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Solid Waste Management: Generation, Characteristics, Disposal, and Recommendations for Sustainable Management at a Tertiary Institution in Bangladesh

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ABSTRACT: The study was carried out at a public university regarded as the cleanest campus in Bangladesh because of its immaculate appearance and abundant greenery. However, the university's cleanliness has recently been severely impacted by irresponsible solid waste disposal and improper waste management. Hence, the objective of this study was to evaluate the generation, characteristics, disposal, and recommendations of sustainable solid waste management at a tertiary institution, the University of Rajshahi in Bangladesh using appropriate standard methods. During the study period, the university's average monthly solid waste generation was estimated to be 32033.30 kg (32.03 metric tons), of which the greatest portions were made up of food waste or organic waste and paper (69.30% and 10.84%, respectively). There were 5.05%, 3.39%, 2.23%, 0.82%, 1.12%, and 7.24%, of plastics, textiles and wood, leather and rubber, metal, glass, and other wastes, respectively. The campus generates about 0.10 kg of solid waste per person per day. The total amount of waste generated daily was 250.19 kg (23.45%) of recyclables and 816.52 kg (76.55%) of non-recyclables. There are 48 dumping sites on campus, most unsanitary and seriously threaten the university's safety. Therefore, university authorities must quickly enhance the campus's environmental conditions through efficient solid waste management.

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Waste is the unproductive byproduct of human activity that physically contains the same material as the valuable product (White *et al.*, 1995). Solid wastes are waste or abandoned materials and objects from commercial, industrial, mining, agricultural, and everyday activities (Bamgbose *et al.*, 2000). Previous studies (Abedin and Jahiruddin, 2015; Rahman, 2017; Shams *et al.*, 2017) indicated that fast urbanization and population expansion significantly contribute to the substantial output of solid waste in Bangladesh. Even so, since the ancient period, waste production has been a significant cause of concern (Chandler *et al.*, 1997). Recently, there has been a significant increase in the quantity and rate of waste generation. The variety of waste also grows in proportion to the volume of waste (Vergara and

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Tchobanoglous, 2012). In contrast to the ancient past, when waste was only a source of annoyance that needed to be disposed of.

A significant volume of solid waste is produced by the extensive population size. Waste management includes the collection, transportation, treatment, and disposal of discarded substances and materials (Unnisa and Rav, 2012). Waste characterization is essential for effective municipal solid waste collection, the selection of transportation equipment, energy transformation and recovery, the retrieval of reusable materials, and the strategic planning and execution of optimal disposal routes and methods (Ugwu *et al.,* 2020). Planning, urbanization, administration, finance, legal, and engineering processes are all included in SWM (Patel and Bundela, 2024).

A significant portion of waste (40–60%) is not adequately collected, disposed of, or stored in the locations designated for ultimate disposition due to a lack of consciousness and incentive with the appropriate technology and adequate budget (Ahsan *et al.,* 2014). Depending on the source, and the type of risk factor involved with its treatment, storage, and final disposal, waste can be divided into distinct sorts.

Several studies show that the amount of waste production is increasing day by day with the economic growth of Bangladesh. According to two distinct research studies, the total quantity of municipal solid waste (MSW) produced in urban areas of Bangladesh in 2013 was 52,00,919 tons per year by 3,69,86,768 residents (rate 0.35 Kg/cap/day), meanwhile in 2015, it was 5,11,000 tons per year by 3,94,88,000 residents (0.32 Kg/cap/day) (Shams *et al.,* 2017; Islam, 2017). According to another source, the country's population of 15,57,27,053 generated 1,47,78,497 tons of MSW in 2012. (Kaza *et al.,* 2018). In various urban areas, the average daily production of MSW per capita is from 0.2 to 0.56 kg/cap (Ahsan *et al.,* 2014). By 2025, it is anticipated that waste generation in Bangladesh's urban areas will increase by 0.6 Kg/cap/day, (Bhuiyan, 2010) resulting in a daily average waste volume of 57,718 tons/day (Hoornweg and Perinaz, 2012). The insufficient management of solid waste in numerous cities within developing nations engenders issues that detrimentally affect both human and animal health, culminating in significant economic, environmental, and biological repercussions (Wilson *et al.,* 2006; Kapepula *et al.,* 2007; Sharholy *et al.,* 2008). Waste is carelessly discarded in various locations, resulting in unsanitary dumping sites. There has been no investigation conducted at the Rajshahi University Campus regarding the generation, characteristics, and disposal of solid waste. This study is essential for assessing the quantity and quality of solid waste generation, including its physical composition, disposal systems, environmental impact, and the overall management framework within the Rajshahi University campus.

MATERIALS AND METHODS

The study was conducted in Rajshahi University (RU) campus (24° 22′ 12″ N, 88° 38′ 13.2″ E). The approach undertaken for the research endeavor encompassed a survey strategy implemented on the campus. Field surveys have been conducted in residential halls, faculties or academic buildings, and administrative offices. Both qualitative and quantitative data collection methods were used in the study. Additionally, both primary and secondary data were used in this study. Interviews with key informants, such as the management and personnel of academic buildings and residence halls, cleaners, garbage workers, and the general public who live near the dump site were used to gather primary data. The University document included very little secondary data. Data were collected through a semi-structured questionnaire. Basic information on Hall and academic building e.g. types of waste, waste management practices; knowledge on solid waste; recuse or recycling of waste; quantity of waste generated; health and environment consequences; limitation of the management, etc. were included. Before beginning the major fieldwork, a reconnaissance survey was conducted in 2022 to determine the amount of solid waste generated in the study area, assess the area's physical state, and collect data on the quantity and quality of solid waste as well as the various campus disposal locations. In this Research, there was another aim to take the weight (kg) of solid waste generated from the different halls (3 male and 3 female halls), academic building (2 academic buildings), administrative building No. 1, and also Rajshahi University medical center. For this data is collected every day (within a week). After that total amount of waste generation is measured by taking the sum off all residential halls, academic buildings, and others.

Selection of study area: To assess the generation of solid waste across various locations within the Rajshahi University campus, the campus is categorized into three distinct areas: i) residential halls, ii) administrative buildings or offices, and iii) academic buildings or faculties, facilitating a comprehensive evaluation of solid waste generation and disposal practices. The standard procedures and

methods have been applied for sampling, assessing daily solid waste generation, segregation, and waste classification and their characteristics.

Collection of the primary data: A structured questionnaire is meticulously developed, pre-tested, and refined to gather data on solid waste and the everyday characteristics of solid waste from specific residence halls, academic buildings, or administrative facilities. The academic buildings, residential halls, offices, and faculties have their own waste storage devices where solid waste is collected. Waste that has been collected is weighed and recorded. After that, the wastes inside the bag are weighed and recorded individually. The collected rubbish from the dumpster or device is spread out on a clean plastic sheet and manually sorted during the segregation process. According to their characteristics, solid wastes are divided into the following groups: i) Vegetables and food waste; ii) Paper; iii) Packaging materials; iv) Plastic; v) Textile; vii) Glass; viii) Metals; viii) Wood; and ix) Miscellaneous (dirt, etc.). The classification of these groups draws upon the methodologies established by Hossain *et al.,* (2013), Das *et al.,* (2013), Salam *et al.,* (2012), Sujauddin *et al.,* (2008), and Enayetullah *et al.,* (2005).

Data analysis: The collected data has been analyzed using appropriate statistical tools and techniques. The data collected from the questionnaire survey and field study were analyzed using MS Excel and SPSS version 22 software.

RESULTS AND DISCUSSION

Types of Solid Wastes: Rajshahi University, the third-largest university in Bangladesh, possesses all the necessary infrastructure to support its enormous size. Due to the immense volume of solid waste produced by this population and its careless disposal, the citizens are increasingly at risk. The Residential Hall, academic buildings, administrative buildings, and Rajshahi University Medical Center (RUMC) are all part of the university's campus, and this investigation has uncovered the solid waste kinds that these buildings produce. The data presented in Table 1 illustrates the different types of waste collected from diverse sources and areas within the Rajshahi University Campus.

Table 1: Different sources and types of waste are produced in the Rajshahi University area.

Source	Location	Waste Type
Domestic	Households(Residential Hall)	Food waste, vegetables, paper, plastics, wood, metal, etc.
Commercial	Hotels, shops, Restaurants, Canteen etc.	Plastics, food waste, etc.
Academic and administrative building	Teacher/ office rooms, classroom.	Paper, plastics food waste etc.
Medical waste	University medical center	Medical waste and paper, plastics, etc.

Amount of Waste Generated in RU Campus: This research attempted to quantify the amount of waste generated on the RU campus, including different spots or places (residential halls, academic buildings, administrative buildings or offices, and university medical centers). A significant amount of waste is generated at various spots across the Rajshahi University campus. Over a month, the total waste generated amounts to 32,033.30 kg. The Rajshahi University campus generates 1067.77 kg of solid waste daily whereas the University of Nigeria, Nsukka produces 2,218.66 kg by weight of solid waste on average daily (Ugwu *et al.,* 2020). Among all spots, Mannujan Hall has the most trash generation, demonstrating its big residents of 1,200.

On average, Mannujan Hall produces 301.90 kg of waste per day, making it the highest daily contributor. In contrast, the Rajshahi University Medical Center (RUMC) generates the least waste, averaging 22.21 kg per day. Rajshahi University (RU) produces 0.10 kg/day a lesser amount of waste per person per day which is comparable with the University of Nigeria, Nsukka campus produced 0.06 kg per person per day (Ugwu *et al.,* 2020). In contrast, the University of Lagos, Akoka campus, Nigeria produces substantially more waste per person per day which is 0.34 kg/day in contrast to comparable universities outside of Bangladesh, such as the University of Tabriz, Iran, and the Bahir Dar Institute of Technology, Ethiopia which produce 0.13 kg and 0.17 kg daily, respectively (Tadele *et al.,* 2015 and Sepideh *et al.,* 2012). The variation in waste generation across campus locations depends largely on the population density and usage patterns at each spot. The average daily waste generation from different areas, such as residential halls, academic buildings, administrative offices, and the medical center, is summarized in Table 2. Additionally, Fig. 1 illustrates the average daily waste (kg/day), and Fig.

2 displays waste generation per person/ day (in kg) generated at various spots at the Rajshahi University campus. This data highlights the relationship between population size and waste generation, emphasizing the need for targeted waste management strategies at high-output locations like Mannujan Hall.

Different Types and Physical Compositions of Solid Waste Generation at the RU Campus:

Following data collection (total waste), the data was then separated by type (food waste, paper, plastic, textile and wood, leather and rubber, metal, glass, and others), and the results were then analyzed to determine the percentage (Table 3; Fig. 3). According to Ashikuzzaman and Howlader (2020), paper, textiles, food, and vegetables are classified as biodegradable trash, whereas cardboard and wood are moderately biodegradable waste and non-biodegradable waste includes leather, plastics, rubbers, metals, glass, and electronics. In the RU campus Food waste ranks highest (69.30%) among the various waste ingredients, contributing 739.38 kg daily or per day whereas Adeniran *et al.,* (2017), found a similar amount of food waste 66.67% in the University of Lagos, Akoka campus, and University of Nigeria, Nsukka campus reported less food waste or organic waste (34.29%) by Ugwu *et al.,* (2020). The amount of textile and wood, leather and rubber, glass and metal waste generated in RU campus is 3.39%, 2.23%, 0.82%, and 1.12% whereas S*et al.,* (2013) found 2%, 2%, 1%, and 3% in Chittagong University campus. This finding is also in line with research by Rahman *et al.,* (2013), Salam *et al.,* (2012), and Enayetullah *et al.,* (2005), which found that food and vegetable waste make up the largest percentage of solid waste.

Table 2: Total and average solid waste generation per day at different spots/sources in the RU campus

Source/Spots	Population	Total waste (kg/month)	Total waste (kg/day)	Waste per person/day(kg)	Average Waste per person/day(kg) at RU
Bangabandhu Sheikh Mujibur Rahman Hall (BSMRH)	496	3841.40	128.05	0.258	0.10
Sher-E-Bangla Fazlul Haque Hall (SBFHH)	311	2335.00	77.83	0.250	
Shah Makhdum Hall (SMH)	463	4087.60	136.5	0.294	
Mannujan Hall (MNH)	1200	9057.00	301.90	0.252	
Taposhi Rabeya Hall (TRH)	600	4200.80	140.03	0.233	
Rahamatunnesa Hall (RTH)	677	4957.90	165.26	0.244	
Sir Jagadish Chandra Bose Academic Building (SJCBAB)	2477	959.50	31.98	0.013	
DR. Muhammad Sahidullah Academic Building (DMSAB)	3802	913.00	30.43	0.008	
Administration Building 1 (ADMN 1)	249	1017.80	33.93	0.136	
Rajshahi University Medical Centre (RUMC)	217	663.30	22.11	0.102	
Total	10492	32033.30	1067.77	1.79	

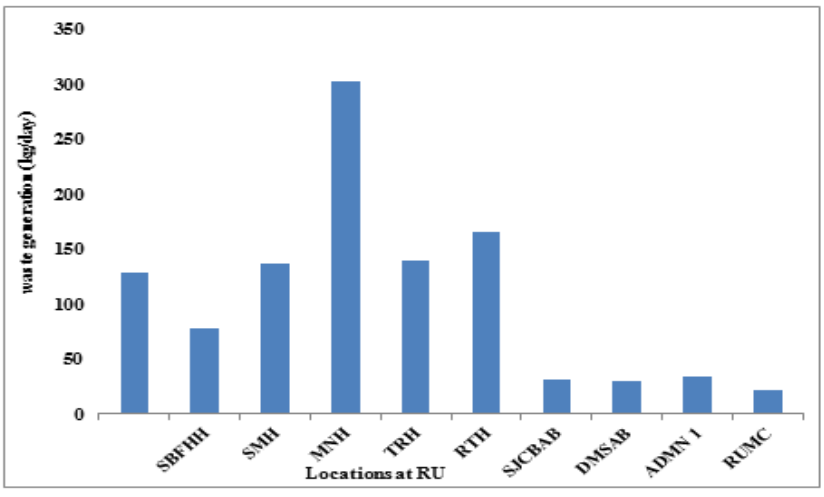

Fig. 1: Average waste generation (kg/day) in different spots at Rajshahi University

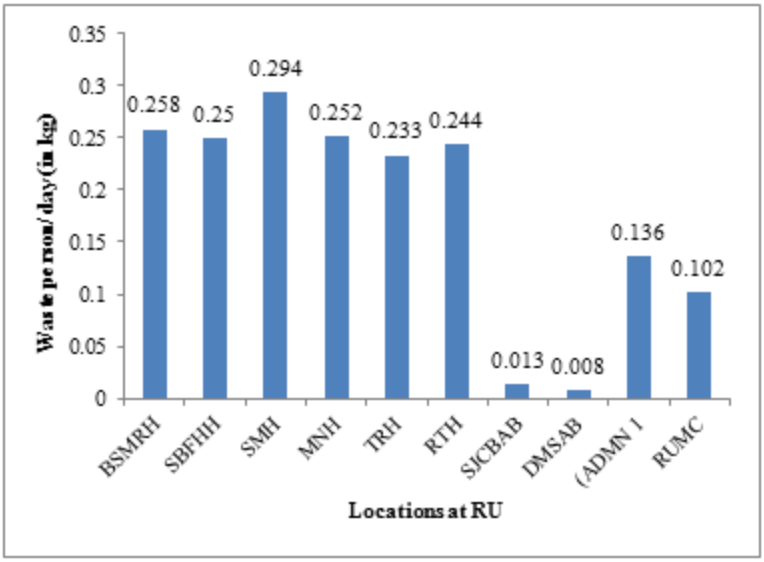

Fig. 2: Average waste generation per person per day in different spots at Rajshahi University

If organic waste is not properly disposed of, it may discharge greenhouse gases into the atmosphere, lure vectors to residences, and present several health and environmental risks. Paper is a waste item that predominates in all MSW streams, particularly in academic and administrative buildings of universities. Compared to paper waste in developed countries, Smyth *et al.,* (2010) reported that paper waste accounted for 32% of total waste in universities across British Columbia, Canada. In contrast, the collected paper waste at the RU campus constituted only 10.84% of the total waste generated. This is also comparable with some studies by Adeniran *et al.,* 2017, Ugwu *et al.,* (2020), Rahman *et al.,* (2013) at the University of Lagos and the University of Nigeria, and the University of Chittagong campus at 15 %, 14.05 %, 8 %. Plastics include bottles made of polyethylene terephthalate (PET), which makes up a significant amount of the MSW stream. 5.05% of the waste stream produced by the University of Rajshahi was made up of plastics. The MSW stream described in several studies conducted at other universities bears little resemblance to this one. For example, the University of Lagos' Akoka campus generated 9% (Adeniran *et al.,* 2017) and the University of Nigeria, Nsukka campus generated 8.53% (Ugwu *et al.,* 2020) of plastic waste, whereas the University of Baja generated 8% (Smyth *et al.,* 2010). Every day, the RU campus generates 250.19 kg (23.45%) of recyclable waste. This result is consistent with Rahman *et al.,* (2013), and Adeniran *et al.,* (2017) data, which reports 28%, 15%, and 25% recyclable waste when taking Dhaka City's waste generation and Chittagong University into account. The amount of non-recyclable waste generated 816.52 kg (76.55%) is greater than that of recyclable waste. This result is also consistent with research on the generation of solid waste in Dhaka city and Chittagong University campus where 70–80% (Anon, 2004) and 72% (Rahman *et al.,* 2013), of waste is not recyclable. The amount of solid waste generated is mostly determined by human behavior, economic development, and the efficiency of recycling and reuse systems, even while growing populations directly contribute to waste management (Ding et al., 2021; Khan et al., 2022). Few people living in residential halls are aware that it is safe to dispose of waste in this way. Additionally, it has been found that open waste disposal sites near residential halls lack hygienic conditions. The residents of the hall and staff quarters, which are turning into a sanctuary for flies, rodents, mosquitoes, and other microbes, experienced the same situation. This is one of the main reasons that parasites and gastrointestinal illnesses are spreading across campus. Some halls don't have designated waste disposal areas. They carelessly dispose of their waste. Few people in residential areas are aware of the proper ways to dispose of waste. Growing awareness among all classes of people is one of the most fruitful tactics for waste management. There are 48 disposal sites spread throughout the campus, and because they lack hygienic conditions, they pose a risk to the environment. People want clean and orderly conditions in medical centers, which are essential for healthcare facilities.

Table 3: The amount of solid waste generation at the Rajshahi University campus

Types of waste	Waste Materials	Waste(kg/day)	Waste(kg/month)
Non-Recyclable waste	Food waste	739.28	22178.40
	Others (dirt etc)	77.24	2317.10
Recyclable waste	Paper	115.59	3467.60
	Plastic	53.88	1616.30
	Textile and wood	36.20	1086.10
	Leather & Rubber	23.84	715.10
	Metal	8.78	263.50
	Glass	11.90	357.10
Total		1066.71	32001.20

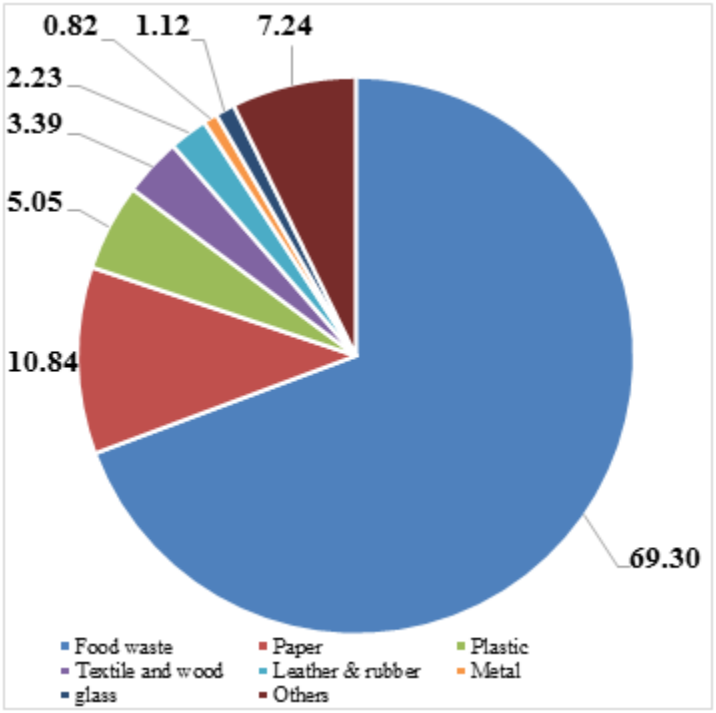

Fig. 3: Percentage of different types of waste generated at Rajshahi University Campus

Conclusion: Effective solid waste management is crucial for maintaining environmental sustainability at Rajshahi University. The report examines waste composition and disposal techniques, underlining the need for enhanced waste disposal practices. To enhance sustainability, the university should implement source segregation, promote recycling initiatives, and establish waste-to-energy programs. Awareness campaigns and strict waste disposal policies should be introduced to encourage responsible waste management among students and staff. Furthermore, cooperation with local government agencies is crucial for effective garbage collection and disposal. Implementation of modern waste treatment technologies and composting organic waste can further reduce environmental impact. A dedicated monitoring system should be established to assess waste generation patterns and improve management strategies. By adopting these measures, Rajshahi University can create a cleaner campus while contributing to broader environmental sustainability goals.

*Declaration of Conflict of Interest***:** The authors declare that there is no conflict of interest.

*Data Availability***:** Data are available upon request from the first author or corresponding author.

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