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Estimation of the generation rate of different types of plastic wastes and possible revenue recovery from informal recycling

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ABSTRACT

Plastic waste generation is an inevitable product of human activities, however its management faces challenges in many cities. Understanding the existing patterns of plastic waste generation and recycling is essential for effective management planning. The present study established a relationship between plastic waste generation rate and the identified socioeconomic groups, higher socioeconomic group (HSEG), middle socioeconomic group (MSEG), and lower socioeconomic group (LSEG) of the study area (Dhanbad, India). For identification of the socioeconomic groups, four different socioeconomic parameters were considered (total family income, education, occupation and type of houses). The information related to the identified parameters were obtained using questionnaire survey conducted in the selected households. One week plastic waste sampling was carried out in the households of all the socioeconomic groups. The plastic waste generated in the study area was 5.7% of the total municipal solid waste. In terms of total plastic waste generation rate, it was found that HSEG had maximum (51 g/c/d) and LSEG had minimum (8 g/c/d) generation rate. The present study area does not have any formal waste recycling system. Thus, the amount of plastic waste recovered and the revenue generated from recycling of plastic waste by the active informal recyclers (waste pickers, itinerant waste buyers and scrap dealers) in the study area have been evaluated. Additionally, three non-linear machine learning models i.e., artificial neural network (ANN), support vector machine (SVM) and random forest (RF) have been developed and compared for the prediction of plastic waste generation rate.

1. Introduction

Various types of plastic products have become an indispensable part of lifestyle. Plastic production has increased tremendously in past 50 years. In India, approximately 12 million tonnes of plastic products are used annually and 70% of them is disposed of indiscriminately as waste (Singh et al., 2017). India being one of the fastest growing plastic market, has an annual plastic production growth rate of 16%, followed by 10% per annum for China and 2.5% per annum for UK (BPF, 2012). With such a high production rate, an established waste processing route for its recycling and recovery is necessary. Unlike the developed countries, recovery of plastic waste remains mostly an informal activity in the developing countries like India. Informal sector include unregulated and unregistered individuals or groups such as waste pickers, scavengers, itinerant waste buyers (IWBs) and scrap dealers involved in recycling of waste materials. In most of the Indian cities, the waste segregation and identification for potential recyclable items are carried out by informal sector (Nzeadibe, 2009; Nandy et al., 2015). Government of India has provided a few regulatory framework (such as Solid Waste Management Rules, 2016 and Plastic Waste Management Rules, 2016) for the management of waste generated in the country. As per the Solid Waste Management Rules, 2016 the state policies and strategies should acknowledge the contribution of the informal sector for waste recycling. For effective management of plastic waste in particular, Government of India has notified Plastic Waste Management Rules, 2016 that

Abbreviations: ANN, artificial neural network; ASTM, American Standard for Testing Material; CD, compact disc; CPCB, Central Pollution Control Board; DMC, Dhanbad Municipal Corporation; GDP, gross domestic product; HDPE, high density polyethylene; HSEG, higher socioeconomic group; INR, Indian Rupees; IWB, itinerant waste buyer; LDPE, low density polyethylene; LSEG, lower socioeconomic group; MAPE, mean absolute percentage error; MLR, multiple linear regression; MoEFCC, Ministry of Environment Forest and Climate Change; MSEG, middle socioeconomic group; MSW, municipal solid waste; PC, polycarbonate; PET, polyethylene terephthalate; PP, polypropylene; PS, polystyrene; PU, polyurethane; PVC, poly vinyl chloride; R^2, coefficient of determination; RF, random forest; RMSE, root mean square error; SVM, support vector machine; UK, United Kingdom; US, United States; USA, United States of America.

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contains some set regulations, laws, goals as well as roles and responsibilities of waste generator, Municipal Corporation, manufacturer, producer and importer of plastic waste. Through these rules, the Government of India aims to achieve the objective of clean India (a flagship program of Government of India). In India, identification, collection and recycling of plastic waste follow a hierarchy (as shown in Fig. 1), where waste pickers, scavengers and IWBs sell their scavenged items to scrap dealers. Small-scale exporters purchase sorted plastic wastes from scrap dealers. Ultimately, the exporters sell compacted plastic wastes to the industries for recycling and making new products (Sembiring and Nitivattananon, 2010). A certain amount (depending on the quantity and quality of the recyclable waste) is recovered by the involved service provider (scrap dealers, IWBs, etc.). Studies on the contribution of informal sector in plastic waste recycling in India is still lacking. Thus, quantification of material recovered by the informal sector remains a challenging task. In India, about 6.5 tonnes to 8.5 tonnes per day of plastic waste is collected by IWB's, scrap dealers, household waste collectors, etc. From this collected waste, about 50 to 80% of plastic waste is recycled (Nandy et al., 2015). A study conducted in one of the Indian cities in 2008 revealed that the earnings of waste pickers and scrap dealers were approximately US$ 24 and US$ 165 per month respectively from waste recycling (US$ 1 = INR 65; April 2018) (Zia et al., 2008). However, their earnings might have been increased up to two to three folds in last 10 years due to increase in generation, collection and price of recyclable wastes.

In order to know the quantity and composition of plastic waste and to reduce future generation, it is essential to understand how different factors are related to plastic waste generation. In the present study, plastic waste generation rate and composition have been evaluated based on the socioeconomic groups of the study area. The socioeconomic parameters considered for identification of the socioeconomic groups in the study area were education of head of the family, occupation of the head of the family, total family income and type of houses. The parameters considered for the present study have been widely used for the prediction of municipal solid waste (MSW), but not for the plastic waste generation prediction at city or municipality level. Income represents the consumption and waste generation pattern of any household. People with higher incomes would be expected to consume more packaged products and dispose larger quantities of plastic wastes (Emery et al., 2003). Education reflects the awareness among different socioeconomic groups from plastic waste related problems. Occupational status reflects the income and eventually the residents' willingness to pay for plastic waste collection services. Xiao et al. (2015) and Al-Khatib et al. (2015) also reported that the type of occupation of the head of a family was one of the main factors responsible for household waste generation rate because, it is expected to affect the awareness of the problems due to indiscriminate dumping of wastes. Previous research indicated that households' attitude towards recycling reflects from their socioeconomic status (Sidique et al., 2010).

Modeling methods are the most common techniques for plastic waste generation rate estimation at municipality and city level. Goel et al. (2017) categorised modeling methods into conventional and non-conventional methods. Conventional modeling methods includes sample survey (Thanh et al., 2010), multiple linear regression (MLR) (Kumar and Samadder, 2017), time series (Chung, 2010), system dynamics (Dyson and Chang, 2005), and geographical information system method (Purcell and Magette, 2009). Non-conventional methods are data-driven models such as artificial neural network (ANN) (Abdoli et al., 2012), random forest (RF) (Kannangara et al., 2017), support vector machines (SVM) (Abbasi et al., 2013), and fuzzy logic (Khan and Farooqi, 2012). All the modeling techniques have their own advantages and limitations. Conventional techniques are no longer effective due to heterogeneity in solid waste generation process (Abbasi et al., 2013). However, regression analysis is widely reported as an effective solid waste generation modeling technique, due to its simple algorithm and ability to identify influential parameters. But in order to comply with some stringent theoretical assumptions (such as, independency of input variables, normality of input variables and error term, constant variance), its applicability for complex problem is less. But, in recent years, models using machine learning approach (such as ANN, SVM and RF) has been gaining popularity (Abbasi and El Hanandeh, 2016). Machine learning techniques have high prediction ability and flexibility than MLR because, machine learning models work on complex non-linear data and are free from assumptions (Kannangara et al., 2017). In MLR technique, the relationship between independent and dependent variables is assumed to be linear and the interaction among independent variables must

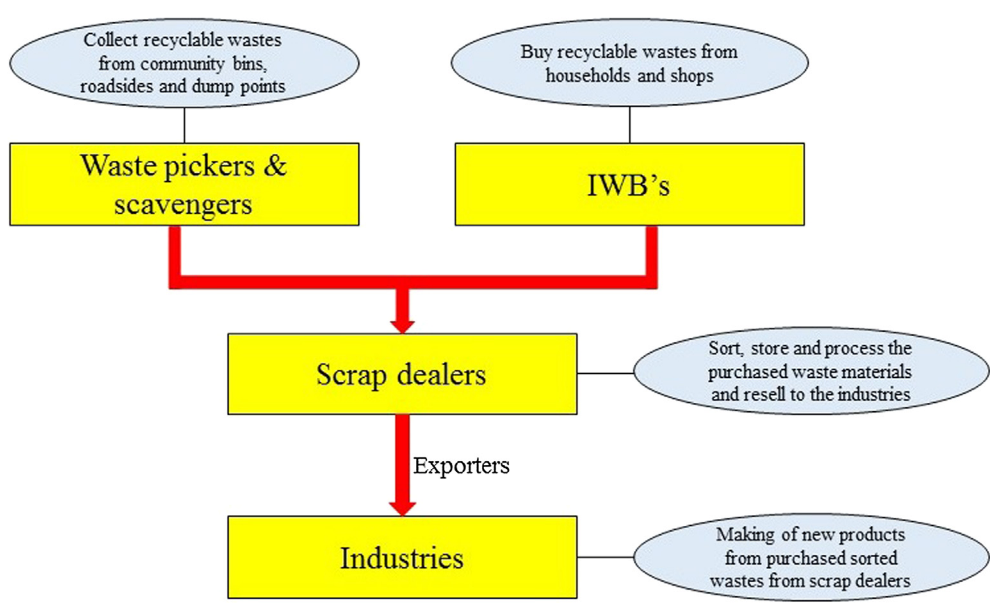

Fig. 1. Hierarchy of waste recycling by informal sectors.