Final Report on

Feasibility Study for the Solid Waste Management Practices in Gandaki Province, Nepal

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फोहोरमैला व्यवस्थापन गण्डकी प्रदेशको एक मुख्य समस्याको रुपमा देखापरेको छ । फोहोरमैलाको अनुचित व्यवस्थापनले वातवरण प्रदुषण संगसंगै जनस्वास्थ्यमा पनि प्रतिकुल असर पर्दछ । मुख्यतः, फोहोरमैला सम्बन्धित समस्याहरुको जरा बढ्दो सहरीकरण साथै फोहोरमैला व्यवस्थापनको लागि आवश्यक पूर्वाधारको कमिलाई मान्न सकिन्छ। यसै सन्दर्भमा, यस अध्ययनले गण्डकी प्रदेश भित्र अहिले भइरहेको फोहोरमैला व्यवस्थापनका अभ्यासहरुको पहिचान र फोहोरमैलाको चरित्रीकरण गरको छ । यस अध्ययनको लागि भिन्नभिन्न बस्तुगत अवस्था रहेका चार नगरपालिकाहरु; पोखरा महानगरपालिका, कुश्मा नगरपालिका, गैडाकोट नगरपालिका, र चामे गाउँपालिका छानिएको थिए । यस अध्ययनको लागि जम्माजम्मी ८० घरधुरीको फोहोरमैला संग सम्बन्धित तथ्यांक संकलन गरिएको थियो । यी ८० घरधुरीमा ७ दिन सम्म जम्मा भएको फोहोरको तौल तथा प्रकारको अध्ययन भएको थियो भने यिनै ८० घरधुरीमध्ये ३९ घरधुरीको भान्साबाट निस्किएको कुहिने फोहोरको नमुना संकलन गरिएको थियो । यसरी संकलन गरिएको नमुना प्रयोगशालामा बम क्यालोरीमीटर द्वारा परिक्षण गरि क्यलोरिफिक तथ्यांक खोज गरिएको थियो । साथसाथै, नगरपालिकामा यसै क्षेत्रसंग सम्बन्धित व्यक्तिहरुसंग छलफल गरि डम्पिंङ साइटको अनुगमन संगसंगै डम्पिंङ साइटमा थुपारिएको फोहोरमैलाको चारित्रिकरण पनि गरिएको थियो । अध्ययन गरिएका पलिकाहरु मध्ये पोखरा महानगरपालिकामा सबै भन्दा धेरै १३४ (२९३ ग्राम प्रति व्यक्ति प्रति दिन) टन प्रति दिन फोहोरमैला उत्सर्जन हुने गरेको पाइएको छ भने चामे गाउँपालिकामा सबै भन्दा कम ०.१८ टन प्रति दिन (१४६ ग्राम प्रति व्यक्ति प्रति दिन) फोहोरमैला उत्सर्जन हुने गरेको पाइएको छ। त्यसैगरि कुश्मा नगरपालिकाले ६.७५ टन प्रति दिन (१५३ ग्राम प्रति व्यक्ति प्रति दिन) र गैडाकोट नगरपालिकाले १४ टन प्रति दिन (१७९ ग्राम प्रति व्यक्ति प्रति दिन) फोहोरमैला उत्सर्जन हुने पाइएको छ। जम्मा एक तिहाई फोहोर मात्रै स्थानीय निकायद्वारा संकलन गरि डम्पिङ साइटमा डम्प गरेको पाइएको छ। दैनिक रुपमा पोखरामा ६० टन प्रति दिन, कुश्मा नगरपालिकामा १ टन प्रति दिन, गैडाकोट नगरपालिकामा ६.५ टन र चामे गाउँपालिकामा ०.१४ टन प्रति दिन फोहोरमैला संकलन गर्ने गरेको पाइएको छ। ठूलो मात्राको फोहोर भने सहरभित्रै थुपारिन्छ, जुन दैनिक जीवन र वातावरणका लागि निकै हानिकारक छ। संकलन गरिएको फोहोरमध्ये अधिकांश (६०% देखि ७२%) जैविक फोहोर रहेको पाइएको छ भने प्लास्टिकलाइ मुख्य अजैविक फोहोर मान्न सकिने अवस्था छ। कुल अजैविक फोहोरमैलामध्ये प्लास्टिकको मात्रा मनाङमा ३७% देखि पोखरामा ८८% सम्म पाइएको छ । फोहोरको वर्गीकरण, संकलन तथा परिवहन, पुनःप्रयोग र ल्याण्डफिल साइट सबै नगरपालिकामा समस्याग्रस्त अवस्थामा रहेको पाइएको छ । अध्ययन गरिएका सबै पालिकामा नमुना संकलन गरिएको घरधुरीले भने फोहोरको वर्गीकरण सन्तोषजनक रुप गर्ने गरेको देखिन्छ। यहाँ निस्केको फोहोरमा भान्साको फोहोर, प्लास्टिक, धातु/काँच, रबर, कपडाजन्य फोहोर, बायो-मेडिकलजन्य फोहोर, इलेक्ट्रोनिक फोहोर र अन्य किसिमका फोहोर पर्दछन् । गण्डकी प्रदेशको सहरबजारहरुमा नै पनि अजैविक फोहोरको तुलनामा जैविक फोहोर त्यति ठूलो समस्याको रूपमा देखिदैन किनभने जैविक फोहोर धेरै हदसम्म घरमा व्यवस्थित हुने साथै अजैविक फोहोर भने धेरै आयतनमा डम्पिङ साइटमा पुग्ने गरेको पाइएको छ । सबै नगरपालिकामा जैविक फोहोर व्यवस्थापनका लागि ऊर्जा उत्पादनको सम्भावना राम्रो छ। चामेमा गरिएको भान्साको फोहोरको नमुना परीक्षणमा यसको क्यालोरीफिक मान २७१० क्यालोरी/ग्राम पाइएको छ। पोखरा, कुस्मा र गाइडाकोटमा यो क्रमशः ३१६८ क्यालोरी/ग्राम, ३०७७ क्यालोरी/ग्राम र २३६३ क्यालोरी/ग्राम रहेको छ । यसबाट जैविक फोहोर व्यवस्थापनका लागि कम्पोस्ट मल बनाउने र फोहोरबाट ऊर्जा उत्पादन गर्ने प्रविधि स्वच्छ, आर्थिक र दिगो विकल्प हुन सक्छ भन्ने निष्कर्ष निकाल्न सकिन्छ। मनाङ जस्ता उच्च हिमाली क्षेत्रमा भने चिसो मौसमका कारण कुहिने दर निकै कम हुने हुनाले कम्पोस्ट मलभन्दा फोहोरबाट ऊर्जा उत्पादन उपयुक्त विकल्प हुन सक्छ। प्लास्टिक, काँच तथा धातुजन्य फोहोर व्यवस्थापनको लागि भने वृस्तित अध्ययन गरि उपयुक्त प्रबिधिको प्रयोग गर्नु नै अनुकुल हुने देखिन्छ । दीर्घकालीन सोचका लागि यस प्रदेशमा फोहोर व्यवस्थापन गर्दा ल्याण्डफिल साइटको अवधारणालाई त्यागी अझै उपयुक्त विकल्पको खोज अध्ययन गरि त्यसै विकल्पलाई आवलम्बन गर्नु पर्ने देखिन्छ

Executive Summary

Solid waste management has emerged as the considerable issue in Gandaki Province. Improper handling of solid waste not only leads to environmental pollution but also poses risks to public health and hazards. In this context, we have identified current practices and status of solid waste characterization in Gandaki Province. The four different municipalities i.e. Pokhara Metropolitan City, Kusma Municipality, Gaidakot Municipality and Chame Rural Municipality of the province were considered as sample study sites. Altogether, 80 households were visited to collect 7 days of waste sampling to assess the waste volume and composition. Fresh kitchen waste samples from 39 households were taken for the calorific value analysis in the laboratory analysis. The municipal and stakeholder consultation was done and landfill sites of the sampled four municipalities were visited, i.e., Lamiahal (Pokhara), Alaichibari (Kusma), Devchuli (Gaidakot) and Chatang (Chame, Manang). As the large Metropolitan city, Pokhara generates a higher volume of the waste i.e. 134 TPD (293 g/day/person) and the Chame Rural Municipality generates 0.18 TPD (146 g/day/person). The Kusma and Gaidakot generate 6.75 TPD (153 g/day/person), 14 TPD (179 g/day/person), respectively. Only one third of waste is collected by the municipality and transported to the dumping sites i.e., 60 TPD in Pokhara, 1 TPD in Kusma, 6.5 TPD in Gaidakot and 0.14 TPD in Chame. The large fraction of waste sink inside the cities, which can impact daily life and the environment. The majority of the waste was found to be organic >60% to 72%, and plastics are the major dominant waste among non-degradable types, with volume found at 37% in Manang and 88% in Pokhara. The segregation of the waste at municipal level, packaging, recycling and landfill site issues are main problems in all the municipalities. In majority, household level waste segregation is satisfactory. The main household waste types are kitchen waste, plastics, metal/glass, rubber, fiber and clothes, biomedical, e-waste and other types. Organic waste is not a big problem in the cities compared to inorganic waste because the large volume of inorganic waste goes to dumping sites. The energy potentiality of organic solid waste in all the municipalities is considerable. In Chame, the average calorific value of the organic waste found was 2710 cal/g. Similarly, calorific values in Pokhara, Kusma and Gaidakot were 3168 cal/g, 3077 cal/g and 2363 cal/g respectively. From this study, it can be concluded that composting and waste to energy techniques could be the best fit for organic waste management. However, for highlands like Manang, waste to energy could be an appropriate option compared to composting because the decomposition rate is very slow due to the cold climate. The inorganic waste like plastic, glasses and metal should be managed by applying appropriate technologies after a detailed feasibility investigation. Considering long term approach, waste volume reduction at the source, increas reuse and recycle strategy and appropriate management through sanitary landfill compared to open dumping should be adopted for municipal waste management. In a long term approach, the province should aim to achieve a zero-landfill future for municipal waste through comprehensive source reduction strategies.

Keywords: Organic waste, waste characterization, landfill, management technologies, calorific value

Table of Contents

List of Tables

List of Figures

List of Photos

Acronyms and Abbreviation

ADB	Asian Development Bank
Cal	Calorie
CBS	Central Bureau of Statistics
CDES	Central Department of Environmental Science
CO_2	Carbon dioxide
EPA	Environment Protection Act
EPA	Environmental Protection Act
g	Gram
G/C_{daily}	Generation and Collection ratio
HHs	Households
Kg	Kilogram
KII	Key Informant Interview
KJ	Kilo Joule
Km	Kilometer
LFG	Landfill Gas
MoU	Memorandum of Understanding
MSW	Municipal Solid Waste
MSW	Municipality Solid Waste
NTNC	National Trust for Nature Conservation
°C	Centigrade
PMC	Pokhara Metropolitan City
PPPC	Province Policy and Planning Commission
PPSP	Public Private and Stakeholder Partnership
PPT	Polyethylene Terephthalate
SWMRMC	Solid Waste Management and Resource Mobilization Center
TPD	Tonnes of Waste per Day
WTE	Waste to Energy

1. Introduction

Waste often denoted as refuse or detritus, encompasses a wide array of discarded materials deemed useless and unwanted, ranging from product packaging to kitchen scraps, furniture to appliances, clothing, bottles, kitchen waste, food scraps, newspapers, appliances, paint, and batteries. Originating from households, schools, hospitals, and businesses alike, this conglomerate of waste commonly known as municipal solid waste (EPA, 2023). This category encapsulates any solid or semi-solid waste discarded by owners, spanning residential, commercial, institutional, construction, demolition, and certain industrial sources (Tchobanoglous et al., 1993; Franklin, 2002). The predicament of solid waste management is compounded by the staggering volume of waste generated, a predicament exacerbated by population growth, industrialization, and economic expansion. A report by the World Bank projects a drastic surge in urban waste generation, estimating it to have reached 2.24 billion tons in 2020, with expectations of a 73% increase to 3.88 billion tons by 2050 (Pathak et al., 2002). The mounting waste poses significant environmental hazards, capable of polluting air, water, and soil when improperly disposed (Vyas et al., 2022). Insufficient solid waste incineration contributes to air pollution, while soil and water contamination further exacerbate the issue, ultimately jeopardizing public health by fostering a spectrum of ailments (Nathanson, 2004). Moreover, it may create serious environmental impacts like generation of methane, spread of infectious diseases, clogging of drains and loss of biodiversity (Ejaz et al., 2010). It is a commonly accepted concept that waste generation follows increase in population. With the estimation that the world's urban population reaching up to 4,285 million by 2025, 1,229 million in East Asia Pacific and 734 million in South Asia Pacific will be residing in the city (Hoornweg et al, 2012). This situation appears grim, specifically for developing and underdeveloped nations including Nepal. In case of Nepal, a steep increase in urban population was observed in the last decade, and solid waste production followed a similar pattern creating one of the severe environmental problems in Nepal. In Nepal, ten categories of waste are defined namely organic, plastics, paper and paper products, metals, glass, rubber and leather, textiles, dirt and construction debris, hazardous wastes, and other wastes (Dangi et al., 2013, 2011). However, ADB (2013) and Pathak et al. (2020) reported only eight categories (dirt and construction debris and hazardous wastes were not reported). Additionally, the new categories namely organic, plastics, paper and paper products, metals, glass, rubber and leather, textiles, and others are defined by CBS (CBS, 2021)

The Government of Nepal passed the Solid Waste Management Act on 15 June 2011 (SWMC, 2011). The objectives are to maintain a clean and healthy environment by minimizing the adverse effects of solid waste on public health and the environment. According to this act, municipalities and other local bodies are responsible for constructing, operating, and maintaining the infrastructure for collecting, treating, and disposing of municipal solid waste (MSW). The act requires local bodies to encourage the "3Rs" - reduce, reuse, and recycle - and to sort MSW at the source. As per this act, private-sector companies, community-based organizations, and non-government organizations can also participate in solid waste management (SWM) by submitting bids. The act allows for the imposition of service fees and provides guidelines for fixing and collecting them. Despite these rules and regulations, many municipalities are facing problems in scientific disposaling of solid waste. In a study conducted by ADB in Nepal in 2013, out of 58 municipals surveyed, only six municipalities use sanitary landfills for disposing of solid waste, and the rest are practicing open dumping, including riverside and roadside dumping (ADB, 2013). The total amount of waste generated from the country is approximately one million mt/year, of which 3,86,690 mt/year is contributed by households, 2,45,884 mt/year by business houses, 1,03,244 mt/year by educational institutes, 94,392 mt/year by industries, 1,01,507 mt/year by health institutions, and

66,220 mt/year by other sectors (CBS, 2021). Landfill is engineered facilities used to deposit residual solid waste on the surface of the earth that require careful planning, operation and management of waste with daily soil cover and post closure plan. However, with growing regulation and limited applications of them in developing countries, the definition of landfills is not strictly adhered in Nepal (Dangi, 2021).

The municipal waste is generated from varied sources such as households, institutions, business/commercial complexes, hospitals, etc. Among the metropolitan cities, the quantity of daily waste collection was highest in the household (15900 kg/day), followed by business complex (7700 kg/day) and the educational institutes (4680 kg/day). Similarly, the households remained the major sources of waste generation in the sub-metropolitan cities (3300 kg/day) and municipalities (1440 kg/day) (CBS, 2020). Out of total generation, only half is collected and disposed without any treatment. Of the 293 urban local level (out of a total 753 local level governments) only a few cities have developed sanitary landfills for the scientific disposal of collected waste (World Bank, 2020). Landfilling is commonly used in developing countries to dispose of solid waste. However, landfilling practices are associated with several problems as they pollute the surrounding air, contaminate surface and groundwater bodies, increase greenhouse gases, and clog the city drains (Vinti, 2021). The recovery values of solid waste in terms of biogas from landfill, compost and plastic/glass waste are very high among municipal waste types in Nepal (Dhakal and Adhikari, 2018). Landfills are considered as cornerstone of solid waste management. Landfill gas (LFG) and leachate are principal outputs from landfills. Methane, occupying significant volume of landfill gas, has considerable potential as a source of energy replacing enormous amounts of fossil fuels currently in use. Similarly, biogas plants based on huge volume of organic waste generation in cities are another potential option to minimize global warming and offset significant amounts of fossil fuels (Kumar et al., 2014). Moreover, the landfill site requires enormous land resources, which are scarce. The scientific disposal of municipal solid waste (MSW) reduces environmental pollution, promotes resource conservation, and supports sustainable urban development. Therefore, different technologies, such as mechanical, biological, and thermal technologies, have been developed to manage municipal solid waste (MSW) scientifically (Escamila, 2020). Among these technologies, waste incineration and plastic pyrolysis are considered the most effective, and reliable form of waste management that converts waste into energy worldwide (Sun et al., 2021). The resource recovery and economical conversion of plastic waste and development of iron–silicate composites by glass and iron wastes are another key adopting practices (Rada et al., 2023). The pedal power i.e., khalisisi.com has become a proud recycler in Nepal who recycled 40% of recyclable waste. They buy paper, glass, plastic, metal and steel, e-waste, brass, PET bottle daily from each household (Khalisisi.com, 2024). The three tier of Nepal government is facing the big problem of solid waste management. Now, the federal structure and the local governments are given management authority and responsibility to manage the waste generated in their municipality. Therefore, they are themselves authorized to reform human resource, infrastructure setup, management plan and innovative technologies for municipal solid waste management in the context of growing urbanization and their increasing consumption ratio in Nepal

1.1. Scope of the study

The management of solid waste is becoming an increasingly concerning issue in Nepal as urban population densities rise and available flat usable land becomes scarce. Although small urban centers have been declared municipalities (with populations exceeding 20,000 and annual revenues of NRs. 10 million), they face challenges due to a lack of infrastructural and technical resources to address waste management issues. In recent decades, Nepal has struggled to effectively manage its municipal solid waste (MSW), with MSW posing a critical issue in both Pokhara and Kathmandu Metropolitan City, as highlighted by Neupane (2004a, 2004b) and SWMRMC et al. (2004). Only

18% of the urban population in Nepal is served by MSW management units (Sharma, 1992), leading to trial-and-error approaches evident in the indiscriminate waste disposal observed in the streets of Kathmandu and Pokhara. These practices have resulted in significant declines in air and water quality, as well as overall public health. In this context, the main task and scope of this study are to identify and assess

- Status and current practices of solid waste management
- Volume and composition of solid waste generation (Daily/Annual)
- Review on sanitary landfilling, biogas plant, incinerator, plastic pyrolysis plant, vermi composting, organic manure, 3R and source reduction technologies.
- Assessment of required human resource and infrastructure setup
- Recommend best possible techniques based on results observed

2. Objectives

The overall objective of this project is to recommend environment-friendly alternatives for solid waste management practices in Gandaki Province. Current waste management practices and the volume and composition of the waste generated were identified through pilot field visits and laboratory experiments. Then, feasibility study on different possible options of waste management techniques was reviewed through literature and scientific publications and obtained output from waste composition and strength (calorific values of decaying waste) observation. Finally, the best possible options of solid waste management techniques for both decomposable and non-decomposable wastes will be recommended. The sub-objectives of the proposed project are as follows:

- Identify the status and current practices of solid waste management in the Gandaki Province concerning segregation, collection, treatment, and final disposal
- Estimate the volume and composition of solid waste generation in major cities of the Gandaki Province.
- Feasibility study on sanitary landfilling, biogas plant (waste to energy), incinerator and plastic pyrolysis plant (waste to fuel), vermi composting, organic manure, 3R and source reduction technologies.
- Assess the required level of human resources, service allocation and infrastructure setup for waste management in municipalities.
- Identify and recommend the best possible options for solid waste management practices in the province.

3. Study area, data and method

3.1. Study area

Gandaki Province, the third-largest province in terms of geographical area, has a population of 2,479,745, according to the latest Population Census Survey 2021. Of this population, 65.71% reside in urban areas, while 34.29% live in rural areas (CBS, 2021). Pokhara, the capital city of Gandaki Province, is one of the million-plus cities in Nepal. The province comprises eleven districts, including one metropolitan city, 26 municipalities, and 58 rural municipalities (Nepal Outlook, 2023), with several major cities such as Pokhara, Kawaswoti, Gaindakot, and Baglung.

These cities currently rely on landfilling for managing their municipal solid waste, although there have been recent public protests against this practice. For instance, in Pokhara Metropolitan City, solid waste was left unattended for weeks after the closure of the landfill near Pokhara International Airport due to local objections. Instead, the metropolis began dumping waste at a temporary garbage management site on the bank of the Seti River at Lameahal in Metropolis-32 (Republica, 2023). Unfortunately, residents protested against this move, citing a lack of implementation of an earlier agreement. In the future, other major cities in Gandaki Province may encounter similar issues. The Pokhara, Kusma (Mid land), Nawalpur Gaidakot (Lower land) and Chame Manang (High land) are selected for our field study and represent cities of the Gandaki Province (**Figure 1**)

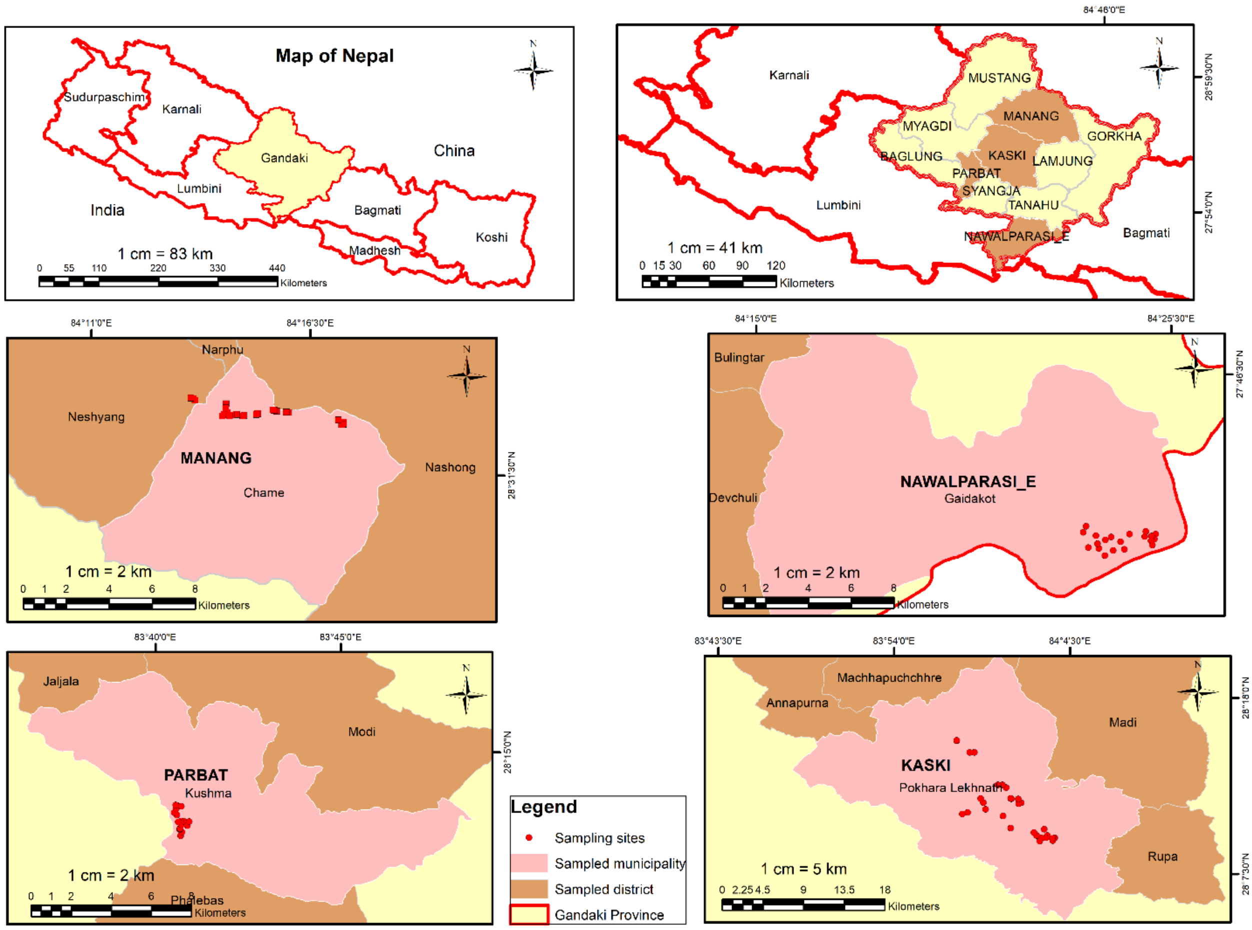

Figure 1: Location map of study area showing major cities (Pokhara, Kusma, Gaidakot and Chame, Manang) and sample sites in the Gandaki Province

3.2. Data

Waste generation in seven days from each household in four cities, as shown in Figure 1, were used to record and measure different types of organic and inorganic waste generation. Approximately 10-15 samples of fresh organic waste from each city were collected and taken to the laboratory to determine their calorific values. The landfill sites were visited and sampled to identify different types and volumes of waste disposed. Besides, the data were compiled and collected from government and non-government reports, stakeholder consultation and scientific literatures.

3.3. Methods

3.3.1. Waste characterization at the households

Thirty-two households in Pokhara, Kaski, twenty households in Kushma, Parbat, twenty households in Gaidakot, Nawalparasi, and twenty-seven households in Chame, Manang were randomly selected as sampling points. Two polythene bags, one labeled ‘degradable waste’ and the other labeled ‘non-degradable waste’, were distributed to each household. Household owners were instructed to separate their waste and place it into two designated bags for a week. The separated waste was collected after one week. A short interview was conducted with the household owner to gather information about the practice of solid waste segregation, the tentative mass of waste generated per day, the frequency of waste collection by the municipality, and the family size.

All the households selected for sampling were revisited on the seventh day to weigh and characterize the waste generated by those households over the seven days. The organic waste was weighed in sum total. However, non-degradable waste was classified into plastics, rubber, textiles, metal and glass, and others. Furthermore, the weight of each subcategory was recorded.

3.3.2. Waste characterization at landfill site

A quadrat of one cubic meter was randomly laid down over the waste dump site at the landfill in Pokhara. The dumped waste was first segregated, then collected and weighed to characterize the waste at the site. Waste characterization at the landfill site was not done for Kushma and Chame. In Kushma, the dumped waste was already segregated, while in Chame, the dumped waste was being burned.

3.3.3. Organic wet waste sample collection

Organic wet waste samples were collected from twelve households in Pokhara, ten in Kushma, ten in Gaidakot, and seven in Chame. These wet waste samples were analyzed to determine their calorific value.

3.3.4. Determination of calorific value

The calorific value was determined using a bomb calorimeter (**Photo 1**). The organic wet sample was collected in a zip-locked plastic bag. In the CDES laboratory, the sample was oven-dried at 100°C for 24 hours. The dried sample was then ground using a grinding machine and sieved through a 200 µm sieve. The resulting sample was used to determine the calorific value.

A portion of the waste, weighing between 0.7 and 0.9 grams, was transferred to the receptacle of the bomb calorimeter. A nichrome wire was fitted on the ignition rod, and oxygen was supplied to the bomb and kept inside the calorimeter containing 2 liters of distilled water. The bomb inside the nichrome wire was ignited and the raise in temperature of the water was noted. The calorific value was calculated following the equation

$$\text{Calorific value } \left(\frac{\text{cal}}{\text{g}}\right) = \frac{2325 \times \text{raise in temperature of the water (°C)-45}}{\text{Weight of the sample taken (g)}}$$

Photo 1: Measuring the calorific value of the organic waste samples brought from the field at CDES laboratory

3.3.5. Key informant's interview

In all four local governmental levels, Key Informant Interviews (KII) were conducted. These included meetings with Municipal Environment and Sanitation Officers, the Environment and Sanitation Department Head, and Chief Administrative Officers.

In Pokhara Metropolitan City, the team met with Sanitation Department Head Ms. Kalpana Baral and Environment Officer Mr. Nirmal Bhandari on May 8, 2024. In Kushma Municipality, the team met with the Mayor and municipal officials working in the waste management sector as key informants on May 10, 2024. In Gaidakot Municipality, Nawalparasi, the team met with Mr. Shankar Kharel, Environmental Officer, as key informant on May 26, 2024. Similarly, in Chame, Manang, a meeting was arranged with the chief administrative officer of Chame Rural Municipality. Also, information about solid waste management practices was obtained from National Trust for Nature Conservation (NTNC) office.

3.3.6. Focused group discussion

Besides meeting with municipality officials, the CDES team scheduled a meeting with private companies working in the waste management sector. In Pokhara Metropolitan City, the team met with representatives from all eight companies that work in waste management in Pokhara on 9th May 2024. This focused group discussion was conducted to obtain data and information from the private companies' perspective. However, none of the other three municipalities had the active participation of the private sector in waste management; thus, no such meetings were arranged.

4. Data analysis

Daily waste generation was analyzed based on data obtained from 7 days of household-level waste collection, which were characterized by organic and different types of inorganic wastes in four municipalities of Gandaki province. The daily waste collection at landfill sites was analyzed based on daily vehicles used to collect and transport the water from sources to landfill/dumping sites. The daily waste generation, collection and transportation were estimated in four sample municipalities. The samples of organic waste were taken from the fields to the lab where the calorific values were measured and analyzed to recommend for energy use. Solid waste management in highland municipalities like Chame, Manang was critically analyzed because the waste decomposition rate was slow and difficult to transport recyclable waste to the resource center. Beside this, the current practices observed during the field visits, available literatures, official documents and useful practices in other municipalities were systematically reviewed.

5. Results and discussion

5.1. Status, volume and composition of MSW in Gandaki Province

5.1.1. Pokhara Metropolitan City, Kaski

From discussions with key informants, including the head of the Sanitation Department and the Environment Department of the municipality, several issues and insights were revealed about waste management in Pokhara. The old sanitary landfill site at Bachhebudha was closed because it was only 2 km from Pokhara International Airport, posing a risk due to its proximity. Currently, waste is being dumped at the Lameaahal landfill site, as shown in photo 5, which is about 13 km from the airport. However, Lameaahal is not a sanitary landfill site; the waste is covered with earth daily to prevent bad odors. Most households practice waste segregation, but the segregated waste is still dumped in the same landfill site, rendering the effort ineffective. The proposed site for a new sanitary landfill is located at Punitar, Jhakrikhola. There is ongoing conflict between the local community and the government regarding compensation at this proposed site. Pokhara Metropolitan City is searching for an alternative landfill site because the current site at Lameaahal is expected to be full within the next five years. Waste collection occurs once a week in core urban areas and once a month in suburban areas. The metropolitan city has fully handed over waste collection to private companies. Currently, six private waste collection companies are in operation in Pokhara. The estimated waste generation in the metropolitan area is 180-200 tonnes per day. There are 35 vehicles in operation, each making three daily trips, totaling 105 daily trips to the landfill site. These private companies collect waste tariffs from the community and pay 20% of their revenue to the metropolitan city. Previously, when waste segregation was practiced, the metropolitan city could generate up to 4.5 million rupees annually by selling recyclable waste. However, now the municipality receives only 2 million rupees from the private companies. Waste segregation is a problem for the Lameaahal site because the public wants the site to be filled quickly to avoid the problems created by this dumping site, causing conflicts between the government and the general public.

In Pokhara, six private waste collection companies are responsible for managing the waste collection process under the authority of the metropolitan city (photograph 4). These companies own a fleet of 35 vehicles, comprising 12 larger trucks and 23 mini trucks, which operate daily to collect waste across the metropolitan area. The landfill site at Lameaahal, currently used for waste disposal, is managed by two people in charge: one city police officer, two excavator operators, one helper, and one driver. The waste collection tariff is set by the metropolitan city and is based on the size and stories of the house rather than the number of residents. This system has raised concerns among private companies, as they believe a tariff system based on the number of residents would be more equitable. Waste collection is allowed from as early as 5:30 AM to between 3:30-4:00 PM, but private companies have expressed a willingness to work longer hours if permitted to enhance efficiency. At the Lameaahal landfill site, the excavator, owned by the metropolitan city, is used exclusively to level the dumped waste and cover it with earth material. This process requires 16-18 trips of earth material daily, which is excavated from Riththepani and transported to the site. After covering the waste with earth material, an Effective Microorganism (EM) solution is sprinkled over the surface to manage odors and enhance decomposition. Despite these efforts, the current landfill site at Lameaahal is not a sanitary landfill, leading to concerns about its long-term sustainability. The private companies highlighted that the waste collection system, which relies on private firms, could benefit from extended operational hours and a revised tariff structure to improve efficiency and fairness. They also noted the pressing need for a more sustainable landfill solution, given that the Lameaahal site is expected to reach capacity within the next five years.

 **Photo P 1:** Study team with Sanitation Department Head in Pokhara Metropolitan City	 **Photo P 2:** Study team with the representatives from private waste collecting companies at Pokhara Metropolitan City
 **Photo P 3:** Expert team of CDES at Lameahal sanitary Landfill site of Pokahara Metropolitan City	 Photo P 4: Expert team of CDES consultation with stakeholders at Pokhara Metropolitan City
 **Photo P 5:** Waste sampling for segregation at Lameahal sanitary Landfill site of Pokahara Metropolitan City	 **Photo P 6**: Kitchen waste sampling at household level for Calorific Measurement at Pokahara Metropolitan City

Waste characterization at the household

A week-long observation of solid waste generated at the households in Pokhara Metropolitan City revealed that it comprises 60% degradable and 40% non-degradable waste (Figure 2). Residential biodegradable waste is mainly composed of paper and kitchen waste, that is composted at the household level. Households use wet waste to feed livestock such as chickens and pigs. The non-biodegradable waste from households is collected by the garbage trucks and dumped at the landfill site. In other ways, households generate an estimated 134 tonnes of waste per day (TPD). Of this, 82 TPD (61%) is organic wet waste and 52 TPD (39%) is inorganic waste. Per capita, households generate 180 grams of organic wet waste and 113 grams of inorganic waste daily.

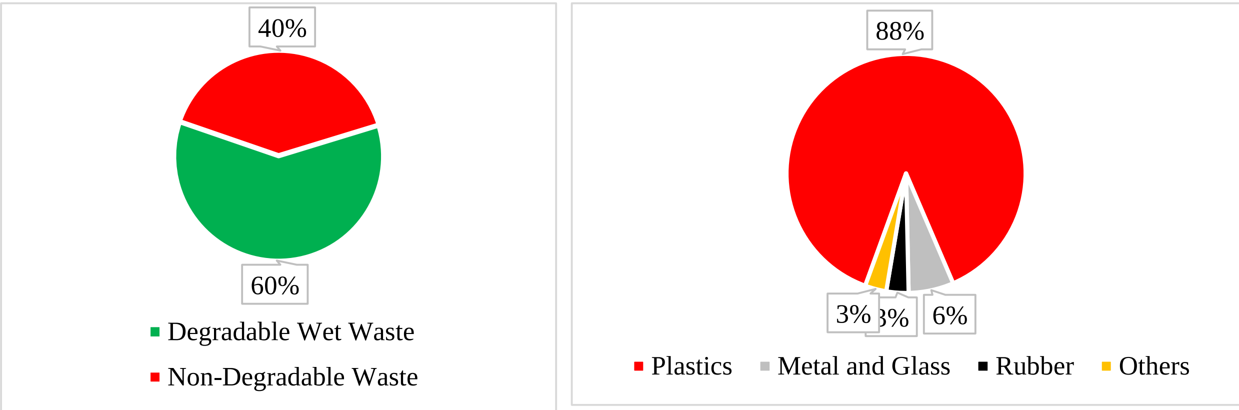

Figure 2: Characterization of residential non-degradable solid waste of Pokhara Metropolitan

Out of 40% non-biodegradable waste, plastic waste was found to be 88%, the highest fraction among any other categories of non-biodegradable waste. Likewise, metal and glass, rubber and others (textiles, earthen materials, etc.) accounted for 6%, 3%, and 3%, respectively. Solid waste dumped at Lameaahal Landfill Site was characterized. A one-meter cubic plot (1m3) was excavated at the landfill site to segregate waste from the plot. After segregating the materials, it was found that plastic constituted the largest portion, accounting for 23% of total waste (Figure 3).

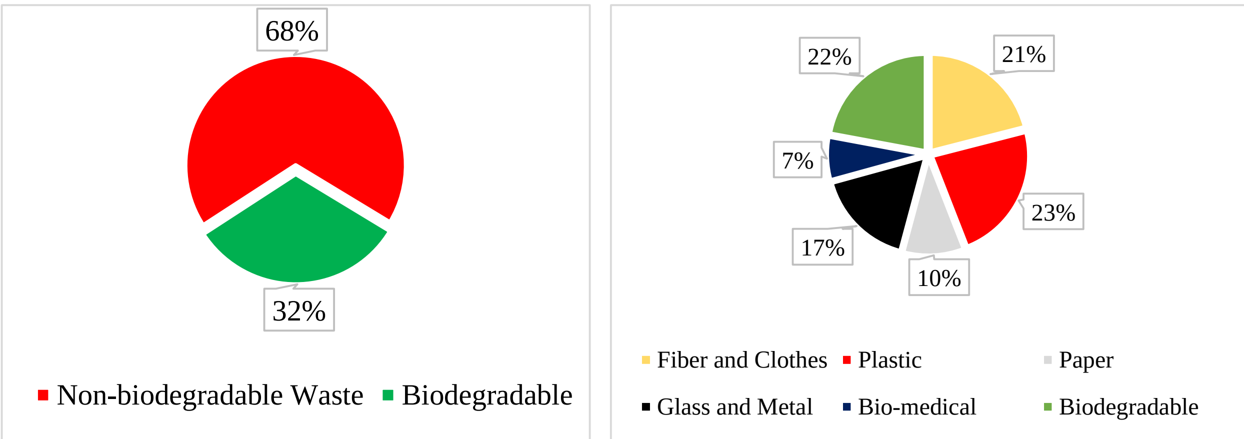

Figure 3: Waste characterization and composition of Pokhara Metropolitan City based on landfill site observation at Lameaahal Landfill Site

Moreover, textile based waste, paper based waste, bio-medical waste, metal and glass, and the biodegradable wet waste accounted for 21%, 10%, 7%, 17% and 22%, respectively. Altogether, biodegradable waste at Lameaahal Landfill Site accounted for 32% of the total waste dumped. The non-biodegradable waste accounted for more than twice the percentage of biodegradable waste i.e., 68%.

Calorific value of the organic waste

In Pokhara Metropolitan City, 12 residential wet waste samples were collected (photo 6) and analyzed for calorific values using a bomb calorimeter. The mean calorific value of these samples was found to be 3168±849.3 KJ/g with calorific values ranging from 1279.2-3994.1 KJ/g (Table 1 and Table 2).

Table 1: Sample-wise calorific values of kitchen waste in Pokhara Metropolitan City

Location	Sample	Energy (Cal/gm)	Energy KJ/g
	OS1	3659.2	15.3
	OS2	3953.3	16.5
	OS3	1917.1	8.0
	OS4	3206.1	13.4
	OS5	3994.1	16.7
Pokhara	OS6	3543.3	14.8
Metropolitan City	OS7	3570.4	14.9
	OS8	3510.3	14.7
	OS9	2464.0	10.3
	OS10	3163.6	13.2
	OS11	1279.2	5.4
	OS12	3755.3	15.7

Table 2: Summary statistics for calorific values of kitchen waste in Pokhara Metropolitan City

Summary Statistics	Pokhara Metropolitan City	
	Energy (Cal/g)	Energy (KJ/g)
Mean	3168.0	13.3
Max	3994.1	16.7
Min	1279.2	5.4
Std Dev	849.3	3.6

Based on a week-long observation, the estimated mean per capita energy generation per day from residential wet waste is 790.5±548.5 with the values ranging from 181.8-2799.5 KJ/g (Table 3).

Table 3: Estimated per capita energy generation per day (KJ/g) of Pokhara Metropolitan City

Summary Statistics	Estimated per capita energy generation per day (KJ/g) of Pokhara
Mean	790.5
Max	2799.5
Min	181.8
Std Dev	548.8

5.1.2. Kushma Municipality, Parbat

The Kusma Municipality has rented approximately 5 Ropani land for ten years in Alaichibari, which is located at ward no 4 of Kusma Municipality to manage the solid waste as shown in pictures below. The municipality has collected 2-ton organic waste and 1.5-ton of inorganic waste daily from households and dumped in the dumping sites i.e., at Alaichibari landfill site on the way to Beni/Baglung. Household level segregation (organic and inorganic) seems good but dumping in same places makes havoc in Kusma Municipality. Hospital waste dumping without sterilization and mixing with other organic waste and glasses is a major problem on the sites. A meeting with representatives from Kushma Municipality, including the mayor and other relevant staff, revealed that the municipality collects solid waste from urban areas. The collected waste is dumped at Alaichibari, 3 km northwest of the main city. The annual revenue from waste collection amounts to 2.4 million rupees. The municipality operates two vehicles for waste collection. Although segregated waste is collected from households, both organic and inorganic waste are ultimately dumped at the same site. It was observed during field visit that the landfill site of Kushma Municipality lies in sloppy land near to drinking water source posing health risk to local people.

Photo K 1: Study team with Sanitation Department team of Kusma Municipality at Alaichibari Dumping site

Photo K 2: Waste at Alaichibari Dumping site, Kusma Municipality

Photo K 3: Haphazard dumping of hospital waste at Alaichibari Dumping site, Kusma Municipality

Photo K 4: Haphazard dumping of glass waste at Alaichibari Dumping site, Kusma Municipality

Photo K 5: Household consultation at Kusma Bazar

Photo K 6: Consultation with relevant local stakeholder/staff at Kusma Municipality

Household waste characterization

A week long observation of solid waste generated at the households in Kushma Municipality revealed that out of 6.75 TPD residential waste generated in the municipality is composed of 72%

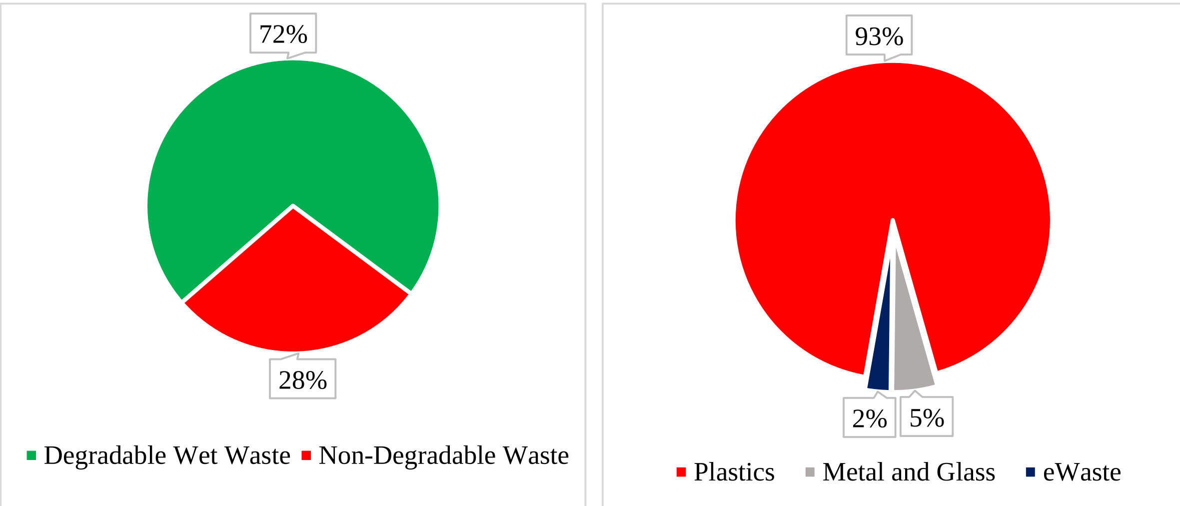

Figure 4: Characteristics of Residential Solid Waste and types of non-degradable waste of Kushma Municipality

degradable and 28% non-degradable waste (Figure 5). Residential biodegradable waste, mainly composed of paper and kitchen waste, is mostly composted at the household level. Households use wet waste as feed for the livestock. The non-biodegradable waste from households is collected by the garbage trucks and dumped at the dumping site.

Out of 28% non-biodegradable waste, plastic waste was found to be 93%, the highest fraction among any other categories of non-biodegradable waste (Figure 5). Likewise, metal and glass and e-waste accounted for 5% and 2%, respectively.

Calorific value of organic waste

In Kushma Municipality, 10 residential wet waste samples were analyzed for calorific values using bomb calorimeter. The mean calorific value of these samples was found to be 3077.7±559.9 KJ/g with calorific values ranging from 2490.7-4250.6 KJ/g (table 4 and table 5).

Table 4: Sample-wise calorific values of kitchen waste in Kushma Municipality

Location	Sample	Energy (Cal/g)	Energy (KJ/g)
Kushma Municipality	KOS1	3109.7	13.0
	KOS2	3454.7	14.5
	KOS3	4250.6	17.8
	KOS4	2965.9	12.4
	KOS5	2641.5	11.1
	KOS6	2666.5	11.2
	KOS7	2490.7	10.4
	KOS8	3659.0	15.3
	KOS9	2598.2	10.9
	KOS10	2940.5	12.3

Table 5: Summary statistics for calorific values of kitchen waste in Kushma Municipality

Summary Statistics	Kushma Municipality	
	Energy (Cal/g)	Energy (KJ/g)
Mean	3077.7	12.9
Max	4250.6	17.8
Min	2490.7	10.4
Std Dev	559.9	2.3

5.1.3. Gaidakot Municipality, Nawalparasi

The Key Informant Interview (KII) was conducted with the representative of an Environment and Disaster Management Officer of Gaidakot Municipality. The municipality is actively seeking to secure land for a proper landfill site, with the proposed site already identified at Narayani Kinar, Gaidakot-07. Currently, waste is being dumped at Narayani Kinar, which is not a designated landfill site. The waste management service currently covers only 65% of the municipality. The waste collection process in Gaidakot involves four vehicles, two owned by the municipality and two rented. These vehicles make a total of 12 trips per day, each carrying 6 cubic meters of waste. Every day, the dumped waste is covered with earthen material using an excavator. Despite these efforts, the municipality faces significant financial challenges in waste management. The total annual revenue from waste management is 16-17 lakhs, with a tariff of 300 rupees per household per year. However, the municipality incurs a loss of about 60 lakhs annually in waste management operations. The human resources involved in this work include 12 employees, comprising 4 drivers and 1 site assistant sub-engineer.

Table 6: General scenario of MSW of GKM in a nutshell (GKM, 2024)

Total Area (km^2)	**159.93**
Total Population	80737
Population Density (persons per km^2)	505
Total number of Households	17,151
Total number of wards	18
Average HH size	4
Average HH waste (kg/day)	0.72
Average per capita HH waste (g/capita/day)	152.69
Total HH waste (ton/day)	12.33
Total institutional waste (ton/day)	0.32
Total commercial waste (ton/day)	3.49
Average per capita MSW (g/capita/day)	199.91
Total MSW generation (ton/day)	16.14

	
Photo G 1: Proposed Landfill site at Debchuli Gaidakot Municipality, Kawasoti	**Photo G 2: Current dumping at the bank of Narayani River in Gaidakot**
	
Photo G 3: Consultation with Environment Engineer at Gaidakot Municipality office	**Photo G 4: Organic sample collection at Household level in Gaidakot Municipality**

Household waste characterization

A week-long observation of 20 households in Gaidakot Municipality revealed that 71% of the waste generated was biodegradable (Figure 6). Of the 29% non-biodegradable waste, 58% was plastic, 26% was glass and metal, 4% was rubber, 8% was e-waste, and 4% was classified as other types of waste (Fig. 8). These findings highlight the significant proportion of biodegradable waste, as well as the composition of non-biodegradable waste generated by households.

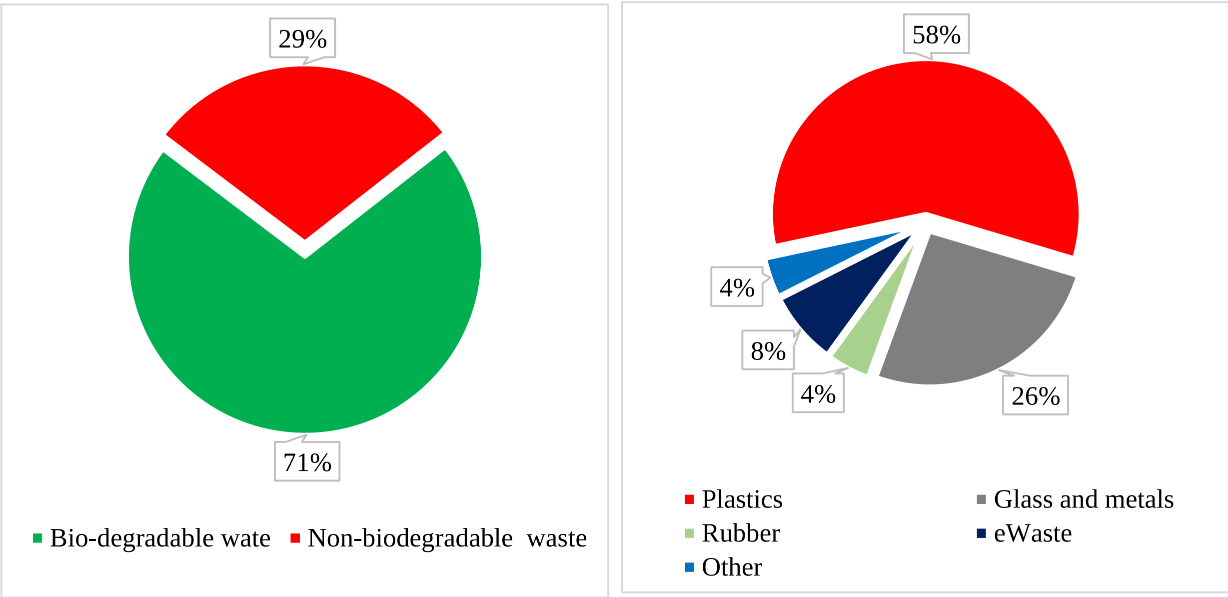

Figure 5: Characteristics of residential solid waste and non-degradable waste types of Gaidakot Municipality

Calorific value of organic waste

The calorific value of wet waste collected from Gaidakot Municipality was analyzed, revealing the following results: the minimum calorific value was 2363.4 cal/g, the maximum was 3961.7 cal/g, and the average was 3232.9 cal/g with a standard deviation of 455.6 cal/g (Table 7 and table 8)

Table 7: Sample-wise calorific values of kitchen waste in Gaidakot Municipality

Location	Sample Code	Calorific Value (cal/g)
Gaidakot Municipality, Nawalparasi	GDOS1	2363.36
	GDOS2	3663.43
	GDOS3	3330.47
	GDOS4	3157.11
	GDOS5	3329.94
	GDOS6	3269.59
	GDOS7	3961.68
	GDOS8	3489.03
	GDOS9	2711.38
	GDOS10	3053.44

Table 8: Summary statistics for calorific values of kitchen waste in Gaidakot Municipality

Summary Statistics	Energy (Cal/g)
Min	2363.4
Max	3961.7
Mean	3232.9
Std Dev	455.6

5.1.4. Chame Rural Municipality, Manang

Chame Rural Municipality has several expectations from the federal and provincial governments, including recommendations for treatment and dumping in cold climates, improved transportation management for segregated recyclable waste, and technical knowledge for managing and operating a sanitary landfill site and other waste management technologies. A meeting with the acting Chief Administrative Officer and relevant municipal officers of Chame Rural Municipality revealed that the municipality is in the preliminary stages of waste management. Recently, a tractor was acquired to collect and transport municipal solid waste to the newly constructed dumping site. The new dumping site is within five minutes' distance of Chame Bazaar.

Municipal solid waste is collected every morning, with one trip per day, but there are no figures on waste generation. Waste collection is limited to three out of five wards (wards 3, 4, and 5), with no collection from wards 1 and 2. The rural municipality has managed to segregate cartons, glass bottles, and other recyclables, except plastics at the dumping site. Also, it was observed during the site visit that the remaining waste after segregation is burned at the landfill. It was mentioned that most organic waste is composted or managed at the household level. Hospital waste from government hospitals is managed in a ditch. The primary challenge in waste management is the transportation and selling of segregated waste due to the municipality's mountainous location and poor road accessibility. The municipality is currently seeking technical assistance to purchase waste management technologies, such as a shredder and a hydraulic compactor. Municipal officers have visited Waling and other exemplary sites to improve waste management practices, recognizing that significant improvements are still needed. The municipality has recently discouraged open dumping and riverside dumping. Although no budget is allocated for solid waste management campaigns, the municipality has worked closely with organizations such as NTNC to place dustbins along trekking trails.

 **Photo M 1:** Discussion with municipal staff at Chame Rural Municipality	 **Photo M 2:** Stack of glass bottles segregated at Chame dumping site
 **Photo M 3:** Dumping site at Chame Rural Municipality	 **Photo M 4:** Segregated plastic bottles at Chame dumping site

Characterization of household waste

A week long observation of solid waste generated at the households in Chame Municipality revealed that it comprises 62% degradable and 38% non-degradable waste (Figure 6). Residential biodegradable waste, mainly composed of kitchen waste, is mostly composted at the household level. Households use wet waste to feed the livestock such as chickens and pigs, same as other municipalities studied. The non-biodegradable waste from households is collected by the garbage tractor and dumped at the dumping site. Categorically, plastic waste was found to be 37%, the highest fraction among any other categories of non-biodegradable waste (Figure 7)

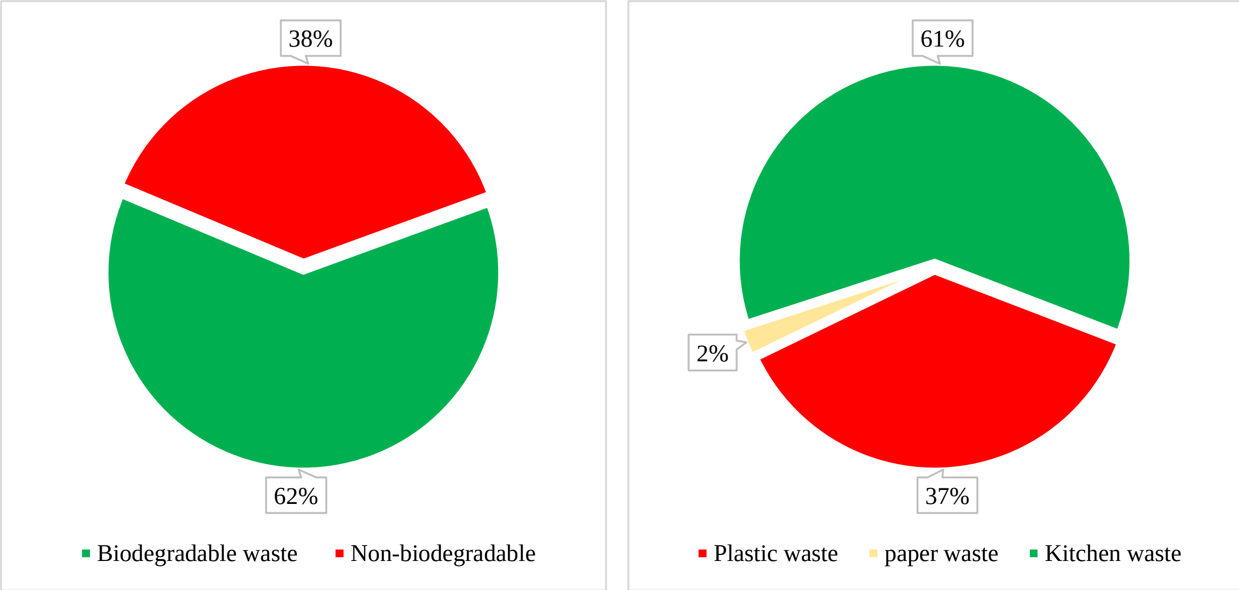

Figure 6: Characteristics of residential solid waste of Chame Municipality

Calorific value of organic waste

The calorific value of wet waste collected from Chame Municipality was analyzed, revealing the following results: the minimum calorific value was 2065.2 cal/g, the maximum was 3446.1 cal/g, and the average was 2710.7 cal/g with a standard deviation of 510.8 cal/g (table 1 and table 2)

Table 9: Sample-wise calorific values of kitchen waste in Chame Municipality

Location	Sample Code	Calorific value (cal/g)
Chame Rural Municipality, Manang	MOS1	3109.893
	MOS2	3081.878
	MOS5	2597.853
	MoS8	2240.372
	MOS10	2065.232
	MOS12	3446.078
	MOS13	2433.298

Table 10: Summary statistics for calorific values of kitchen waste in Chame Municipality

Summary Statistics	Energy (cal/g)
Max	3446.1

Min	2065.2
Mean	2710.7
Std dev	510.8

5.1.5. Summary of the results

The waste management practice in Gandaki Province seems problematic. Rapid urbanization is exposing both large metropolitan areas like Pokhara and smaller rural municipalities to the risks of unclear or unscientific waste management practices. The Gandaki Province has an area of 21,773 km^2, which is about 14.66% of Nepal's total area. Regarding terrain, the province is spread over the Mountain, Hill and Terai region of Nepal. Gandaki Province is spread into 11 districts including one Metropolitan City (Pokhara) and 26 municipalities. There are 58 rural municipalities in the province (CBS, 2021). In this context, we have selected three municipalities representing Terai, Hill and Mountain, including Gaidakot, Pokhara, Kushma and Chame municipality. The Chame is the rural municipality, Pokhara is the metropolitan city and Kushma and Gaidakot are the municipalities that represent all the municipalities and rural municipalities in Gandaki province. Based on 7-days sampling at household level, site visits, stakeholder consultation and laboratory experiment, the following results were summarized in each municipality (Table11)

Table 11: Summary of the results in all four municipalities of the Gandaki Province

Municipalities	Total waste generation (TPD)	Total Waste collection (TPD)	Residential waste generation (g/day/person)	Average Energy Potential (cal/g)	Average residential waste character		Dumping Site	Segregation Practices	
					Organic (%)	Inorganic (%)		Household Level	Municipal level
Pokhara Metropolitan City	134	60	293	3168	60	40	Lameaahal	Good	Poor
Kushma Municipality	6.75	1	153	3077	72	28	Alaichibari	Good	Poor
Gaidakot Municipality	14	6.5	179	2363	71	29	Devchuli	Good	Poor
Chame Rural Municipality	0.18	0.14	146	2710	62	38	Chatang	Good	Poor

The main waste types at household levels are kitchen waste, plastics, metal/glass, rubber, fiber and clothes, biomedical, e-waste and other types. The dumping site of Pokhara Metropolitan City is Lameaahal. The estimated waste generation in the metropolitan area is 180-200 tonnes per day and the amount transported to the dumping sites is 60 TPD. The household contributed 60% degradable and the remaining 40% of non-degradable waste is dominated by plastics, making up a substantial 88% of this category. However, the waste composition seems to differ at the landfill, with a lower proportion of plastics observed than what's thrown away from homes. In some wards, the glasses are buried in the community center to manage the glass waste by the community. The mean calorific value of organic samples was found to be 3168±849.3 KJ/g with calorific values ranging from 1279.2-3994.1 KJ/g. Kusma Municipality disposes of its waste on rented land located in Alaichibari.The municipality generates an estimated 6.75 TPD comprising 72% degradable and 28% non-degradable waste. Residential biodegradable waste, mainly composed of paper and kitchen waste, is mostly composted at the household level. Households use wet waste as feed for their livestock. Plastic waste was found to be 93%, the highest fraction among any other categories of non-biodegradable waste. The mean calorific value of these samples was found to be 3077.7±559.9 KJ/g with calorific values ranging from 2490.7-4250.6 KJ/g

In Gaidakot Municipality, landfill sites are located in Devchuli. The municipality generates 71% of biodegradable waste and 29% of non-biodegradable waste. The non-biodegradable waste comprises 58% of plastic. The average calorific values of kitchen waste were 3232.9 cal/g with a standard deviation of 455.6 cal/g. In Chame Rural Municipality, the dumping site of Chame is located at Chatang, ward-4. The municipality generates 62% biodegradable and 38% non- biodegradable waste. Of the non-bio degradable, 37% is plastic. The average was 2710.7 cal/g with a standard deviation of 510.8 cal/g. All municipalities lack scientific sanitary landfill sites. Municipalities collect all household waste in a single vehicle, regardless of its organic or inorganic composition. The mixed waste is then transported and dumped in bulk at the landfill sites.

5.2. Existing waste management practices and adopted technologies

Several new technologies have emerged and practiced to manage solid waste at regional, national and provincial scales. In China, one of the large waste generators in the world where the amount of MSW collected has mainly been decoupled from economic growth and incineration has become an increasingly widespread treatment method for MSW (Chen et al, 2010). Globally, the amount of collected MSW incinerated with energy recovery has reached approximately 324 million tons per year (Levaggi et al., 2022). In 2016, waste incineration contributed to approximately 1 per cent of global renewable energy generation, corresponding to a global total of 52 TWh of electricity (IRENA, 2018). The Waste to Energy (WTE) incineration plants have become the preferred alternative to landfilling in Europe and the US, and their numbers are also increasing in Asia (Makarichi et al., 2018). The advantages of waste incineration over conventional landfills are that requires less land resources than landfilling, reduces the volume of waste by up to 90%, and converts solid waste into energy. Furthermore, incineration prevents the release of methane gas and mitigates soil and water contamination. The solid residues from the plant are inert and can be disposed of in a landfill or blended with building construction materials. Thus, landfilling serves as an alternative energy source, thereby playing a vital role in addressing the energy crisis, offsetting fossil fuel consumption, and increasing the renewable energy share while assisting waste management (CBS, 2021).

Beside landfilling, biogas plant (waste to energy), incinerator and mini waste plastic pyrolysis plant are surrogate the waste management practices. Installation of waste to energy plant is a win-win endeavor. It generates energy making us less dependent on imported fuel, produces organic fertilizer, creates job opportunity which uplifts the local people's economic standard and aids in climate change mitigation and the sustainable management of municipal solid waste. In Kathmandu valley, sanitary landfilling technique were applied in the Bancharedada, Nuwakot. In Dhangadi, biogas plant for organic waste has been installed and produces 50 CNG cylinder in a day which consume 30 TPD waste per day. Simultaneously, compost and liquid fertilizer are produced in Dhangadi. The hospital waste is also managed by sanitizing and autoclaving before discharging into the community. Gandaki Urja biogas is also active in Pokhara but lacks good coordination among stakeholder. In Pokhara, eight private organizations are involved in collecting waste in household level. However, they do not collect organic and inorganic waste separately. In small scale, household level composting and vermi composting are practiced in metropolitan city of Nepal.

Kitchen waste is also having a big problem. Every year, 1.3 billion tonnes of food is wasted globally, when it rots in fields or landfills, this waste equates to 18 million tonnes of CO_2 emissions (WEF, 2024). Waste glass is a type of construction and demolition waste, which carries significant environmental burdens and can be recycled. The glasses are also used as alkali activated binder production (Ruan et al., 2020). Some glasses are also produced from river-born silicate minerals, therefore some glasses can break into small pieces and make and mix as river-bed silicate minerals that can be recycled to prepare the glass and other products (Rajib et al., 2022). This management and recycling of construction and demolition waste offers environmental benefits and conservation of natural resources. The new magnetic composite materials can be prepared by wet chemical synthesis methods using crushed glasses and iron and steel waste powders as raw materials (Rada 2023). Based on waste types and problems faced, different types of management techniques can be designed and applied

Figure 7: Proposed solid waste management model in Gaidakot Municipality, GKM, 2024

At the local level, GKM has a good waste segregation plan, commercialization, and final disposal (incinerator). They have envisioned a resource center instead of landfill site at the community level. In Gandaki Province, the appropriate technologies like compositing, biogass plant, incinerator, glass and metal processing into different products, reuse/recycled plant with good segregation can be practiced with community involvement and participation. Commercializing waste products in a community with suitable technologies can help meet the goals of zero waste management approach.

5.3. Human resource, infrastructure setup and landfill site reform requirement

The human resource planning, infrastructure setup and existing landfill site reclamation are very crucial in Gandaki Province. Here, we have envisioned that the environment department would operate and handle waste management. They will regulate all the units, community volunteers and daily waste collection by using three different types of vehicles. Segregation at household levels and municipal levels is very utmost. To empower the staff, the department can ensure their health insurance and PPE practices. The technical human resource in the center and skilled resource in different units can handle both the plan and practices. The infrastructure of waste management should also be reformed. The existing landfill site in all the observed municipalities are not equipped and segregated. All types of waste have been dumping in the same vehicle collection. It has planned to reform landfill site into "Community Resource Center (CRC)" with multiple segregated chambers, storage chambers, packaging, incinerators, biogas plant, composting, and resource circularity promotion. The detail unit and infrastructure plan are mentioned as follows (Figure 8).

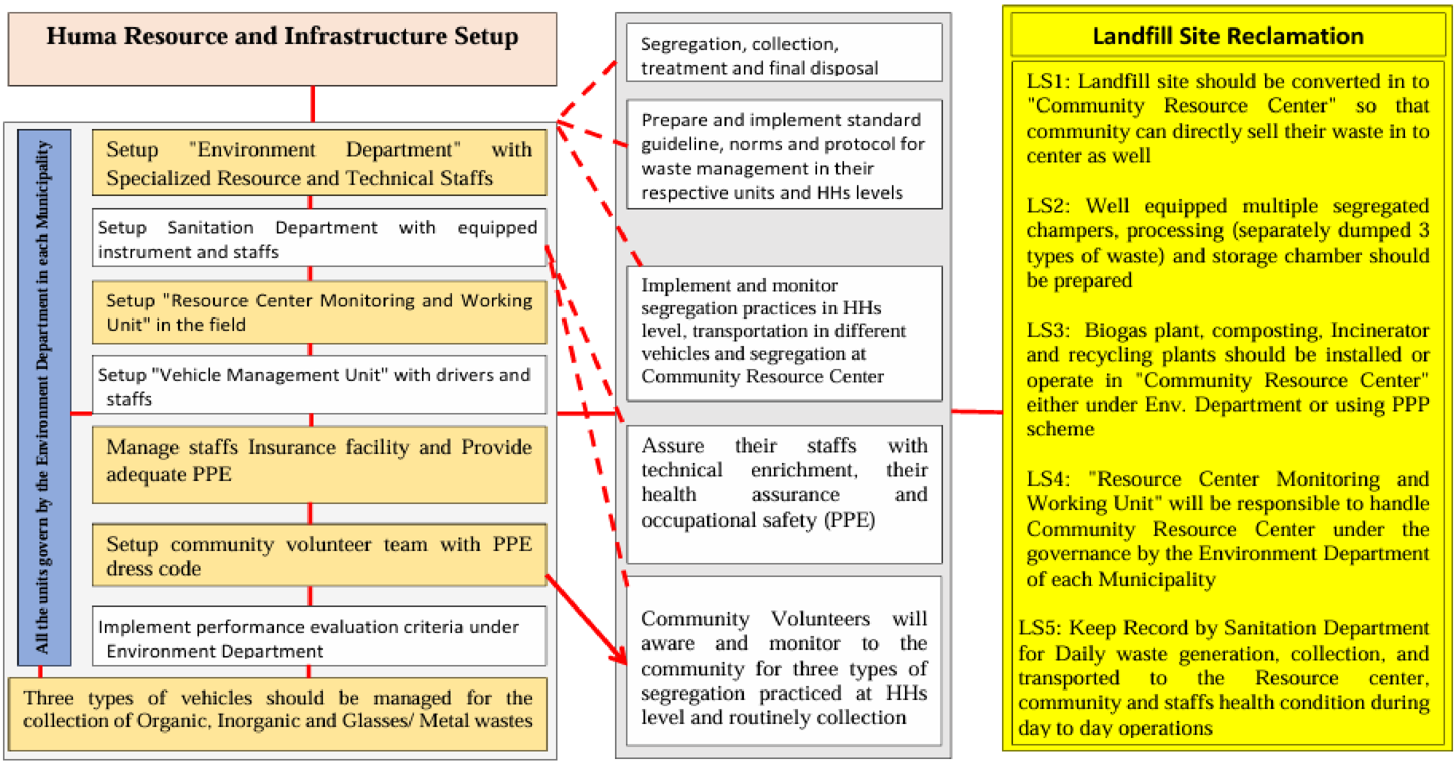

Figure 8: Human resource, infrastructure setup and landfill site reform requirement plan

The material circularity promotes using renewable and recyclable materials in construction projects with materials passport. In term of composting, the community resource center shall be bio-reactive. The proposed community resource center shall be live, surveillance, protective and productive. The resource center monitoring and working unit with good resources has planned to look over the center activities. As proposed, the sanitation department should monitor daily waste generation, collection and dumping at landfill sites. Simultaneously, the unit will look over health, hygiene and safe working environment, managing required PPP and dress codes with all staffs and officers.

5. Best possible option of MSW in Gandaki Province

The segregation is first requirement at both HHs and municipal level. Based on Calorific values, we can recommend to start biogas plant to produce CNG cylinder in community level (waste to Energy). Composting is also another good option in the province except in highland municipalities because it may take more time to decompose the waste in cold climate. So, composting in highland is not feasible. The controlled incineration could be good practice for remaining organic waste in landfill or collection center. The good segregation in different chambers, packaging, grinding for metal and glasses and transport to recycler/reuse team for inorganic waste can be practiced. In the mountain, the glasses can be made into small silicates materials like river bed silicate materials and also used as an alkali activated binder production in construction project. No landfill option is recommended for the Gandaki Province. Instead of landfill design, it is recommended to well designed and equipped "Community Resource Center". Multiple number of segregation chambers, packaging and storage chambers, management unit and technologies operation like composing, biogas energy plant, incineration and recycling plant that could be designed based on public-private and stakeholder participation. The effective waste management has also depended on the financial management system and resource sharing so that we have planned circular economic practice and Material Bank. In this approach, government should pay each HHs for the waste and they can burrow fund from the third party involved in recycling and reuseing the waste. Later, the community pays for reused and recycled materials to the third party as follows (Figure 10).

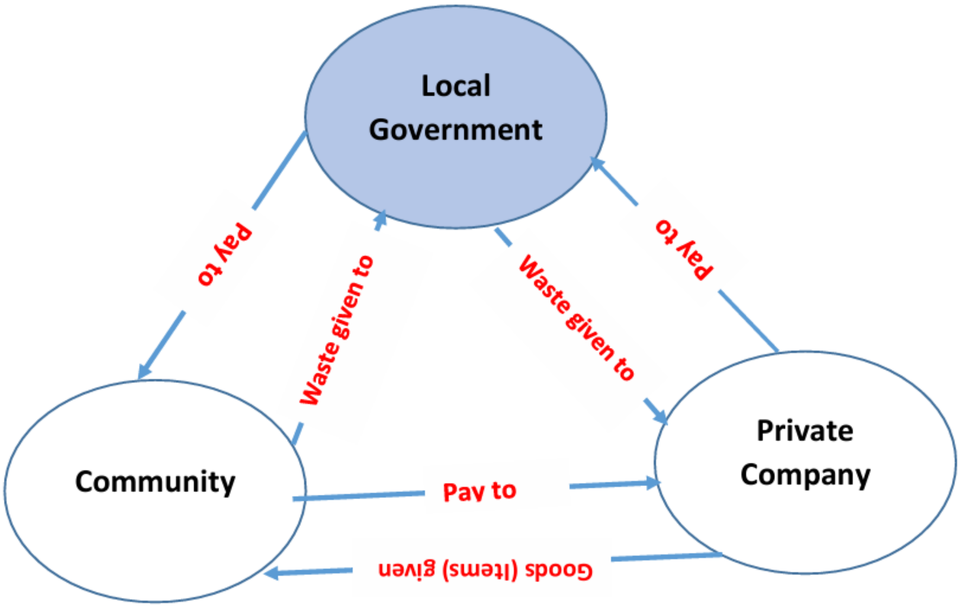

Figure 9: Economic cycles (Circular economy) in between Government, community and Private stakeholders for waste management approach

Paying for the waste modality helps establish the economic value of the waste, which changes people's behaviors to play and love the waste generated inside the home. The "Material Bank" as like the material collection center can be formulated by government (local government) with public-private-stakeholder partnership (PPSP). The "Material Bank" can assure the waste management practionnaire to deposit their materials based on their waste passport. The material circulatory team can burrow the advanced fund for material bank based on their annual collection and recycled waste. In return, they will have developed recycled/reused materials and sell the items to the people and pay the loan back to the Bank.

To manage the solid waste in Gandaki Province, local governments should to be categorized into hilly, mountainous, and terai regions local government. And, with this categorization, there should be some policy adjustments for local government belonging to each of these category. This is important because the type of waste and the best ways to handle it are different for each area. For example, composting and making compressed natural gas (CNG) are difficult in mountainous regions due to the cold winter temperatures, even though the waste has high calorific value. In the Terai regions, however, composting and CNG production are good options. Some municipalities want to segregate waste and sell recyclables, but their remote locations make it too expensive for recyclers to collect the materials. The provincial government can help by creating policies to support waste transportation from these remote areas. Providing subsidies to these local governments could also be beneficial. Additionally, financial support for buying waste management equipment like glass crushers and waste segregation conveyors would be useful. In many hilly and Terai regions, there is an urgent need for separate facilities to handle organic and inorganic waste. Some municipalities, despite having good conditions and accessibility, are not segregating waste during collection. These municipalities should be consulted to understand their needs, and a detailed feasibility study should be conducted to improve their waste management practices.

6. Conclusion

The study investigated residential waste characterization, management practices and further feasibility of the best management options in Gandaki Province. The four different natures of municipalities i.e., Pokhara Metropolitan City, Kusma Municipality, Gaidakot Municipality and Chame Rural Municipality of the province were taken as samples study sites. The daily waste generation in PMC was found 134TPD which is the highest rate and followed by Gaidakot 14 TPD and 6.75 TPD, 0.18 TPD by Kusma and Chame, respectively. More than 60% waste are found biodegradable and the plastic is the dominated non-degradable waste in all the municipalities. Out of non-degradable waste types, 88%, 93%, 58% and 37% are the plastics waste in Pokhara, Kusma, Chame and Gaidakot Municipalities. Similarly, the average calorific values of the Kitchen waste were found higher i.e. 3446 cal/g in Manang, 3168 cal/g and 3077 cal/g in Pokhara and Kusma respectively, the low land municipality i.e. in Gaidakot has observed relatively lower 2363 cal/g. All of the above municipalities have their own dumping sites and collecting municipal wastes in daily basis such as LLameaahal in Pokhara, Alaichibari in Kusma, Devchuli in Gaidakot and Chatang in Chame are the dumping sites for waste collections. The Pokhara Metropolitan city as a second large metropolitan city of Nepal produce huge amounts of daily wastes including both degradable and non-degradable wastes but the management practices seems poor and unsustainable. Similarly, other municipalities also do not practice any commercial and scientific techniques for the waste management in source collection, transportation and deposition stages of the waste management practices. The following conclusion was drawn from our observations, though our study was limited to residential waste only.

- The waste generation of Pokhara Metropolitan city was 134 TPD in which the daily per capita waste generation was found 293g, similarly, Kusma, Gaidakot and Manang produce 6.75 TPD (153g/day/person), 14TPD (179 g/day/person) and 0.18TPD (146 (g/day/person) respectively.
- Municipalities appear to generate a higher amount of waste than what is regularly collected. The current waste collection system seems irregular, resulting in some waste not being transported to the landfill site. Some community groups in Pokhara have initiated glass waste management by burying glasses within the community center grounds.
- All municipalities have good waste segregation practices at household levels. Still, collecting all types of waste in the same vehicle and bulk dumping at landfill sites has created a havoc situation, which is problematic and unsustainable.
- In Pokhara, Kusma, Gaidakot and Chame, most of the non-degradable waste is plastic comprising 88%, 93%, 58% and 37%, respectively. This could be a good source for exporting recyclers and collecting revenue.
- Pokhara, Kusma, Gaindakot, and Chame municipalities boast significant amounts of biodegradable waste – 60%, 72%, 71%, and 62%, respectively. This presents a valuable resource for composting and the potential for energy generation, ultimately benefiting households. However, Chame's cold climate presents a challenge, as lower temperatures slow down the decomposition rate, making composting more costly.
- Kitchen waste in all the municipalities has the highest energy content, averaging 2710 cal/g calorific values in the Chame, which are 3168 cal/g in Pokhara, 3077 cal/g in Kusma and 2363 cal/g in Gaidakot Municipality. The higher calorific values of kitchen waste recommend energy generation potential in those areas.

- In Pokhara, eight private organizations are working under PMC roster, but other municipalities manage waste through their own efforts. In Chame, even though recyclable waste like glass gets segregated, its bulky nature makes transportation costly, and selling to recycling centers in cities is difficult and nonbeneficial.
- All the municipalities mentioned (Pokhara Metropolitan City (PMC), Kusma, Gaindakot, and Manang) have a much lower daily waste collection ratio than their daily waste generation (G/C_{daily}). For instance, in PMC, they generate 134 TPD (tons per day) of waste but only collect 60 TPD. Similar disparities exist in Kusma (6.75 TPD generation vs. 1 TPD collection), Gaidakot (14TPD generation vs. 6.5 TPD collection) and Manang (0.18 TPD generation vs. 0.14 TPD collection), which means the large volume of waste remain or sink inside the city environment which is very havoc and problematic.

7. Acknowledgement

This project is completed under G2G MoU between Gandaki Province Government, PPPC and CDES. TU (Grant No: 879/2080/081). The project team would like to acknowledge Gandaki Province Government, Province Policy and Planning Commission (PPPC) Pokhara, Nepal for their financial grant and Central Department of Environmental Science (CDES), Tribhuvan University (TU), Kirtipur for institutional supports. The project team is very much pleased to all the Municipal staffs, private and government stakeholders, research associates and local stakeholders. It is our great pleasure to anonymous reviewer to refine this report.

8. Team composition

The research team involved in proposal submission and subsequent research preparation consisted of Dr. Binod Baniya as a Principal Investigator (Team Leader) and Dr. Udhab Raj Khadka, Dr. Ramesh Prasad Sapkota, Dr. Kumar Khatri and Dr. Rashila Deshar served as Co-investigators. Mr. Sushil Dahal and Mr. Anup Neupane assisted as Research Associate throughout the project.

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Annex I

Checklist used during field visit for stakeholder consultation

Solid Waste Assessment (Field Survey Form)

Date of Survey:

Name of the Municipality/Sub-metro /Metro:

Current Population:

Table 1: Average Waste Generation (Supply) in the Municipality by Waste Types and Sectors

S.N.	Waste Type	Sub-category	Household waste (kg/day)	Business House/Commercial Complex waste (kg/day)	Industrial waste (kg/day)	Educational Institutes waste (kg/day)	Health Institutions/ Hospitals waste (kg/day)	Other (kg/day) (if any)	Total Quantity (kg/day)
1.	Organic	Food and vegetables							
		Textile							
		Leather							
		Paper							
		Agricultural/Garden management							
		Other Organic							
2.	Inorganic	Plastic							
		Glass							
		Rubber							
		Metals and Minerals							
		Other inorganic waste							
3.	Other	Toxic							

		Hospital Waste							
		Electronic and Electrical Waste							
		Other Chemical Waste							
		Other							
4.	Total								

Table 2: Average Waste Recycle and Reuse in the Municipality by Waste Types and Sectors

S.N.	Waste Type	Sub-category	Household waste (kg/day)	Business House/Commercial Complex waste (kg/day)	Industrial waste (kg/day)	Educational Institutes waste (kg/day)	Health Institutions/ Hospitals waste (kg/day)	Other (kg/day) (if any)	Total Quantity (kg/day)
1.	Organic Wastes Used for Recycle and Reuse	Food and vegetables							
		Textile							
		Leather							
		Paper							
		Agricultural/Garden management							
		Other Organic							
2.	Inorganic Wastes Used for Recycle and Reuse	Plastic							
		Glass							
		Rubber							
		Metals and Minerals							
		Other inorganic waste							
3.	Other Wastes Used for Recycle and Reuse	Toxic							
		Hospital Waste							
		Electronic and Electrical Waste							
		Other Chemical Waste							
		Other							
4.	Total								

(Note: also note the cost associated with selling wastes)