Mapping the Waste Handling Dynamics in Mombasa Using Mobile Phone GPS

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Abstract

In many Sub-Saharan African cities, informal collectors, waste pickers, and middlemen provide the bulk of waste management and recycling services. These workers also retain useful tacit knowledge about urban form and activities. However, such knowledge is often poorly understood and rarely documented from a geographic perspective. We designed and deployed an application to map informal waste management in Mombasa, Kenya. The phone application provided easy location tracking with the collectors' existing Android phones, and mapped the traces in real-time through a simple web interface. We selected three neighborhoods and worked with local waste cooperatives to map their collection routes. From the generated datasets, we observed how they operate and adapt to each community. Such data not only delineates the areas serviced by the waste collectors, but could also improve operating efficiency of informal waste handling services. The platform also gives planners useful contextual knowledge for areas lacking official geographic data.

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1. Introduction

In many cities in Sub-Saharan Africa, informal collectors, waste pickers, and middlemen provide the bulk of waste management and recycling services. Even where municipal services exist, informal players often complete the first-mile collection from households, as well as primary segregation to extract recyclable materials, critically extending the reach and efficiency of the formal waste service. These workers also retain useful tacit knowledge about urban form and activities in the areas they serve. However, such knowledge is often poorly understood and rarely documented from a geographic perspective.

In this study, we designed and deployed a phone and web-based application to map informal waste management in the city of Mombasa, Kenya. Based on prior work tracking individual waste objects in the United States and informal collection routes in São Paulo, Brazil with GPS-based devices, this work extends the capability of collectors to track themselves. The phone application provides easy location tracking with the collectors' existing Android phones, and maps the traces in real-time through a simple web interface.

With the help of the Mombasa municipal council, we first built a detailed map of the primary garbage collection points, as well as a limited number of informal recycling points in the city. We then selected three particular neighborhoods of Mombasa and worked with local waste cooperatives to map their collection routes. From the datasets generated by the phone application, we could observe how the cooperatives operate and adapt to each community.

Such data not only specifically delineates the areas serviced by the waste collectors, but could also lead to improvements in the operating efficiency of informal waste handling services in a given neighborhood. The platform enables a more powerful city-wide waste mapping endeavor that would improve communication and coordination amongst the various informal waste handling groups, by allowing them to share the generated maps with each other and with city managers. This also gives planners useful contextual knowledge for areas of the city lacking official geographic data.

1.1 Waste Management Status in Mombasa

With 0.9 million residents, Mombasa is the major port of Kenya and its second largest city, compared with 3.1 million in Nairobi, the country's capital (Kenya National Bureau of Statistics, 2014). Due to rapid population growth, the urban waste management system—first designed in the colonial era for a much sparser population density—has faced many challenges in recent years, such as open dumping and insufficient landfill space (Okot-Okumu, 2012). For example, much of Mombasa's municipal waste currently goes to the Kibarani dumpsite, which was unlicensed in 2000. However, the lack of a replacement landfill meant that the city's only choice was to continue to use Kibarani, which currently operates under a special permission from the National Environmental Management Authority (NEMA). Today, Mombasa generates about 660–750 tons of household waste per day (Mugaza, 2013).

In 2007, funded by the French Agency for Development (AFD), several international corporations collaborated on two urban waste management projects (AFD, 2014). The first project set up a community-run comprehensive recycling facility that includes composting, briquetting, plastic recycling, and other processes in Jomvu Kuu, about 10 km outside of Mombasa. The second project was the establishment of the Mwakirunge sanitary landfill, located about 17 km northwest of Mombasa proper. The authors visited the Jomvu Kuu plant in 2013, which had not yet started running (Fadhil, 2013). According to the local reports, the facility may be slated to be in operation in the near future. However, due to disputes, NEMA has not licensed the Mwakirunge landfill to date (Hanga, 2013). Thus, both Kibarani and Mwakirunge operate as unlicensed dumpsites, though private waste collection companies are forbidden to make use of Kibarani.

As illustrated in Figure 1, municipal household waste collection typically follows a three-stage process (Davydenko, 2013). First, the waste is collected from households or the nearby neighborhood. In more affluent neighborhoods (such as the Old Town), municipal services collect from public dumpsters, though only about 13% of the households are served by this formal network. Larger institutions such as schools and restaurants must hire private companies to collect their waste, a service which we also consider to be part of the formal network. Such private companies also collect waste directly from about one-third of Mombasa households (Tan, 2012). However, the remaining households are not within reach of these formal services, and the role of informal waste collectors becomes important in such neighborhoods. For a monthly subscription fee, these groups go door-to-door twice a week on foot to collect trash from unserved areas.

Second, collectors bring waste to an intermediate transfer point (illustrated in Figure 2), typically located within or near the neighborhood. Valuable recyclable materials such as plastics and metals are sorted out first-pass, either by the waste collection groups themselves, or by itinerant waste-pickers. Finally, about every two to seven days, trucks transport the remaining waste from the transfer point to the large dumpsites. In some cases, the municipal council provides this pick-up service, but informal waste collection groups often need to arrange and pay for their own pick-ups from private entities.

Thus, waste management throughout all levels in Mombasa is an intricate mixture of government services, private enterprises, and informal groups. Increasingly, the distinction between the latter two has blurred given the emergence of "youth groups" in Kenya, which is a way for the government to facilitate formal registration of otherwise informal groups or enterprises. In fact, a few successful youth groups in waste management eventually become incorporated entities, effectively becoming part of the formal private sector. However, since many youth groups in waste management in Kenya play similar roles as waste collector groups in other countries (which are often informal or semi-formalized), for simplicity we will treat them as informal players in this study.

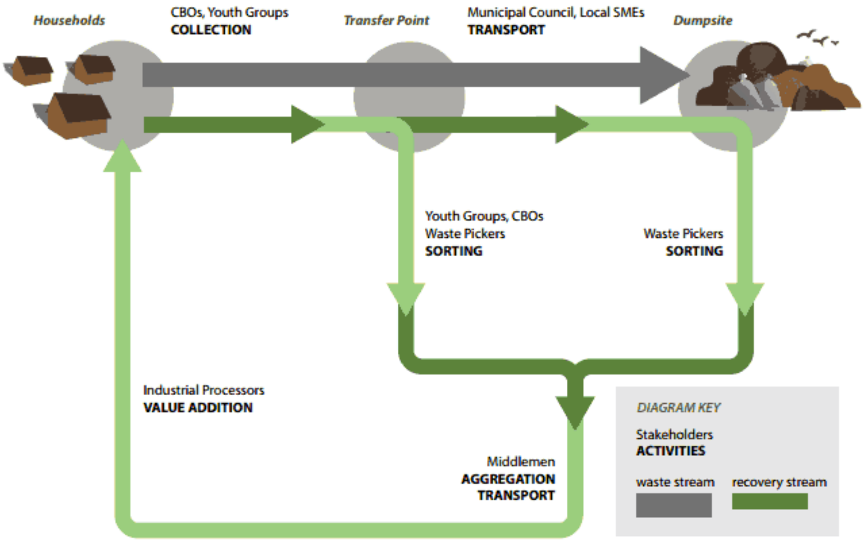

Fig. 1. Schematic of Mombasa's waste collection, transport, and value chains. Figure reproduced from (Davydenko, 2013).

Fig. 2. Photographs illustrating a formal waste collection dumpster at the Old Ports (left) and an informal transfer point within the Kisauni community (right) in Mombasa, Kenya. Photographs taken by Maria Davydenko.

1.2 Integrating Informal Waste Collection

Historically, waste management interventions and reforms in developing urban centers have been modelled after the formalized systems commonly found in North America and Europe (Medina, 2007). Such practices are often perceived as incompatible with existing informal waste collection networks, given that many formalized systems call for exclusive collection and recycling of the entire waste stream, displacing the work of any informal and community-based waste collectors and waste-pickers. However, centralized waste management services, whether through public or private monopoly, have a long history of failure in developing cities, whether due to exogenous political and economic instability, explosive informal settlement growth, or lack of timely investment (Oosterveer & Spaargaren, 2010). Scholars have sought a "modernized mixtures" approach that combines the best features of both centralized and decentralized systems (Tukahirwa, Mol, & Oosterveer, 2013).

Recent works have increasingly identified the pivotal roles of the informal sector in waste management. For example, the waste recovery and recycling rates by informal systems in many cities may actually be on par with those of more formalized systems found in North America and Europe (Wilson, Velis, & Cheeseman, 2006). In Brazil, there are more than 50,000 self-organized catadores, who recover enough recyclable material to reduce waste in landfills by 20%; an estimated 90% of material recycled by industry is collected by waste pickers (Fergutz, Dias, & Mitlin, 2011). In many places, the labor-intensive model of informal recycling might be more cost-effective than capital-intensive models from the developed world, and thus a better target for investment (Ahmed & Ali, 2004).

Scheinberg and Anschutz (2006) and Joseph (2006) have argued that engaging the informal sector is essential to any sustainable, participatory waste management approach, since waste collectors and pickers already engage with the local communities. However, such integration presents many challenges from the perspective of urban planning. Offenhuber and Lee (2012) noted that it is often difficult to codify informal operations and local knowledge, given the relatively high cost (in labor hours, training, and infrastructure) to capital-poor subsistence workers. Information about collection routes, timing, and open trash transfer points may be unavailable outside the group and the immediate vicinity of the community. Therefore, developing a method to easily collect and quantify such tacit knowledge is crucial for city-wide planning and integration of informal waste management in the future.

Yet as Gutberlet (2008) notes, informal workers and cooperatives are often excluded because of their lack of visibility and representation, despite the valuable knowledge they retain about their communities and best practices. Activists and academics have often employed action research to make the recyclers' voices heard, and media tools such as video documenting help facilitate dialogue in both directions. However, while these tools can periodically illuminate the personal plight of informal workers, they do not capture how they work as a system. In order to close the information loop and build a sustainable partnership between stakeholders, we need to make their operations visible on a regular basis (Fergutz et al., 2011).

1.3 Waste Tracking Technology

In this paper, we explore the role of sensing technology to provide details about waste management activities in the informal sector. This work builds upon prior attempts to quantify municipal waste handling dynamics since 2010. For example, the Trash Track project, described previously in (Phithakkitnukoon et al., 2013) and (Offenhuber et al., 2012), placed self-reporting GPS tags within sample waste items of different types. Traces collected in Seattle show the temporal dynamics of the waste transport and recovery chain for different types of waste within the United States.

In São Paulo, Brazil, the Forage Tracking project used off-the-shelf GPS loggers (HOLUX Technology, Hsinchu, Taiwan) to track the collectors themselves (Offenhuber & Lee, 2012). We spatially mapped the waste collection activities of recycling cooperative *COOPAMARE* over a period of one week, resulting in detailed resolution of the trash collection routes. However, in these cases, the GPS signal devices were either highly specialized, expensive equipment unavailable to city planners and the informal sector, or standalone devices unwieldy for regular data transfer and sharing. Single-purpose GPS hardware is also difficult to repair, replace, or upgrade as needed.

2. Methodology

We designed a GPS tracking application for smartphones that addresses the challenges described above. While many Kenyans currently possess basic feature phones without GPS capabilities, smartphone ownership is steadily increasing. From our experience in Mombasa working with several waste collector groups, it was not difficult for a given waste group to locate at least two or three smartphones amongst themselves for use on the project. Because our tracking platform has the potential to be freely downloaded and used on the phones of the local stakeholders, it drastically eliminates the cost and complications associated with employing exotic hardware.

The application runs on Android operating systems, and uses the Parse application platform to handle phone-to-server communication. During waste collection, the user presses an on-screen button to begin recording their route; in the background, the application records its GPS coordinates on a fixed time interval of one minute, and uploads these logs to the Parse backend when in reach of a mobile phone connection. A separate web interface allows any remote user to view the trace overlaid on a digital map (generated from OpenStreetMap data and styled in Mapbox), and observe the route develop in real-time.

We conducted a pilot of the platform in Mombasa, Kenya for a period of three weeks. First, by working with the Mombasa Municipal Council, we mapped the prominent formal and informal waste collection points within the city. Second, through informal networking, we approached four waste collection groups in different neighborhoods of Mombasa, and observed their work activities. The groups agreed to use the application to track their own collection routes over a one-week period. Finally, we shared the visualized data with the groups and municipal government to understand what value it might provide for their operations and analyses.

3. Results

3.1 Locations of Collection Sites

We first met with the Mombasa Municipal Council to obtain information on the city's formal waste management practices, as well as the status of formal and informal waste transfer points. The distinction between formal and informal, in this case, was also nuanced: formal waste transfer points typically have one or more dumpsters in place (though these are often unmanaged and overflowing), and may be regularly collected by the municipal waste trucks to be transferred to one of the two dumpsites. Informal waste transfer points are open dumping sites which may or may not be managed. When too much waste accumulates in informal points between shipments to landfill, the waste may simply be set on fire.

We visited many of these transfer points both on the Mombasa Island and in the surrounding neighborhoods, and interviewed the waste-pickers at some of these transfer points. A map showing the locations of these waste transfer points is plotted in Figure 3 below, with red concentric circles marking formal community transfer points and smaller orange circles representing informal transfer points.

Fig. 3. Locations of informal dumps (orange circles) and community transfer points (red concentric circles) on Mombasa Island. The base map was generated using Google Maps.

Overall, there are more informal waste transfer points (38 recorded) than formal waste transfer points (18 recorded), and the formal points tend to be located near or on trunk routes. This makes sense, as these points need to be accessible to large vehicles such as garbage collection trucks. The distribution of the informal transfer points is also spatially uneven. Qualitatively, we noted that they are more concentrated near the Old Town area, which is frequented by tourists. The informal sector here appeared to be capitalizing on higher value materials in an area less well-served by municipal collection.

3.2 Dynamics of Waste Collection

We proceeded to characterize the detailed dynamics of the waste collection from the perspective of informal waste collectors. Figure 4 below illustrates the sample GPS traces of three collection groups in different neighborhoods as preliminary results from our pilot. In particular, panels (d) and (e) illustrate the same waste collection group with different pushcarts/collection routes being tracked on the same day.

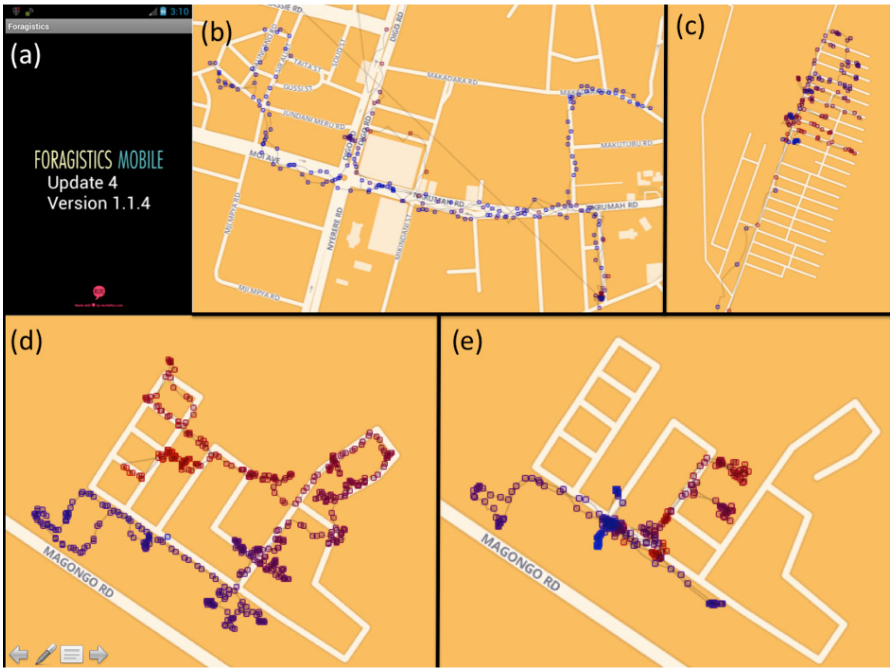

Fig. 4. Foragistics tracking platform in action. (a) Screenshot of the Foragistics mobile application. (b)–(e) Sample traces of waste collection service in different neighborhoods in Mombasa, showing different geographical layout and therefore different waste collection dynamics. The color gradients show progression of time. The base map was generated from OpenStreetMap and Mapbox.

The first distinction we note is that the dynamics of waste collection vary greatly from community to community. Given that each consecutive point in the track reflects equal time intervals, the differing densities of points within a given track reflect on the activities occurring along the way. Along tracks where the individual points are sparsely spaced, this indicates a higher speed of travel, which typically corresponds to waste transport with little collection activity. Segments where the individual points are densely spaced indicate more stopping for collection from clients.

In panel (b), the collection was done primarily for institutional customers (e.g. restaurants) in a dense neighborhood, and we generally see consistent movement rates from place to place. Panel (c) presents a different waste collection dynamic for a different community geography. There are numerous byways that branch off from a long service road, which in turn leads to the main trunk road about 800 m to the southwest. As their main transfer point was located next to the trunk road, the waste collectors needed to shuttle back and forth between the network of byways and the trunk road. This particular pushcart covered about 40% of the byway network shown on the top-right portion of panel (c), while another pushcart (not being tracked) covered the byway system shown towards the middle part of panel (c). This is a residential neighborhood primarily served by the informal sector, in contrast with that shown in panel (b).

Finally, panels (d) and (e) show two independent tracks on the same day, from two different pushcarts of the same waste collection group. We make two observations here. First, we note that the density of points is much more clustered at certain places, which reflects fewer but longer stops. This corresponds well to this specific neighborhood, which comprises of blocks of multi-story apartment buildings. As the waste collectors travel through the different floors to reach households, the stop becomes longer, and the load per stop also increases.

Second, we can see that while the two tracks primarily follow different but complementary collection routes, there are sections of apparent redundancies, especially in the area closest to Magongo Road. This area actually corresponds to a dense network of roadside restaurants and markets, where large quantities of waste—especially organic waste—is generated in bulk. Given the limited capacity of a single pushcart, several trips are often needed in order to completely transport all the waste from this area to the community's transfer point.

4. Conclusions and Discussion

In this study, we discussed the context and stakeholders within Mombasa's municipal waste management system. We identified the informal waste management sector as one which warrants further understanding, and described our deployment of mobile-phone-based GPS tracking to help us track and map the waste collection dynamics. We worked with several informal groups in Mombasa to pilot our platform, and obtained promising results.

We also presented a preliminary tracking dataset as a proof of functionality. Despite its limitations, visualizing the dataset already yields some interesting insights. For example, in panels (d) and (e) of Figure 4, we noted that this particular group needed to make repeated trips to a cluster of restaurants and markets. This presents an opportunity from the logistical point of view; currently, the closest waste transfer point is located about 500 m away from this cluster of restaurants at the center of the community along a narrow road. One testable hypothesis that could potentially benefit the group would be to have the municipality relocate its community transfer point closer to the restaurant cluster and main road, such that the multiple pushcart pick-ups from the restaurants become less time- and labor-consuming.

This also echoes earlier experiments in São Paulo, Brazil, where the collected data showed that the waste collectors tend to selectively service spatially dispersed customers in order to maximize profit, but risked unpredictable logistical costs (Offenhuber & Lee, 2012). Such mapping data, when shared and communicated between the waste collectors, municipal authorities, and communities, can initiate a participatory dialogue about current practices and challenges, and how these relate to the future visions of the urban waste management system. While not described in this study in detail, we were subsequently able to carry out such a human-centered design session with a waste collector group in Mombasa and public officials, with both parties successfully learning from each other.

As a side benefit, we also could infer characteristics of the communities from their collection dynamics, such as building density, building use (e.g. residential, commercial), and road hierarchy. These observations, coupled with other crowdsourcing efforts, could help planners update their spatial information on informal areas that are poorly surveyed or rapidly changing.

Ultimately, we see such spatial mapping, when used in the appropriate context, as a powerful tool towards integrated municipal waste management. The Mombasa Municipal Council has expressed interest in the GPS tracking platform, for the purpose of ensuring its trucks follow set routes and schedules; their participation could help groups to coordinate pickups from informal transfer points as well. Given increasing government and private interest in many urban areas of Sub-Saharan Africa to improve waste management, a clearer perspective of the informal waste network's geographic reach and tacit knowledge will be critical to planning efficient, inclusive waste handling strategies.

References

AFD. (2014). *AFD in East Africa*. Retrieved from http://www.afd.fr/webdav/site/afd/shared/PUBLICATIONS/THEMATIQUES/AFD-east-africa-VA.pdf

Ahmed, S. A., & Ali, M. (2004). Partnerships for solid waste management in developing countries: linking theories to realities. *Habitat International*, *28*(3), 467–479.

Davydenko, M. (2013). *Taka ni pato: technology for entrepreneurship in Mombasa's waste management program* (M.P.A. Thesis). Harvard Kennedy School.

Fadhil. (2013). Project Implementation Committee, Mombasa Integrated Solid Waste Management. Personal Interview.

Fergutz, O., Dias, S., & Mitlin, D. (2011). Developing urban waste management in Brazil with waste picker organizations. *Environment and Urbanization*, *23*(2), 597–608.

Gutberlet, J. (2008). Empowering collective recycling initiatives: Video documentation and action research with a recycling co-op in Brazil. *Resources, Conservation and Recycling*, *52*(4), 659–670.

Hanga, B. (2013). Impact Assessment Officer, National Environmental Management Authority (NEMA). Personal Interview.

Joseph, K. (2006). Stakeholder participation for sustainable waste management. *Habitat International*, *30*(4), 863–871.

Kenya National Bureau of Statistics. (2014). *Population Distribution by Administrative Units* (No. Volume 1A). Retrieved from http://www.knbs.or.ke/

Medina, M. (2007). Waste Picker Cooperatives in Developing Countries. *Membership-Based Organizations of the Poor*, 105–21.

Mugaza, D. (2013). Superintendent, Environmental Health Department, Mombasa Municipal Council. Personal Interview.

Offenhuber, D., & Lee, D. (2012). Putting the informal on the map: tools for participatory waste management. In *Proceedings of the 12th Participatory Design Conference: Exploratory Papers, Workshop Descriptions, Industry Cases-Volume 2* (pp. 13–16).

Offenhuber, D., Lee, D., Wolf, M. I., Phithakkitnukoon, S., Biderman, A., & Ratti, C. (2012). Putting Matter in Place. *Journal of the American Planning Association*, *78*(2), 173–196.

Okot-Okumu, J. (2012). *Solid Waste Management in African Cities-East Africa*. INTECH Open Access Publisher. Retrieved from http://cdn.intechopen.com/pdfs-wm/40527.pdf

Oosterveer, P., & Spaargaren, G. (2010). Meeting Social Challenges in Developing Sustainable Environmental Infrastructures in East African Cities. In B. van Vliet, G. Spaargaren, & P. Oosterveer (Eds.), *Social Perspectives on the Sanitation Challenge* (pp. 11–30). Springer Netherlands.

Phithakkitnukoon, S., Wolf, M. I., Offenhuber, D., Lee, D., Biderman, A., & Ratti, C. (2013). Tracking Trash. *Pervasive Computing, IEEE*, *12*(2), 38–48.

Scheinberg, A., & Anschutz, J. (2006). Slim pickin's: Supporting waste pickers in the ecological modernization of urban waste management systems. *International Journal of Technology Management & Sustainable Development*, *5*(3), 257–270.

Tan, Y. J. (2012). *The Management of Residential Solid Waste in Mombasa, Kenya*. SIT Digital Collections.

Tukahirwa, J. T., Mol, A. P. J., & Oosterveer, P. (2013). Comparing urban sanitation and solid waste management in East African metropolises: The role of civil society organizations. *Cities*, *30*, 204–211.

Wilson, D. C., Velis, C., & Cheeseman, C. (2006). Role of informal sector recycling in waste management in developing countries. *Habitat International*, *30*(4), 797–808.