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Original Article

Waste Amount Characterization Survey of Municipal Solid Waste Generated in Sahiwal, Punjab-Pakistan

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Abstract - *In today's contemporary world, rampant urbanization and changes in living standards followed by other factors have made waste management challenges. In urban areas, per capita waste generation increases rapidly over time, and its composition varies due to income levels, climatic conditions, and social behavior. The present study was designed to analyze per capita waste generation, physical characteristics, household size, and waste composition of municipal solid waste generated in Sahiwal city in October 2018. Waste was collected from residential, commercial, and designated sites for eight days. All the data was recorded and analyzed through Microsoft Excel at regular intervals. For all types of testing, ASTM standard method was used. The average household size from all income levels was about 6.0. In contrast, the average per capita waste generation was about 0.36 kg/capita/day encompassing 0.44kg/c/d in high-income areas, 0.36 and 0.35kg/c/day in middle and low-income areas and 0.27kg/c/day for rural area. The accumulative specific gravity of all waste streams was about 204.15 kg/m^3.*

Moreover, most of the waste can be categorized into four major components that revealed 60% organic and compostable, 16% earth fill material, 15% refuse-derived fuel (RDF), and only 9% recyclable might reduce to over 70% during secondary collection respectively. The waste amount characterization survey (WACS) is a mandatory tool for designing waste management services from collection to disposal. Sahiwal municipal committee intends to build a material recovery facility (MRF) to reduce the burden of dumping sites, environmental consequences, and overall collection to disposal expenses.

Keywords - *Municipal solid waste (MSW), Income areas, Recyclables, Compost, and Environment.*

1. Introduction

Solid waste management is a global issue and is being faced worldwide nowadays. Any unwanted or useless material emanating from domestic and commercial activities is considered solid waste (Wikener, 2009). Waste is defined in various ways, such as any material not intended for sale or needs to be discarded (Ali et al., 2015). Similarly, any non-gaseous and non-liquid substance generated because of any anthropogenic activity that can cause any detrimental and harmful impact on living organisms, and their environment can be termed solid waste (Govindaraju, 2011). Waste management problems are prevalent owing to uncontrolled population explosion, which is inevitable – other factors encompass industrialization and rampant urbanization, which contribute to massive waste generation. Its management has become challenging throughout the world (Ilaboya, 2011). According to Berkun et al. (2005), Solid Waste Management (SWM) practices are being neglected by concerned authorities due to inadequate capacity, resulting in waste handling problems. Changing lifestyles and bad consumption patterns followed by misuse of resources emanated unprecedented issues, which concerned authorities must take into account on an emergent basis (Ali et al., 2015). Owing to better opportunities in cities, more than 400 million people prefer to reside in urban areas, which in turn generate a huge quantity of municipal solid waste (MSW) that has resulted in serious threats to the environment and human health, and half of the population are predicted to be residing in cities by 2050 (United Nations, 2012). Another reason for cities that have been changing rapidly over the past few decades is due to inadequate management of solid waste, which became the biggest hurdle or challenge for concerning departments in decades that culminated in stern environmental pollution and health problems (Azmi et al., 2010; Shah et al., 2013; Chatterjee, 2010; Kumar, 2009). The UNEP reported that agricultural and industrial activities encouraged rampant population expansion, resulting in the massive waste quantity deteriorating the surrounding environment and resources (UNEP, 2005).

Waste amount from each household has been continuously increasing due to population explosion and increased demand for food resources. The waste generated from households is eventually disposed of in vacant non-engineered sites. The inadequate practices wreak havoc on several health ramifications and are disastrous for the environment (Majid et al. 2012). As per the estimation of Hoornweg, municipal solid waste (MSW) will reach 2.2 billion tons in 2025 annually, which is currently around 1.3 million metric tons (Hoornweg, 2012). A solid waste management system exists only in large cities and a few intermediate ones. It is pertinent to mention that the solid waste generation rate is greatly influenced by socio-economic factors such as education, income level, and public behaviors (Sehker & Beukering, 1998). MSW generation mainly depends on lifestyles, living standards, and population expansion (Liu, 2012; Saeed et al., 2009). The per capita waste generation in Asian countries kept increasing over the year owing to an inevitable increase in population (Khajuria, 2010). Low-income countries (LIC) waste generation patterns range from 0.3 to 0.9 kg/cap/day. On the other hand, high-income countries (HIC) reach up to 1.4 to 2 kg/cap/day (Khatib, 2011).

The composition of solid waste is highly dependent on income level, climatic conditions, and cultural norms (Khajuria, 2010). Seasonal changes in solid waste composition and generation are mainly associated with the socio-economic development of the countries (Gómez et al., 2009). The least developed countries contain a higher proportion of organic waste concerning developed countries (Oyelola & Babatunde, 2013). According to Ali et al. (2015), solid waste quantities and composition vary among low-income, middle-income, and high-income communities. In the past, from earlier primitive human societies, waste management was not a big problem, and they managed their waste precisely.

However, in the contemporary world, waste quantification and characterization are the most vital components of the reliable and effective SWM system. Characterization is a useful instrument to obtain information about the quantity of waste followed by its composition (Gawaikar & Deshpande, 2006). To maintain proper handling of solid waste, it is mandatory to have enough information regarding quantity and characterization (Gawaikar & Deshpande, 2006). In addition, waste characterization is highly important to identify the techniques from collection to disposal of waste and handling at different phases and levels. Many studies have been done worldwide to develop enough insight into the waste composition. Undoubtedly, the composition plays a pivotal role in rendering suitable and sound waste management options based on waste composition (Senzige et al., 2014; Gomez et al., 2008). Knowledge of the sources and types of solid waste, along with data on the composition and rates of generation, is a basic requirement for the design and operation of the functional elements associated with the management of solid waste (Khajuria, 2010).

The present study was conducted in district Sahiwal in October 2018, with moderate weather conditions. Sahiwal comes out by its name from local tribesmen "Sahu." It lies between 30° 35′ 0″ north latitudes and 73° 21′ 0″ east longitudes, having a population of about 1,843,194 (Population Census Organization, 1998). It has two tehsils, Chichawatni and Sahiwal, with almost 530 villages (Al-Khatib et al. 2010). It is also noticeable that Sahiwal's population has constantly increased over the last decade (PDS, 2013). The basic aim of the WACS study was to determine the feasibility and suitability of the state-of-the-art Segregation, Treatment, and Disposal Facility (STD) system. The system intends to separate organic waste and recyclable through conveyor belts. Organic waste would then be converted into compost, and local nurseries would be engaged in its utilization. Similarly, this modern system would reduce transportation costs and increase the life of landfill sites.

Through WACS, data on the municipal solid waste composition and its amount in the district Sahiwal was generated. The results of the survey will be helpful to formulate plans in terms of collection of waste and its treatment and also useful to highlight the inefficiencies of the existing waste management system. It will also be helpful in terms of waste recovery facilities to reduce the amount of municipal solid waste. Similarly, municipal solid waste (MSW) comprises different recyclables and recovered materials that ultimately can be used as Refuse Derived Fuel (RDF) and feedstock for composting.

The main objectives of the WACS are the following such as:

- Estimating per capita waste generation rate (Kg/cap/day).
- Determination of the waste components and measurement of their fractions percentage/weight).
- Determination of the variation of waste generation in different income levels (low, middle, and high income).
- Estimation of recyclables, compostable and combustibles fractions.

2. Study Area

The district Sahiwal study area sampling points are shown in Figure 1.

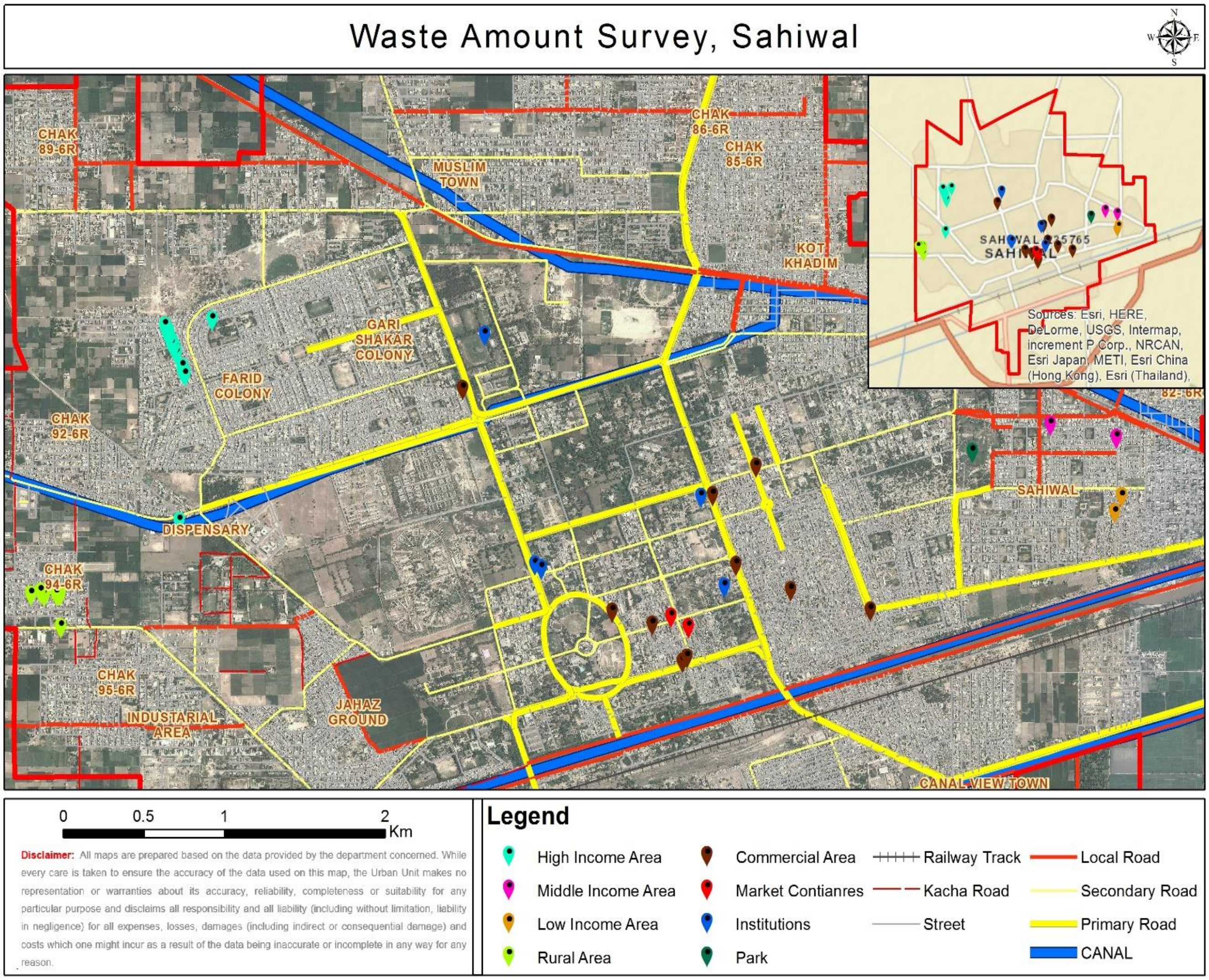

Fig. 1 Sampling points of waste survey in Sahiwal

3. Materials and Methods

3.1. Sampling Design

The waste amount and characterization survey area covered all the areas of the Sahiwal, including households (high, medium, and low-income areas), rural areas, markets, hotels and restaurants, institutions (schools & colleges), offices, and other commercial establishments of the district.

To conduct the survey, a stratified sampling method was carried out for households divided into three income groups: high-, middle- and low-income. The criteria for the categorization of income levels were road infrastructure, house width and overall size, access to electricity, water, and gas network, and other necessities, and with the help of Tehsil Municipal Administration (TMA) staff. All source locations, including households and all commercial establishments, were also chosen after having a detailed conversation with the representatives of TMA, Sahiwal. With the help of TMA, Sahiwal staff deployed in these areas, samples from residential areas such as high-, middle- and low-income areas, rural areas, and commercial areas like restaurants, hotels, markets, bakeries, institutions, parks, and streets were collected on eight consecutive days and analyzed as shown in Table .

A total of 120 sampling points were selected for the survey for each type of waste generation source concerning income levels through a random sampling method. The survey was carried out for eight consecutive days. It is pertinent to mention the for-sampling size; a certain number of households concerning their income levels were randomly selected. The sample size was determined with the help of the reduction method (Julious, 2009). Calculation of sample size (*n*) is based on general statistical methods like the ones described by Salant (1994) and Rea (1997) and on the equation below:

Table 1. Sources of waste generation and No. of Samples for Waste Amount Survey

Type of Waste		Waste Amount Survey		
		Number of Samples	Survey Days	Total Samples
Household	High	20	8	160
	Middle	40	8	320
	Low	30	8	240
	Rural	10	8	80
Commercial	Restaurants	5	8	40
	Others	5	8	40
Markets		2	8	16
Institutions		5	8	40
Street Sweeping		2	8	16
Parks		1	8	8
Total		120		960

$$\text{Equation} = \frac{N}{(E/k)^2 \times (N-1)/P(1-P) + 1} \qquad (1)$$

The above equation is used to find the representative samples for the perception survey. With the help of the equation, the representative sample of a population of 300,000 is about 384, while considering the recovery rate, it makes a sample size of about 427 samples, respectively. The selected samples are selected through the reduction method. However, the no. of samples collected was 960 from different sources and analyzed.

The basic purpose and the duration of the survey were communicated to the residents of the particular areas and other concerned persons of the respective locations chosen for solid waste collection. Upon obtaining the consent of the household owners for cooperation with the survey teams, the data regarding no. of individuals in each household and other relevant information, along with GPS coordinates, were documented.

3.2. *Waste Amount Analysis*

Input and output methods are useful in the determination of solid waste generation. At the National level, most input methods seem to be in practice to estimate waste generation by collecting data from production industries and firms. Data is obtained from specialized agencies or institutions regularly collecting and publishing data. However, for the local level, the output method is widely acceptable and accurate for sampling studies. Sample size and characterization method are the most significant variables of this method. For instance, the load count analysis method for sampling studies requires less effort and finance than the input method. Moreover, the characterization method and, most importantly, the waste's sample size are considered the most significant variables that need special attention before commencing the waste composition study of any waste stream.

The output method was utilized for the present study. After careful observation, plastic bags were distributed among all the designated points before the sampling survey execution except the market's designated point. A special collection vehicle was hired for waste collection from designated and selected points of markets.

To avoid confusion, each sample bag was given a specific code number per the generation source, and then samples were collected daily with a specific code. The weight of each measured sample was recorded on the excel sheet for eight consecutive days, whereas the first day's results were not considered for further analysis. The average household size of high, middle, and low-income areas and rural areas was 6.00 people.

3.3. *Waste Composition Analysis*

Collected wastes from all the designated sites released and quantified at Sahiwal disposal station. According to the American Society for Testing Materials (ASTM), a sample

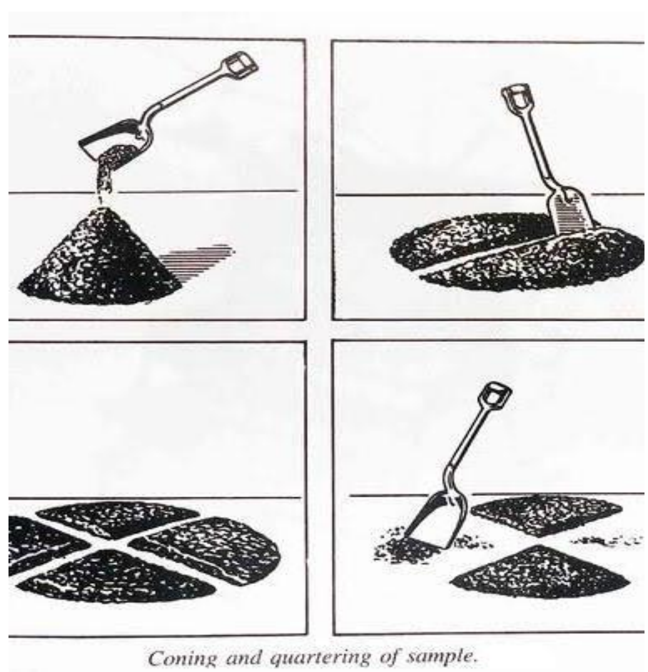

Fig. 2 Coning and quartering method

of 100-200kg is suitable for the analysis; otherwise it is subjected to reduce up to 200 for segregation and sorting. This method is useful for municipal waste composition analysis and is named the ASTM-D5231-92 standard method. The detailed process is illustrated below.

- Wastes mixing; bulky items are cut into several pieces
- When the mixture is homogeneous, waste is divided into four piles of the same volume.
- Two portions are removed at diagonally opposite ends, and the remaining two are mixed for further analysis.

After preparation of the desired representative sample, the solid waste was loaded into a plastic barrel of 50 liters capacity to measure apparent specific gravity. The Barrel was lifted to a height of about 30 cm, repeatedly dropped three times, and then measured the volume of waste. The Apparent Specific Gravity (ASG) is measured with the help of the formula (2.1) given below:

$$AS = \frac{\text{Weight of the solid waste in Barrel (Kg)}}{\text{The volume of the waste(m3)}} \quad \ldots\ldots\ldots.. (2.1)$$

The sample was manually sorted into 16 categories, as shown in the table below:

Table 2. Categories of waste components

SR. #	CATEGORIES	WASTE COMPONENTS
1	Kitchen Waste	Food, bread, vegetable, fruit, etc.
2	Paper (Recyclable)	All office paper, white paper, color paper, newspaper (bags and strings removed), magazines (all types), catalogs (all types), phonebooks (all types), paperboard, tissue boxes, etc
3	Paper (Non-Recyclable)	Napkins, tissue paper, paper towels, wax paper, wrapping paper, and any paper product that can potentially be contaminated.
4	Textile	Thread, Yarn, Fabric, Rugs, Cotton, etc.
5	Grass and Wood	Plant parts, Grass, Wooden pieces, etc.
6	Plastic (Recyclable)	All plastics types: PET containers, clamshell take-out containers, plastic cups
7	Plastic (Non-Recyclable)	Plastic baggies, plastic tableware, Styrofoam containers
8	Leather and Rubber	Leather, Rubber, nylon items lycra
9	Metal (Recyclable)	Metal and tin beverages containers, metal and tin food containers, Aluminum Foil, Aluminum take out containers
10	Metal (Non-Recyclable)	Motor Oil Cans, paint cans, metal, and cardboard mixed containers
11	Bottles and Glass (Recyclable)	Color/ transparent glass bottle and Jars, beer, and wine bottles (unbroken)
12	Bottle and Glass (Non-Recyclable)	Light Bulbs, Mirror glass, Window glass, Crystal, etc.
13	Ceramic and Stones and Sand	stone and ceramic
14	Domestic Hazardous Waste	Battery cells, paint boxes, medicine bottles, chlorine bottles
15	Sieve Upper	Particles larger than 6 mm
16	**Miscellaneous**	
	a. Hairs	Human / Animal hairs
	b. Bones	Bones
	c. Tetra pack	Milk box, fruit juice box, tetra pack
	d. Diapers	Nappies /pampers
	e. Dust/Sieve	Waste particles < 6 mm

4. Results and Discussion

A total of 960 samples from 120 sampling points were analyzed in the waste amount survey for eight consecutive days except for the first day to avoid accumulating the previous day's waste. In the light of calculation, approximately 2799 kg was collected and transported to a designated site where homogenous mixing was followed by segregation.

4.1. Waste Generation

During the visit of each sampling point about income areas, data from each household size in terms of no. of members and per day waste generation were obtained to determine per capita waste generation. The average waste generation at each household level is shown in Fig. 4.1.

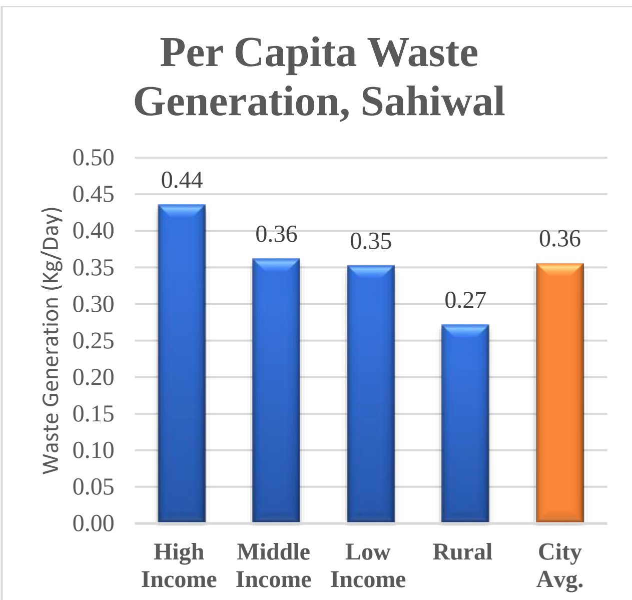

Fig. 4.1. Average household per capita waste generation

The waste amount survey was also conducted for commercial areas, including restaurants and shops, fruit and vegetable markets, institutions, street sweeping, and public parks. As there is no information available for several personnel generating the specific amount of waste, the average weight for the 7 days has been used for plotting the graphs as shown in 4.2.

Standard procedures calculated the average Specific gravity or density for each category. The representative sample of each income area and volume of the bucket (50L or 100L) was used to determine ASG. Daily data for eight days was recorded. The accumulated average for all types of waste sources is calculated as 204.15 kg/$m^{3,}$ as shown in the figure.

4.2. Physical Composition

The average waste composition encompasses different income levels followed by commercial areas.

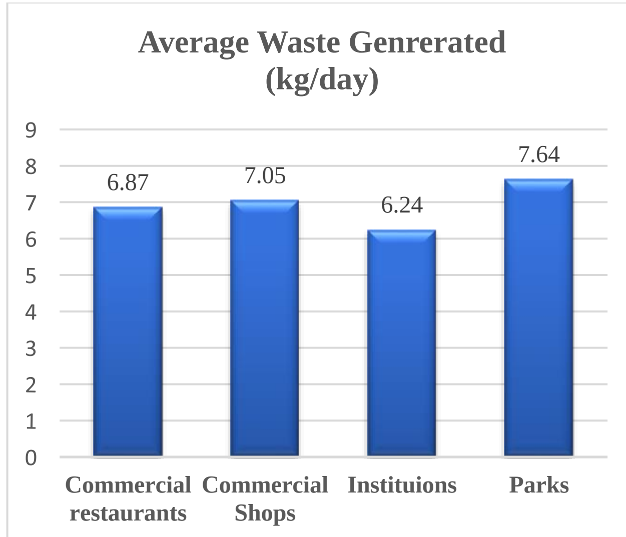

Fig. 4.2. Other waste generation sources

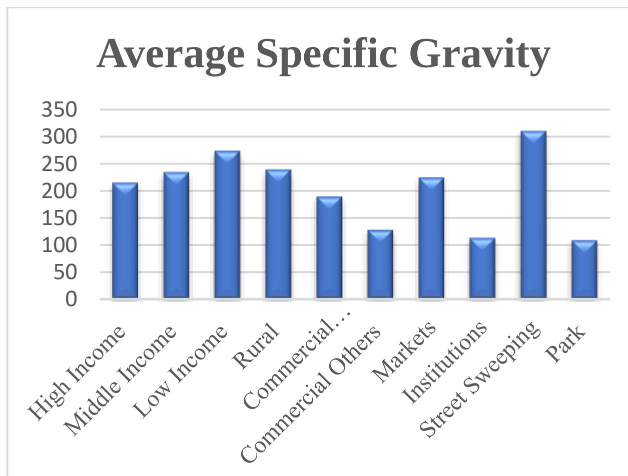

Fig. 4.3. Average Specific Gravity (Kg/m3) of different locations

In Low, middle, and upper-middle-income countries, the organic waste fraction is always higher concerning other waste components. According to the finding, over 56% of waste was biodegradable and consisted of green and kitchen waste, paper, diaper, textile, combustibles, and non-combustibles, respectively. In the study areas, the accumulated waste of the whole city consisted of 53% of total green waste and 14% of inert material consisting of dust and sieve. The third most abundant component was non-recyclable plastic mostly consisted of shopping bags – difficult to tackle during collection and disposal.

The organic waste proportion remained higher in higher and middle-income areas, up to 65%, than in rural and low-income areas. One prominent reason was the presence of cattle such as goats, buffaloes, and cows. Therefore, the generation was slightly lower because livestock relied on it. Other waste forms included non-recyclable plastic (8%), paper recyclable (4%), textile (3%) and plastic recyclable

(2%) respectively. In addition, a low percentage of recyclable plastics and metals were found throughout the survey, which categorically reflected the socio-economic status of the area. Other items comprised 1% leather, rubber, and textiles, followed by 11% dust traces and ceramics.

Commercial establishments include restaurants, bakeries, vegetable and fruit markets, institutions, offices, parks, and street/ road sweeping. The waste stream varied significantly in residential areas. However, green and kitchen waste remained higher among these commercial establishments. On the other hand, non-recyclable plastic and non-recyclable papers were the second and the third most prominent components in the waste. These waste components remained prominent throughout the survey owing to the utilization of paper for packing or other everyday use. Similarly, plastic bags are also used for packing and daily shopping bags. Interestingly, 8% recyclable bottle and glass material was obtained from bakeries.

The findings of the physical composition of the WAC survey have been illustrated in Table 3.2 and presented in Fig. 4.3.

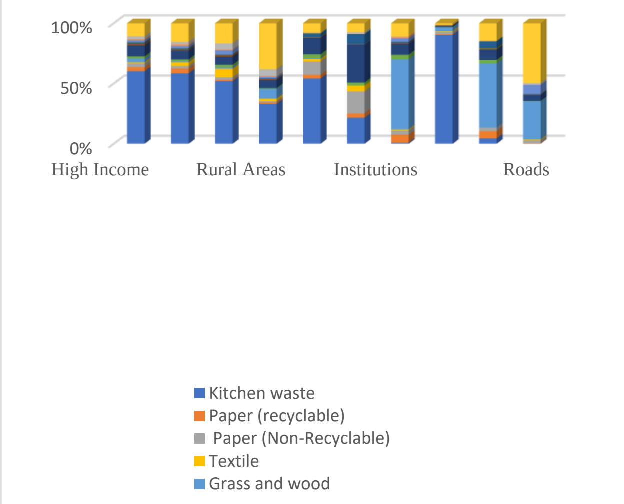

Fig. 4.3. Physical Composition of Each Generation Source

4.3. Average Waste Composition of Households

As described in the literature and found in multiple studies, the waste composition is essential to identifying the waste management mechanism. Before conducting a survey, it was expected that a Material Recovery Facility would be a feasible option to tackle the waste of Sahiwal city. Still, after a thorough and detailed survey of every component, it's unequivocal that MRF is not a feasible option. One may not ignore the informal sector, such as scavengers, waste pickers, and buyers. The WACS survey was limited to households; waste collection witnessed only 9% recyclables on the source. This proportion would surely reduce to more than 80% during secondary collection when the informal sector plays its part. However, other components might not show major fluctuation due to the influence of the informal sector, unlike recyclables. The average composition of all the waste-stream was ten converted into four major categories are shown in 3.

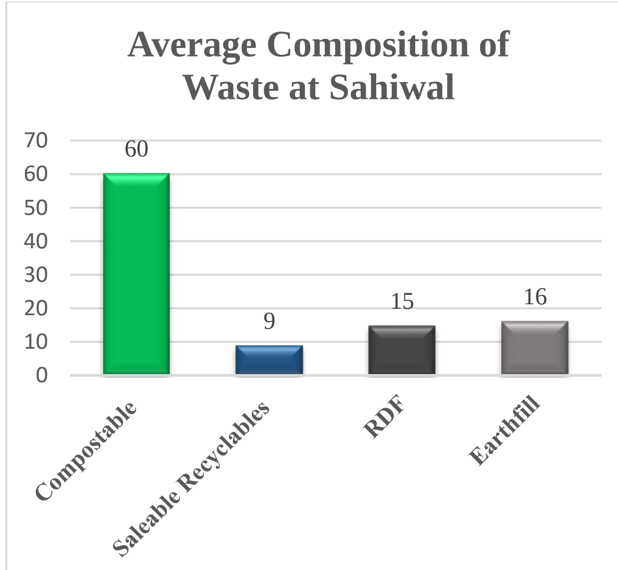

Fig. 4.5. Average Waste Composition of Sahiwal

The organic waste or compostable waste proportion was about 60%; hence, composting is the most viable option, but due to lack of awareness, generated waste is usually mixed with high moisture content and does not provide desired results. Due to mixed waste, composting normally takes around 90 days. Lahore compost is treating around 800 tons of daily waste through windrow composting. The market for compost is another hurdle due to the availability of fertilizers. Awareness among the masses and state-of-the-art technologies are the need of the hour to grapple with the menace of uncontrollable waste. Compost quality can only be maintained when a segregated form of waste is available for treatment. Other components such as RDF and earth fill remain unchanged mostly. During the survey, 15% of refuse-derived fuel (RDF) waste produced had the potential to produce energy. Its application is widespread in specialized waste to energy facilities. RDF is largely dependent on combustible components such as non-recyclable plastics, papers, cardboard, wood material, and other forms of corrugated material. In Pakistan, it's being used in the cement industry, but the scope of waste to energy is limited due to waste composition and the public's attitude. The other component was earth fill material, about 16%; it contains sieve, stones, and other inert materials that can be used as construction material.

5. Conclusion

Solid waste characterization and composition surveys were carried out in the city of Sahiwal by dividing areas into income-wise residential areas and commercial settlements. It was found that the population's socioeconomic status plays a significant role in the composition. The average household size for all income levels was 6, whereas per capita waste generation was 0.36 kg/capita/day. The analysis further revealed different specific gravities of all income areas, for instance, High-Income Areas (HIA), 215 kg/m^3, 235 kg/m^3 for Middle-income areas (MIA), and 274 kg/m^3 for Lower income areas (LIA). At the same time, 239 kg/m^3 was found in rural income areas (RIA). Organic waste accounted for 60%, whereas recyclables accounted for only 9% of the waste, 15 % combustible material, and only 16% earth fill material can be used for construction activities. A waste composition study is highly useful for designing a waste management system from collection to disposal. In light of composition, the composting facility is highly useful for waste treatment if segregated properly. Moreover, there is a dire need to create awareness among staff of the municipal committee, Sahiwal, and people to manage waste effectively to reap productive and fruitful results.

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