", and the remaining waste was reused and recycled (Singh et al 2014). There are a handful of private companies and organisation practising green technologies for organic waste, including vermicomposting and windrow composting, yet it is rarely used on mega-scale for commercial purposes. The first landfill was constructed in 1984 at Gokarna with the help of German Technical Cooperation (GTZ) and another landfill site at Sisdole with the help of the Japan International Cooperation Agency (JICA) in 2005 (Dangi et al 2009). The municipal solid waste of KMC is currently disposed of at the Sisdol landfill site located in the Nuwakot district (Khanal et al 2021). Table 1 shows the history of solid waste management in Kathmandu, Nepal (JICA 2005; Pokhrel and Viraraghavan 2005; Bahadur et al 2015). The researchers agree that the government has failed in the sound management of the landfill, leading to a negative impact on the surrounding environment.

Table 1 History of solid waste management in Kathmandu, Nepal.

Date	Details
1919	*Safai Adda* was established and sanitation duties were provided to the workers, which was later renamed as Municipality Office.
1980	Nepal received its first solid waste management aid from GTZ.
1984	A landfill was constructed at Gokarna to manage the waste of Kathmandu Valley.
1988	The solid waste act was introduced to control the haphazard dumping of solid waste, which covered three cities of Kathmandu Valley.
1994	The Gokarna landfill site was closed and waste was dumped nearby the Bishnumari River.
2005	A new landfill was operated at Sisdol.
2011	Introduced solid waste management act, which focuses on waste minimization.
2019	The Five Year Plan 2019/2020 has set a goal for processing the waste generated in Kathmandu Valley by establishing a modern sanitary landfill site at Banchare Danda by 2023.
2022	The construction of 'Cell One' of the Banchare Danda landfill site was completed and waste was dumped at the Banchare Danda Landfill site for the first time on May 24, 2022.

The Solid Waste Management Act 2011 of Nepal focuses on decentralized solid waste management practices and has asked Local Authority (LA) to adopt the Integrated Solid Waste Management (ISWM) system (Maharjan et al 2019). The modern waste management strategy needs to give priority to handling the waste at source (Giri 2021). Household source segregation helps in increasing the value of waste (Khanal 2022). The waste collector also needs to collect the solid waste in a segregated form, which eases the recyclable extraction process. Sustainable Development Goal 11 has a target to reduce the adverse per capita impact of cities by 2030. Also, Goal 12 focuses on the reduction, recycling and reuse of waste. The solid waste generation data helps with the effective management of solid waste generated in a city.

The solid waste generation data from the government and other institutions vary widely in Kathmandu. There is no uniformity in the data gathered from the study conducted by the government, institutions, organizations or even individual researchers. A survey conducted in 2007 found the municipal solid waste generation of KMC as 523.8 metric t/d or 0.66 kg/capita/d, and it was higher than 320 metric t reported by the government (Dangi et al 2011). Another study shows solid waste generation in KMC in 2005 as 245 t and in 2006 as 260 t/d (Alam et al 2008). The report prepared by KMC on solid waste generation is incomplete as it only calculates the waste collected for disposal purposes (Dangi et al 2011). There is a lack of solid waste generation data with KMC as it only presents the tentative data based on waste collection and disposal at the Sisdol landfill site. In most of these cases, KMC generates data based on the number of trips carried by the tripper (trucks) from the Teku transfer station to the Sisdol landfill site. The regression analysis has been used globally to predict solid waste generation. Researchers in Kuwait (Al-Salem et al 2018), Thailand (Sun and Chungpaibulpatana 2017), Romania (Ghinea et al 2016), Mexico (Benítez, Lozano-Olvera, Morelos, and Vega 2008; Buenrostro, Bocco, and Vence 2011), Iran (Azadi and Karimi-Jashni 2016) and India (Kumar and Samadder 2017) have developed a model using regression. This study is the first of its kind to be used in Nepal for predicting the municipal solid waste of Kathmandu. The solid waste prediction equation can be used to find the waste generation of KMC on a yearly basis. The waste composition and quantity of solid waste differs in an urban and rural setting. This study is limited to predicting urban solid waste generation

2. Materials and Methods

The KMC generated the highest amount of MSW in Nepal and was purposively chosen for this study. Kathmandu is the capital city of Nepal and is located in the South Asian region. It lies at an average altitude of 1350 m above sea level (Thapa et al 2008). There are 32 wards in KMC where the MSW is collected by both government and private companies (Figure 1).

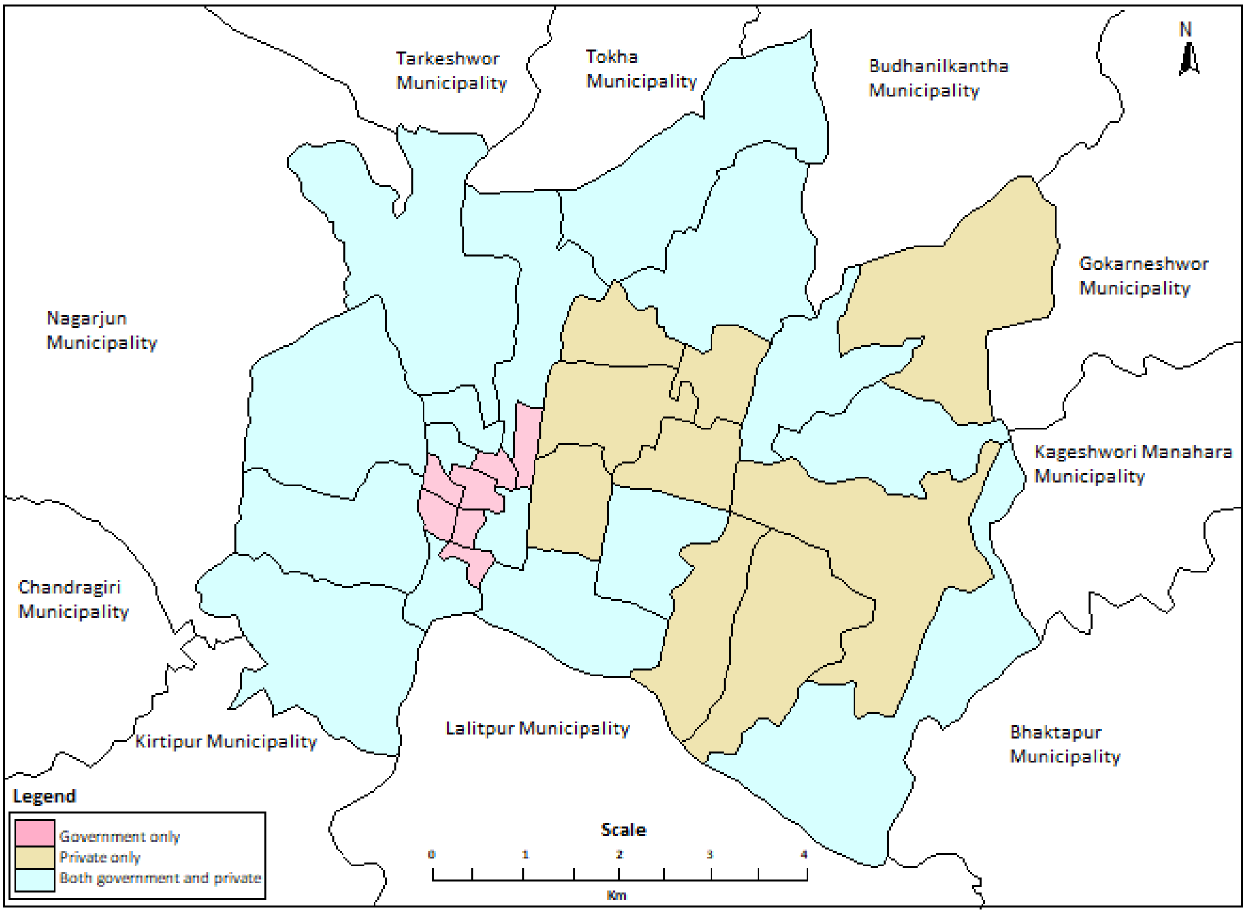

Figure 1 Map of KMC showing waste collection areas of public and private parties.

Statistical Package for the Social Sciences (SPSS) was used for the development of the MSW generation model for KMC. The population and MSW generation from 2005-2013 were considered for this study. After 2013, no record of MSW generation for KMC was found for every consecutive year after that. So the MSW generation and population data was used from 2005-2013.

The Linear Regression Equation is given as:

$$Y = a + bX \qquad (1)$$

Where Y is the dependent variable (amount of MSW);
X is the independent variable (population of KMC);
b is the slope;
a is the y-intercept.

The secondary data for population and MSW was used for this study (Table 2). The MSW generation data of KMC from 2005 to 2013 has been considered as the dependent variable and the population has been taken as the independent variable for this study. The past data of population and MSW generation of KMC was used to determine the regression coefficient. The annual waste generation of KMC from 2005-2013 was extracted from the Environment Statistics of Nepal report published by the Central Bureau of Statistics (CBS 2019). The population (from 2005-2013 and 2021-2035) of KMC used in this study was extracted from the United Nations population prediction data (United Nations 2022).

Table 2 Population and municipal solid waste generation of Kathmandu from 2005-2013.

Year	Population	MSW generation (t)
2013	1088000	524
2012	1045000	492
2011	1004000	480
2010	965000	435
2009	927000	365
2008	890000	354
2007	855000	343
2006	822000	338
2005	790000	336

3. Results and discussion

The obtained data of the population of KMC from 2005-2013 and the respective MSW generation data were entered in the SPSS to perform the regression.

The prediction equation was found as:

$$0.659X - 204222.952 \quad (2)$$

Where X is the population for a particular year.

The R-value was found to be 0.956, which shows a high degree of correlation between population and waste generation. In 2007, a study conducted in Kathmandu also found the coefficient of correlation to be 0.94 (Dangi et al 2011). Though there are other socioeconomic variables (population density, income, GDP) for forecasting the MSW generation, the population trend is widely used by researchers (Khan and Burney 1989; Wei et al 2013; Ghinea et al 2016; Azadi and Karimi-Jashni 2016; Araiza-Aguilar et al 2020). The coefficient of 0.956 obtained for solid waste generation of KMC is also near to the study conducted in Mexico, which found a coefficient of 0.975 (Araiza-Aguilar et al 2020). The MSW generation for KMC was calculated using the above prediction equation till 2035 (Table 3). The analysis showed that the average MSW generation of KMC is 1006 t/d till 2035, with an average per capita/d waste generation of 0.54 kg. The obtained value is within the range of 0.5-0.75 kg per capita/d for low-income countries (Cointreau 2006). The linear regression validation was also performed to know how the obtained data fits within the line. The r-squared (R^2) value was calculated for the regression model validation (Ghinea et al 2016) and was found to be 0.913 showing the obtained model to be very strong.

Table 3 Municipal solid waste generation forecast for Kathmandu with household waste and per capita.

Year	Municipal solid waste generation per d (t)	MSW generation per capita/d (kg)	Household waste generation per d (t)	HHs waste generation per capita/d (kg)
2021	766	0.52	528	0.36
2022	798	0.52	550	0.36
2023	831	0.53	572	0.36
2024	865	0.53	595	0.37
2025	898	0.54	617	0.37
2026	933	0.54	640	0.37
2027	967	0.54	663	0.37
2028	1002	0.55	687	0.38
2029	1038	0.55	711	0.38
2030	1074	0.55	735	0.38
2031	1110	0.56	760	0.38
2032	1147	0.56	785	0.38
2033	1184	0.56	810	0.38
2034	1221	0.56	835	0.39
2035	1259	0.57	860	0.39

The MSW for KMC for 2021 was found to be 766 t/d and is forecast to reach 1259 t by 2035, as shown in Figure 2. The MSW generation of KMC is predicted to increase by 64% in the next 15 years. As the current resources aren't adequate, it would be much more difficult for KMC to manage the MSW in the coming years. There is an urgent need for waste management technologies for efficient collection, treatment, and disposal.

The study found that household waste occupies 69% of the MSW. This finding was within the range as specified by a study conducted in Nepal in 2012 which claimed the HHs waste to be 50%–75% of the total MSW (ADB 2013). The major portion of household waste is occupied by organic matter. If organic waste can be managed at the household level, it would drastically decrease waste generation. The high volume of waste generation, lack of collection space, and the presence of dump sites cause serious health risks (De and Debnath 2016; Rana et al 2017; Chikaire et al 2022). The household needs to make aware of the impact of mixed waste and help them realize their role in environmental protection. The direct handling of mixed waste can also cause infectious and chronic diseases to the waste workers. Exposure to different hazardous wastes affects human health and also impacts the environment.

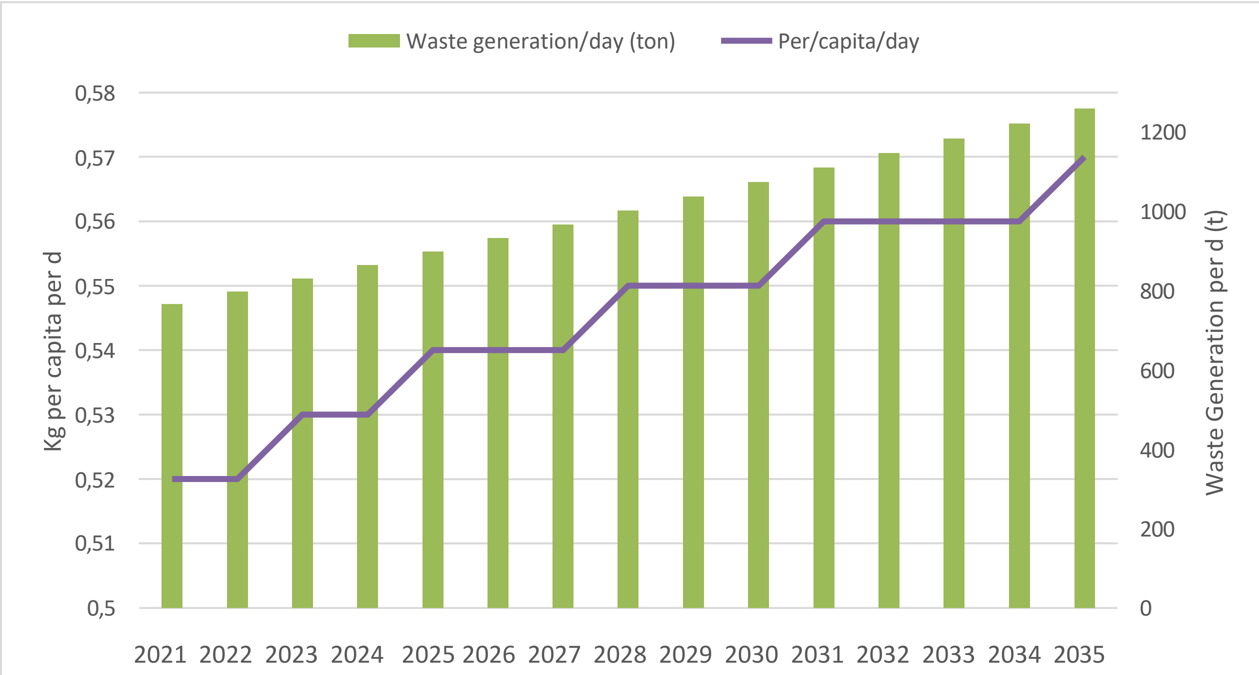

Figure 2 Municipal solid waste generation forecast for Kathmandu Metropolitan City.

4. Conclusions

The conclusions from the study were derived as follows:

- A strong relationship was found between the population and solid waste generation of Kathmandu, with a coefficient of 0.956.
- The prediction equation for MSW generation of Kathmandu was found to be 0.659X - 204222.952.
- The R^2 value was found to be 0.913 showing the obtained waste prediction model to be very strong.
- The MSW generation of Kathmandu was found to be 1006 t/d on average till 2035 with an average per capita/d waste generation of 0.54 kg.
- The MSW generation of Kathmandu was 766 t in 2021 and is forecast to reach 1259 t/d by 2035. The study found that household solid waste occupies 69% of the total MSW generated in KMC.
- The prediction equation for MSW generation will be helpful for the municipality to forecast the waste generation and deploy human resources and allocate the budget accordingly.

The government should promote educational campaigns for waste reduction, which will benefit humans and the environment. If the source segregation is properly implemented, the recyclables can be extracted properly, leading to less burden on the Banchare Danda landfill site.

Acknowledgment

The author is thankful to the KMC office, publication house, and anonymous reviewers.

Ethical considerations

Not applicable.

Conflict of Interest

The author declares that there is no conflict of interest.

Funding

This research did not receive any financial support.

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