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Sustainable Management Of Household Organic Waste Through Vermicomposting: Evaluating The Nutrient Potential And Financial Sustainability

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Abstract

Solid waste management is becoming a major environmental challenge for sustainable development, especially in developing countries due to urbanization, industrialization, and improper dumping practices. Waste management techniques such as recycling, incineration, landfilling, and composting are designed to manage waste materials to reduce environmental impact. This study examines the nutrient composition and economic viability of household-scale vermicomposting using organic waste in Shuklagandaki Municipality, Tanahun. A 90-day bin experiment was carried out using *Eisenia fetida* earthworms, with kitchen waste, garden residues, and paper serving as feedstock. The findings indicate that vermicompost meets standard nutrient criteria for nitrogen, phosphorus, and potassium, though moisture content and pH are slightly above recommended levels. The economic analysis showed strong financial feasibility, with a net present value of NRs. 801,460 over five years at a 6.05% discount rate. Sensitivity analysis identified investment cost and annual benefits as the key factors influencing project viability. Household survey results (n = 109) indicated an estimated daily organic waste generation of 8,866 kg. Overall, the findings suggest that vermicomposting is a practical, environmentally sustainable, and economically viable approach for managing household organic waste in municipalities.

Keywords*—Eisenia fetida, Economic Feasibility, Nutrient Analysis, Waste Management, Vermicomposting*

1. INTRODUCTION

Environmental degradation has emerged as one of the most pressing global challenges of the contemporary world. Rapid economic development, population growth, accelerating urbanization, and changing consumption patterns have substantially increased the extraction of natural resources and intensified the generation of waste across industrial, commercial, and household sectors [1, 2]. As consumption levels rise, waste generation continues to escalate, exerting significant pressure on ecosystems, public health, and environmental sustainability [3]. Among the diverse environmental concerns confronting modern societies, solid waste management

(SWM) has gained particular importance due to its direct and indirect impacts on soil quality, water resources, air pollution, and human well-being [4-6].

The challenges associated with waste management are especially pronounced in developing countries, where rapid urban growth often outpaces the development of adequate waste collection and treatment infrastructure [7, 8]. In many low-income and underdeveloped regions, waste disposal practices such as open dumping and open burning remain widespread [9, 10]. These practices contribute to environmental pollution, greenhouse gas emissions, water contamination, and the spread of vector-borne and communicable diseases [10]. Household-generated solid waste, frequently referred to as non-sewage waste, constitutes a substantial proportion of municipal solid waste streams. Improper handling and disposal of household waste have been identified as major contributors to the decline of urban sanitation and environmental quality in many developing contexts [11, 12].

Across developing regions of Asia, rapid urbanization combined with population growth and rising income levels have significantly altered both the quantity and composition of municipal solid waste [13, 14]. Urban waste is largely generated in residential areas, commercial establishments, and community institutions. Inadequate waste management has been linked to blocked drainage systems, unhygienic living conditions, and heightened risks of communicable diseases, particularly in densely populated urban settlements [15]. As a result, effective solid waste management requires not only technological interventions but also behavioral change, public awareness, improved hygienic practices, and active participation of local communities [15].

At the global level, urban solid waste management has become increasingly complex due to population pressure, economic expansion, land scarcity, insufficient infrastructure, and limited financial and institutional capacity [16, 17]. Environmentally sound waste management systems emphasize waste reduction at the source, segregation, recycling, and safe disposal, with active involvement of waste generators, particularly households [18, 19]. Households represent the dominant source of municipal waste, generating significant quantities of food waste, paper, plastics, metals, and glass. Among these components, food waste poses a critical challenge, as nearly one-third of all food produced globally, approximately 1.3 billion tons annually, is lost or discarded [20]. In response, governments and development agencies have increasingly promoted waste minimization, recycling, reuse, and waste-to-resource conversion strategies as integral components of sustainable waste management systems [21].

Organic waste constitutes a major fraction of municipal solid waste, particularly in developing countries. Global projections indicate that municipal solid waste generation will continue to rise sharply, with a World Bank study estimating an increase of nearly 70% between 2012 and 2025, reaching approximately 2.2 billion tons per year [22]. Low- and middle-income regions account for nearly 80% of global waste generation, with organic materials comprising about 20–30% of the total waste stream [22, 23]. Organic waste is predominantly generated from agro-food systems and household food consumption. Globally, more than 1.3 billion tons of food waste are produced each year, creating severe environmental and public health concerns, particularly in areas with limited waste treatment capacity [20, 24, 25].

Improper management of organic waste leads to significant environmental consequences. Due to its high organic carbon content, organic waste undergoes anaerobic decomposition in landfills, producing methane, a potent greenhouse gas that substantially contributes to climate change [25]. In addition to greenhouse gas emissions, unmanaged organic waste generates leachate, unpleasant odors, and attracts disease vectors, threatening soil and groundwater quality. Consequently, the adoption of appropriate organic waste management strategies is essential not only for environmental protection but also for climate change mitigation and sustainable resource use.

Scientific utilization of organic waste presents opportunities for both waste reduction and resource recovery. Biological treatment methods, particularly composting, can transform organic waste into valuable soil amendments that improve soil fertility, enhance soil structure, and supply essential nutrients for plant growth, thereby reducing reliance on chemical fertilizers [26]. These benefits make organic waste composting especially relevant for developing countries with agrarian economies and high organic waste generation rates.

Nepal exemplifies many of the global challenges associated with solid waste management. Rapid urbanization, population growth, and limited landfill capacity have intensified environmental and public health problems across urban centers. The country is administratively divided into 753 local governments across diverse geographical regions, each facing distinct waste management challenges related to terrain, accessibility, and resource constraints [27]. Despite policy initiatives aligned with the Sustainable Development Goals (SDGs 2015–2030) and institutional efforts coordinated by the National Planning Commission, solid waste management remains one of the most pressing environmental concerns among urban residents in Nepal [28, 29].

In this context, sustainable household level management of organic waste has gained increasing attention. Composting and vermicomposting have emerged as environmentally sound biological treatment options capable of converting biodegradable household waste into nutrient-rich organic manure. Vermicomposting, which involves the biological degradation of organic waste through the activity of earthworms, offers a promising approach for managing household organic waste while simultaneously recovering nutrients and generating economic value [30]. This study therefore focuses on evaluating vermicomposting as a sustainable household level waste management strategy, with particular emphasis on its nutrient potential and financial sustainability.

Comparative studies have shown that vermicomposting produces compost with higher nitrogen, phosphorus, and potassium content and lower heavy metal concentrations than conventional composting methods [31]. In addition to environmental benefits, vermicomposting offers economic advantages by producing valuable organic fertilizer and animal feed, contributing to circular economy principles and supporting sustainable livelihoods [32].

Despite the growing adoption of eco-friendly waste management methods, landfilling remains the dominant waste disposal practice worldwide. Landfills pose serious environmental risks by generating methane and producing leachate containing ammonia, heavy metals, pharmaceuticals, and persistent organic pollutants [33]. Excess organic waste in landfills accelerates landfill saturation, emits unpleasant odors, attracts pests, and threatens soil and groundwater quality, while simultaneously wasting valuable nutrients that could be recovered through biological treatment.

In Nepal, continued industrialization and urban expansion have increased organic waste accumulation and open burning practices, contributing to air pollution and greenhouse gas emissions [34]. Vermicomposting offers a sustainable alternative, capable of transforming biodegradable waste into nutrient-rich manure through the biological activity of earthworms [34, 35]. Given Nepal's agricultural dependence and high organic waste fraction, vermicomposting represents a promising household level solution.

Waste management is a growing problem worldwide, particularly in developing countries such as Nepal, where limited landfill capacity and poor waste handling practices create serious environmental challenges. A large portion of municipal solid waste in Nepal consists of organic materials, yet current disposal methods fail to utilize this waste as a valuable resource. Although previous studies have identified the potential for compost production from organic waste, practical and household level solutions remain insufficiently studied and implemented. Therefore, there is a clear need for research that evaluates vermicomposting as an effective, low-cost, and sustainable method for managing organic waste and producing nutrient-rich biomass in the Nepalese context.

This study seeks to examine the potential of composting as an effective approach for the sustainable management of household organic waste. Specifically, the research aims to investigate how the composting process can be applied to properly manage organic wastes generated at the household level and to evaluate whether household organic waste can produce an adequate quantity of nutrient-rich biomass suitable for beneficial use.

2. METHODOLOGY

This study adopted a systematic and experimental research design to evaluate the effectiveness of household organic waste management through vermicomposting, with specific emphasis on nutrient quality and financial feasibility. The methodology was structured to assess the technical, environmental, and economic dimensions of vermicomposting using locally generated household organic waste. Since organic waste constitutes the largest fraction of municipal solid waste and contributes significantly to greenhouse gas emissions when unmanaged, this research emphasizes waste segregation at the household level and its conversion into nutrient-rich organic fertilizer.

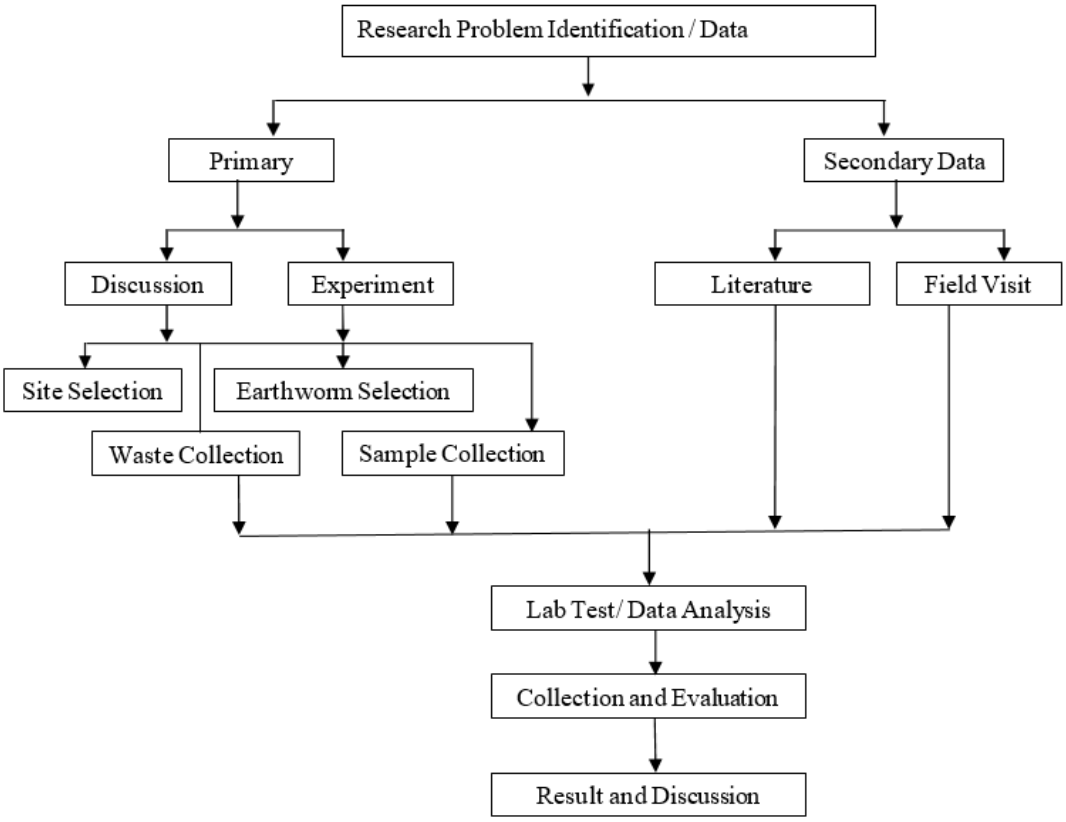


Figure 1: An overview of sample collection, analysis and discussion of research study

The study integrates field-based experimentation, laboratory analysis, household-level waste assessment, and economic evaluation. The overall methodological framework followed a sequential process beginning with site selection, assessment of local waste management practices, experimental vermicomposting setup, physicochemical analysis of compost products, estimation of compost generation potential, and financial feasibility analysis. The general workflow of the methodology is illustrated in Figure 1.

A. STUDY AREA

The study was conducted in Shuklagandaki Municipality, located in Tanahun District of Nepal. Nepal is geographically divided into three major regions: the Himalayan region, Mid-hill region, and Terai region. The Mid-hill region covers approximately 68% of the country's total land area and hosts a large proportion of Nepal's settlements. Shuklagandaki Municipality lies within this Mid-hill region in the western part of the country. Shuklagandaki Municipality falls within the Midlands (Lesser Himalaya) zone, with elevations ranging from 479 m to 609 m above mean sea level. Geographically, the municipality is located between latitudes 28°02′14″ N and longitudes 84°05′06″ E and covers an area of 164.8 km^2. Geologically, it lies within the Lesser Himalaya formation.

Although the municipality provides a door-to-door waste collection service, it is limited to wards located near the municipal headquarters due to inadequate resources. The municipality owns only one tractor and one power trailer, and waste collection is carried out once a week in selected wards (3–8). This limited coverage and absence of waste segregation highlight the need for household-level waste management solutions such as vermicomposting.

This study is based on a prototype setup, but the system is designed to scale due to a modular and distributed architecture that can be reproduced across municipal units. Resource requirements are predicted to increase proportionally with demand while integrating with existing infrastructure. A staged strategy is recommended, starting with a pilot, progressing to ward-level, and finally to citywide implementation. However, large-scale implementation may involve additional challenges; thus, the findings suggest scaling potential rather than full municipal validation.

B. MUNICIPAL SOLID WASTE MANAGEMENT

Based on a national survey conducted in 2012, the average per capita municipal solid waste generation in Nepal was estimated at 317 g per day. Using this rate, Shuklagandaki Municipality was estimated to generate approximately 17,631 kg of waste per day, amounting to about 6,435 tons annually. Given increasing consumption patterns, current waste generation levels are likely higher.

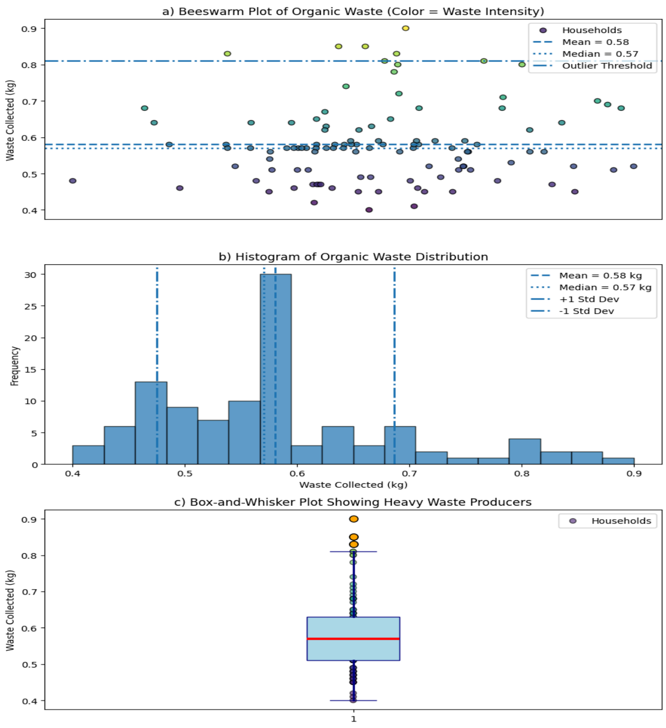
Waste management infrastructure in the municipality is limited, with no designated landfill site or formal waste segregation system. Collected mixed waste is openly dumped near the Seti River, posing environmental and health risks. Informal recycling occurs through scrap dealers without institutional oversight. Key challenges include inadequate human resources, lack of technical expertise, insufficient transportation facilities, minimal composting practices, weak institutional coordination, political constraints, and limited community participation. These challenges justify the selection of Shuklagan-daki Municipality as a representative site for evaluating household-based vermicomposting.

C. VALIDATION

The reliability of the household organic waste dataset was evaluated using statistical descriptors, normality testing, and graphical analysis. The dataset exhibited a mean of 0.581 kg and a median of 0.570 kg, indicating slight asymmetry. This is supported by a positive skewness of 0.949, suggesting a moderate right-skew due to a few higher waste-generating households. The kurtosis value of 0.627 indicates a mildly leptokurtic distribution with moderate tail behavior and no extreme outliers. The standard deviation of 0.106 kg reflects a reasonable spread in the data.

Normality was assessed using the Shapiro–Wilk test, which yielded a statistic of 0.9217 and a p-value < 0.001, leading to rejection of the null hypothesis of normality. This confirms that the dataset deviates from a perfect normal distribution, which is typical for real-world environmental data. It simply reflects the natural variability in household waste generation (e.g., differences in family size, consumption habits).

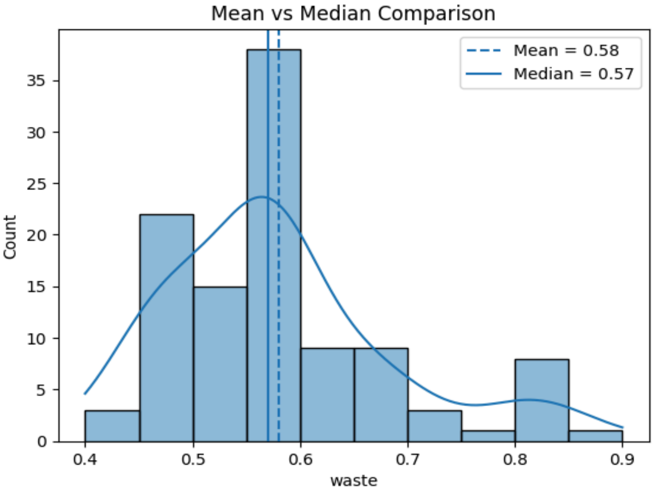
Graphical analyses (Figure 2: histogram, box plot, beeswarm plot, and Q–Q plot,) consistently indicated slight right-skewness without abnormal clustering or extreme values. The agreement between statistical measures and graphical observations confirms that the dataset is internally consistent, reliable, and suitable for further analysis.


a) Beeswarm Plot of Organic Waste (Color = Waste Intensity)

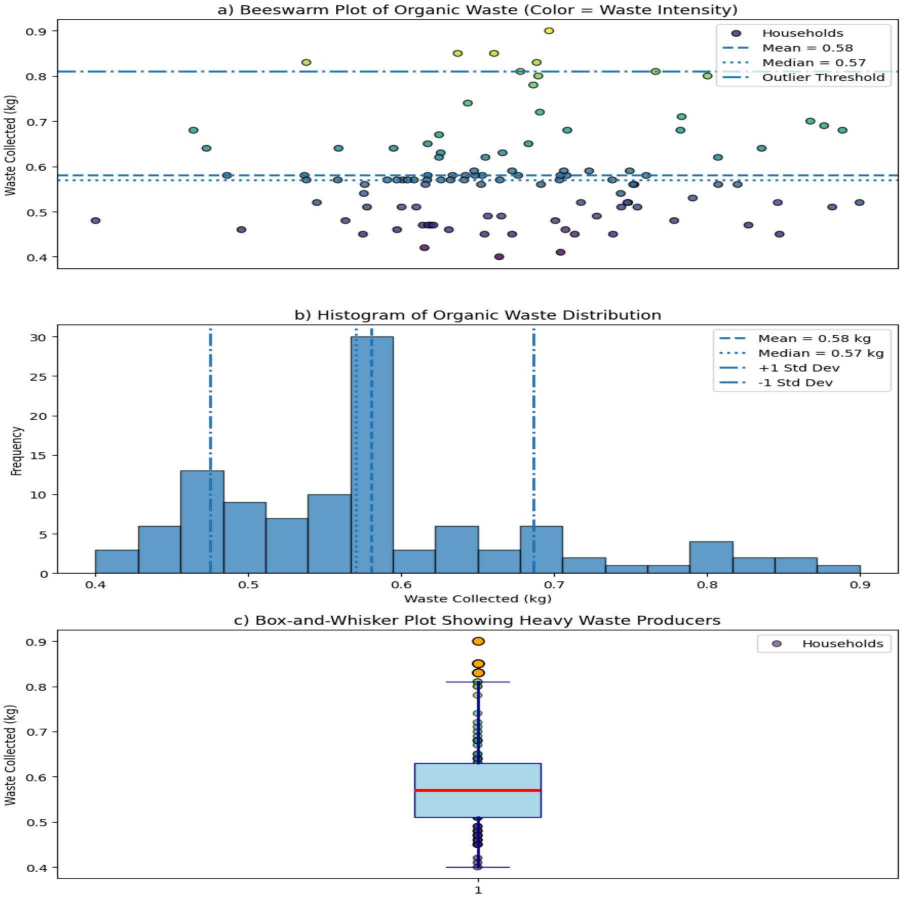
b) Histogram of Organic Waste Distribution

c) Box-and-Whisker Plot Showing Heavy Waste Producers

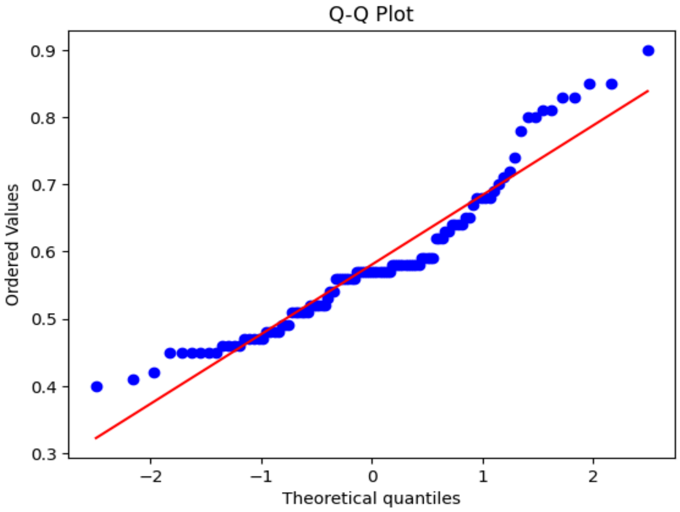
(a)


Mean vs Median Comparison
Mean = 0.58
Median = 0.57
Count
0
5
10
15
20
25
30
35
0.4
0.5
0.6
0.7
0.8
0.9
waste

(b)


a) Beeswarm Plot of Organic Waste (Color = Waste Intensity)
Waste Collected (kg)
0.4
0.5
0.6
0.7
0.8
0.9
Households
Mean = 0.58
Median = 0.57
Outlier Threshold
b) Histogram of Organic Waste Distribution
Frequency
0
5
10
15
20
25
30
Mean = 0.58 kg
Median = 0.57 kg
+1 Std Dev
-1 Std Dev
0.4
0.5
0.6
0.7
0.8
0.9
Waste Collected (kg)
c) Box-and-Whisker Plot Showing Heavy Waste Producers
Waste Collected (kg)
0.4
0.5
0.6
0.7
0.8
0.9
Households
1

(c)



(d)

Figure 2: Organic waste collection (a). Beeswarm plot, (b). Histogram: Mean Vs Median comparison, (c). Box and Whisker plot, and (d). Q-Q Plot

D. SCREENING AND OPTIMIZATION OF EARTHWORM SPECIES

The selection of appropriate earthworm species is critical for successful vermicomposting [36]. Vermicomposting relies on the synergistic action of earthworms and microorganisms to decompose and stabilize organic waste. The microorganisms drive the biochemical breakdown of organic matter, while earthworms improve aeration, break the material into smaller particles, and substantially stimulate microbial activity [37].

Earthworms are broadly classified into burrowing and non-burrowing species. Burrowing species such as Perionyx asiatica reside deep in the soil, whereas non-burrowing (epigeic) species such as Eisenia fetida inhabit surface organic layers [38]. For this study, Eisenia fetida was selected due to its proven efficiency in composting kitchen waste, agricultural residues, and animal manure [26].

Eisenia fetida was procured from a commercial breeder and used in all experiments. This species consumes approximately 90% organic waste and 10% soil, has a high reproduction rate, and adapts well to confined composting systems [38, 39]. Its optimal temperature range is around 25°C, although it can survive between 10°C and 30°C [40]. These characteristics make Eisenia fetida suitable for vermicomposting under local climatic conditions.

E. EXPERIMENTAL SETUP AND WASTE COMPOSITION

A household-level bin method was adopted as a pilot vermicomposting system. The household organic waste was systematically collected, segregated, and quantified by weight. The experimental setup used a lightweight plastic fish box measuring 0.6 m × 0.45 m × 0.35 m, selected for ease of handling and suitability for small spaces.

The organic waste consisted primarily of kitchen waste, vegetable residues, paper, and kitchen garden waste. The average daily organic waste generation per household was 0.58 kg. Over a 30-day period, a total of 17.4 kg of organic waste was added to the bin. Approximately 0.5 kg of Eisenia fetida earthworms were introduced into the system (Figure 3). Manual turning was conducted at regular intervals to maintain adequate aeration. The experiment was carried out over a period of 120 days, after which the vermicompost and biomass were harvested for subsequent analysis.

Figure 3: Experimental set-up for pilot plant

Household waste collected for composting was mechanically shredded into smaller fragments to enhance the rate of decomposition. The waste materials, sourced from various origins, were thoroughly mixed to achieve a homogeneous composition. Moisture content was consistently maintained through periodic water sprinkling at regular intervals. Adequate aeration was ensured throughout the process to prevent the development of anaerobic conditions.

Samples of raw waste and finished vermicompost were collected in airtight plastic bags and analyzed for physicochemical properties. Parameters analyzed included pH, organic carbon, nitrogen, phosphorus, potassium, and moisture content. Laboratory analysis followed standard procedures outlined by the Soil Management Directorate [41].

The pH of the samples was measured using a pH meter, whereas total nitrogen content was determined by the Kjeldahl method in accordance with standard analytical procedures. Available phosphorus was extracted using the Modified Olsen method (pH 8.5). Potassium was measured using a flame photometer. Organic carbon was determined using the Walkley-Black method, and moisture content was measured using the oven-drying method [41].

F. EXPERIMENTAL DESIGN JUSTIFICATION AND LIMITATIONS

The experimental design used a single-bin pilot-scale vermicomposting device to model household-level organic waste management under realistic settings. This technique was chosen to reflect the practical constraints, spatial limitations, and operational simplicity common to urban and rural households in countries with limited resources.

The utilization of a single experimental unit enabled the controlled monitoring of critical process parameters such as waste input, moisture content, aeration, and decomposition dynamics. It also allowed for thorough observation of earthworm activity and compost maturation under controlled settings. However, it is noted that this design does not account for the variability that may occur across numerous houses or under various environmental and operating situations.

The absence of replicated experimental units restricts the statistical generalizability of the findings. Furthermore, variations in waste composition, seasonal temperature fluctuations, and user habits can all have an impact on vermicomposting performance in larger applications. As a result, the findings of this study should be considered as indicators of system performance under restricted pilot conditions rather than globally representative outcomes.

To enhance reliability, standardized procedures were followed, and a statistically representative household sample was used for waste data collection. Future studies should incorporate replicated and comparative experimental designs, including multiple bin configurations, varying operational conditions, and cross-household implementation.

G. DATA COLLECTION

Primary data on household organic waste generation were collected using a sampling approach based on Slovin’s formula [42]. With a 95% confidence level and margin of error of 5%, a sample size of 109 households was selected. Average daily organic waste generation was calculated based on measured weights. In addition, secondary data were obtained from existing literature to support and contextualize the study findings.

H. ECONOMIC ANALYSIS

Vermicomposting is considered a profitable and environmentally sustainable waste management practice. Research indicates that it can achieve an internal rate of return (IRR) of approximately 65%, largely because of its relatively low setup costs and effective conversion of organic waste into valuable compost. With a production cycle of about 40–45 days, it can generate substantial economic returns, often reflected in benefit–cost ratios exceeding 2.5, thereby making it a promising income-generating option for both farmers and entrepreneurs. Total production cost was determined by summing fixed and variable costs and key financial indicators including Net Present Value (NPV), was calculated over a five-year economic life using a 6.05% discount rate based on Nepal Rastra Bank inflation data [43]. Sensitivity analysis was also performed to assess the impact of variations in investment cost, annual benefit, annual cost, and interest rate on project viability using the Present Worth method, providing insight into the risk and robustness of the investment.

3. RESULTS AND DISCUSSION

The laboratory analysis of vermicompost samples produced from the household pilot plant shows a consistent pattern across all parameters. Moisture content ranged from 71.16% to 76.76%, with an average of 73.97%, which is significantly higher than the recommended value (<25%) reported by Directorate (2018) [41], clearly indicating excess water retention in the system. This deviation is substantial and indicates that the composting system retained excess water, likely due to continuous watering, the inherently wet nature of feedstock materials, and limited aeration and drainage conditions. Such high moisture levels, although beneficial for sustaining earthworm activity, may adversely affect handling, storage, and microbial balance if not controlled. Moisture-rich organic fertilisers can be beneficial when used properly. They increase soil water-holding capacity, promote microbial activity, and contribute to improved soil physical qualities such as porosity, aggregation, and bulk density, all while gradually delivering nutrients. Similar moisture ranges (50–80%) have been reported by Contreras-Ramos et al. (2005) [44]and Ganiger et al. (2020) [45], suggesting that such elevated values are common in small-scale or less-controlled systems. The pH values (8.2–8.8, average 8.5) are slightly alkaline and exceed the ideal range (5–8), which aligns with findings by Shrestha et al. (2024) [46] and Yatoo et al. (2022) [47], who also observed alkaline conditions in mature vermicompost. This shift towards alkalinity can be explained by the mineralization of nitrogen-rich substrates, reduction in organic acids during compost stabilization, and the inclusion of alkaline materials such as ash and eggshells. While slightly alkaline compost is not necessarily harmful, prolonged deviation may influence nutrient availability in soil applications. Similarly, a higher pH, though unsuitable for alkaline soils, can be advantageous for acidic soils by helping neutralize soil acidity and supporting crops such as cabbage, broccoli, peas, and beans [48].

Table 1: Comparison table between lab report with different research and national guideline used in vermicomposting experiments.

Parameter References		Moisture	Nitrogen	Phosphorus	Potassium	pH
This Study	Sample 1	74.9	1.45	0.2	1.36	8.2
	Sample 2	76.76	1.74	2.41	2.31	8.6
	Sample 3	71.16	1.85	1.63	1.7	8.4
	Sample 4	73.06	1.9	1.55	3.38	8.8
	Average %	73.97	1.73	1.44	2.18	8.5
[41]		<25	1.5	0.5	1	6-8
[44]		50–80%				5–8
[46]		64.8 – 69.3 %	0.1 – 4 % (general); observed 1.83 – 4.22 %	0.92 – 1.66 %	0.19 – 0.85 %	7.49 – 8.12
[49]		-	1.5 ± 0.05 mg\g	1.4 ± 0.08 mg\g	1 ± 0.05 mg\g	7.43±0.6
[50]						4.5 - 9.0
[45]		70 – 80%	395.75 – 435.90 kg/hec	16.00 – 19.2 kg/hec	310.87 – 370.51 kg/hec	7.39 – 7.98
[47]		60–70%	2.87%	0.86%	3.74%	7.65–7.98

As a results, the macronutrient content shows promising effects. The average nitrogen content (1.73%) is close to the standard (1.5%) and falls within the broader ranges reported by Shrestha et al. (2024) [46] and Chakrabarty et al. (2009) [49]. Phosphorus (1.44%) and potassium (2.18%) contents are notably higher than the minimum standard values (0.5% and 1%, respectively), indicating strong nutrient enrichment. These values are comparable or even superior to those reported by Yatoo et al. (2022) [47]and fall within the variability observed by Ganiger et al. (2020) [45]. The relatively higher phosphorus and potassium levels suggest efficient mineralization and nutrient release during decomposition. From both a research and review standpoint, this indicates that despite some deviations in physical parameters, the vermicompost produced is nutritionally rich and suitable for agricultural application. However, optimizing moisture management and aeration could further enhance compost stability and bring all parameters closer to recommended standards.

Based on the Population Census 2078, Shukla Gandaki Municipality has a total of 15,272 households, which was used to estimate household organic waste generation (Table 2). Due to time and practical constraints, direct waste data from all households could not be collected; therefore, Slovin's formula was applied to determine a representative sample. Accordingly, organic waste data were collected from 109 households selected based on family size, economic status, and geographical conditions. The field survey results, summarized in the table, reflect one-day household organic waste generation and are consistent with standard research approaches where sampling methods are commonly used to reliably estimate municipal waste generation patterns. The field survey results show that an average household in the study area generates about 0.581 kg of organic waste per day. Based on this value and the total number of households, the estimated total organic waste generation is 8,866 kg/day in the municipality. This level of organic waste generation is comparable to values reported in similar municipal solid waste studies and highlights strong potential for composting and resource recovery initiatives.

Table 2: Data of population through population census

Description	Quantity
Total Population	55620
Total number HHs	15272
Total Area (KM²)	165
Number of wards	12
Average Household Size	4

The Net Present Value (NPV) analysis was carried out using the annual cash flow derived from fixed and variable costs of vermicompost production, discounted at a rate of 6.05% as shown in Table 3. The total expense of the project includes both fixed and variable components. The fixed cost includes the construction of five composting pits (1×5 m each), costing NRs. 60,000. The variable cost is made up of operational expenses such as household waste processing (NRs. 132,990 per year), earthworm procurement (NRs. 50,000), and miscellaneous costs such as gunny bags, marketing, packaging, and watering (NRs. 15,000), for a total annual variable cost of NRs.197,990. As a result, the total first-year investment, including fixed and variable expenditures, is expected to be NRs. 257,990. The total annual revenue is obtained by the selling of earthworms and compost. Earthworms produce 90 kg per year (30 kg per lot × 3 cycles) at NRs. 2000/kg, yielding NRs. 180,000. Compost output amounts to 9000 kg per year (3000 kg per lot × 3 cycles) at NRs. 30/kg, giving NRs. 270,000.Thus, the total annual income is Rs. 450,000. Although the project shows a negative cash flow in the initial year due to high investment cost, positive net cash flows are observed in subsequent years, indicating financial recovery over time (Figure 4). The positive cumulative NPV obtained from the analysis suggests that vermicomposting is an economically viable and financially sustainable option in the long run [51].

Table 3: Cash flow in vermicomposting production per year

Year	Investment	Cost(NRs)	Revenue	Net Cash flow	Cumulative cash flow	Discount factor at 6.05%	PV of benefits @6.05%	PV of costs @6.05%	NPV @6.05 %
0	-257990			-257990	-257990	1	0		
1		197990	450000	252010	-5980	0.942	237393.4	186506.6	
2		197990	450000	252010	246030	0.889	224036.9	176013.1	
3		197990	450000	252010	498040	0.838	211184.4	165915.6	
4		197990	450000	252010	750050	0.79	199087.9	156412.1	
5		197990	450000	252010	1002060	0.745	187747.5	147502.6	
							1059450		801460

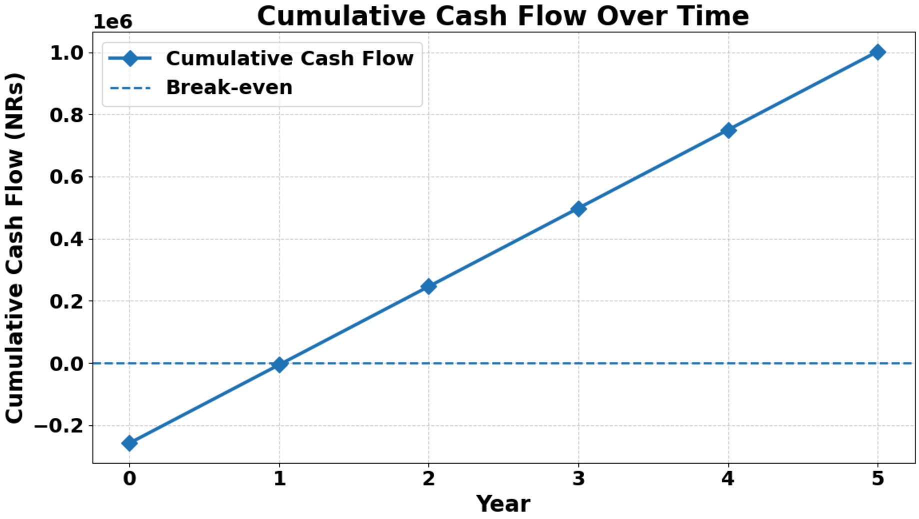


Figure 4: Cumulative Cash Flow diagram over the time period

Figure 5 presents the sensitivity analysis of economic indicators under variations in investment cost, annual benefit, annual cost, and interest rate, and the sensitivity analysis clearly shows a sequential impact of these variables. Investment cost is the most sensitive parameter, as indicated by the steep decline in the red line from −20% to +20%, with a large variation of NRs 1,129,504, demonstrating that small changes in initial investment significantly affect project feasibility. Annual benefit is the second most sensitive factor, represented by the green line showing a steady increase, indicating that higher returns can substantially improve profitability but may introduce uncertainty if estimates are inaccurate. Annual cost shows moderate sensitivity, as reflected by the gradual change in the yello line, suggesting that cost variations have a manageable impact and can be optimized without severely affecting financial stability. As a result, the interest rate, represented by the blue line, exhibits only slight variation, making it the least sensitive parameter and indicating that the project's economic feasibility remains relatively stable under.

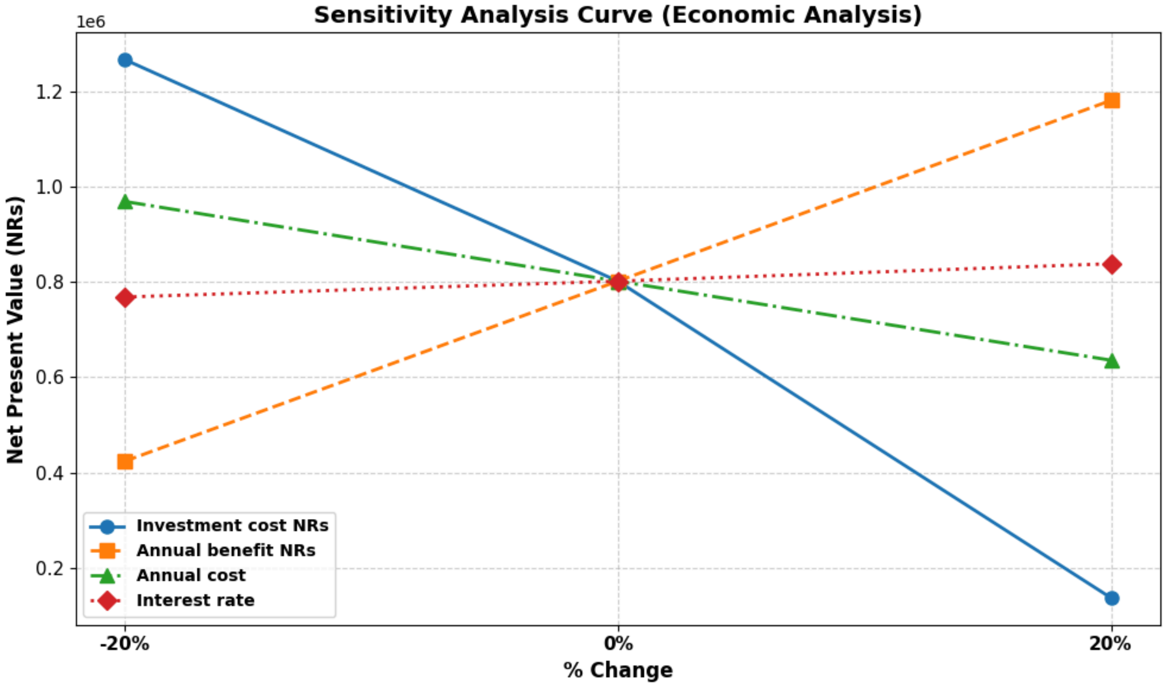


Figure 5: Sensitivity analysis of economic indicators under variations in investment cost, annual benefit, annual cost, and interest rate.

Organic waste forms a major share of municipal solid waste in developing countries, often accounting for more than 50% or more of the total waste stream [52]. When this biodegradable waste is disposed of in landfills, it contributes significantly to greenhouse gas emissions, particularly methane and carbon monoxide, and accelerates the exhaustion of landfill capacity. Vermicomposting offers a sustainable alternative by converting organic waste into useful compost while minimizing environmental impacts. Studies show that vermicomposting can reduce greenhouse gas emissions by 30–70% compared to landfilling [53].

In the context of Nepal, methane emissions from landfill sites such as Sisdol in Kathmandu Valley are already high and projected to increase further [54], highlighting the urgency of waste diversion strategies. Shukla Gandaki Municipality generates approximately 8.8 tons of organic waste per day, which would occupy about

17.6 m^3 of landfill volume, assuming a bulk density of 500 kg/m^3. With an average landfill depth of 4 m, this translates to around 4.4 m^2 of landfill area consumed daily. Diverting this organic waste to vermicomposting can therefore save valuable landfill space, reduce environmental pollution, and recover nutrients in the form of compost. Overall, promoting household and community level vermicomposting in Shukla Gandaki Municipality can significantly extend landfill lifespan while delivering environmental and economic benefits, supporting its role as a practical and sustainable waste management solution.

4. CONCLUSION

Solid waste in Nepal is largely organic; therefore, managing organic waste at the source can significantly reduce landfill pressure. This study evaluated the feasibility of household level vermicomposting using organic waste in Shukla Gandaki Municipality. Nutrient analysis of the vermicompost confirmed that essential parameters Nitrogen (Average 1.73%), Phosphorus (Average 1.44%), and Potassium (Average 2.18%), meet the minimum standards set by the Department of Agriculture, Government of Nepal, although pH (Average 8.5) and moisture content (Average 73.97%) exceeded recommended limits, highlighting the need for better process control. This suggests that the vermicompost generated is nutrient-rich and appropriate for use in agriculture, despite minor variations in physical characteristics. Based on the 2078 Population Census, the municipality generates approximately 8,866 kg of organic waste per day, and a representative sample of 109 households was established using Slovin's formula to support reliable data collection and scaling.

The economic evaluation demonstrates that vermicomposting is financially viable. At a discount rate of 6.05%, the Net Present Value of the vermicompost plant was calculated as NPR 801,460, indicating profitability. Sensitivity analysis shows that initial investment cost is the most influential factor affecting project feasibility, followed by annual benefits and operating costs, while the interest rate has minimal impact on economic performance.

Environmentally, vermicomposting offers substantial benefits by reducing landfill dependency, greenhouse gas emissions, and leachate generation. Composting 8.8 tons of organic waste reduces landfill space requirements by approximately 17.6 m^3, assuming a bulk density of 500 kg/m^3, and helps mitigate methane emissions through aerobic decomposition. Overall, the findings confirm that household-level vermicomposting is a practical, sustainable, and economically sound waste management solution, and its adoption is strongly recommended for municipalities and households, particularly in semi-urban and rural areas.

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