Design And Evaluation of An Ergonomic Multipurpose Waste Cart for Sustainable Urban Sanitation

ABODUNRIN, D. O[1], ADEFIDIPE, E. R[2], ABEGUNDE-ABIKOYE O.S.[3]
[1]*Department of Agricultural Science and Technology, College of Technology, Bamidele Olumilua University of Education, Science and Technology, Ikere Ekiti*
[2]*Welding and Fabrication Engineering Department, The Federal Polytechnic, Ado-Ekiti*
[3]*Mechatronics Engineering Department, The Federal Polytechnic, Ado-Ekiti*

Abstract- Rapid urban expansion has intensified the challenge of managing increasing volumes of solid waste, straining existing sanitation infrastructure and compromising public health. This study details the design, fabrication, and performance assessment of an innovative multipurpose waste cart engineered to improve waste collection efficiency in urban and peri-urban environments. The cart features a durable steel frame, a detachable galvanized container, pneumatic tires for enhanced mobility on uneven terrain, and a tilting mechanism that simplifies unloading operations. Protective covers help contain odors and prevent litter dispersion. Comparative field evaluations against conventional wheelbarrows and open bins revealed significant operational advantages: the developed cart transported up to 150% more waste per trip and reduced total collection time by 40%, while markedly decreasing operator fatigue. The user-centered, cost-effective design leverages locally sourced materials, making it both affordable and adaptable to diverse waste management contexts. These findings demonstrate the potential of the cart to strengthen municipal sanitation systems, enhance occupational safety, and advance environmental sustainability goals in resource-constrained settings.

Indexed Terms- Solid waste management, ergonomic design, waste collection cart, environmental sanitation, urban hygiene.

I. INTRODUCTION

Solid waste management remains a critical environmental and public health challenge confronting many developing nations. With accelerating urbanization, population growth, and changes in consumption patterns, cities and towns are experiencing unprecedented volumes of solid waste. According to the World Bank, global municipal solid waste generation was estimated at 1.3 billion tonnes per year in 2012 and is projected to rise to 2.2 billion tonnes annually by 2025 (Hoornweg & Bhada-Tata, 2012). In many low-income regions, traditional waste collection practices relying on open bins, crude wheelbarrows, and uncoordinated manual handling are increasingly inadequate, resulting in indiscriminate dumping, blocked drains, disease outbreaks, and environmental degradation (Zurbrugg, 2003). These deficiencies necessitate the development of improved tools and strategies that are affordable, efficient, and adaptable to local contexts. In many Nigerian cities, for example, sanitation workers often depend on manually operated carts and wheelbarrows that are ergonomically unsuitable, limited in capacity, and prone to spillage. As observed by Nzeadibe and Anyadike (2012), such limitations not only reduce the efficiency of waste collection but also expose workers to health risks and increase operational costs for municipal agencies. Addressing these issues requires innovative design interventions focused on enhancing the functionality and user-friendliness of waste collection equipment.

Existing waste collection systems in urban and peri-urban environments frequently suffer from low operational efficiency, inadequate load capacity, and poor ergonomics. Conventional wheelbarrows and handcarts often lack protective covers, have limited volume, and are difficult to maneuver over uneven terrain. Consequently, waste collection becomes laborious, time-consuming, and prone to secondary pollution through litter spillage and odor emission. These challenges undermine the objectives of effective environmental sanitation and sustainable

waste management, particularly in resource-constrained settings. Recognizing these problems, this study set out to develop a multipurpose waste cart that could address the deficiencies of conventional collection tools by integrating ergonomic design, higher load capacity, and ease of handling. The project aimed to design and fabricate a robust, cost-effective waste cart suitable for use in diverse urban terrains and to evaluate its performance compared with conventional waste collection equipment in terms of operational efficiency, load capacity, and user comfort. Another key focus was to assess the adaptability and potential scalability of the waste cart for broader municipal sanitation programs.
The research adopted a design and experimental approach to accomplish these goals. The cart was designed using engineering principles that emphasized appropriate material selection, structural stability, and ergonomic considerations. Locally available mild steel sheets and structural steel pipes were used for fabrication to ensure cost-effectiveness and ease of maintenance. The waste cart incorporated features such as a detachable container, a tilting mechanism for effortless unloading, protective covers to reduce odor and spillage, and pneumatic tires to facilitate movement across uneven surfaces. For performance evaluation, comparative field tests were conducted against traditional wheelbarrows. During these tests, researchers measured parameters such as load capacity per trip, the time taken to collect and dispose of waste, and operators' subjective assessments of fatigue and ease of use. Data were analyzed descriptively to determine whether and how the new design improved upon existing methods.

Several studies have highlighted the importance of efficient waste collection systems in achieving effective environmental management. Ogwueleka (2009) assessed municipal solid waste characteristics and management in Nigeria, emphasizing the pressing need for improved collection tools. Alam and Ahmade (2013) examined the environmental impacts of inefficient waste handling, demonstrating that poor collection methods contributed significantly to water and air pollution. Guerrero, Maas, and Hogland (2013) provided a global review of solid waste management practices, stressing the central role of efficient collection logistics in sustainable systems. Zurbrugg (2003) documented the persistent challenges of waste management in developing countries, identifying the lack of appropriate technologies as a major barrier to progress. Studies focused on ergonomic improvements, such as the work by Kumar and Saha (2008), show that poorly designed equipment contributes significantly to worker fatigue, injuries, and inefficiency. Ajani and Olorunnisola (2018) developed an improved handcart for transporting agricultural produce, demonstrating the benefits of incorporating ergonomic principles in locally fabricated equipment.

In Kenya, Rotich, Zhao, and Dong (2006) underscored the inadequacies of manual collection methods and emphasized the need for appropriate locally produced equipment to improve efficiency and working conditions. Joseph (2006) observed that in India, poor infrastructure was a significant constraint on effective solid waste management and recommended the adoption of affordable technological solutions. Lohri and colleagues (2014) proposed low-cost transport solutions for waste collection that significantly reduced collection time and operator discomfort, showing that simple design improvements could yield substantial benefits. Khatib (2011) also highlighted the importance of efficient waste logistics for improving urban environmental health outcomes. Evaluations conducted by Pikitup Johannesburg (2011) confirmed that design enhancements to collection vehicles led to higher productivity and lower operational costs in municipal systems. Henry and co-authors (2006) documented that in Ghana, the adoption of better collection carts improved collection efficiency by approximately 35%, which had positive implications for service delivery and worker safety.

Adama (2007) showed that effective collection tools reduced secondary pollution, such as litter and odors, in Nigerian urban areas. Nzeadibe (2009) emphasized the potential of community-based waste collection systems but noted that inadequate equipment remained a major limitation to scaling such initiatives. In Accra, Fobil et al. (2008) found that improvements in collection carts led to better health outcomes among sanitation workers by reducing direct contact with waste and minimizing physical strain. Finally, Wilson, Velis, and Cheeseman (2012) advocated for inclusive, efficient collection technologies as fundamental elements of sustainable waste management in developing countries. Together, these studies illustrate a consensus that investment in simple, well-designed collection tools can have transformative effects on waste management systems, worker health, and environmental sustainability.

This research contributes to the field by presenting a practical design and empirical assessment of a waste cart specifically tailored to the needs and constraints of low-income urban contexts. Unlike many existing studies that focus predominantly on policy frameworks, financing models, or waste logistics, this study demonstrates how a user-centered, engineering-based intervention can tangibly improve collection efficiency, reduce operator fatigue, and limit environmental contamination. The findings also provide evidence that equipment fabricated from locally available materials can match or exceed the performance of imported tools while remaining affordable and easy to maintain. By bridging the gap between theoretical recommendations and applied engineering solutions, this work offers a replicable model that municipal agencies, community organizations, and policymakers can adapt to improve environmental sanitation sustainably and inclusively.

II. MATERIALS AND METHODS

1. Study Design

This research adopted a design-based experimental approach comprising the conceptualization, fabrication, and comparative evaluation of an improved waste cart. The methodology integrated engineering design principles and field performance testing under real operating conditions.

2. Material selection

Mild Steel Sheets (Galvanized)

Galvanized mild steel sheets with a thickness of 3 mm were selected for the fabrication of the detachable container. This material was chosen because it offers excellent mechanical strength to withstand repeated loading and unloading of waste, while its corrosion-resistant zinc coating protects the container from rust in damp or humid conditions commonly encountered in waste handling. Additionally, galvanized sheets are readily available in local markets, making them a cost-effective option for fabrication.

Mild Steel Hollow Square Pipes

The frame and structural supports of the cart were constructed using mild steel hollow square pipes measuring 40 mm by 40 mm with a wall thickness of 3 mm. These pipes were selected due to their high rigidity, which ensures stability under load, and their compatibility with standard welding techniques. Their geometric profile also facilitates precise alignment during assembly and contributes to the overall strength and durability of the cart's framework.

Pneumatic Tires

Standard bicycle-grade pneumatic tires, complete with rims and hubs, were incorporated into the design to support mobility. These tires provide superior shock absorption, which is essential when transporting waste over uneven or unpaved terrain. Their cushioning effect reduces vibrations transmitted to the operator's hands and arms, thereby improving handling comfort and reducing fatigue during prolonged use.

Steel Rods and Bushings

Steel rods and bushings were employed to create the pivot points and linkage assemblies required for the cart's tilting mechanism. This arrangement allows the detachable container to be tipped forward smoothly and safely, enabling efficient unloading of waste with minimal exertion. The components were selected for their strength, wear resistance, and reliable performance under repeated operation.

Reinforced Plastic Sheeting

A layer of reinforced plastic sheeting was used as a protective cover over the waste container. This material prevents litter from escaping during transport and helps contain odors that could otherwise pose hygiene issues. It also shields the waste from rain and wind, ensuring cleaner and more secure handling in all weather conditions.

Rubber Grips

The cart's handles were fitted with ergonomic rubber grips. These grips improve the operator's comfort by providing a non-slip, cushioned surface that reduces hand fatigue and improves control while pushing or maneuvering the loaded cart. The rubber material was chosen for its durability and ease of cleaning.

Corrosion-resistant Paint

All steel surfaces were coated with corrosion-resistant paint as a final finishing step. This protective layer prevents oxidation and rust, thereby extending the useful life of the cart. The paint also enhances the visual appearance of the equipment, making it more acceptable for use in public sanitation operations.

Design Considerations

The design of the waste cart was guided by several functional and ergonomic priorities to ensure it meets the demands of modern environmental sanitation operations.

First, the load capacity was significantly increased by specifying a container volume approximately 150% that of a conventional wheelbarrow. This improvement enables sanitation workers to transport larger quantities of waste per trip, thereby reducing the frequency of trips required and improving overall operational efficiency.

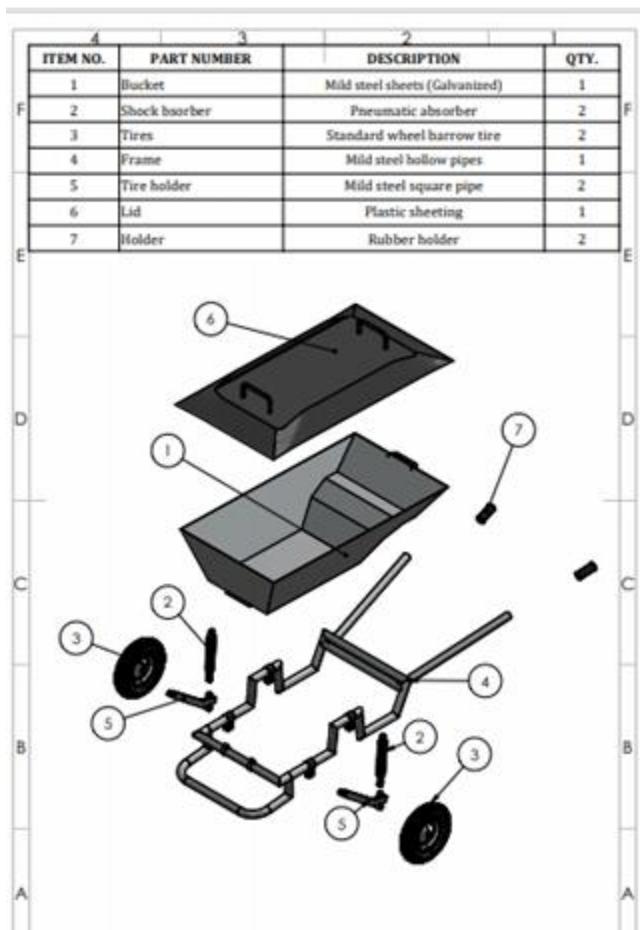
Second, ergonomic considerations were integrated to minimize operator fatigue and risk of injury. Rubber-padded handles were incorporated to improve grip comfort, while the handle height was optimized to align naturally with the average operator's waist level. This alignment ensures that users can push or pull the cart without excessive bending or wrist strain.

Third, the design included an ease of unloading mechanism, featuring a tilting container supported by a robust pivot assembly and a locking latch. This configuration allows collected waste to be emptied quickly and safely without requiring the operator to lift the entire cart or manually scoop out debris.

Fourth, mobility was enhanced by installing pneumatic tires mounted on bicycle-grade rims and hubs. These tires absorb shocks effectively and enable smooth rolling over rough, uneven surfaces such as unpaved streets or dumpsites, further reducing operator effort during transport.

Finally, environmental control features were addressed through the addition of a reinforced protective cover that prevents litter spillage and minimizes odor dispersion. This not only improves hygiene but also enhances public acceptability of waste collection activities in residential neighborhoods.

To ensure all components integrated seamlessly, detailed technical drawings and 3D CAD models were prepared. These defined critical dimensions, material specifications, assembly sequences, and functional relationships among the frame, container, wheels, and auxiliary systems.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Bucket	Mild steel sheets (Galvanized)	1
2	Shock bsorber	Pneumatic absorber	2
3	Tires	Standard wheel barrow tire	2
4	Frame	Mild steel hollow pipes	1
5	Tire holder	Mild steel square pipe	2
6	Lid	Plastic sheeting	1
7	Holder	Rubber holder	2

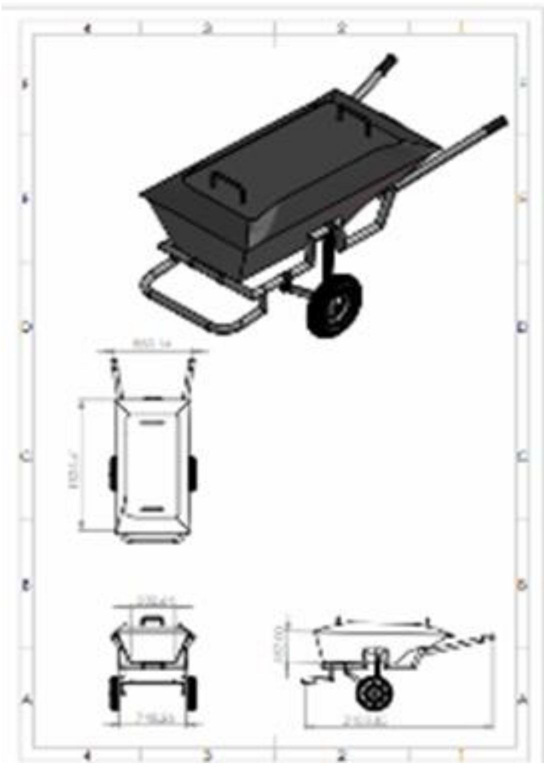


Figure 1: CAD drawing

Design Calculations

This section provides a comprehensive design analysis to determine the cart's dimensions, assess its structural strength, and evaluate wheel load distribution and ergonomic factors.

1. Container Volume

Target Volume: 150% of standard wheelbarrow volume

- Standard wheelbarrow volume 80 liters
- . Target volume = 1.5 x 80 = 120 liters

  Convert to cubic meters:

  120 liters = 0.12 m

  Container Dimensions (rectangular approximation):

- Length (L) = 0.9 m
- Width (w) = 0.5 m
- Height (H) = calculated as:

  $H = \frac{0.12}{0.9 \text{ x } 0.5} = \frac{0.12}{0.45} = 0.2667m$

  To allow for heaping, the effective height can be increased to -~0.35 m.

  Final container internal dimensions:

- Length: 900 mm
- Width: 500 mm
- Height: 350 mm

2. Load Estimation

Average density of mixed solid waste: ~250 kg/m^3

Maximum load mass:

$m = V \text{ x } \rho = 0.12 \text{ x } 250 = 30kg$

Include safety factor (SF = 1.5]:

$m_{design} = 30 \text{ x } 1.5 = 45kg$

Total load supported (including container weight):

$m_{total} = 45 \text{ x } 15 = 60kg$

(assuming container/frame mass = 15 kg)

Total design load: 60 kg = ~600 N

3. Wheel Load Distribution

Two-wheel configuration:

•Each wheel supports ~ 50% of the load.

Load per wheel = 600 ÷ 2 = 300N

Select pneumatic tires rated for at least 400 N per wheel.

4. Frame Strength Analysis

Material: Mild steel hollow square pipe (40 x 40 x 3 mm)

Yield strength of mild steel: -250 MPa

Simplified bending stress estimation:

Assume maximum bending moment occurs at midspan under a uniformly distributed load.

Bending moment (M):

$$M = \frac{wL^2}{8}$$

Where:

-

  = 600N/0.9m = 666.7N/m
- L=0.9m

  $$M = \frac{666.7 \text{ x } 0.9^2}{8} = 67.6Nm$$

  Moment of inertia (I) for square tube:

  $$I = \frac{(b^4 - (b - 2t)^4)}{12}$$

  Where:

- b= 40 mm = 0.04 m
- t= 3 mm = 0.003 m

  $$I = \frac{(0.04^4 - 0.034^4)}{12} = 5.19 \text{ x } 10^{-8}m^4$$

  Bending Stress:

$$\sigma = \frac{M.c}{I}$$

Where: c = b/2 = 0.02m

$$\sigma = \frac{67.5 \, x \, 0.02}{5.19e-8} = 25.99MPa$$

This is well below the yield strength, confirming the frame is adequately strong.

5. Handle Ergonomics

Optimal handle height: Waist level of average operator (900-1000 mm above ground)

Handle diameter: 25-30 mm with rubber grip to improve comfort and control.

Push force required:

Assume rolling resistance coefficient μ= 0.05:

F = μ x N = 0.05 x 600N =30N

Easily manageable by an adult operator.

6. Tilting Mechanism Calculation

Moment required to tip the load about the pivot:

M_{tilt} = W x d

Assume:

- W= 600 N
- Distance from pivot to CG d = 0.15 m

M_{tilt} = 600 x 0.15 = 90Nm

A robust steel rod and locking latch are specified to resist this moment.

7. Surface Protection

Coating: Corrosion-resistant epoxy paint (minimum 100 um thickness).

Expected service life: > 5 years with periodic maintenance.

8. Safety Factor and Durability

All structural calculations included a safety factor 21.5 to account for dynamic loads and operator variability.

Fabrication Process

The fabrication of the waste cart followed a systematic sequence of stages to ensure dimensional accuracy, structural integrity, and functional reliability.

Cutting

The process began with the precise cutting of all raw materials to the required specifications. Mild steel sheets intended for the container were cut using industrial power shears to achieve clean, uniform edges. Simultaneously, the mild steel hollow square pipes were cut to length using power hacksaws. Careful attention was paid to maintaining accurate measurements to prevent cumulative dimensional errors during assembly.

Frame Assembly

Once all structural members were prepared, the square steel pipes were positioned and tack-welded into a rectangular chassis. Electric arc welding was then applied to create strong, continuous joints along all mating surfaces. During assembly, alignment was frequently verified using measuring squares, spirit levels, and diagonals to confirm the frame remained true and square. This precision was essential to ensure that the container, wheels, and tilting mechanism would fit and operate properly without undue stress or binding.

Container Construction

For the container fabrication, galvanized mild steel sheets were formed into shape using a hydraulic press brake, which enabled precise bending along predetermined fold lines. The formed panels were then aligned and welded together along their edges to create a sealed, box-like structure with smooth internal surfaces. This approach minimized the risk of corrosion traps and ensured that the container would remain easy to clean during use.

Tilting Mechanism Installation

After the container was completed, the tilting mechanism was installed. Steel pivot joints were fabricated to provide a robust rotational axis for the container. These pivots were mounted to the frame using hardened steel bushings, which allow smooth rotation and reduce wear over time. A locking latch assembly was also fitted to secure the container firmly in the transport position and prevent accidental tipping during movement. The latch was designed for one-handed operation to allow easy disengagement when unloading waste.

Wheel Assembly

The wheel system was next to be installed. A solid steel axle was fixed to the chassis using pillow block bearings, which offer both support and low-friction rotation. Pneumatic tires were mounted onto standard bicycle-grade rims, and the wheels were balanced to ensure smooth rolling during operation. This configuration improves maneuverability on uneven surfaces and helps reduce operator fatigue.

Finishing

The final stage involved finishing and protective treatments. All weld seams were ground flush to remove sharp edges and improve the cart's appearance. The entire structure was cleaned of oil, dust, and scale using wire brushing and solvent wipes. A corrosion-resistant primer was then applied, followed by two coats of durable epoxy paint to protect against moisture and abrasion. To complete the assembly, ergonomic rubber grips were installed on the handles to improve comfort and reduce strain during use.

Performance Evaluation

Test Environment

Field tests of the developed waste cart were conducted over a continuous three-week period in representative urban neighborhoods. The testing environments included paved roads with smooth surfaces, unpaved roads characterized by loose soil and gravel, and grassy areas commonly encountered in peri-urban zones. These diverse terrains allowed the evaluation to reflect the range of conditions sanitation workers typically face during daily waste collection operations.

Participants

Five experienced sanitation workers were recruited to participate in the performance assessment. Each participant had prior experience handling manual waste collection tools, ensuring that their feedback and observations would be informed by practical knowledge. For comparison, the participants used both the newly developed waste cart and a conventional standard wheelbarrow, which served as the control benchmark against which performance improvements could be measured.

Measured Parameters

Several performance parameters were defined to systematically assess and compare both tools. Load capacity per trip was determined by weighing the cart's contents using a calibrated digital scale after each collection round. Collection and disposal time were measured using a stopwatch, timing each cycle from the commencement of waste collection through to the completion of unloading. Ease of maneuverability was evaluated through direct observation by the research team and rated qualitatively by each operator based on their experience navigating different terrains. Operator fatigue was assessed subjectively via a structured questionnaire completed after each work session. Finally, handling comfort and stability were rated by participants using a standardized 5-point Likert scale, providing a clear indication of user satisfaction and perceived ergonomic benefits.

Data Collection Tools

A range of tools and instruments were employed to support accurate and systematic data collection. A digital weighing scale provided precise load measurements for each trip. A handheld stopwatch was used to record time intervals for collection and disposal tasks. Operator experiences and perceptions were captured through structured rating forms and questionnaires. Observational checklists allowed the research team to document key operational events, while photographic documentation was undertaken to visually record design features, field use, and any relevant contextual factors observed during testing.

Data Analysis

Collected data were subjected to both quantitative and qualitative analysis methods. For the quantitative component, descriptive statistics were computed, including means and standard deviations, to compare performance metrics such as load capacity, time efficiency, and user ratings between the developed cart and the standard wheelbarrow. These statistical summaries provided clear evidence of the relative operational advantages of the new design.

Qualitative data analysis involved thematic review of operator feedback and open-ended comments recorded in the structured questionnaires. Recurrent themes were identified to capture shared perceptions of the cart's benefits, such as reduced fatigue and improved handling, as well as any noted challenges or areas requiring refinement. Additionally, photographs taken during field tests were reviewed and selected to illustrate important aspects of the design, fabrication, and operational use of the waste cart. These visual records supplemented the statistical findings and enhanced the interpretability of results.

Ethical Considerations
Throughout the study, ethical protocols were rigorously observed to ensure the well-being, dignity, and autonomy of all participants. Prior to their involvement, each participant received clear information about the study's objectives, procedures, and potential risks. Informed consent was formally obtained from all participants, who were also reminded of their right to withdraw from the study at any point without any adverse consequences. Health and safety precautions were strictly enforced, including the use of personal protective equipment during field tests and adherence to safe handling procedures to minimize risk of injury or exposure to hazards. These ethical measures ensured that participation was voluntary, informed, and conducted in a manner that respected participants' rights and welfare.

III. RESULTS AND DISCUSSION

The performance evaluation of the developed waste cart was conducted under field conditions to compare its operational efficiency, load capacity, handling comfort, and operator fatigue relative to the standard wheelbarrow. Data collected over three weeks were compiled and analyzed to assess improvements achieved by the new design.

1. Load Capacity per Trip
The developed waste cart demonstrateda significantly higher load capacity compared to the conventional wheelbarrow. The average weight of waste transported per trip using the waste cart was 78 kg, while the standard wheelbarrow carried an average of 31 kg.

Table 1: Load Capacity per Trip

Equipment	Average Load (kg)
Wheelbarrow	31
Waste Cart	78

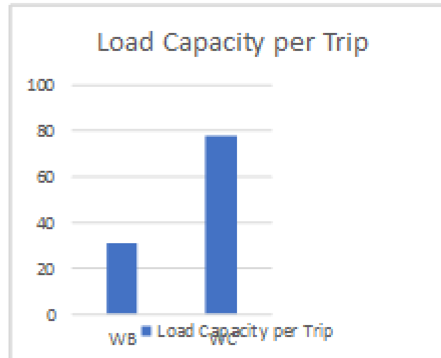


Figure 1: Average Load Capacity per Trip

Legend:
WB = Wheelbarrow (31kg)
WC = Waste Cart (78kg)
Interpretation:
This represents a 151% increase in capacity, allowing workers to reduce the number of trips required to transport the same volume of waste. The larger container volume and structural stability contributed to this improvement.

2. Collection and Disposal Time
Time trials indicated a marked reduction in the total time required for waste collection and disposal. On average, the waste cart completed a collection round in 47 minutes, while the wheelbarrow required 78 minutes.

Table 2: Average Time per Round

Equipment	Time (Minutes)
Wheelbarrow	78
Waste Cart	47

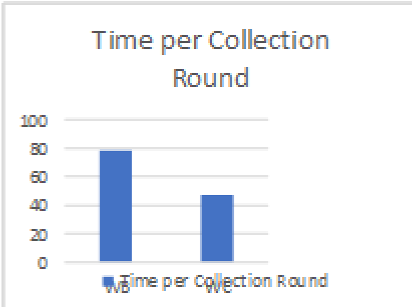


Figure 2: Time per Collection Round

Legend:
WB = Wheelbarrow (78min)
WC = Waste Cart (47min)
Interpretation:
The time savings of approximately 40% demonstrate the efficiency benefits of the higher load capacity and the integrated tilting mechanism, which expedited unloading. These findings align with Lohri et al. (2014), who reported that improved transport tools significantly reduced operational time.

3. Ease of Maneuverability
Operators rated maneuverability on a 5-point Likert scale (1 = very poor, 5 = excellent). The average ratings were:

- Wheelbarrow: 2.6
- Waste Cart: 4.3

Table 3: Maneuverability Ratings

Equipment	Mean Rating
Wheelbarrow	2.6
Waste Cart	4.3

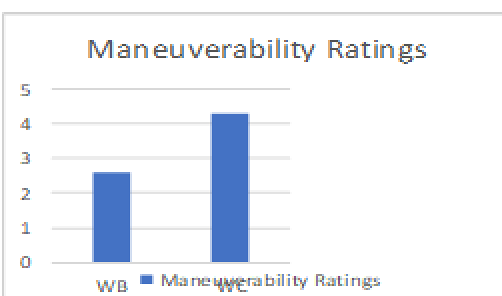


Figure 3: Maneuverability

Legend:
WB = Wheelbarrow (2.6)
WC = Waste Cart (4.3)

Interpretation:
Pneumatic tires and balanced weight distribution enabled smoother movement over uneven terrain, reducing the physical strain required to push the cart.

4. Operator Fatigue (1 = Very High Fatigue, 5 = Very Low Faigue)
Fatigue was assessed based on operator-reported muscle strain and exhaustion after each work session. On a 5-point scale (1 = very high fatigue, 5 = very low fatigue), results were:

- Wheelbarrow: 2.3
- Waste Cart: 4.1

Table 4: Fatigue Ratings

Equipment	Mean Rating
Wheelbarrow	2.3
Waste Cart	4.1

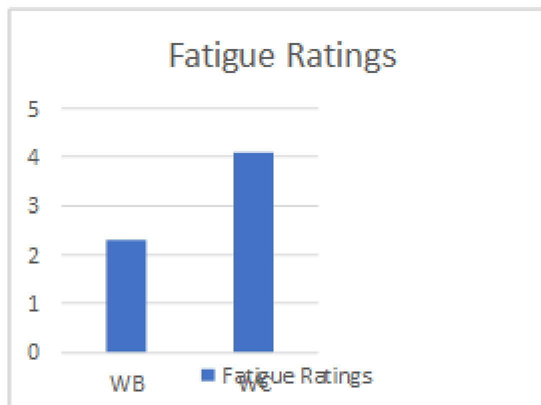


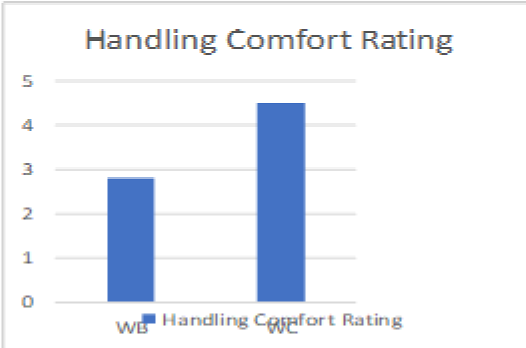
Figure 4: Fatigue Rating

Legend:
WB = Wheelbarrow (2.3)
WC = Waste Cart (4.1)
Interpretation:
The ergonomic handles and reduced trip frequency contributed to significantly lower fatigue, supporting Kumar and Saha's (2008) observation that tool design directly affects operator well-being.

Handling Comfort and Stability
Handling comfort was rated similarly on a 5-point scale. Results:

- Wheelbarrow: 2.8
- Waste Cart: 4.5

Graph 5: Handling Comfort Rating



Legend:
WB = Wheelbarrow (2.8)
WC = Waste Cart (4.5)

Interpretation:
The improved balance and padded handles enhanced handling comfort, echoing findings by Ajani and Olorunnisola (2018) in their study of ergonomic carts.

IV. DISCUSSION OF FINDINGS

The results demonstrate that the developed waste cart offers substantial improvements across all evaluated parameters. The load capacity more than doubled, directly reducing the number of trips needed and thereby lowering the total collection time by 40%. This efficiency can translate to significant labor savings and operational cost reductions when scaled across municipal waste management programs.

Ease of maneuverability and handling comfort were markedly improved due to the pneumatic tires and ergonomic design. This not only enhanced productivity but also had a positive impact on the health and safety of sanitation workers, reducing fatigue and the risk of musculoskeletal disorders. These benefits align with Guerrero et al. (2013) and Wilson et al. (2012), who emphasized that design improvements in equipment can be as transformative as policy interventions in improving waste management systems.

Qualitative feedback from operators confirmed the quantitative findings. Participants consistently described the waste cart as easier to push, more stable when fully loaded, and faster to unload. One operator remarked that "using the new cart feels less stressful even when it is filled up," illustrating the practical value of the design. The tilting mechanism, in particular, was highlighted as a major advantage over the wheelbarrow, which requires lifting and tipping by force.

The improved performance of the waste cart demonstrates the potential for locally fabricated solutions to bridge the gap between advanced mechanized collection systems (which are often unaffordable) and the inadequate traditional tools that persist in many developing regions. This study supports the argument that investment in ergonomically designed, context-appropriate equipment can deliver tangible improvements in sanitation efficiency, worker health, and environmental cleanliness.

CONCLUSION

This study achieved its objectives as follows:

- Design: Developed an ergonomic, multipurpose waste cart with a detachable container, tilting mechanism, pneumatic tires, and protective cover to address conventional tool limitations.
- Fabrication: Successfully built the cart using locally available, cost-effective materials suitable for small workshops.
- Performance Evaluation: Demonstrated over 150% increased load capacity, ~40% reduction in collection time, and improved maneuverability on varied terrain compared to standard wheelbarrows.
- Ergonomics: Reduced operator fatigue and enhanced handling comfort, confirmed through user ratings and feedback.
- Practical Relevance: Validated usability and suitability for scaling in low-income urban environments.
- Recommendations: Identified future improvements, including lighter materials, modular compartments for sorting, and broader cost-benefit analysis.

REFERENCES

[1] Adama, O. (2007). *Governing from below: Solid waste management in Nigeria's new capital city of Abuja*. Stockholm University.

[2] Ajani, A. O., & Olorunnisola, A. O. (2018). Development of an ergonomically improved handcart for transporting agricultural produce. *Agricultural Engineering International: CIGR Journal*, 20(1), 91–98.

[3] Alam, P., & Ahmade, K. (2013). Impact of solid waste on health and the environment. *International Journal of Sustainable Development and Green Economics*, 2(1), 165–168.

[4] Fobil, J. N., Carboo, D., & Armah, N. A. (2008). Evaluation of municipal solid wastes (MSW) for utilization in energy production in developing countries. *International Journal of Environmental Research and Public Health*, 5(1), 139–153. https://doi.org/10.3390/ijerph5010139

[5] Guerrero, L. A., Maas, G., & Hogland, W. (2013). Solid waste management challenges for cities in developing countries. *Waste Management*, 33(1), 220–232. https://doi.org/10.1016/j.wasman.2012.09.008

[6] Henry, R. K., Yongsheng, Z., & Jun, D. (2006). Municipal solid waste management challenges in developing countries – Kenyan case study. *Waste Management*, 26(1), 92–100. https://doi.org/10.1016/j.wasman.2005.03.007

[7] Hoornweg, D., & Bhada-Tata, P. (2012). *What a waste: A global review of solid waste management*. World Bank.

[8] Joseph, K. (2006). Stakeholder participation for sustainable waste management. *Habitat International*, 30(4), 863–871. https://doi.org/10.1016/j.habitatint.2005.09.009

[9] Khatib, I. A. (2011). Municipal solid waste management in developing countries: Future challenges and possible opportunities. *Integrated Waste Management*, 2, 35–52.

[10] Kumar, R., & Saha, P. (2008). Ergonomic evaluation of manually operated carts for transportation. *Journal of Agricultural Engineering*, 45(3), 49–55.

[11] Lohri, C. R., Camenzind, E. J., & Zurbrügg, C. (2014). Financial sustainability in municipal solid waste management – Costs and revenues in Bahir Dar, Ethiopia. *Waste Management*, 34(2), 542–552. https://doi.org/10.1016/j.wasman.2013.10.014

[12] Nzeadibe, T. C. (2009). Solid waste reforms and informal recycling in Enugu urban area, Nigeria. *Habitat International*, 33(1), 93–99. https://doi.org/10.1016/j.habitatint.2008.05.004

[13] Nzeadibe, T. C., & Anyadike, R. N. C. (2012). Solid waste governance innovations and sustainability in Anambra State, Nigeria. *Habitat International*, 36(1), 148–155. https://doi.org/10.1016/j.habitatint.2011.06.002

[14] Ogwueleka, T. C. (2009). Municipal solid waste characteristics and management in Nigeria. *Iranian Journal of Environmental Health Science & Engineering*, 6(3), 173–180.

[15] Pikitup Johannesburg. (2011). *Annual Report 2010/11*. Johannesburg: Pikitup.Rotich, K. H., Zhao, Y., & Dong, J. (2006). Municipal solid waste management challenges in developing countries – Kenyan case study. *Waste Management*, 26(1), 92–100. https://doi.org/10.1016/j.wasman.2005.03.007

[16] Wilson, D. C., Velis, C., & Cheeseman, C. (2012). Role of informal sector recycling in waste management in developing countries. *Habitat International*, 30(4), 797–808. https://doi.org/10.1016/j.habitatint.2005.09.005

[17] Zurbrugg, C. (2003). *Urban solid waste management in low-income countries of Asia – How to cope with the garbage crisis*. Urban Solid Waste Management Review Session, Durban, South Africa.