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RESEARCH

A Case Study on Characterization and Management of Solid Waste at Selected Spiritual Sites in Dehradun, India

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Abstract

The objective of this study is to evaluate the nature and extent of solid waste generated in selected areas of Dehradun, examining the disposal techniques employed and characterizing the waste produced during both normal days and festival days. Additionally, the study aims to educate the community on solid waste management practices and to calculate the average per capita waste generation. The results demonstrate that the ratio of biodegradable waste, primarily comprising flowers, fruits, and vegetables, constituted the highest proportion of waste in all analyzed temples. Of these, flowers represented the most prevalent form of biodegradable waste. The high percentage of floral waste indicates a significant volume of offerings, underscoring the necessity for the development of effective composting and organic recycling plans. Furthermore, the study demonstrates a correlation between an increase in the average generation of waste and the occurrence of holidays or festivals. Consequently, an analysis of waste-to-energy projects will facilitate the transformation of waste into electricity, thereby creating additional space in temples and promoting the utilization of environmentally friendly energy sources.

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Statement of Sustainability: This study examines the management of solid waste in specific holy sites in Dehradun. The assessment of both biodegradable and non-biodegradable waste identifies significant waste generation trends on normal and festival days, underscoring the necessity of sustainable waste management measures, particularly for flower and plastic waste. The findings advocate for the implementation of environmentally conscious disposal technologies, such as composting and waste-to-energy conversion, which facilitate the reduction of environmental contamination and the advancement of resource recovery. This study aligns with the Sustainable Development Goals (SDGs) 12, which pertains to Responsible Consumption and Production, and SDG 11, which concerns Sustainable Cities and Communities. It does so by promoting sustainable waste management practices that diminish environmental impacts while enhancing community engagement.

1. Introduction

The generation of solid waste is an inevitable consequence of human existence on Earth. The generation of waste has been a constant feature of human habitation since ancient times. The waste material typically comprised food waste, fruit and vegetable peels, and other similar items (Bisht et al., 2024). Such materials were organic and returned to the soil or were fed to cattle. However, with the advent of plastic, the nature of waste has undergone a gradual transformation. Additionally, the growth of the population and the expansion of urban areas have resulted in the generation of considerable quantities of waste (Gour and Singh, 2023). The majority of waste can be classified as either solid, liquid, or gas. Solid waste is defined as useless, undesirable, discarded solid materials generated by humans in residential, industrial, and commercial areas (Bisht et al., 2022). It is composed of an innumerable array of discrete components, including vegetable refuse, paper, glass, plastics, wood, garden clippings, food waste, radioactive waste, and hazardous waste (Das and Bhattacharyya, 2014). The composition and quantity of municipal solid waste vary considerably between different municipalities and at different times of the year. The significant factors contributing to these discrepancies are industrialization, urbanization, festivals, per capita income, climate, social customs, geography, and geology, among others. The process of urbanization is responsible for an increase in the generation of solid waste, as evidenced by higher generation rates of MSW among urban populations compared to rural ones (Sharholy et al., 2008; Bisht et al., 2024). With a population of 1.43 billion, India is the most populous country in the world. As India is experiencing rapid population growth and an accompanying upliftment in terms of socio-economic status, technology, and socio-economic status, these factors have direct effects on waste generation (Kumar et al., 2017).

In India, religion is an integral aspect of life. Religion is an intrinsic element of Indian culture. People engage in acts of worship directed towards a higher power and are accustomed to visiting temples, gurudwaras, mosques, and churches, offering a variety of items in accordance with the traditions of each religious institution. As the number of visitors and pilgrims increases, so too does the generation of solid waste, which presents significant health, sanitation, and environmental challenges. The composition of solid waste includes 44.61% biodegradable waste, 22.56% non-biodegradable waste, and 32.83% miscellaneous waste (Singh and Gupta, 2011). The mean composition of total solid waste generated during the Kumbh festivals and normal days, when visitation ranges from 15,000 to 5,000 per day, is 64% biodegradable waste, 11% non-biodegradable waste, and 25% miscellaneous waste. The environmental impact of pilgrims on Mansa Devi and Chandi Devi hillocks in Haridwar, India, has been the subject of considerable research (Kaushik and Joshi, 2014; Bisht et al., 2024). The Tulja Bhavani temple plays a pivotal role in the local economy, with 70% of the resident population deriving their livelihood from the temple (Shinde, 2011). On a daily basis, devotees present flowers at temples, where they are subsequently discarded as waste. India is a country with a rich cultural heritage, characterized by a multitude of festivals and occasions that are celebrated throughout the year. This has resulted in the generation of significant quantities of solid waste.

This particular category of waste is often overlooked and merits further attention. Due to the influence of religious beliefs, a considerable number of individuals refrain from discarding or recycling flowers utilized in prayer ceremonies. Instead, they are placed in plastic bags and directly discarded into water bodies. Additionally, these flowers are often disposed of in close proximity to sacred trees, with inadequate methods of disposal. Banaras, a city of great religious significance, lacks a policy for the disposal of the considerable quantities of waste generated by its numerous temples (Mishra, 2013). The degradation of floral waste is a markedly slower process than that observed for kitchen waste (Jadhav et al., 2013). It is therefore evident that there is a necessity for the implementation of an appropriate and environmentally conscious methodology for the treatment, management, and utilization of floral waste. The Kashi Vishwanath temple, attracts the greatest number of pilgrims throughout the year, particularly during the month of Shravan. The temple has its own system for the disposal of the considerable quantity of waste resulting from the offerings made by devotees. The floral waste generated in the temple is transformed into a fertilizer (Mishra, 2013). In India, it is estimated that 1,450 tons of flowers are offered to deities on a daily basis. Unfortunately, these flowers are often discarded and subsequently regarded as waste, contributing to environmental pollution (Ravishankar et al., 2014).

Dehradun city is home to numerous spiritual destinations, including Sai Baba Temple, Tapkeshwar Temple, Mindrolling Monastery Buddha Temple, Ram Rai Gurudwara, Shiv Mandir, and Islamia Hall Mosque. These sites attract pilgrims from across the region, who come to engage in spiritual practices and visit sacred sites. Of the various products presented at these sites, flowers remain the most common. However, there is a significant loophole in the practice itself, as the disposal of used flowers contributes to an increase in solid waste in the area. This element is not only environmentally detrimental but also contributes to the exacerbation of waste management and collection issues in this region. A significant challenge that must be addressed is the need to improve energy efficiency and reduce emissions while integrating local traditions into the construction process.

The objective of this research is to assess the nature and extent of solid waste generated in selected areas of Dehradun, examining the disposal techniques employed and characterizing the waste produced during both normal days and festival days. Secondly, the research aims to implement an awareness program to educate the community on solid waste management practices, while calculating the average per capita waste generation. This dual approach is designed to enhance community engagement and inform strategies for more effective waste management practices in the region.

2. Material and Methods

2.1. Description of Study Area

Uttarakhand, a region renowned for its sacred temples, is celebrated for its numerous pilgrimage sites and a vast array of ancient religious sites dedicated to Lord Shiva. Shiva is regarded as the Hindu deity of destruction and transformation. Uttarakhand is renowned for its magnificent temples (Kamboj et al., 2022). Dehradun is the capital and most populous city of the Indian state of Uttarakhand (Bahukhandi et al., 2023). Uttarakhand is also known as Dev Bhoomi, a term signifying the region's profound spiritual significance. Dehradun is situated in the Doon Valley, at the foot of the Himalayas. It is located between the Song River, a tributary of the Ganges, to the east and the Asan River, a tributary of the Yamuna, to the west. The primary source of revenue in Dehradun is derived from tourism. Dehradun boasts a plethora of tourist destinations, including the Dehradun Zoo, Kalanga Monument, FRI, Tapovan, Lakshman Siddha Peeth, Tapkeshwar Temple, Santala Devi Mandir, Mindrolling Monastery, Prakasheshwar Mahadev Temple, Sai Mandir, Maa Bala Sundari Mandir, Robbers Cave, and numerous others (Figures 1-3 and Table 1). Dehradun boasts a plethora of temples, which also contribute to the local economy. Dehradun serves as a central hub for the numerous renowned tourist attractions in Uttarakhand, situated at the heart of these destinations. The site of the study was selected with careful consideration of major tourist and spiritual destinations in Dehradun, particularly during the designated study periods. These locations not only attract a considerable number of visitors but also represent pivotal points of reference for the analysis of solid waste generation dynamics. By focusing on specific areas, the research aims to provide a comprehensive overview of the challenges associated with waste management. These locations are frequented for their spiritual significance, making them optimal for assessing the nature and extent of solid waste, as well as evaluating the disposal practices associated with the offerings made by devotees. This targeted approach permits a nuanced comprehension of both the environmental impact and community engagement in waste management at these prominent locations.

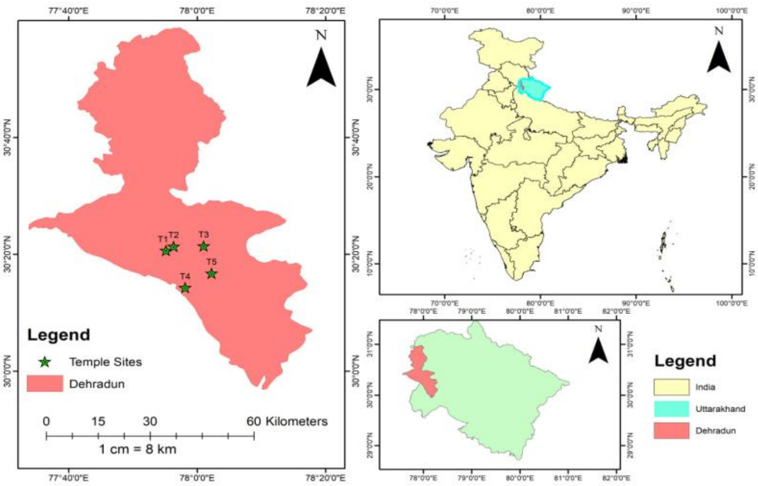

Figure 1. Map depicting sampling location.

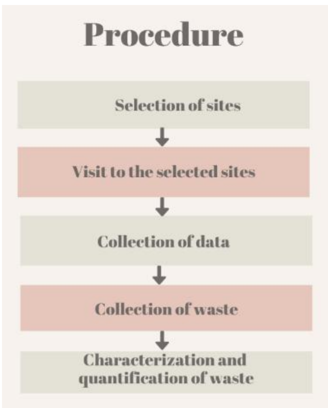

Figure 2. Process of study conduction.

Table 1. Geocoordinates of the selected temples.

Temple Code	Name of the Temple	Latitude	Longitude	Location Type
T1	Bala Ji Temple Jhajra	30°20'39.84'	77°55'19.20'	Located in a rural area
T2	Mahamaya Maa Bala Sundri Temple	30°2157.60''	77°56'11.04''	Located in forest area
T3	Tapkeshwar Mahadev Temple	30°21'31.68''	78°00'56.16''	Located in an urban area
T4	Daat Kali Temple	30°14'11.04''	77°57'28.80''	Located in a forest area
T5	Shri Siddeshwar Temple	30°34'96.27''	77.93'51.43''	Located in a rural area

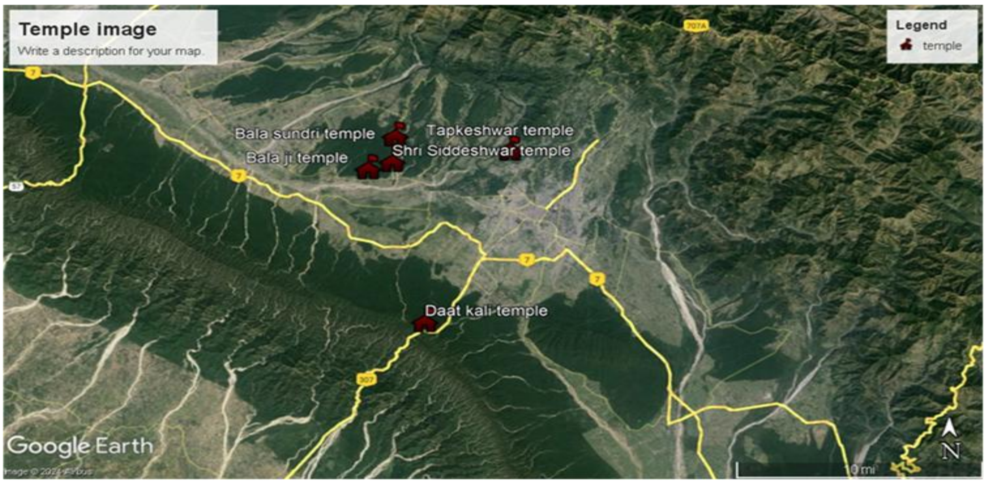

Figure 3. Google Earth view of the selected sampling locations.

2.2. Methodologies Adopted

2.2.1. Quartering and Coining Technique (QCT)

This technique is typically employed for the assessment of waste composition through the utilization of a limited quantity of waste material. This technique is employed to reduce the size of the sample set from a larger to a smaller one. The steps of the QCT method are illustrated in Figure 4.

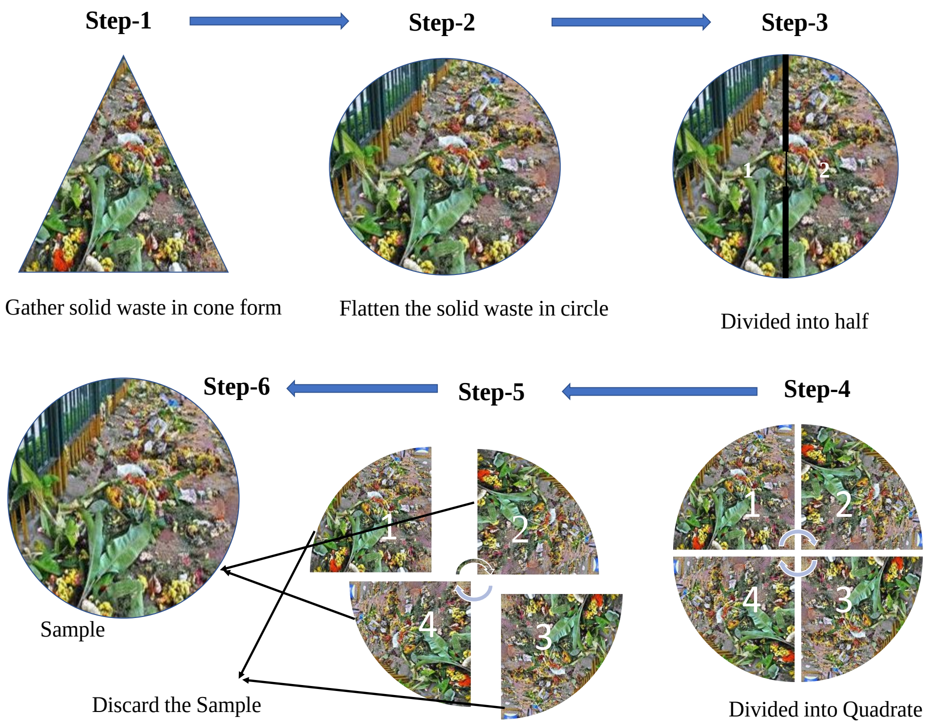

Figure 4. Quartering and coining technique (QCT) used for waste composition in selected temples.

2.2.2. Methodology Adopted for Waste Generation in Selected Temples

In this study, primary and secondary data were employed to ascertain the approximate total solid waste generated in the temples. The quantity of total solid waste generated exhibited considerable variability, with the total amount dependent upon the number of individuals visiting the temples and the frequency of visits, which was historically highest during festive days or holidays. Consequently, the greatest amount of solid waste was generated during festive days or holidays.

2.2.3. Procedure Adopted for Primary Data

The most common method for assessing waste generation in temples is to calculate the amount of waste produced per capita on normal days and holidays. This method involves dividing the number of people who visit the temple by the total amount of solid waste generated on that day.

2.2.4. Assessment of Waste Generation Per Capita

In this study, the waste generation per capita was determined through an assessment of the waste generated by temples and the population that visits the temple on normal days and on holidays or festive days. A random sampling method was employed. The random sampling method was employed to select the temples for study, and the establishment and spiritual activities within each temple were observed. The number and volume of bins or containers used for waste disposal were recorded.

The weight of waste disposed of in each bin was measured using a weighing balance, and the readings were recorded. Interviews were conducted with temple authorities to ascertain the number of visitors and the approximate daily waste generation. The disposal techniques for solid waste generated in the temples were also documented. The waste generation per capita was calculated using the following formula:

$$\text{Waste Generation per capita} = \frac{\text{Total weight of solid waste generated}}{\text{Total population visit the temple}}$$

2.2.5. Secondary Data

The secondary data were collected through a field survey, interactions with local people, and interviews with temple authorities.

3. Results and Discussion

3.1. Nature and Characteristics of Solid Waste

The nature and characteristics of the solid waste, as well as the composition of the waste, are analyzed by dividing the activity of the temple into two categories: normal days and holidays or festival days. The analysis is based on the number of tourists and local people who visit the temple on each of these days. Normal days encompass workdays, during which there is typically a lower influx of pilgrims into the temple. Consequently, the amount of solid waste generated on normal days is relatively minimal. In contrast, the category of "holidays or festival days" encompasses weekends, vacation periods, and other holidays that fall on non-working days. During periods of increased visitation, such as holidays or festivals, the quantity of solid waste generated is higher than that observed on normal days. This is due to the elevated number of pilgrims within the temples during these periods.

Table 2. Categorization of solid waste.

Type of Waste	Categories	Abbreviation	Description
Non- biodegradable	Polyethylene materials	PEM	Polythene carry bags, milk packing rappers etc.
	Plastics bottle	PB	Water bottles, Oil bottles, Cold drinks bottles, etc.
	Balloons	BN	Plastic balloons used for the decoration of the temples
	Metallic materials	ML	broken, discarded metal lamps
Biodegradable	Flowers	FL	Marry gold flowers, Rose flowers, etc.
	Paper waste	PW	Paper plates, discarded papers, etc.
	clothes	CL	Scarf, wasted mop clothes, etc.
	Wasted fruits	WF	Bananas, apples, etc.
	Soil lamp	SL	Scarf, wasted mop clothes, etc.
	Organic matter	OM	Leaves, flowers, etc.

The waste materials collected from religious sites in the Central Doon Valley, Dehradun, can be broadly classified into two categories: biodegradable and non-biodegradable (Table 2). The non-biodegradable waste materials include polyethylene material (PEM), which is polythene carry bags and milk packaging wrappers; plastic bottles (PB), which are used for water, oil, and cold drinks; and balloons (BN), which are commonly used in temples for decoration. The category of metallic materials (ML) encompasses items such as discarded metal lamps. Due to their non-biodegradable nature, these materials require extended periods of decomposition, posing a significant challenge to pollution and waste management initiatives. In contrast, biodegradable waste comprises materials that can be broken down by natural processes. However, the accumulation of these wastes continues to represent an environmental concern. Additionally, offerings in the form of flowers (FL), such as marigolds and roses, paper (PW), including paper plates and paper, and clothing (CL), such as scarves and mops, were observed. Other biodegradable waste items include fruit waste, soil lamps, and general organic waste, such as leaves and flowers. These materials, which are often considered sustainable, actually degrade more rapidly than previously thought. Their disposal results in unhygienic living conditions and elevated pollution levels, underscoring the need for rigorous management strategies.

3.2. Waste Composition in Normal Days

Table 3 and Figure 5 provide a summary of the biodegradable and non-biodegradable waste collection information from the five distinguishable collection centers (T1 to T5). The principal categories of biodegradable waste are flowers (FL) and wasted fruits/vegetables (WF/S/V). A total of 38% of the waste in T1 is comprised of wasted fruits and vegetables, with flowers accounting for an additional 22.76%. The contamination and microbiological deterioration of fruits and vegetables may be initiated by a number of well-characterized microorganisms, which can be introduced at any point along the farm-to-fork continuum (Siroli et al., 2017). Gram-positive and gram-negative bacteria, as well as members of the fungal kingdom, including yeasts and molds, are among the most common spoilage agents of fruits and vegetables (Barth et al., 2009). T2 indicates that the biodegradable waste is primarily composed of flowers, representing 32.13% of the total, with paper waste accounting for an equal 17.39%. In contrast, T3 demonstrates a markedly elevated proportion of floral waste (64.73%), accompanied by a markedly diminished quantity of other biodegradable materials, including paper and textiles.

Table 3. Average waste composition through QCT during the normal days.

Collection Code	Biodegradable Waste					Non-degradable Waste		
	FL	PW	CL	WF/S/V	OM	PEM	PB	ML
T1	26.42	4.33	11.4	42.64	0.03	2.84	12.34	0
T2	32.13	17.39	10.19	24.96	0.03	12.52	2.78	0
T3	64.73	0.07	0	24.96	6.42	2.59	1.23	0
T4	40.6	32.55	6.65	0	4.31	3.4	12.49	0
T5	23.17	1.54	1.4	11.02	12.32	13.34	18.1	19.11

Note: all values are in percentage.

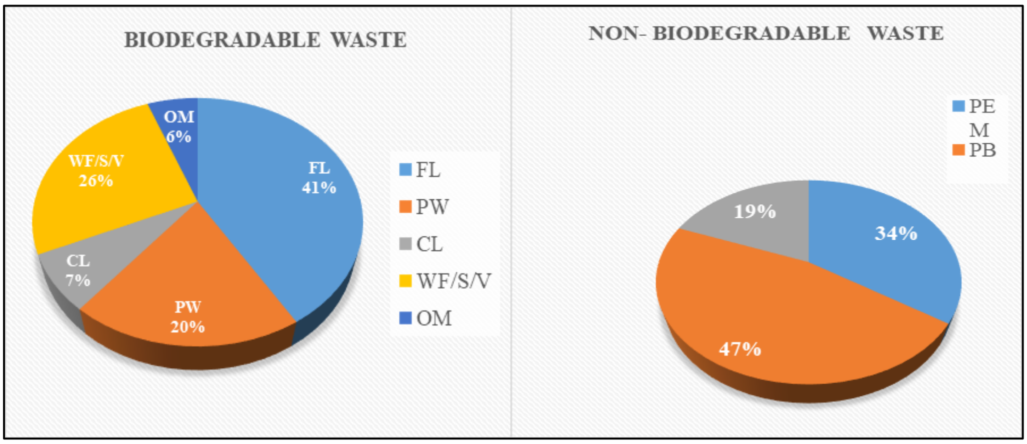

Figure 5. Waste composition in temples during the normal days.

The generation of flower waste from such activities has been identified as a significant environmental concern, given its potential to cause harm to numerous life forms. Effective management of this waste has therefore become a crucial and emerging issue, as it can not only attract pests but also lead to sanitation issues (Kumar et al., 2020). T4 demonstrates a higher rate of paper waste (32.55%) and flowers (40.6%), while T5 exhibits a significantly higher proportion of organic matter (12.32%). However, the percentages of flowers and wasted fruits remain relatively low. The high quantity indicates frequent usage and disposal, necessitating the implementation of efficient recycling programs to effectively manage this waste stream. The paper is biodegradable in nature, reflecting the growing public concern for the conservation of natural resources and the general awareness of the environmental consequences of waste disposal. This is reflected in the current legislative measures aimed at reducing waste. Recycling is frequently identified as a preferred method of waste reduction (Virtanen and Nilsson, 2013). The recycling of paper conserves wood resources, which provide habitats for living organisms and help to regulate the climate. A medium-sized tree absorbs approximately 6 kg of CO_2 per year. Additionally, forests serve as natural reservoirs for excess moisture, but in arid conditions, they can also provide a source of refreshment. The recycling of paper has been demonstrated to result in a reduction in the emission of CO_2, NO_2, and SO_2 into the atmosphere, as well as a reduction in water pollution caused by the presence of chlorine compounds resulting from bleaching processes and the use of chemicals (Ozola et al., 2019).

In the case of non-biodegradable waste, polybrominated (PB) compounds are consistently observed, with T5 exhibiting the highest proportion (18.1%). The presence of various toxic components as additives in plastics, including di-(2-ethylhexyl) phthalate, bisphenol (A), polyhalogenated compounds, and heavy metals, represents a significant health risk to humans. These substances have been linked to disruption of the endocrine system (Halden 2010; North and Halden, 2013). As plastics are not readily biodegradable and exhibit considerable stability in the environment, their disposal has resulted in a significant environmental pollution problem (Tonjes et al., 2012). A similar trend is observed for polyethylene materials (PEM), which are present in adjusted proportions on T5 (13.34%) and T2 (12.52%). Metallic materials (ML) are exclusively present in T5, with a particle count of 19.11%. This indicates that the waste types are distinct at each collection point. The ultimate destination of all municipal solid waste is through burial as waste disposal or landfilling. The primary concern regarding solid waste disposal is leachate contamination, which has the potential to affect vast expanses (Azarafza et al., 2015; Azarafza and Ghazifard, 2016). The data demonstrate that the composition of waste is as diverse as the geographical areas in which it is deposited. Furthermore, each area has established standards regarding the types of containers used for biodegradable and non-biodegradable waste.

3.3. Waste Composition in Festival Days

Table 4 and Figure 6 illustrate the proportionate distribution of biodegradable and non-biodegradable waste at the five sites (T1, T2, T3, T4, T5) on festival days. The largest proportion of the biodegradable waste at T3 is flowers (FL), representing 74.88% of the total. This is in contrast to T2, where flowers account for only 35.64% of the biodegradable waste, and T1, where they account for 34.48%. Paper waste is observed to be particularly prevalent in T2 and T4, with proportions of 20.56% and 20.96%, respectively. Clothing (CL) exhibits a moderate correlation and contributes at respective rates, with T2 demonstrating the highest value of 10.02%. WF/S/V constitute a significant proportion of the waste in T1 (24.79%) and T5 (14.86%), whereas SL is absent in T1 but represents the majority fraction in T5 (22.16%). Additionally, organic matter (OM) is present, with the highest percentage observed in T2 (11.13%) and T1 (10.02%). With regard to non-biodegradable waste, considerable variation was observed at the various collection points. Among T4, PEM is identified as the most prevalent material, representing 8.58% of the total waste, and in T5, it accounts for 1.87%. The results indicated that PB was the most utilized material in T5 (12.22%), followed by T1 (6.24%) and T4 (7.86%). Balloons (BN) are present in noteworthy quantities in T1 (10.14%) and T5 (3.26%) but are absent in T3 and T4. One of the critical issues derived from festival management is the management of waste.

Waste can be classified as either biodegradable or non-biodegradable based on its prevalence in the region (Bharadwaj et al., 2015). A significant portion of festival waste is comprised of floral materials that can be repurposed in various sectors. These include the production of biofertilizers, pullulan, and biochar using microbial consortia (Suneetha et al., 2021). The Sustainable Development Goals can be attained through the implementation of improved floral waste management practices, which will result in a reduction of environmental pollution and the production of value-added products such as incense sticks, perfumes, and bio-gas (Srivastav and Kumar, 2020). A significant challenge in India is the alarming prevalence of non-biodegradable waste, particularly plastic. According to Sharma (2018), approximately 15,000 tons of plastic are generated daily, yet only 1/3 is collected, leaving 6,000 tons uncollected. The recycling and reuse of materials are regarded as effective measures to address these issues and mitigate the environmental impacts associated with waste management.

Table 4. Average waste composition through QCT Method during the holidays or festival days.

Collection Code	Biodegradable Waste						Non-biodegradable Waste		
	FL	PW	CL	WF/S/V	SL	OM	PEM	PB	BN
T1	34.48	9.76	3.14	24.79	0	10.O2	1.43	6.24	10.14
T2	35.64	20.56	10.02	12.97	0	11.13	3.6	4.03	2.05
T3	74.88	2.81	0	8.44	0	5.54	3.83	4.5	0
T4	48.16	20.96	5.44	8.98	0	0.02	8.58	7.86	0
T5	27.79	6.32	9.85	14.86	22.16	1.67	1.87	12.22	3.26

Note: all values are in percentage.

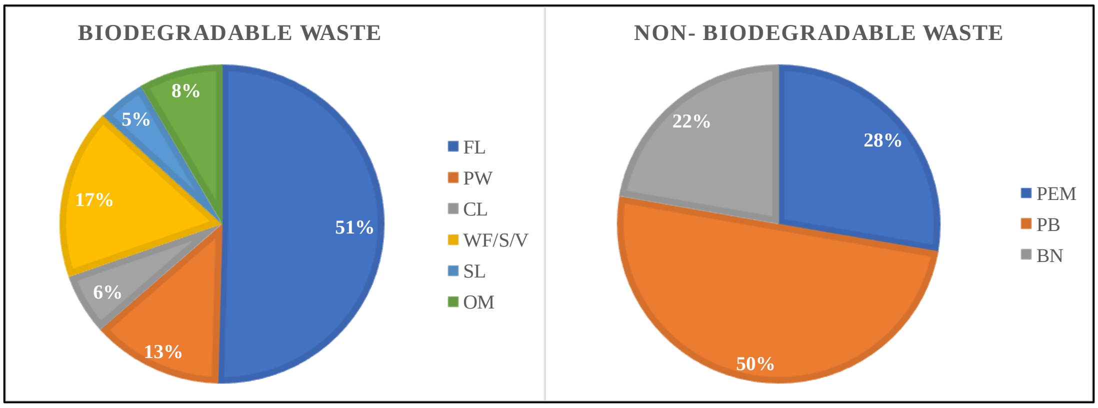

Figure 6. Average waste composition in temples during the holidays or festival days.

Table 5. Average waste generation per capita.

Temple Code	Normal Days	Festival Days
T1	1.27	2.16
T2	1.4	2.06
T3	1.78	2.78
T4	1.53	2.58
T5	0.78	1.67

Note: all values are in kg.

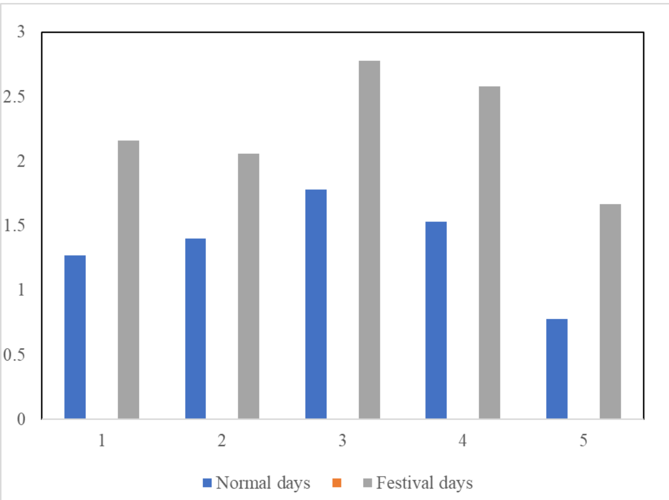

Figure 7. Graph depicting average waste generation per capita.

3.4. Average Waste Generation (Per Capita) During Normal and Holidays/Festival Days

As illustrated in Table 5 and Figure 7, the mean waste generation per capita was found to fall within the range of 0.78 kg (minimum) to 1.78 kg (maximum), with an average value of 1.352 during normal days. In contrast, during the festival days, these values range from 1.67 kg (minimum) to 2.78 kg (maximum), with an average value of 2.25. The per capita waste generation was observed to be higher during the festival days than on normal days, which can be attributed to the higher level of offerings during the festival period. The generation rate of municipal solid waste in India is once again found to be inconsistent, with a range of 200 to 870 gm per capita per day and an annual increase of approximately 1.3% (Sabeet, 2017). It is evident that the generation of waste is correlated with increases in urban growth, economic growth, and population density (Rajput et al., 2009). The mean waste generation on a typical day is estimated to be between 0.78 and 1.78 kg per capita. However, during festivals, the mean waste generation is reported to be between 1.67 and 2.78 kg per capita, with an estimated mean per capita of 2.25 kg (Zargar et al., 2023).

4. Conclusion and Recommendations

The study of waste composition at various temples in Dehradun reveals a significant discrepancy in the ratio of biodegradable to non-biodegradable waste between normal working days and festival days. The results demonstrate that biodegradable waste, primarily comprising flowers, fruits, and vegetables, constituted the largest proportion of waste across all analyzed temples. Among these, flowers exhibited the highest generation rate. The high percentage of floral waste indicates a significant number of offerings, which necessitates the development of effective composting and organic recycling plans. Non-biodegradable waste constitutes a relatively minor proportion of the total. However, plastic bottles and polyethylene materials are present in this waste stream due to their non-biodegradable nature and the numerous adverse effects they have on the environment. Furthermore, the study indicates that the average generation of waste tends to increase during holidays or, more specifically, during festival days. A comparison of the per capita waste generation rates for these days with those of normal days revealed higher rates of generation during religious and cultural events. With regard to the management of waste at temples, it is essential to implement source segregation, in addition to supporting composting and recycling initiatives for biodegradable temple waste, including flowers and fruits. Another evident necessity is to extend the prohibition on single-use plastic products and to encourage the use of reusable containers in their place. It would be beneficial for recycling firms and authorities to collaborate in order to enhance the efficiency of waste collection during events such as festivals. The implementation of awareness campaigns and the protection of sustainable festival practices, such as the utilization of biodegradable decorations, will serve to further mitigate the adverse effects of environmental degradation. Consequently, an analysis of waste-to-energy projects will facilitate the transformation of waste into electricity, thereby creating additional space within temples and promoting the utilization of environmentally friendly energy sources.

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