Circularity Assessment Protocol in Cities: A Systematic Tool for Managing Plastic Pollution, Insights from Atlanta city

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Rationale: Plastic pollution as a significant challenge at both global and local levels and has detrimental effects on environmental health and community well-being. Addressing this chronic issue requires targeted, context-sensitive interventions that not only consider the global scales but also align with the specific needs of individual communities. **Aim:** This study aims to apply the Circularity Assessment Protocol (CAP) in Atlanta, Georgia, to assess plastic packaging flows, identify actionable opportunities, and enhance community engagement in managing plastic waste. **Methods:** Data were collected through field surveys, stakeholder interviews, and the CAP framework to analyze material inputs, leakage patterns, and community reflections. For the Atlanta study, a 100 km^2 area was identified using ArcMap as the fieldwork site for CAP surveys in June and July 2022. The area was divided into three tertiles (high, medium, low) based on ambient population data from the 2019 LandScan dataset. Using NOAA's Sampling Design Tool, nine 1 km^2 transects were selected, with 27 leakage survey sites identified within these areas. **Results:** The analysis of 155 Fast Moving Consumer Good items showed candy had the longest average distance, primarily from Asia/Europe, while beverages had the shortest due to Coca-Cola in Atlanta. Leakage assessment found 1,661 litter items, 40% being plastic fragments/food wrappers. Litter density was 1.46 items/m^2 in high-population areas and 0.89 items/m^2 in low-population areas, with glass most prevalent in low/high-population areas and food plastics in mid-population areas. **Conclusions & Outlook:** The CAP results inform targeted interventions and strategy development to enhance circularity in Atlanta. The CAP tool is adaptable to other cities, supporting broader efforts to establish sustainable, circular systems in diverse communities for managing plastic pollution.

The Circularity Assessment Protocol (CAP): A Tool for Facilitating the Transition from a Linear Material Life to a Circular Life Cycle

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Introduction

Concerns about the life cycle of plastic materials are growing rapidly, with research highlighting their deep connections to broader issues like climate change, sustainability, environmental degradation, biodiversity loss, human health, social justice, etc. [1, 2, 3]. While global discussions on managing plastic pollution continue, it is essential to recognize that local communities are the first to face these challenges as plastics become part of their daily lives. Traditional waste management practices are inadequate to handle the expanding use of plastics, leading to direct detrimental impacts on the livelihoods and health of the communities due to direct exposure to these materials. This reveals a gap between high-level policymaking and the practical realities of implementing solutions at the community level [4]. To bridge this gap, the Circularity Informatics Lab at the University of Georgia developed the Circularity Assessment Protocol (CAP), illustrated in Figure 2., as a standardized tool for assessing material flows at the community level by collecting localized data [4, 5]. CAP uses principles of circularity and systems thinking to analyze how plastics enter, are used, and exit communities—either through waste management or leakage into the environment. The goal of CAP is to provide community-specific data to support informed decision-making and identify areas for improvement based on their specific needs. The protocol has been implemented in 56 communities across 16 countries, proving its effectiveness as a framework for evaluating material management [5, 6]. This study applies CAP to Atlanta, Georgia, USA, to organize and implement a CAP focused on plastic packaging materials in common convenience items and identify actionable opportunities by integrating CAP data with community engagement to better manage plastic flows in the city.

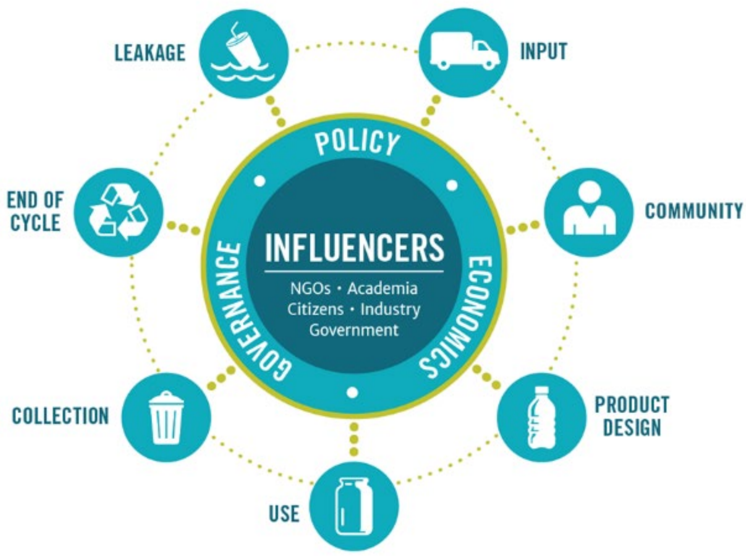


Figure 2. Circularity Assessment Protocol (CAP) Hub-and-Spoke Model: Seven Spokes of the Plastic Materials Life Cycle Driven by Policy, Economics, and Governance at the Center

1. Materials and Methods

2.1. Site selection and sampling strategies

For the Atlanta city study, a consultative process identified a 100 km^2 area centered around the city using ArcMap as the designated fieldwork site for the CAP survey conducted in June and July 2022. This area, illustrated in Figure 3, was classified into three tertiles (high, medium, and low) based on ambient population data, which reflects societal activity rather than residential population density. The data was sourced from Oak Ridge National Laboratory's 2019 LandScan dataset, which provides ambient population estimates at a 1 km spatial resolution. Using the National Oceanographic and Atmospheric Administration (NOAA) Sampling Design Tool, three 1 km^2 transects were randomly selected within each tertile, resulting in a total of nine 1 km² transects as survey areas. Within each of these nine areas, the Sampling Tool further identified three 100 m² sites for conducting leakage surveys.

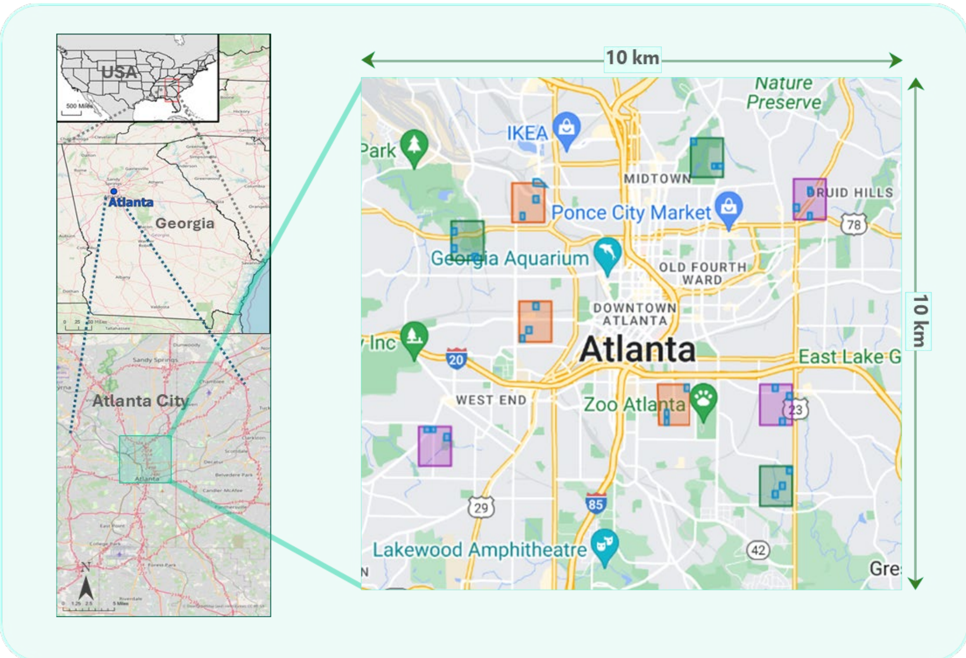


Figure 3. Overview Map of Survey Area: 10 x 10 km area centered over Atlanta city. The colored grid represents nine 1 × 1 km² areas classified into three tertiles based on ambient population levels—high, medium, and low. The small blue grids within these tertiles indicate the randomly selected 100 m² transects for leakage surveys, totaling twenty-seven 100 m² transects across nine different 1 km² areas.

2.2. Sampling methodology and data collection

2.2.1. Start of the Cycle: Inputs of materials into the community and complementary insights from the Community: To understand the sources of plastic packaged for top convenience items in Atlanta, the CIL team sampled 155 products in the Fast Moving Consumer Goods items (FMCG) (focusing on popular brands of candy, chips, beverages) across nine 1 km² survey areas. They documented packaging types, brands, parent companies, and manufacturing locations. The study also examined community usage through field observations, semi-structured interviews, and document analysis. Stakeholders, including government officials and non-profits, provided insights into recycling, composting, and circular economy initiatives[7].

2.2.2. End of the Cycle: Disposal and leakage assessment: To assess solid waste management in Atlanta, data was collected through a combination of previously completed waste characterization studies, interviews with key stakeholders—including government officials and waste management professionals—and field observations of waste collection practices and infrastructure. Additionally, a leakage assessment was conducted to evaluate materials that have leaked into the environment. Data on litter was recorded using the open-source Debris Tracker mobile application [6], ensuring accurate and consistent data collection across the surveyed locations to better understand environmental leakage.

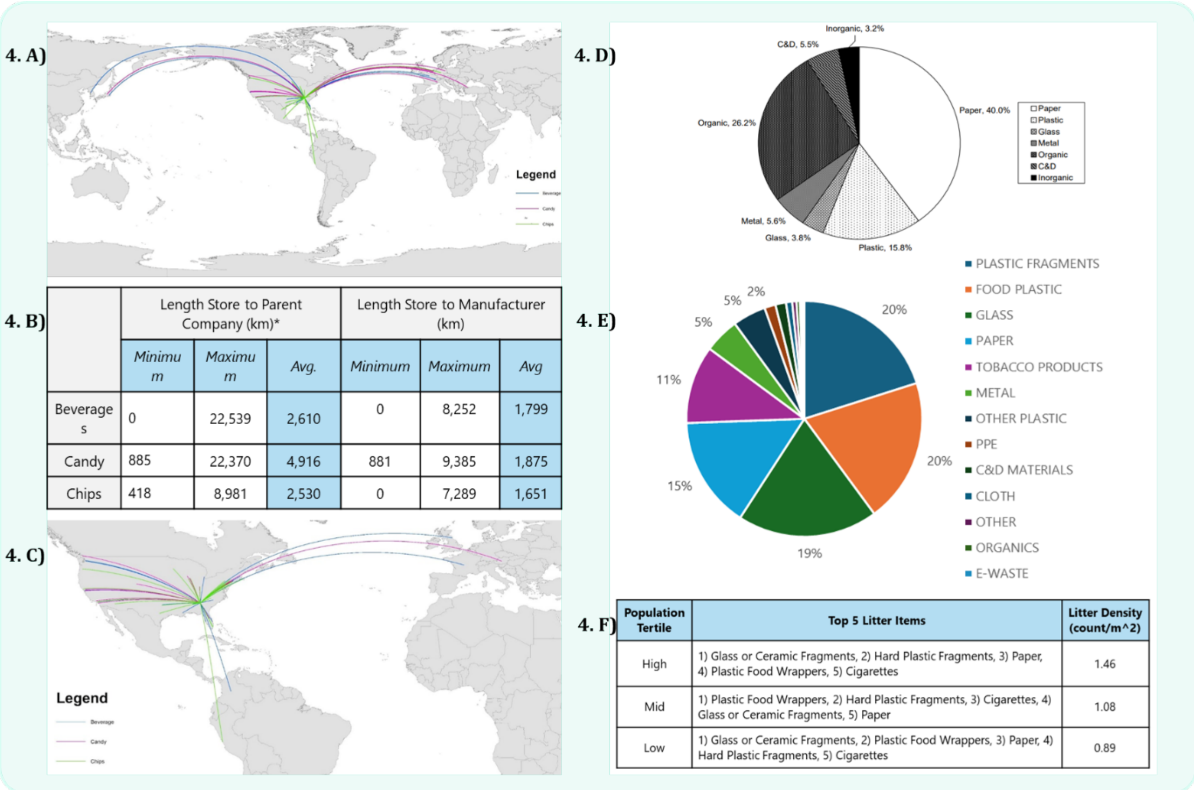
2. Results and Discussion

3.1 Results on material inputs and community reflections:

The analysis of 155 sampled FMCG items in three groups of chips candy and beverages, as presented in Figure 4.A, 4.B and 4.C, revealed that candy had the highest average distance for both parent companies and manufacturers, while beverages had the lowest, due to Coca Cola's Atlanta headquarters. However, beverages still showed broad distribution, indicating many were shipped from distant locations. Most chip parent companies are based in the U.S. or South America, while many candy and beverage parent companies are located in Asia or Europe. The assessment of community engagement in improving waste management shows that education and transparency efforts led to a 30% reduction in recycling contamination and a 35% increase in composting participation. However, challenges with composting infrastructure and limited plastic recycling options remain. Field observations revealed disparities, with low-income areas more exposed to plastic and EPS (Expanded Polystyrene) products, while higher-income neighborhoods have better access to sustainable alternatives. Enhanced signage and clearer communication are crucial for reducing contamination and boosting participation across all communities.

3.2 Results on solid waste management practices and leakage assessment

A review of waste characterization studies shows that Atlanta households generate an average of 814 pounds of waste per person annually [8]. The waste composition in the Atlanta Regional Commission area, as shown in Figure 4. D., includes 40% paper, 15.8% plastic, and 26.2% organic materials. Based on field surveys of Atlanta's current waste management programs, the city recycles plastics #1-5, but contamination and high tipping fees increase costs. Only plastics #1 and #2 are the most cost-effective to recycle. Landfilling in Atlanta costs $45 per ton while recycling costs $75 per ton, primarily due to reliance on private MRFs. For the leakage assessment of materials into the environment in this area, a field survey was conducted across 27 transects, recording a total of 1,661 litter items. As presented in Figure 4.E, plastic fragments and plastic food wrappers were the most common types, together making up 40% of all recorded litter. Glass was the second most prevalent at 19%, followed by paper at 15%, tobacco products at 11%, and metal at 5%. Figure 4.F shows also variations in litter densities and types across the three population tertiles. Litter density was highest in high-population areas (1.46 items/m^2) and lowest in low-population areas (0.89 items/m^2). Additionally, there is also variation in litter compositions, with glass being most prevalent in both low- and high-population areas, while food plastics were most common in mid-population areas.



4. B)

	Length Store to Parent Company (km)*			Length Store to Manufacturer (km)		
	Minimum	Maximum	Avg.	Minimum	Maximum	Avg
Beverages	0	22,539	2,610	0	8,252	1,799
Candy	885	22,370	4,916	881	9,385	1,875
Chips	418	8,981	2,530	0	7,289	1,651

4. F)

Population Tertile	Top 5 Litter Items	Litter Density (count/m^2)
High	1) Glass or Ceramic Fragments, 2) Hard Plastic Fragments, 3) Paper, 4) Plastic Food Wrappers, 5) Cigarettes	1.46
Mid	1) Plastic Food Wrappers, 2) Hard Plastic Fragments, 3) Cigarettes, 4) Glass or Ceramic Fragments, 5) Paper	1.08
Low	1) Glass or Ceramic Fragments, 2) Plastic Food Wrappers, 3) Paper, 4) Hard Plastic Fragments, 5) Cigarettes	0.89

Figure 4. Results of CAP assessment on FMCG packaging materials' input, waste management, and leakage into the environment in Atlanta city. **4. A)** Global map of parent company locations for top convenience items in Atlanta, **4. B)** Distances between Atlanta and the locations of manufacturers and parent companies for top FMCG items, **4. C)** Global map of manufacturing locations for top convenience items in Atlanta, **4. D)** Atlanta Regional Commission Regional Development Center municipal solid waste composition [9], **4. E)** Breakdown of leaked materials in Atlanta as litter, **4. F)** Leakage densities across population tertiles (societal activity) in Atlanta.

3. Conclusions & Outlook

Analyzing material inputs and manufacturing data highlights that with approximately 30% of beverage parent companies and 20% of manufacturing based locally, the city is well-positioned to engage these companies in Extended Producer Responsibility (EPR) discussions. Although Georgia currently lacks EPR legislation, such policies could drive producers to take responsibility for the entire lifecycle of their products, fostering circular economy goals. Additionally, the field survey and community reflections emphasize the need for ongoing investment infrastructure and community engagement. Enhancing access to sustainable alternatives and improving composting facilities are crucial steps toward increasing circularity and providing equitable access across the city. By addressing these areas, Atlanta can strengthen its sustainability efforts and reduce the environmental impact of material usage. Field observations and stakeholder interviews reveal that the absence of a comprehensive municipal composting program in Atlanta offers a significant opportunity to develop a residential initiative, supported by centralized composting facilities and on-site composting in large organizations. Enhanced community outreach and improved signage can reduce contamination and benefit organic waste processing. Additionally, the leakage survey highlights opportunities for brands to invest in alternative packaging, infrastructure enhancement and recycling initiatives. Data on litter density and composition, alongside socioeconomic factors, can further inform the assessment of material usage patterns and the effectiveness of waste management strategies distributed in the city. Collecting data and fostering open dialogues, as done in this study and other CAP projects globally, brings the power of data plus a community's local knowledge and expertise to collaborate on interventions to combat plastic pollution. The University of Georgia's CIL is creating a digital platform to link CAP cities and a training portal to improve accessibility. By scaling local efforts and providing transparent data, tools like Debris Tracker and CAP can drive systemic change from production to leakage.

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Data availability: All geospatial data, including litter and waste receptable locations collected with Debris Tracker is open access and available at https://www.debristracker.org/. Other raw data for tables/graphs in the CAP report are posted and downloadable at https://www.circularityinformatics.org/.

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References

[1] Seewoo, B. J., Wong, E. V., Mulders, Y. R., Goodes, L. M., Eroglu, E., Brunner, M., ... & Dunlop, S. A. (2024). Impacts associated with the plastic polymers polycarbonate, polystyrene, polyvinyl chloride, and polybutadiene across their life cycle: A review. *Heliyon*.

[2] Ford, H. V., Jones, N. H., Davies, A. J., Godley, B. J., Jambeck, J. R., Napper, I. E., ... & Koldewey, H. J. (2022). The fundamental links between climate change and marine plastic pollution. *Science of the Total Environment*, *806*, 150392.

[3] Jambeck, J. R., & Walker-Franklin, I. (2023). The impacts of plastics' life cycle. *One Earth*, *6*(6), 600-606.

[4] Jambeck, J. R., Maddalene, T., Youngblood, K., Oposa, A., Perello, H., Werner, M., ... & Brooks, A. L. (2024). The Circularity Assessment Protocol in cities to reduce plastic pollution. *Community Science*, *3*(1), e2023CSJ000042.

[5] Maddalene, T., Youngblood, K., Abas, A., Browder, K., Cecchini, E., Finder, S., ... & Jambeck, J. R. (2023). Circularity in cities: A comparative tool to inform prevention of plastic pollution. *Resources, Conservation and Recycling*, *198*, 107156.

[6] Jambeck, J. R., & Johnsen, K. (2015). Citizen-based litter and marine debris data collection and mapping. *Computing in Science & Engineering*, *17*(4), 20-26.

[7] Youngblood, K., Brooks, A., Das, N., Singh, A., Sultana, M., Verma, G., ... & Jambeck, J. R. (2022). Rapid characterization of macroplastic input and leakage in the Ganges river basin. *Environmental Science & Technology*, *56*(7), 4029-4038.

[8] City of Atlanta. (2009). The City of Atlanta, Georgia SMART Waste Management. https://www.ilsr.org/wp-content/uploads/2012/02/atlanta-payt.pdf

[9] Georgia Department of Community Affairs (2005). Final Report: Georgia Statewide Waste Characterization Study. https://epd.georgia.gov/sites/epd.georgia.gov/files/related_files/site_page/MSW_Study.pdf