Journal of Environment Sciences (2024), **Volume X**, 34-45
https://doi.org/10.3126/jes.v10i1.66965

Estimation of Greenhouse gas emission from municipal solid waste management techniques - A case of Rampur Municipality, Palpa District, Nepal

Bibek Khanal*, **Kishor Kumar Maharjan**
[1]Department of Environmental Science, Tri-Chandra Multiple Campus, Tribhuvan University, Nepal
*Correspondence: bibekkhanal5698@gmail.com

Abstract

This paper explores the rising global solid waste issue and its often-overlooked contribution to climate change. Most studies view waste as a significant parameter of public health and aesthetic value but neglect its role in climate change. Focusing on Rampur municipality, the study quantifies waste from households, commercial hubs, and institutions, using IPCC guidelines for greenhouse gas emission estimates. The waste generated by 84 households, 26 commercial hubs, and 14 institutions for seven consecutive days was studied and quantified. The IPCC's 2006 Guidelines for National GHG Inventories were applied to estimate GHG emissions from landfills and composting. In Rampur municipality, 2772 tons of waste was generated and only 40 % of the generated waste was landfilled. The generation rates of Households, Commercial, and Institutions were 141.5 ± 7.16 g/capita/day, 1933 ± 0.32g/day, and 826 ± 0.46 g/day respectively. Organic waste emerges as a key contributor in Households and Commercials while Paper dominates institutions. Rampur Municipality emits approximately 2,629.77 tons of CO2eq GHG annually from waste management, divided as 0.06 tons of CO2eq GHG annually per individual, with households contributing 55%, commercial sectors 41%, and institutions 4%. Furthermore, composting was identified as an effective mitigation strategy, potentially reducing emissions by 81%. Overall, this research sheds light on the significant contribution of municipal waste to GHG emissions. It underscores the need for enhanced waste management strategies, particularly emphasizing composting's role in global climate change mitigation. It can be useful for policymakers to address waste-related emissions.

Keywords: *Climate change, composition, emission, generation, mitigation*

Introduction

The global waste generation was 2.24 billion tons of solid waste in 2020 and is projected to increase by 73% to 3.88 billion tons by 2050 due to rapid urbanization (World Bank, 2022). Although it's widely known that proper waste management is important for people's health; many do not realize that waste management practices also affect the climate (US EPA , 2002). Municipal solid waste (MSW) encompasses waste from households, businesses, and discarded items that are no longer useful (Tchobanoglous and Krieth, 2002; Vergara and Tchobanoglous, 2012). In landfills, organic waste breaks down and releases GHG, primarily methane into the air. The methane's warming potential is 28 times stronger than carbon dioxide's (Clean Energy Regulator, 2022; IPCC, 2021). Improper waste disposal, like open dumping and inadequate landfilling, contributes to 3-19% of human-caused methane emissions globally. Addressing methane emissions from landfills can significantly reduce greenhouse gases in the atmosphere (Taylan et al., 2007).

In the context of Nepal, the rapid and uncontrolled growth of cities, along with limited public awareness and poor management by municipalities, has worsened environmental issues (Asnani and Zurbrugg, 2007). Household waste makes up 50% to 75% of all the waste with a generation rate of 170 grams(g) of waste per day (ADB, 2013). Based on this and the population in 2011, the 58 municipalities create about 1,435 tons of waste every day and 524,000 tons each year. Overall, Municipal Solid Waste (MSW) consists of 56% organic waste, 16% plastics, and 16% paper and paper products (ADB, 2013).

In recent decades, global warming has emerged as a significant and pressing concern, evidenced by an approximate temperature rise of 1°C above pre-industrial levels (Rogelj, 2021). The current trajectory suggests a projected temperature increase of approximately 1.5°C between 2030 and 2052, as reported by the Intergovernmental Panel on Climate Change (Beck and Mahony, 2018). During the 21st Conference of Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC), the Paris Agreement was ratified by 192 parties to limit global temperature rise to well below 2°C and striving to keep it below 1.5°C (UNFCCC, 2016).

According to MoPE (2017) for Third National Communication (TNC) to the UNFCCC (MoPE, 2021), Nepal's net GHG emissions were calculated to be 31,998.91 gigagrams of CO_2eq. Taking the waste section only, Nepal emits 923.58 Gg of CO_2eq annually. Solid waste disposal represents about 28% of the total emission from the waste, which is almost equal to 261.581 Gg of CO_2eq per annum (TNC, 2021). So, the contribution of the waste section is around 3 % of the GHG emissions in Nepal.

Existing research has predominantly focused on waste characterization and management, leaving a substantial gap in our understanding of emissions originating specifically from municipal waste sources. Despite growing concern about climate change and global warming, many municipalities lack accurate information on their emissions and contributions to global issues. Without accurate data on their greenhouse gas emissions, municipalities may be unable to effectively manage their carbon footprint and implement strategies to reduce their environmental impact. The local government can select from a variety of solutions for managing solid waste by being aware of the quantity and types of garbage produced within its borders and planning and implementing policies and planning in accordance (Kaza et al., 2018). Thus, in this study, we have attempted to assess the generation and composition of MSW to quantify the GHG emission from the Solid Waste Management (SWM) sector.

Materials and Methods

Study Area

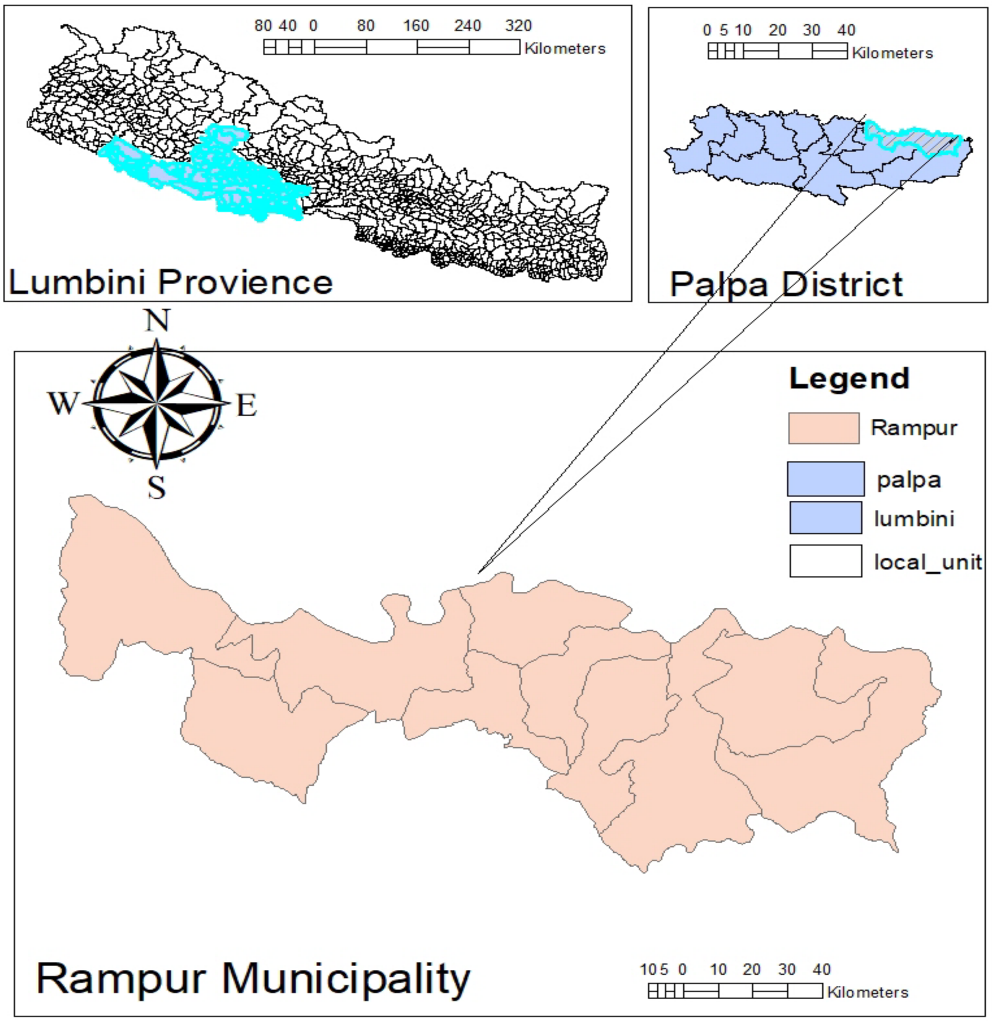

Figure 1: Map of Study Area

This study was conducted in Rampur Municipality as shown in Fig. 1, situated in the Palpa District of Lumbini Province, Nepal. The semi-urban municipality with an area of 123.34 km and a total population of 40883 (NSO, 2023) has a population density of 331 persons per km², which is higher compared to the national urban population density of 207.55 persons per km², and the average household size is 3.6, lower than the national average of 4.37 (NSO, 2023). Solid waste is a growing issue in the municipality but the study hasn't been done yet. So, the study area can represent all urban local bodies of Nepal in the context of waste management and emissions.

Rampur Municipality (27° 51' 41" N latitude and 83° 53' 16" E longitude), with elevation ranges from 350 meters to 1100 meters above the mean sea level lies in the midland range of the nation and Monsoon – Influenced Humid Subtropical Climate according to Köppen climate type (Mindat, 2021).

Methods

A reconnaissance survey was done to know the current status of the Solid Waste Management (SWM) practices, generation rate, and collection and disposal system. A checklist was prepared to record the generation rate and weight of the composition studied. Semi-structured Questionnaires were made to assess the SWM practices in the municipality.

The sample size was calculated using (Arkin and Colton, 1963) model as given in Equation I;

$$= \frac{z^2 * Np(1-p)}{N * d^2 + z^2 * p(1-p)} \quad \text{..(i)}$$

Where,
z = Confidence level (95%, z = 1.96)
N = Total number of households (11363 for this survey)
p = estimated population proportion (0.05)
d = margin of error/Error limit 5% (0.05)
n = Sample size

The total household (HH) in the municipality was 11363 according to census 2021(NSO, 2023), the sample size was found to be 72 with a 5 % margin of error. Altogether 84 samples from HH were taken to mollify the risk of non-response and 26 and 14 were the sample for commercial (total 836) and institutions (total 237), respectively, on a proportionate basis. The sampling was done from 25th May to 19th June 2023.

Sampling for waste generation and composition: Two dustbins were used for sample collection over seven consecutive days in each chosen residence. Each family was encouraged to use a different dustbin for biodegradable and non-biodegradable waste. The biodegradable waste was weighed on the same day for 7 days while non-biodegradable trash was collected in bags, which were then further divided and weighed using a digital spring balance (100 kg). The generation rate of HH, institution, and commercial hub was computed separately.

The sampling was done on a purposive basis. The door-to-door interview was done in households, institutions, and commercial hubs at the time of the sample collection. Different compositions of MSW were separated and sorted out by quartering methods as in multiple papers (Kumar et al., 2004; Babel and Vilaysouk, 2016; Umar, 2022). The categories for the waste composition were classified based on the IPCC Sixth Assessment Report (IPCC, 2021) and the Waste Management model (Shapiro-Bengtsen et al., 2020) which includes yard waste in addition to predominant categories.

Estimation of GHG Emission

Estimation of Methane from Landfill: The estimation of the GHGs from the dumping site was done using the default or Tier 1 methodology outlined in the IPCC 2006 guidelines (IPCC, 2006), primarily due to the absence of country-specific data. Methane (CH_4) emissions were calculated based on the waste composition, quantity, and biodegradable organic carbon content. Tier 1 involves the gain-loss approach outlined in the IPCC GHG Inventory Guidelines and the default emission factors (IPCC, 2021) and other parameters provided by the IPCC (IPCC, 2015). The landfill of Rampur municipality is simple and doesn't fulfill the basic criteria of a sanitary landfill so this landfill is considered as the uncategorized landfill with MCF of 0.6. The CH_4 emitted from the dumping site was measured through Equation ii.

$ECH_4 = MSW_{(Land\ Fill)} \times MCF \times DOC \times DOC_f \times F \times (16/12)\text{-}R) \times (1\text{-}OX)$ .... (ii)

Where, ECH_4 = Total Methane Emitted per year in Gigagram(1Gigagram = 10^9gram), $MSW_{(Land\ Fill)}$ = total amount of MSW in the landfill in wet weight basis (Giga gram/year), MCF = methane correction factor, DOC = the fraction of degradable organic carbon in MSW (Gigagram C/Gg MSW), DOC_f = the fraction of DOC that can decompose, F = the fraction of methane in generated landfill gases, R = the recovered methane(Giga gram/year), 16/12 is the molecular weight ratio CH_4/C, OX = the oxidation factor

The DOC values depend on the composition of the waste in the landfill (Berisha et al., 2018). DOC_f value ranges from 0.42 to 0.77 and depends on pH, temperature, moisture, and waste composition (Aguilar-Virgen et al., 2014). The main GHG emitted is methane which accounts for about 50% of the total GHG emission. So, the F values are taken as 0.5 (IPCC, 2006). Due to the lack of a proper energy recovery system in the landfill, R is taken to zero. The landfill is unmanaged with proper liner and cover so the OX, the amount of methane oxidized at the cover of the landfill is taken to zero.

The collection efficiency of the municipal waste collection was 75% for commercial and institutional sectors and roughly 30% for HH waste according to the municipality. The waste collection has been done only in four wards to date. The annual waste generation per annum going to the dumping site was calculated by multiplying the per day waste generation of three sectors, number of the establishments or individuals, no. of days in a year, and the collection efficiency of the respective sectors.

GHG Emission from the Transport of the Waste: The emissions of greenhouse gases (GHG) during waste transportation from the generation site to the disposal site are significant. Three months of data on fuel consumption by Truck and tractor for waste transport was generalized to calculate the annual fuel consumption. The GHG emitted by the combustion of fossil fuel used in the Trucks and tractors for the transport of Municipal waste was derived using the following equation iii (IPCC, 2006; Umar, 2022).

$Emissions_t$ = Fuel(l)/Waste (tons) × Energy (MJ/unit) × EF (kg CO_2/MJ).................................. (iii)

Where,

$Emissions_t$ = the amount of GHG (CO_2 in kg) emitted per ton of the waste transported.

Fuel = amount of diesel consumed in a liter

Waste = amount of the waste transported.

Energy = Energy content of the fossil fuel used. (Diesel 36.42 MJ/L)

EF = Emission factor for the fossil fuel. (Diesel: 0.074 kg CO_2/MJ)

Composting and Anaerobic Digestion: GHG emissions from composting and anaerobic digestion processes were estimated considering the biogenic carbon content. Methane and Nitrous oxide production during composting depends on factors such as material quantity, moisture, temperature, and aeration (Kumar et al., 2014). Equation iv is used to estimate CH_4 and N_2O emissions in our research. (IPCC,2006; Babel and Vilaysouk, 2016; Umar, 2022).

E_{GHG} = $[W \times ef] \times 10^{-3}$ - R ....(iv)

Where;

E_{GHG} = GHG emissions from composting (Giga gram/year)

W = amount of MSW composted (Giga gram/year)

ef = emission factor (gram /kg of waste) ;(EF for CH_4 and N_2O is 4 and 0.3 respectively)

R = amount of methane recovery (Gg/year); (value used is 0)

Conversion of GHGs emitted in CO_2eq: The term "Carbon dioxide equivalent" denoted as "CO_2eq," is a standard unit used to measure different greenhouse gases consistently. It represents the quantity of CO_2 that would produce an equivalent global warming impact for a specific amount and type of greenhouse gas. To convert greenhouse gas quantities into CO_2eq, you multiply the gas amount by its Global Warming Potential (GWP). For example, emitting 1kg of methane is expressed as 29.8 kg of CO_2eq

(1kg CH4 * 29.8 = 29.8kg CO_2eq).CO_2eq is valuable as it facilitates representing bundles of greenhouse gases as a single values and enables easy comparison between different GHG bundles (IPCC , 2021). For the conversion of methane to CO_2eq, the derived methane is multiplied by the CO_2eq factor as mentioned in the IPCC Sixth Assessment Report (AR6) (IPCC, 2021). For this research, AR6 was followed in terms of all the parameters, guidelines, and values mentioned above and used in the above five equations.

The study acknowledges several limitations during waste sampling and measurement of solid waste composition. Purposive sampling may introduce biases, while inadequate sample sizes might hinder comprehensive understanding. Moreover, temporal variation in waste composition, influenced by factors like seasonality which can alter the value of DOC resulting in the impact on the calculation of GHG emissions from landfills, poses challenges in sampling. Extended study durations and multiple samplings are vital for accurate representation over time.

Results and Discussion

Generation and Composition of solid waste

The Household (HH) waste generation was found to be 141.5 ± 7.16 g/capita/day. The maximum and minimum waste was recorded as 385.71 g/capita/day and 11.43 g/capita/day, respectively. Each household had a waste generation rate of 730 g per household per day. This waste generation rate is slightly lower than the national waste generation rate of 170.2 g per capita per day (ADB, 2013) and the rate of 330.4 g per capita per day in Tulsipur of Dang district (Dangi et al., 2013),240 g/capita/day at Gorkha (Maskey and Singh, 2017)and slightly higher than the study done in 60 urban municipalities, 115 g/capita/day(Pathak et al., 2020), 110 g/capita/day at Bhaktapur (Kc and Karmacharya,2012), 120 g/capita/day at Simara (Dahal and Adhikari, 2018). The comparatively lower per capita waste generation may be due to differences in samples considered, collection time, and seasonal variation (Liguori et al, 2013). As the study area is a semi-urban area, the public uses the organic waste generated for animal feed. The generation rate can be affected by the lifestyle of the public, urban and rural proportions, and socio-economic factors (Kaza et al., 2018).

The average generation per commercial hub and institution was 1933 ± 0.32 g/day and 826 ± 0.46 g/day respectively. The average daily waste generation was 950g/office, 1100 g/shop, and 3100 g/hotel or restaurant in 60 urban municipalities(Pathak et al., 2020). A similar study in the Butwal sub-metropolitan city revealed commercial and institutional waste generation as 1960 g and 6970 g per day (Bhusal et al., 2020). As seen in other developing countries such as Uganda (Okot-Okumu and Nyenje, 2011), India (Pattnaik and Reddy, 2010), Tanzania (Kaseva and Mbuligwe, 2005), Kenya (Henry et al., 2006), and Indonesia (Supriyadi et al., 2000; Henry et al., 2006), households in Nepal (Pathak et al., 2020) are the primary sources of solid waste.

The waste generated by Rampur municipality is shown in Table 1. The total waste generated by the municipality was 2772.79 tons per annum. But only about 40% of the waste, 1129 tons of the waste was found collected. The yearly average cumulative waste collected per municipality of the nation was 2231.0 tons in FY 2073/74, 2164.40 tons in FY 2074/75, and 2232.7 tons in FY 2075/76 (CBS, 2020). The waste collected was comparatively lower than in other municipalities of Nepal because of the low collection efficiency.

Table 1: Waste generation and landfilled

Sector	Avg. Waste per sector per day (g)	Total Waste generated per Annum (tons)	Waste Landfilled per Annum (tons)
Per capita per HH	141.5	2111.50	633.45
Commercial hub	1933	589.83	442.38
Institutions	826	71.45	53.58
Total		**2772.79**	**1129.42**

Table 2: GHG Emission from various sectors and management technique

The Composition of the solid waste collected was divided into nine different categories (IPCC, 2018) viz; Organic, yard waste, plastic waste, rubber and leather, paper and cardboard, glasses, mixed metals, textile waste, wood waste, and other waste. The composition of Household waste, Institutional waste, and Commercial waste are presented in Figure 2 which shows that the amount of organic waste is higher in the HH and commercial sector while paper waste is predominant in institutions.

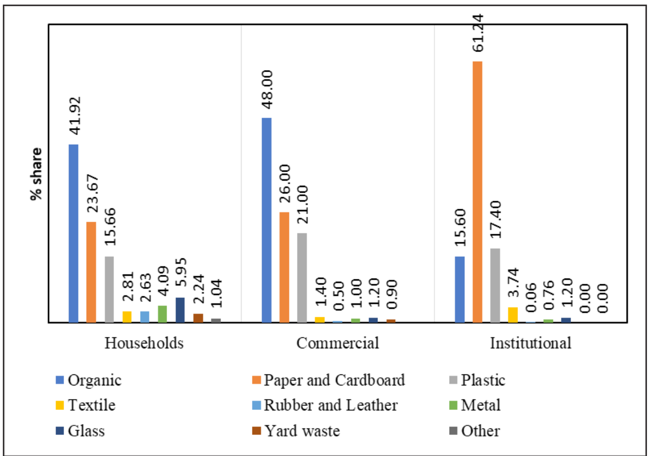

Figure 2: Composition of the waste in categories based on source

The volume and composition of municipal solid waste disposed of have a direct impact on the quantity of methane released (Hoeks, 1983; US EPA, 1994; Mor et al., 2006, Kumar et al., 2014). Organic and paper waste was found predominant in our study. The worldwide composition of waste demonstrates that 44% consists of food and green waste, while plastics and paper waste account for 12% and 17%, respectively, with the remaining categorized as "others" (Kaza et al., 2018). The organic waste fraction in Asian cities varies significantly by lifestyle; Jabalpur, India shows 39%, 47%, and 44% for high, middle, and low-income areas respectively (Thanomnim, Papong, & Onbhuddha, 2022), 46% in Tulsipur (Dangi et al., 2013), 67% in Butwal (Bhusal et al., 2020), and 71 % in Kathmandu (Dangi et al., 2011). Yard waste was found dominant in HH in Bukidnon city of Philippines (Medina and Forten, 2015) but in our study organic or food waste was dominant. It can be because the yard waste is treated as agricultural waste in the majority of the HH and also the garden waste was found to be used for cattle feeding.

The average composition of municipal solid waste (MSW) in the 60 newly declared municipalities was as follows: Organic waste constituted 62% of the waste stream, followed by plastics (12%), paper and paper products (11%), glass (6%), metals at 1%, textiles (1%), rubber and leather (1%) and other (6%) (Pathak et al., 2020). The study by ADB in 2012 in Tansen municipality of the Palpa district reveals the composition of the commercial establishments as 46% organic followed by 24% of paper and 10% of plastic (ADB, 2013). The organic content ranged significantly, from nearly zero to 57%, in Api Municipality in ward-wise data, while the plastics varied from the lowest of 3% in Kamalbazar Municipality to a maximum of 62% in Shani Arjun Municipality (Pathak et al., 2020). The result of the baseline study by ADB in 2012 in Siddharthanagar municipality reveals an organic content of 1% while the paper segment dominates almost 75% of the total waste composition (ADB, 2013). The lower fraction of organic was found as fresh foods are less handled by the institutions (Ramchandra et al., 2018).

Greenhouse gas emission

The findings regarding emissions resulting from municipal solid waste (MSW) management practices are displayed in Table 2. The total GHG emission was found to be 2696.39 t CO_2eq and the per capita emission of the municipality was 0.066 tCO_2eq/capita/annum.

The Valentine City in 2011 with waste generation of 0.69 kg/capita /day and collection efficiency of 31 % emitted 110182 tCO_2 eq/annum, which is 0.15tCO_2eq/capita/annum (Babel and Vilaysouk, 2016). The GHG emission from the waste sector in Nepal was 923590 tCO_2 eq/annum i.e. 0.035 tCO_2 eq/capita/annum(TNC, 2021). The higher per capita emission in this paper may be due to the higher population density of the study area compared to the urban population density of 58 municipalities in 2012. GHG emissions from MSW management vary significantly across regions. In the Lao People's Democratic Republic, the emissions are notably low at 0.02 tCO_2 eq/capita/annum (Ministry of Natural Resources and Environment of Lao PDR, 2013). Similarly, European nations release 0.19

Table 2: GHG Emission from various sectors and management technique

Category	Annual Waste Generated	Waste Landfilled	GHG emitted annually		CO_2eq
	Tons	Tons	Tons		Tons
Household	2112.41	633.45	48.53		1446.12
Institution	71.45	53.58	3.72		110.71
Commercial	589.84	442.39	36.01		1073.10
GHG from Landfill	2773.70	1129.42	88.25		**2629.93**
Composting	278.59		CH_4	1.11	33.21
			N_2O	0.08	22.82
Transport	1129.42				10.602
Total	**2696.56**				

tCO_2 eq/capita/annum (EEA, 2019). In contrast, the United States exhibits relatively high MSW-related emissions, equaling 0.4 tCO_2 eq/capita/annum, primarily due to the widespread practice of landfilling. Conversely, Japan and Germany have achieved relatively low per capita emissions by utilizing incineration processes for energy recovery, with current figures at 0.02 tCO_2 eq/capita/annum and 0.17 tCO_2 eq/capita/annum, respectively (UNFCCC, 2014). These variations underscore the significant impact of waste management practices on GHG emissions at the national level. In 2007, the methane (CH_4) emissions from the majority of landfills in China were relatively low, measuring less than 700 tons of CO_2 equivalent. However, emissions from 279 landfills exceeded 1,000 tons of CO_2 equivalent, and only 10 landfills had emissions surpassing 10,000 tons of CO_2 equivalent (Bo-Feng et al., 2014). The uncategorized dumping site of Rampur municipality lies similar to the majority of landfills in various states of China. A similar study in Germova landfill located in the Mitrovica Region found that the cumulative methane (CH_4) emissions produced in the landfill totaled 19.3 gigagrams (Gg), which is equivalent to 485 gigagrams (Gg) of carbon dioxide (CO2) emissions between 2006 and 2019. It further illustrated the GHG emission per year was 0.22-0.24 Gg of GHGs equivalent to 4620 CO_2 eq per year (Dimiskovska et al., 2021). The GHG per capita per annum of this study is similar to this research.

The greenhouse gas (GHG) emission intensity of the landfill based on the waste generated and waste landfilled was estimated to be 0.97 tCO2e/t MSW generated and 2.38 tCO_2e/tMSW landfilled for the Rampur Municipality. This finding is quite higher than 1.79 tCO_2e/t MSW in Beijing (Li et al., 2022), 0.27 tCO_2e/tMSW in Saudi Arabia (Yaman et al., 2020), 0.78 tCO_2e/tMSW in Vietnam (Verma & Borongan, 2022), 0.49 tCO_2e/tMSW in Malaysia (Devadoss et al., 2021) and 0.40 tCO_2e/tMSW in UK (Jeswani et al.,2013). This discrepancy is attributed to differences in waste generation and disposal methods. The emission in this paper is higher compared to other studies because the dumping site of Rampur municipality is unmanaged category compared to other sanitary landfills in other areas. It lacks the resource recovery mechanism, incineration system, Oxidation system, advanced composting practices, methane recovery or capture facilities, and lower collection efficiency as compared to other regions. Methane emissions were found to be strongly linked to economic progress and population increase, while greater population density led to increased municipal solid waste (MSW) generation (Singh et al., 2018). So, with the rise in economic activities and population, proper technologies for the SWM can not only reduce the waste landfilled but also mitigate the GHG emissions. The intensity of the emission is also related to the constituent of the waste landfilled.

Sectoral Contribution

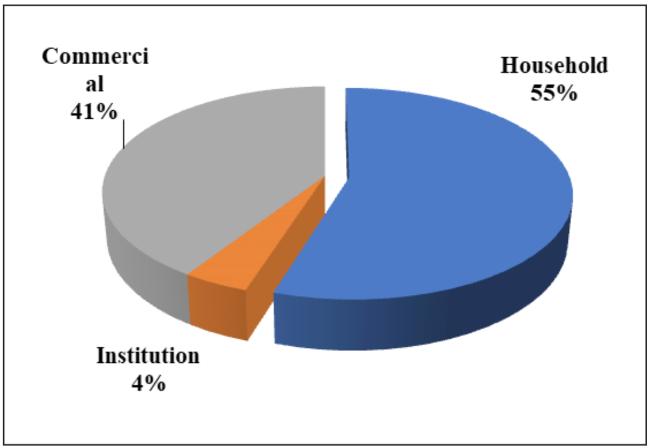

Figure 3: Sectoral contribution to emission

The contribution of Household (HH), Commercial, and Institutions in overall emissions are shown in Fig. 3. The HH is responsible for more than half of the total emissions from the waste sector while institutions have a minimal contribution of 4%. The biodegradable waste contributes about 76.9 % of the total MSW in the dumping site of the municipality. The GHG emission is directly proportional to the organic waste content (Kumar et al., 2014). In this study, organic waste dominates HH followed by Commercial and Institutional, as their contribution to GHG emissions.

In China, MSW typically exhibits a high organic fraction (60-70%) and moisture content exceeding 50%, particularly in smaller and medium-sized cities. These characteristics of MSW in China result in notably higher greenhouse gas (GHG) emissions from MSW treatment compared to developed countries. This is due to the rapid decomposition of organic matter and low efficiency in gas collection systems at initial storage sites (Liu et al., 2017). In a similar study in Hanoi city of Vietnam with approximately 71% of organic waste, the scenarios for organic waste recovery have been found to reduce GHG emissions by 15 % - 98 % (Thanh et al., 2015). Furthermore, a study in India underscores the higher composition of biodegradable waste (50-60%) in developing nations results in higher GHG emissions per ton of the MSW compared to developed nations (BP et al., 2023). This highlights the strong correlation between organic waste and the intensity of GHG emissions.

GHGs from Transportation of the Waste

The annual greenhouse gas (GHG) emissions resulting from waste transport between the generation site and disposal site amount to approximately 10.602 tons of CO_2 equivalent, representing a minimal fraction of the total emissions, specifically less than 0.4%. In Ho Chi Minh City, Vietnam, the emission from the transport of waste was 0.7 % of the total emission (Verma & Borongan, 2022). In contrast, the total carbon emissions from household waste in Shanghai reached 4.7 million in 2015, with the collection and transportation processes accounting for 2.2% of the overall emissions from solid waste management (Jiang et al., 2020). Factors such as collection efficiency, landfill location, and the presence of waste treatment facilities like transfer stations, resource recovery facilities, and so on contribute to this variation. The municipality's landfill, situated 4km from the commercial hub and within a 7km radius of major populated areas, likely minimizes transportation emissions. However, the absence of a transfer station and poor household waste collection efficiency may also play a role in limiting emissions from waste transport.

Composting Practice as a Means of GHG Mitigation

20 % of the respondents were found using the composting practice as the means of waste management at the HH. This diversion of 278.59 tons of waste from going to landfills prevents approximately 81.6% of the greenhouse gas emissions from being released into the atmosphere. Composting results in the release of 56.01 tons of CO2 equivalent into the atmosphere, significantly lower than the 306.04 tons of CO2 equivalent that would have been emitted if the waste had been landfilled, as depicted in Fig. 4.

Composting organic waste, as opposed to depositing it in landfills, has the potential to mitigate over 50% of carbon dioxide-equivalent greenhouse gas emissions, totaling 2.1 giga tons from 2020 to 2050, assuming successful mitigation of climate change to limit global temperature rise to 2 degrees Celsius (TALT, 2020). An emission reduction of 1.8 t CO_2 eq/t of MSW was possible with composting as per

Figure 4: Composting vs. landfilled emission statistic

the study done in 2002 (Ngnikam et al., 2002). Waste recovery, encompassing recycling and composting, emerges as a pivotal force in curbing greenhouse gas emissions. A study in Switzerland underscores this significance, with an impressive 87% probability that altering the waste recovery variable could yield emission reductions (Magazzino et al., 2020).

The difference in GHG emissions between landfills and composting systems is notable, mainly because anaerobic decomposition in landfills produces methane with a global warming potential (GWP) 25 times greater than carbon dioxide. Although methods such as energy recovery and appropriate landfill capping can help reduce this impact, composting remains a straightforward and highly efficient approach to diminish GHG emissions(Lou & Nair, 2009).

Conclusion and Recommendations

The GHG emission from MSW management of the Rampur municipality was estimated considering the current SWM practices. About 2772.79 tons per annum of solid waste was generated while only 1129.42 tons of the waste was landfilled due to poor collection efficiency of the Household (HH) waste. Organic waste dominates the HH and Commercial sector while paper-based waste is a major chunk in Institutions. A total of 2696.39 tCO_2eq with GHG emission intensity of 2.38 tCO_2 e/t MSW landfilled was emitted from the waste handling and operation. The composting practice has diverted 20 % of HH waste from landfills and abated 81 % of the GHG emissions. So composting practices can be used as the mitigating option for global climate change. The transport sector contributed 0.4 % of the total GHG emissions of the waste sector. Thus, it can be recommended that the priority to Composting practice can significantly mitigate GHG emissions. These findings can be useful for policymakers to prioritize the means for proper SWM and GHG mitigation.

Recommendations

In this research, composting has been found to reduce GHG emissions by 81.6 % compared to waste landfilled. Composting, known for its lower greenhouse gas emissions compared to landfilling, is a recommended waste management practice at household and municipal levels. For commercial waste, community composting can be a good source of income and employment for youth groups, women's alliances, and marginalized groups in the municipality. The decentralized nature of composting aligns well with waste management practices in smaller settings, ensuring a more localized and efficient approach. The utilization of composting techniques not only reduces the carbon footprint associated with waste disposal but also transforms organic waste into valuable compost that enriches soil fertility when reintroduced into the environment.

At the household level, adopting compost bins proves to be an important strategy for proper organic waste management. These bins provide a convenient and manageable means for residents to segregate and decompose organic waste on-site. By using compost bins, households actively contribute to diminishing GHG emissions. Furthermore, vermicomposting emerges as an additional environmentally friendly option for organic waste management at both household and community levels. Vermicomposting utilizes the natural processes of earthworms to break down organic matter, resulting in nutrient-rich vermicompost.

Nevertheless, composting and vermicomposting face various challenges. To achieve effective waste management and quality compost, users must undergo training. Additionally, access to compost bins is not readily available for all municipal residents. Although vermicomposting is an eco-friendly and straightforward technology, its successful implementation requires adequate knowledge, and acquiring the necessary worms may pose a challenge for those interested in adopting vermicomposting practices. A robust policy intervention regarding waste collection, segregation, composting, and resource recovery is essential to decrease the overall CH_4 emission from the waste.

Acknowledgments

The authors are thankful to the Department of Environmental Science, Tri Chandra Multiple Campus for the administrative support. We are thankful to officials of Rampur municipality for their support and to members of the Eco Club of Shree RamTulsi Secondary School for their contributions to data collection.

References

Aguilar-Virgen, Q., Taboada-González, P., & Ojeda-Benítez, S. (2014). Analysis of the feasibility of the recovery of landfill gas: a case study of Mexico. *Journal of Cleaner Production*, *79*, 53-60.

Arkin, H., & Colton, R.R. (1963). *Tables for Statisticians*. 2d ed. New York: Barnes and Noble. Inc.

Asian Development Bank (2013). *Solid waste management in Nepal: current status and policy recommendations*. Asian Development Bank.

Asnani, P. U., & Zurbrugg, C. (2007). *Improving municipal solid waste management in India: A sourcebook for policymakers and practitioners*. World Bank Publications.

Babel, S., & Vilaysouk, X. (2016). Greenhouse gas emissions from municipal solid waste management in Vientiane, Lao PDR. *Waste Management & Research*, *34*(1), 30-37.

Beck, S., & Mahony, M. (2018). The IPCC and the new map of science and politics. *Wiley Interdisciplinary Reviews: Climate Change*, *9*(6), e547.

Berisha, A., Veselaj, T., & Shallaku, F. (2018). Estimation of methane emission from solid waste landfill in Prizren. *Albanian Journal of Agricultural Science (Special edition 2018)*, *471476*.

Bhusal, P., Bashyal, K., Pandit, R., & Adhikari, B. (2020). Qualitative and quantitative analysis of municipal solid waste (MSW) in Butwal Sub-metropolitan City, Nepal. *Acta Scientific AGRICULTURE (ISSN: 2581-365X)*, *4*(9), 1-7.

Bo-Feng, C., Jian-Guo, L., Qing-Xian, G., Xiao-Qin, N., Dong, C., Lan-Cui, L., & Zhan-Sheng, Z. (2014). Estimation of methane emissions from municipal solid waste landfills in China based on point emission sources. *Advances in climate change research*, *5*(2), 81-91.

BP, N., Tabaroei, A., & Garg, A. (2023). Methane Emission and Carbon Sequestration Potential from Municipal Solid Waste Landfill, India. *Sustainability*, 15(9), 7125.

CBS. (2020). Waste Management Baseline Survey of Nepal 2020. Central Bureau of Statistics, Government of Nepal

Clean Energy Regulator. (2022, June 02). *Global warming potentials. Retrieved January 28, 2024, from https://www.cleanenergyregulator.gov.au/NGER/About-the-National-Greenhouse-and-Energy-Reporting-scheme/global-warming-potentials*

Dahal, Y., & Adhikari, B. (2018). An assessment of resource recovery potential and management of municipal solid waste in Jeetpur Simara Sub-Metropolitan City, Nepal. *Hydro Nepal: Journal of Water, Energy and Environment*, *23*, 93-96.

Dangi, M. B., Pretz, C. R., Urynowicz, M. A., Gerow, K. G., & Reddy, J. M. (2011). Municipal solid waste generation in Kathmandu, Nepal. *Journal of environmental management*, *92*(1), 240-249.

Dangi, M. B., Urynowicz, M. A., & Belbase, S. (2013). Characterization, generation, and management of household solid waste in Tulsipur, Nepal. *Habitat international*, *40*, 65-72.

Devadoss, P. M., Agamuthu, P., Mehran, S. B., Santha, C., & Fauziah, S. H. (2021). Implications of municipal solid waste management on greenhouse gas emissions in Malaysia and the way forward. *Waste Management*, 119, 135-144.

Dimiskovska, B., & Berisha, A. (2021). Calculation of methane emissions from municipal solid waste landfill germova using ipcc method. *Geo-Information*, *26*, 26-36.

EEA (2019). Data viewer on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism (EU

Member States).European Environment Agency. https://www.eea.europa.eu/data-and maps/data/data-viewers/greenhouse-gases-viewer

Hoeks, J. (1983). Significance of biogas production in waste tips. *Waste Management & Research*, *1*(4), 323-335.

IPCC (2015). *Revised IPCC guidelines for national greenhouse gas inventories 1996*.

IPCC (2021). *IPCC Sixth Assessment Report: Climate Change 2021. Intergovernmental Panel on Climate Change. – 6th Assessment Report Values.* Cambridge University Press, Cambridge.

IPCC (2006). *IPCC Guidelines for National Greenhouse Gas Inventories.* https://www.ipcc-nggip.iges.or.jp/public/2006gl/

Jeswani, H. K., Smith, R. W., & Azapagic, A. (2013). Energy from waste: carbon footprint of incineration and landfill biogas in the UK. *The International Journal of Life Cycle Assessment*, *18*, 218-229.

Jiang, Y., Zhang, H., He, J., & Zeng, Y. (2020, August). Carbon Emission of Municipal Solid Waste in Shanghai. In *IOP Conference Series: Earth and Environmental Science* (Vol. 555, No. 1, p. 012058). IOP Publishing.

Kaza S, Yao L, Bhada-Tata P and Van Woerden F (2018) *What A Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 (Urban Development Series)* (Washington, DC: World Bank) https://doi.org/10.1596/978-1-4648-1329-0

Kaseva, M. E., & Mbuligwe, S. E. (2005). Appraisal of solid waste collection following private sector involvement in Dar es Salaam city, Tanzania. *Habitat International*, *29*(2), 353-366.

KC, U., & Karmacharya, S. (2012). Report of Solid Waste Management Baseline Study in Bhaktapur Municipality. Solid Waste Management Technical Support Center (SWMTSC), Ministry of Local Development.

Kumar, A., & Sharma, M. P. (2014). Estimation of GHG emission and energy recovery potential from MSW landfill sites. *Sustainable Energy Technologies and Assessments*, *5*, 50-61.

Kumar, S., Mondal, A. N., Gaikwad, S. A., Devotta, S., & Singh, R. N. (2004). Qualitative assessment of methane emission inventory from municipal solid waste disposal sites: a case study. *Atmospheric environment*, *38*(29), 4921-4929.

Liguori, R., Amore, A., & Faraco, V. (2013). Waste valorization by biotechnological conversion into added value products. *Applied microbiology and biotechnology*, *97*, 6129-6147.

Li, Y., Zhang, S., & Liu, C. (2022). Research on greenhouse gas emission characteristics and emission mitigation potential of municipal solid waste treatment in Beijing. *Sustainability*, *14*(14), 8398.

Liu, Y., Ni, Z., Kong, X., & Liu, J. (2017). Greenhouse gas emissions from municipal solid waste with a high organic fraction under different management scenarios. *Journal of Cleaner Production*, 147, 451-457.

Lou, X. F., & Nair, J. (2009). The impact of landfilling and composting on greenhouse gas emissions–a review. *Bioresource Technology*, 100(16), 3792-3798.

Magazzino, C., Mele, M., & Schneider, N. (2020). The relationship between municipal solid waste and greenhouse gas emissions: Evidence from Switzerland. *Waste Management*, 113, 508-520.

Maskey, B., & Singh, M. (2017). Household waste generating factors and composition study for effective management in Gorkha municipality of Nepal. *Journal of Sustainable Development*, *10*(6), 169-185.

Medina, M. A. P., & Forten, R. R. C. (2015). Estimating Methane Gas Emissions from Solid Waste Generated by Households in an Urban Village in Bukidnon, Philippines. *American–Eurasian Journal of Agriculture and Environmental Sciences*, *15*(5), 837-842.

Mindat.org. (n.d.). Rampur, Pālpā, Lumbinī Zone, Pashchimanchal, Nepal. Mindat.

https://www.mindat.org/feature-7799035.html

MoEP (2017). National GHG Inventory. For Third National Communication to UNFCCC:https://www.climatenepal.org.np/sites/default/files/doc_resources/for%203rd%20communicator-Nepal%E2%80%99s%20GHG%20Inventory-Final_version_1562308551.pdf

Ministry of Natural Resources and Environment of Lao PDR. (2013). The second national communication on climate change submitted to the United Nations Framework Convention on Climate Change. Author

Ngnikam, E., Tanawa, E., Rousseaux, P., Riedacker, A., & Gourdon, R. (2002). Evaluation of the potentialities to reduce greenhouse gas (GHG) emissions resulting from various treatments of municipal solid wastes (MSW) in moist tropical climates: Application to Yaounde. *Waste management & research*, *20*(6), 501-513.

NSO (2023). *National population and housing census 2021(National Report), National Statistics Office,* Thapathali*, Kathmandu, Nepal*

Okot-Okumu, J., & Nyenje, R. (2011). Municipal solid waste management under decentralization in Uganda. *Habitat International*, *35*(4), 537-543.

Pathak, D. R., Mainali, B., Abuel-Naga, H., Angove, M., & Kong, I. (2020). Quantification and characterization of the municipal solid waste for sustainable waste management in newly formed municipalities of Nepal. *Waste Management & Research*, *38*(9), 1007-1018.

Pattnaik, S., & Reddy, M. V. (2010). Assessment of municipal solid waste management in Puducherry (Pondicherry), India. *Resources, Conservation and Recycling*, *54*(8), 512-520.

Ramachandra, T. V., Bharath, H. A., Kulkarni, G., & Han, S. S. (2018). Municipal solid waste: Generation, composition and GHG emissions in Bangalore, India. *Renewable and Sustainable Energy Reviews*, *82*, 1122-1136.

Rogelj, J. (2021). Limiting global temperature increase to 1.5° C above pre-industrial levels.

Shapiro-Bengtsen, S., Andersen, F. M., Münster, M., & Zou, L. (2020). Municipal solid waste available to the Chinese energy sector–Provincial projections to 2050. *Waste Management*, *112*, 52-65.

Singh, C. K., Kumar, A., & Roy, S. S. (2018). Quantitative analysis of the methane gas emissions from municipal solid waste in India. *Scientific reports*, 8(1), 2913.

Supriyadi, S., Kriwoken, L. K., & Birley, I. (2000). Solid waste management solutions for Semarang, Indonesia. *Waste Management & Research*, *18*(6), 557-566.

Talt, G. (2020). *The ComPOSTer: How much can composting help in solving the climate challenge?* Sustainable Composting Research at Princeton

https://scraplab.princeton.edu/2020/03/the-composter-how-much-can-composting-help-in-solving-the-climate-challenge/

Talyan, V., Dahiya, R. P., Anand, S., & Sreekrishnan, T. R. (2007). Quantification of methane emission from municipal solid waste disposal in Delhi. *Resources, conservation, and recycling*, *50*(3), 240-259.

Tchobanoglous, G., & Kreith, F. (2002). *Handbook of solid waste management.* McGraw-Hill Education.

Thanomnim, B., Papong, S., & Onbhuddha, R. (2022). The methodology to evaluate food waste generation with existing data in Thailand. *Thai Environmental Engineering Journal*, *36*(1), 1-9.

Thanh, H. T., Yabar, H., & Higano, Y. (2015). Analysis of the environmental benefits of introducing municipal organic waste recovery in Hanoi city, Vietnam. *Procedia Environmental Sciences*, 28, 185-194.

TNC (2021). *Third National Communication to the UNFCCC.* Government of Nepal:Ministry of Population and Environment (MoPE).

Umar, T. (2022). Greenhouse Gas (GHG) Emissions From Municipal Solid Waste (MSW) in Oman. *International Journal of Social Ecology and Sustainable Development (IJSESD)*, *13*(1), 1-26.

UNFCCC (2014). Greenhouse Gas Inventory Data. United Nations Framework Convention on Climate Change. https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/what-is-greenhouse-gas-data

UNFCCC (2016). *Adoption of the Paris Agreement, unfccc/cp/2015/L*, *9*.

United States Environmental Protection Agency (2002). *Solid Waste Management: A Local Challenge With Global Impacts.* National Service Center for Environmental Publications (NSCEP):

https://archive.epa.gov/region4/rcra/mgtoolkit/web/pdf/folder.pdf

Vergara, S. E., &Tchobanoglous, G. (2012). Municipal solid waste and the environment: a global perspective. *Annual Review of Environment and Resources*, *37*, 277-309.

Verma, R. L., & Borongan, G. (2022). Emissions of Greenhouse Gases from Municipal Solid Waste Management System in Ho Chi Minh City of Viet Nam. *Urban Science*, *6*(4), 78.

World Bank (2022) *Solid Waste Management.* World Bank: https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management

Yaman, C., Anil, I., & Alagha, O. (2020). Potential for greenhouse gas reduction and energy recovery from MSW through different waste management technologies. *Journal of Cleaner Production*, *264*, 121432.