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A three-pronged approach to waste composition determination

Charlotte Nell [a], Catherina Schenck [b,*], Derick Blaauw [c], Lizette Grobler [d], Kotie Viljoen [e]

[a] Consultant to the DSI/NRF/CSIR Chair in Waste and Society, University of the Western Cape, Bellville, Cape Town, South Africa
[b] DSI/NRF/CSIR Chair in Waste and Society, University of the Western Cape, Bellville, Cape Town, South Africa
[c] School of Economic Sciences, North-West University, South Africa
[d] Post Doctoral Fellow at the DSI/NRF/CSIR Chair in Waste and Society, University of the Western Cape, Cape Town, South Africa
[e] Department of Economics and Econometrics, University of Johannesburg, South Africa

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ABSTRACT

Understanding solid waste composition has frequently been cited as one of the most valuable resources to those responsible for the proper management of solid waste. The unique contribution of this article lies in the fact that a waste characterisation study, conducted in a remote rural town in South Africa, was combined with an illegal dumping contents mapping and a household survey. This enabled researchers to gain a more thorough understanding of household waste management practices and challenges in this community, bridging the knowledge gap that is created when illegal dumping and household perceptions are omitted from waste characterisation studies in study areas where illegal dumping is an ongoing concern. The study therefore contributes to understanding the waste behaviour of households within the larger context of the town's waste management practices. Results indicate that, in order for municipalities to fully understand how to manage their waste, the contents of illegal dumping, where present, and household surveys should also be included in waste characterisation assessments.

1. Introduction

The management of municipal solid waste in most countries has become a complicated task, mainly due to the combined pressures of dwindling landfill space and the public's desire to conserve resources (Sawell et al., 1996; Mir et al., 2021). Developing countries in particular struggle to manage waste effectively (UNEP, 2018). To change the face of waste management in a developing country like South Africa there are several interventions to consider, which may vary from low-tech, labour-intensive solutions to extremely high-tech, capital-intensive technology options (Oelofse et al., 2016). Oelofse et al. (2016) argue that informed municipal waste management decisions require knowledge of the composition of the waste streams present in the town or city in question. A deeper understanding of solid waste composition has been cited as one of the most valuable resources to those responsible for the proper management of solid waste (Gay et al., 1993; Yenice et al., 2011; Villalba et al., 2020). Generally, more attention is paid to understanding waste composition trends in urban areas than in rural areas, and also in developed rather than developing countries (Wang et al., 2018).

Dependable waste characterisation data is crucial to decision-making processes (Gay et al., 1993), which can effectively be hamstrung by a lack of data (Edjabou et al., 2012). Optimal methods of collecting and freighting household solid waste, recovering materials from household solid waste, and appropriate 'end-of-life' methods are highly reliant upon the specific characteristics of certain waste streams (Ozcan et al., 2016). The availability of information enables local authorities to increase the accuracy of their predictions concerning remaining landfill airspace, optimise their waste management strategies and comply with budgetary requirements (Haider, 2014). It also helps them to implement appropriate waste management, re-use and minimisation strategies (Hanekom, 2019).

This study is set within a rural area of South Africa, a developing country, and will therefore contribute to this emerging research field. The unique contribution of this study lies in the fact that a waste characterisation study was not used solely to determine the waste composition. In order to fully understand household waste management practices and challenges in this community, the study was combined with an illegal dumping contents mapping as well as a household survey. The study therefore also contributes to understanding the waste behaviour of households within the larger context of the town's waste

* Corresponding author.
E-mail addresses: charlotte@aenv.co.za (C. Nell), cschenck@uwc.ac.za (C. Schenck), derick.blaauw@nwu.ac.za (D. Blaauw), 3924846@myuwc.ac.za (L. Grobler), kotiev@uj.ac.za (K. Viljoen).

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management. This represents an important contribution to the literature given the prevalence of illegal dumping in many of South Africa's urban and rural areas.

Literature shows that waste characterisation studies are usually used as a basis for determining waste composition in order to plan waste management strategies (Parizeau et al., 2006; Gomez et al., 2008). However, many waste characterisation studies do not include the contents of illegal dumping. In research settings where illegal dumping is a concern, the mapping and analysis thereof can provide crucial insight into the entire waste stream, as demonstrated by this study. This study therefore aims to bridge the gap created by studies that do not include the contents of illegal dumping when determining the waste composition characteristics of a study area where illegal dumping is prevalent (Nell, 2020).

2. Defining household solid waste characterisation

A household solid waste characterisation study can be defined as the sampling, collection, sorting and analysis of household solid waste, with the aim of determining its overall composition, as well as the relative contribution of each component (such as glass, metal, paper or plastics) within a specified geographical area (CSIR, 2017; Nell, 2020). Household solid waste is defined as the waste that is generated within residential areas, including waste generated by the activities of families in their homes and home-based businesses (Suthar and Singh, 2014). It is considered acceptable to include waste generated by home-based businesses in a study of household solid waste because the aim is to determine the overall composition and quantity of waste generated by residential areas, rather than to make comparisons between the composition and quantities of household and commercial waste (Parizeau et al., 2006).

Home-based businesses typically include home-based offices, hairdressers, day-care centres and nursing homes (Vorley and Rodgers, 2012), each of which affects the overall compositions of waste differently. A vast number of household solid waste characterisation studies have been carried out in diverse geographical, environmental and political settings and climates throughout the world (Emery et al., 2003; Gomez et al., 2008; Dangi et al., 2013; Ezeudu et al., 2019). In this study, the waste from households as well as from businesses in the study area was included.

3. Study area and its waste management context

This study is set within a rural town (Town C) located in the Northern Cape Province, South Africa, housing 9680 people within 2509 households (StatsSA, 2012). The town is situated approximately 400 km from Cape Town, which is the closest city with markets to which recyclables could potentially be sold (Viljoen et al., 2021). Viljoen et al. (2021) describe the town as having three distinct areas: the central neighbourhood in the business area, the informal settlement located on the outskirts of the town where people live in approximately 200 self-built structures and the western neighbourhood situated between the two aforementioned areas (Viljoen et al., 2021). According to the 2021/2022 Integrated Development Plan (IDP) of the Hantam Local Municipality (2021), the community is characterised by high unemployment, resulting in social grant dependency and many residents living in RDP houses[1] (StatsSA, 2012). The IDP also acknowledges that higher population density is prevalent in the lower-income areas, along with a shortage of houses, prevalence of backyarders[2] and substandard quality of municipal services (Hantam Local Municipality, 2021).

During an initial site visit, litter in the streets, overflowing street waste bins and various illegal dumpsites, as well as the mismanagement of waste at the local disposal site, were observed. Factors contributing to the unkempt state of the disposal site included a lack of required plant and equipment suitable for waste compaction and covering; a lack of access control or security on-site; and the unavailability of sufficient cover material.

In addition, the facility did not have a weighbridge, making recordkeeping of the quantity and types of waste being disposed of on-site difficult, if not impossible. The combination of these factors results in the creation of nuisance conditions in and around the facility such as bad odours, flies and other pests as well as windblown litter (Fig. 1).

In Town C, refuse is collected once a week from households and up to twice a week from businesses by the local municipality, who makes use of tractors with trailers or three-tonne trucks (Zenande Leadership & Linkd Environmental Services, 2013). Approximately 40% of households in Town C are classified as 'indigent',[3] and receive free basic services which includes refuse collection[4] (Hantam Local Municipality, 2021). The municipality does not supply refuse bags or bins to the households for waste containment before collection. In the lower-income areas (the western neighbourhood and informal settlement), used oil drums made of steel, which the households have to source themselves, are used for waste containment. These drums are decanted by municipal workers into the waste transportation vehicle during collection. During this process, small and light waste items often become litter, especially on windy days. Some households buy and make use of plastic refuse bags to assist with waste containment inside the house and then place full bags outside within the steel drum until the waste is collected. In the more affluent area of the town, it was noticed that some households put wheelie bins out on the curb on waste collection days. These wheelie bins are bought by the owner of the house (at a cost of approximately 750 ZAR or 51.48 USD).[5] The municipality

Fig. 1. Windblown litter outside the disposal site's boundary. Source: Rinie Schenck.

[1] RDP houses refer to government-built houses.

[2] Backyarders are residents living in backyard dwellings typically consisting of an informal structure built with temporary materials that do not comply with building regulations and are erected on the same plots as the main, formal house (Donaldson, 2021).

[3] To qualify as an indigent household, the combined monthly income for the household must not exceed 4740 ZAR or 325.33 USD as at 30 June 2021 (Hantam Local Municipality, 2021).

[4] In respect of sewerage charges and charges for household refuse removal, the relief granted shall not be less than a rebate of 100% on the monthly amount billed for the service concerned (Hantam Local Municipality, 2021).

[5] As per the exchange rate on 29 July 2021.

explained that one of the reasons why bins are not provided is that they get stolen and are used for other purposes.

After collection, the waste is transported directly to the local disposal site. At the current rate of disposal, the disposal site is expected to reach capacity by 2025 (Aurecon, 2012) and the conservation of disposal airspace is therefore of critical concern. The disposal of any quantity of general waste is free of charge at the disposal facility. This facility is not an engineered landfill site.

The clearing of illegal dumping sites in Town C is outsourced by the local municipality to a private contractor through a tender process. The streets are cleaned by labourers appointed through the Extended Public Works Programme (EPWP)[6] managed by the local municipality. These programmes are national government-initiated interventions aimed at improving access to public services by, among other things, assisting in the removal of service-delivery backlogs. The workers on the programmes are from the community and work on a rotational basis, aiming particularly at employing the youth and women. This allows for more persons to be employed and to gain work experience.

The municipality does not currently have formal waste minimisation practices in place such as separation-at-source for recycling purposes. There are, however, private individuals and businesses that operate in the waste space. Approximately ten waste pickers actively salvage recyclable waste at the local disposal facility. Three scrap metal dealers in town buy scrap metals directly from waste reclaimers and the public. Although there is no formal buy-back centre focusing on the procurement of household recyclable waste in town, there are two business owners who collect glass and aluminium cans from the disposal site directly or buy from waste pickers. The researchers noticed that recyclable household waste materials such as cardboard, paper and ferrous metals not currently being bought by recyclers are often dumped illegally due to the lack of value associated with those materials in the area.

Interviews were held with the two business owners focusing on recyclable household waste. It was found that the biggest obstacles they currently face are the distance to market for recyclables and the associated costs. Recyclate is sold in Cape Town, which is 400 km away, and materials must be transported by road due to the lack of rail infrastructure. Other challenges noted include a lack of operating space: both business owners stockpile recyclate in their yard until they have enough material to fill a load to Cape Town. A factor exacerbating this lack of space is the lack of baling equipment. Both business owners noted that the availability of a baling machine would not only assist them in reducing the amount of space needed for the storage of the recyclables, but would also increase their net income. Higher prices are paid per kilogram of material sold to the larger buy-back centres in Cape Town if the material is baled (Viljoen et al., 2019). In addition, they would be able to fit more material on a truck going to Cape Town, which would decrease their transport costs.

4. Methodology

To adequately understand the types and amounts of solid waste being generated in the area, three research activities were undertaken. Firstly, a week-long waste characterisation study was done. Secondly, all illegal dumpsites in the area were identified and mapped, and a contents investigation was conducted (contents were listed and noted, but not weighed and measured). Thirdly, a household survey exploring household perceptions about waste behaviour and waste management was also completed. The following section will give a brief overview of the methodology followed during each research activity.

4.1. Waste characterisation study methodology

The household waste characterisation study was conducted between 30 October and November 1, 2018. The methodology prescribed by the Western Cape Provincial Government's Department of Environmental Affairs and Development Planning (DEA&DP, 2017) was followed in the absence of a guideline drafted by the Northern Cape provincial government. Municipalities are often unable to conduct waste characterisation studies themselves due to a lack of skills, especially combined with the high costs associated with appointing external consultants with the required knowledge. DEA&DP's guidelines aim to assist municipalities to conduct waste characterisation studies internally by providing step-by-step instructions for each phase of the process from sampling to waste collection, sorting and finally analysis. The guidelines follow best practice waste characterisation principles as described in the United Nations Environmental Programme's Solid Waste Management Training Manual (UNEP, 2009) (see Fig. 2).

The support received from the local municipality was integral to the successful completion of the household solid waste characterisation study. They supplied 14 waste sorters (all registered on the EPWP database of the municipality); one data capturer; a team responsible for the collection of samples as well as the removal of waste after sorting (consisting of one driver and eight workers); a foreman overseeing collection and removals logistics; and equipment (tables, black bags, cleaning equipment and electrical leads). In addition, the research team ensured that one supervisor, two platform scales and 50 20-L buckets were available.

The study area had 2509 households during the last official census (StatsSA, 2012), requiring the characterisation of 210 bags for sampling to be representative (DEA&DP, 2017). Of the 2509 households, approximately 68% were located in the lower-income areas of the town (±1700 households) and 32% in the higher-income area (±800 households).

The following table shows the number of samples that needed to be collected per income group:

Samples were collected from all areas within the study area and the collection thereof spatially stratified within each suburb.

Four tables, with three to four sorters working at each, sorted the waste into 11 different streams: recyclable plastics; non-recyclable plastics; expanded polystyrene; paper and cardboard; metals; glass; food waste; human hygiene/sanitary waste; garden waste; e-waste and household hazardous waste; and residual waste. Both weight and uncompacted volume data were recorded. In addition, during the sorting of each bag, it was noted whether the bag contained baby or adult diapers, clothing or shoes.

Fig. 2. Waste characterisation study in process. Source: Charlotte Nell.

[6] The Expanded Public Works Programme is one of the South African government's key programmes aimed at providing poverty and income relief through temporary work for the unemployed.

4.2. Illegal dumping high-level contents investigation and mapping methodology

Indiscriminate or illegal dumping is regarded as the unlawful, deliberate disposal of waste and refuse on public and private land, which has not been designated as a site on which waste may be deposited (Liu et al., 2017; UNEP, 2018; Lu, 2019; Niyobuhungiro and Schenck, 2020).

The investigation and mapping of illegal dumpsites were undertaken from 18 to September 19, 2019. The aim of the exercise was twofold: firstly, to identify and plot the geographical coordinates of all existing illegal dumpsites in the study area; and, secondly, to determine the main waste fractions contained in each illegal dumpsite. For this study, an illegal dumpsite was defined as a volume of waste material equal to or exceeding the amount of waste that can fit into a standard wheelie bin (approximately 240 L), which is based on a definition used by the Australian Department of Environment and Heritage Protection (DEHP) (DEHP, 2020). Two of the researchers drove through the streets of the western neighbourhood looking for any illegal dumpsites. The illegal dumpsites were easy to spot, as the spaces within the community were quite open. A mobile application called *Live Mobile Location* was used to capture the coordinates of the illegal dumpsites. Coordinates were provided in degree decimals and, once captured, the researchers noted the dumpsite's general waste composition based on visual analysis, including any peculiar types of waste such as animal carcasses, hazardous waste or bulky waste items. Photos were also taken of each illegal dumpsite. A photographic record provided typical examples of the content of the illegal dumpsites as well as some insight into the type of places waste was being disposed of illegally. The mapping process took a total of 12 h to complete, split over two days.

4.3. Survey methodology

A survey exploring the perceptions of 162 households about their waste behaviour and waste management was also completed. Only responses specifically relating to how households deal with the various waste fractions are used for this article. A group of trained fieldworkers completed the questionnaires with one member per household. The results of the questionnaires were captured in Excel. A non-probability sampling method was used in the form of convenience sampling and the area was geographically stratified.

All areas in Town C were included in the study, but were divided into two main areas: low-income and high-income. In the high-income area, 52 surveys were completed. The low-income area was subdivided into two sections: the western neighbourhood where 69 surveys were completed, and the informal neighbourhood where 39 surveys were completed. Primary data was gathered from the representatives of all households who were willing and available to participate in the study at the time of the fieldwork. The findings also include researchers' observations and information from key informants in the town.

Ethical clearance for the project was obtained from the University of the Western Cape's Research and Ethics Committee.

5. Results

The following section highlights key results obtained from the three sets of data, stemming from the three steps in the methodology.

5.1. Study 1: Waste characterisation results

Table 1 provides the calculation used for the samples to be collected from the various income groups. A total of 976.96 kg of household and business waste was sampled and sorted. This material equates to a landfill airspace volume of 17.86 m^3 (uncompacted). Table 2 indicates the breakdown of the weight and volume of recyclables versus non-recyclables.

From Table 2, it is evident that, when comparing weight, the recyclable components of the waste stream were lighter than the non-recyclables, with a ratio of 1:2.28. In contrast, when comparing volume, it is evident that recyclable materials were bulkier than non-recyclables at a ratio of 1:0.85, filling up valuable airspace on the local landfill site since no compaction equipment is available in this town. These findings reflect the importance of capturing both the weight and volume of materials during a characterisation study.

Table 1
Calculations for the samples that should be collected from the various income groups.

Low income	High income
±1700 households	±800 households
Calculation: 1700/2500 = 68%	Calculation: 800/2500 = 32%
Sample: 68% of 210 = 143 samples	Sample: 32% of 210 = 67 samples
210 households must be sampled in total	

Source: Research data

Table 2
Weight vs volume calculations.

Weight			Uncompacted volume		
Total sorted	967.96	kg	Total volume	17.86	m^3
Recyclables	444.42	kg	Recyclables	12.41	m^3
Non-recyclables	523.54	kg	Non-recyclables	5.45	m^3

Source: Research data

5.1.1. Waste composition results

The following table shows the waste composition results obtained from the study.

Table 3 indicates that some fractions' weight is more significant than their volume, such as glass, food waste, garden waste, human hygiene/sanitary waste and residual waste. In contrast, it is more important to consider the volume than the weight of recyclable plastics, non-recyclable plastics, expanded polystyrene and paper and cardboard.

There were no major differences in the waste composition within the different geographical areas.

Recyclable plastics consisted mainly of polyethylene terephthalate (PET) (soft drink and water bottles and punnets) and low-density polyethylene (LDPE) (carrier bags).

Non-recyclable plastics consisted mainly of chips and chocolate wrappers made from aluminium laminated with polypropylene (also known as multi-laminates). Plastics branded with a chasing arrows triangle "7" indicating "others" were also grouped in this stream. Notably, more chips packets were observed within the bags in the lower-income

Table 3
Overall waste composition by weight and uncompacted volume.

Waste fraction	Weight	Uncompacted volume
1. Recyclable plastics	15%	33%
2. Non-recyclable plastics	4%	12%
3. Expanded polystyrene	1%	5%
4. Paper and cardboard	13%	24%
5. Metals	4%	4%
6. Glass	13%	3%
7. Food waste	28%	6%
8. Human hygiene/sanitary waste	11%	6%
9. Garden waste	4%	2%
10. E-waste and household hazardous waste	1%	1%
11. Residual waste	6%	4%
Total	**100%**	**100%**

areas in comparison to the higher-income areas. The chips packets were mostly inexpensive chips (1.00 ZAR or 0.069 USD[7] per packet), carrying little nutritional value.

Expanded polystyrene is mostly generated from the procurement of takeaway meals from two leading retail stores or the half-dozen takeaway restaurants in the town. The highest-income area contributed the most to this waste stream.

Paper and cardboard consisted mostly of cardboard packaging (cereal or rusk boxes) as well as TetraPak® packaging (mostly milk cartons) and newspapers. Low volumes of white paper and K4 cardboard were observed. In various bags from the lower-income areas, the sorters on the project showed a researcher "diamonds" made from newspapers. These "diamonds" are small spirals used as a filter when using drugs, in particular a drug called "tik" (crystal meth).

Metals consisted mostly of beverage cans or food tins. Hardly any other types of metals contributed to this waste stream.

Glass items found in the waste stream were mainly liquor bottles of various colours (green, clear and brown), including beer, wine and hard liquor bottles (such as brandy and vodka), as well as glass jars that contained food items such as preserves or sauces.

Food waste mostly consisted of food scraps and inedible portions of food, with only a few exceptions. Food wastage was not observed in the study area.

Garden waste was almost non-existent in the waste characterisation study's results. The weight is mostly made up of sand, stones and leaves, which are referred to as "yard waste" by the sorters. No grass cuttings were observed and very few cuttings, twigs or bark.

Human hygiene/sanitary waste had two major components: sanitary pads and diapers, with the latter dominating by both weight and volume. More diapers were also found in the low-income areas.

E-waste and household hazardous waste were seldom observed and were limited to lightbulbs, batteries, electronic cables, lighters and computer components. In the lower-income areas, whole lightbulbs were rarely found; only broken lightbulbs were found, which was another possible indication of drug use.[8]

The **residual waste** category consisted almost entirely of clothes, shoes and ash, with some exceptions. More shoes and clothes were found in the low-income areas.

5.2. Study 2: Illegal dumping mapping results

A total of 63 individual dumpsites were identified during the study period, with 17 identifiable waste fractions: garden waste; glass; plastic; construction and demolition waste; sanitary waste (diapers); metals; cardboard; mixed domestic waste; pet excrement; wood; white paper; renovation-related waste; bulky waste; newspapers; chips packets; animal bones; and automotive waste (including waste tyres).

5.2.1. Waste composition results

Garden waste was the waste fraction most frequently present in the illegal dumpsites (evident in 51% of all cases), followed by glass (44%), plastic (43%) and construction and demolition waste (40%).

Garden waste fractions illegally dumped mostly consisted of cut grass, plant trimmings and branches. Waste heaps were commonly found right outside homes. Glass waste mostly consisted of empty liquor bottles and was concentrated especially around or opposite taverns. Illegal dumping of glass bottles with a return deposit was not observed. Plastic waste mostly consisted of LDPE carrier bags and PET soft drink bottles, but was not found to be greatly influenced by location. In many cases, plastic items seemed to be littered on top of already existing illegal dumps or, if windblown, to be 'caught' by existing dumps.

Construction waste consisted predominantly of demolition waste (plasterboards, drywall and insulation). Dumped renovation-related waste included old carpets and cupboards. Metals included burnt copper wiring and shards of metal pieces, presumably from household appliances and machines. Wood waste included old and used timber that is used to construct informal and backyard dwellings. Cardboard waste seemed to mostly originate from shops, as these were predominantly boxes used for delivery of goods in bulk and may have originated from the informal shops (called 'smokkelhuise' ('smuggling houses')) in the township. White paper waste was mostly old schoolbooks. Bulky waste included white goods such as a broken washing machine, a mattress and also a broken wheelbarrow. Automotive waste included waste tyres as well as various car parts.

Dumpsites also included pet excrement (dog faeces). This appeared to be an established practice, as if the entire community had decided to allocate certain spots to dog faeces dumping. Many households had dogs as pets and there were also many dogs freely roaming the streets. Dumped animal bones included jaw and skull bones of sheep or goats, with some of the bones notably burnt. In some instances, sheep, goat and dog carcasses were observed. The process of burying household pets is not a common practice in the low-income areas. Large quantities of discarded clothes, shoes and other textiles such as curtains and bed linens were also dumped.

5.2.2. Geographical results

When plotting the illegal dumpsites on a map, no illegal dumpsites were found within the high-income area (not shown on the map below). All illegal dumpsites were found in the low-income areas (both the western and informal areas), as illustrated in Fig. 3.

Some dumpsites were found on the outskirts of the town, but most were found in front of houses and even in open spaces where signposts specifically prohibit dumping (see Fig. 4).

5.3. Study 3: Household survey

The household survey established whether the respondents know when to put their waste out for curb-side collection by the municipality. The majority of households (141 of 157, or 89.8%) responded positively (Viljoen et al., 2021).

The survey questionnaire further asked households how they manage the various waste fractions after generation, to develop a clearer understanding of their waste behaviour. Waste fractions included in the survey were paper, plastic, glass, food, old clothes, electronics and batteries. Respondents were asked to indicate how they manage each specific waste fraction. The choices provided were: mix it into the household waste (HHW); donate it; re-use it; burn it; dump it; sell it; put it in separate bags; or use it as compost.

As illustrated in Table 4, respondents indicated that they handle the majority of their waste (more than 50% of each waste fraction) by co-mingling it with other waste fractions and putting it out for collection by refuse removal truck (local municipality collection). In doing so, these waste fractions are ultimately sent to the local disposal site. The second-most popular waste management practice is that of donation of clothes, as 32.7% of all participants indicated that they donate old clothes (which includes items such as curtains, linen and shoes). Some respondents have also indicated that they donate electronics and food, but this is relatively uncommon (5.3% and 4.7%, respectively). The waste item most commonly re-used is food waste (32.4%), which mostly goes to feeding dogs.

A further qualitative question was asked to explore the sort of waste that is dumped. References were made to pet excrement (dog faeces),

[7] Exchange rate as on 29 July 2021.

[8] Lightbulbs are often used when using the drug crystal meth, informally called "tik".

Fig. 3. Mapping of illegal dumpsites in the low-income areas of Town C (red dots). Source: Alexander Kimani.. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 4. Illegal dumpsite at signpost. Source: Rinie Schenck.

'soutbos'[9] (a plant that grows well in this arid area), garden refuse, rubble (construction waste), dead dogs, excess waste and anything that is 'no longer needed'. These answers confirm the composition of waste seen in the illegal dumpsites.

[9] O*umansoutbos* ("old man saltbush"), *Atriplex nummularia*, not indigenous, https://www.feedipedia.org/node/184. In South Africa, this plant is now considered a weed.

6. Discussion

The uniqueness of this research lies in the fact that three datasets (a waste characterisation study, an illegal dumping mapping exercise and a household survey) were used to gain a thorough understanding of the waste composition and household waste management in the area.

The discussion and conclusion sections will therefore focus on what can be learnt when overlaying the results from the three datasets and thereby bridging the gap that would have been created if each dataset was studied in isolation when determining waste composition. In doing so, each waste fraction whose results were influenced by more than one dataset will be discussed.

A **recyclable plastic** waste item rarely found during the waste characterisation study but often found during the illegal dumping exercise is locally referred to as "rooiproppie", or "red cap" (Fig. 5). This is a very cheap wine sold by local taverns and liquor stores in 500 ml, 1 L, 2 L or 5 L PET bottles with red caps. It was found that, although this item was sometimes found during the waste characterisation study, it was also littered in locations close to or opposite taverns where the wine is consumed by customers and the bottles merely discarded there. The littering of these bottles is so common that, in the absence of any waste receptacles, illegal dumpsites form consisting solely of these bottles.

The household survey showed that only one respondent (0.7%) indicated that they re-use plastic in any shape or form. This is an interesting result as the researchers observed how, for example, the 'red cap' plastic bottles were used to collect and carry water.

Similarly, on a question of whether residents re-use shopping bags for other purposes, participants indicated that they use it in their small dustbins inside the house before it goes to the larger bin outside. Some respondents also indicated that they use plastic bags to "freeze food", to "give it to the lady who provides food for the homeless" or to "sell meat in". It seems as if the community is not aware that they "re-use" these plastic products. The questions asked to communities therefore need to be revisited.

A notable absence of aluminium-containing **metal** items such as soft

Table 4
Waste management and disposal practices of households, 2019

Waste fraction	Waste management practice							
	Mixed in HHW	Donate	Re-use	Burn	Dump	Sell	Separate bag	Compost
Paper (n = 149)	127 (85.2%)	4 (2.7%)	9 (6%)	2 (1.3%)				
Plastic (n = 150)	126 (84%)		1 (0.7%)					
Glass (n = 150)	126 (84%)	5 (3.3%)			1 (0.7%)			
Food (n = 148)	78 (52.7%)	7 (4.7%)	48 (32.4%)				1 (0.7%)	1 (0.7%)
Old Clothes (n = 150)	80 (53.3%)	49 (32.7%)		4 (2.7%)	1 (0.7%)		1 (0.7%)	
Electronics (n = 150)	121 (80.7%)	8 (5.3%)			1 (0.7%)	3 (2%)		
Batteries (n = 150)	125 (84.5%)				1 (0.7%)			

Source: Viljoen et al. (2021) and research data

Fig. 5. 'Red lid' wine bottles originating from one household in the low-income areas. Source: Charlotte Nell.

drink cans was noted in both the waste characterisation study and the illegal dumping exercise. This absence is explained by the market available for this type of material in the study area, with three businesses/buy-back centres buying these valuable items and therefore creating income-generation opportunities.

The quantity of **glass** generated within the study area would have been greatly underestimated if only a waste characterisation study was done. Similar to the 'red cap' plastic bottles, broken, non-returnable glass bottles previously containing alcohol (mostly beer) could be seen opposite or adjacent to taverns. These bottles were left uncollected and cause a health and safety risk for the many children walking around barefoot.

The results from the waste characterisation study showed that **food waste** was the most common fraction in the overall stream by weight (28% of total), but that this fraction was mostly made up of inedible portions of food, and that food wastage was not a concern in the study area. The waste characterisation study alone was unable to explain the reasons for the low levels of food wastage seen, but the survey explained this phenomenon. One household indicated that they use their food waste for composting, while food waste is the most common waste product re-used as animal feed (32.4% of households) ("we give it to the dogs"). Of interest was that the food waste left in the buckets, which is not fed to dogs, was mostly onion and potato skins. Potato skins can be edible, if cooked with the potato, and are sometimes served fried in restaurants. Upon being asked why potato skins are not used, some households shared that they do not regard them as edible.

The **garden waste** fraction was essentially absent from the waste characterisation study, being represented only by the 'yard waste' generated when residents swept their homes or cleaned their yards. This was to be expected, as can be seen in the following photo (Fig. 6); due to the arid nature of the area and water scarcity, gardening is not prevalent (Department of Water and Sanitation, 2020).

Gardens in the study area are mostly without lawns, with some shrubs, hedges (from the soutbos (saltbush)) and trees. There are few

Fig. 6. Garden waste fraction (mostly 'yard' waste). Source: Charlotte Nell.

homes with grass lawns, and those are mainly situated in the higher-income areas. In the lower-income areas, garden waste was the most commonly dumped waste item, especially outside people's homes and gates, presumably left there for the municipal trucks to come and collect. This was the perception among many residents interviewed. The lack of own transport in the low-income areas could contribute to the accumulation of garden waste on sidewalks. In the higher-income areas, the lack of garden waste can be explained by a combination of the availability of own transport and the ability to pay a service provider, such as a gardening service, to collect and remove garden waste. It was found during the fieldwork that garden waste was the most common waste fraction responsible for 'establishing' a dumpsite. After the establishment of a dumpsite, other waste materials were systematically added to the growing heaps (Fig. 7).

Another waste item that would have been greatly underestimated in quantity if only the waste characterisation study results were considered is that of disposable diapers, which form part of the **human hygiene/sanitary waste** fraction. The results showed that the low-income areas generated a much higher volume of diaper waste compared to the higher-income area, and this could indicate that there are a higher percentage of homes with infants in these areas. Although a large quantity of diaper waste is disposed of in a proper manner (mixed with HHW and put out for collection), the disposal of diaper waste by means of illegal dumping was common in the study area and creates a health risk.

The abundance of **textile waste** found in both the waste characterisation study (Fig. 8) and illegal dumpsites (Fig. 9) in the low-income areas can possibly be attributed to the poor quality of inexpensive attire, which has shorter lifetimes and leads to higher disposal rates. The overall impression was that the clothes and shoes disposed of had reached their end of life and could no longer be worn. The high disposal rates could also be due to clothes being received second-hand from the higher-income area (as a donation), also decreasing their wear and leading to their eventual disposal within the lower-income areas. This could also partly explain the lack of shoes and clothes found in the waste stream of the higher-income area.

Waste fractions illegally dumped that were not evident during the household waste characterisation study are **construction and**

Fig. 8. Clothes and shoes thrown away by low-income household, seen during waste characterisation study. Source: Charlotte Nell.

Fig. 7. Illegal dumpsite on street corner with garden waste as bottom/establishing layer. Source: Charlotte Nell.

Fig. 9. Clothes and shoes illegally dumped. Source: Charlotte Nell.

demolition waste, **waste tyres**, **renovation-related waste**, **bulky waste** and **automotive waste**. This is an important finding, because households are the main source of illegally dumped waste, which does include these waste fractions. This result therefore shows that there is a gap when doing waste characterisation without including an illegal dumping contents analysis.

There is a clear difference in the efficiency of waste management in the various geographical areas of the town. In the high-income area, very little litter and no illegal dumping sites were observed, whereas, in the low-income areas, 63 individual dumpsites and thousands of littered items were seen. This contrast could possibly be attributed to the fact that higher-income households have access to transport options that can take their waste to the disposal facility. In contrast, transport is not always readily available or affordable in the low-income areas, despite its closer proximity to the disposal area. Additionally, higher-income households also tend to make use of services that include waste removal as part of their service offerings, such as gardening services.

It was found that wheelbarrows are the main mode of transport used by the households when moving waste in lower-income areas. Illegal dumping of waste for the sake of evading disposal tariffs was not found to be a motivating factor, as disposal of any quantity of general waste may be done free of charge (interview with waste manager). Even though the low-income areas presumably receive regular waste removal (at least once per week), there are still 63 illegal dumpsites, which indicates a possible system failure. This is an area for future research.

7. Conclusions and recommendations

The value of waste characterisation studies lies in their ability to influence decisions that increase the effectiveness with which household solid waste streams can be managed and waste management systems be put in place (Oelofse et al., 2016; Nell, 2020). However, this research shows that to have a comprehensive understanding of the entire waste stream and to make integrated and appropriate waste management decisions, a three pronged approach recommended including illegal dumping study and household surveys in waste characterisation studies. As this paper demonstrates, a mapping and content analysis of illegal dumpsites and a household survey add valuable information.

The waste characterisation results of this study showed that the quantity and composition of waste generated within the different areas of the town all followed a similar trend. From these results, it would be recommended to develop a singular waste management strategy for all areas due to the homogeneity of the waste streams. However, by supporting the waste characterisation results with information obtained from the illegal dumping mapping and contents analysis, it is clear that there are several waste fractions that communities struggle to manage when they do not have the means or resources to effectively do so. These waste fractions are often those most harmful to the environment, such as construction and demolition waste, waste tyres and bulky waste.

Planning for preventing illegal dumping needs to be done alongside the communities in question to decide on appropriate ways and infrastructure that can support them. The co-development of a garden waste collection system between the local municipality and the residents of the low-income areas is recommended. A weekly collection should be sufficient if the system is implemented reliably. In addition, the results show that there is sufficient organic matter available in the study area for the establishment of a successful composting facility. A composting facility could be an income-generation opportunity – a positive foresight in an area characterised by high unemployment. Locally produced, high-quality organic compost would likely be in high demand due to the arid climate and rural location of Town C. The availability of compost could spark the development of community gardens, which, in turn, could supply local residents with a variety of vegetables that are usually either unavailable or, if regularly available, are sold at high cost in supermarkets. Additionally, the co-development of a weekly or bi-weekly bulky waste collection system in the low-income areas is of equal importance. Under-resourced communities struggle to cope with these difficult waste streams.

Recyclable waste fractions that are dumped can be solved by assigning value to those materials through accepting them at a buy-back centre. This can only be done through subsidisation in this study area, due to the low value of recyclate and the long distance to market. The question of who should be responsible for funding the subsidy is not yet clear. South Africa is currently in the process of extended producer responsibility (EPR) regulation development and, once finalised, this should shed more light on whether subsidies promoting the recycling value chain will be available.

What also emerged in this particular rural community is that illegal dumping cannot solely be blamed on the community. The origins of illegal dumping are embedded in the waste management system of the town. The removal of household waste on a weekly basis seems to be insufficient in the low-income areas in particular. The mini-drop off system implemented by the Drakenstein Municipality is one possible solution to support low-income households with the waste that does not fit in the bins (Schenck and Tyrrell, 2021). Residents can be encouraged to rather drop their garden-, bulky-, and excess waste at these facilities where it can be contained. Such facilities provide an alternative to illegal dumping. Improved household waste management behaviour can also contribute to a cleaner town. This can also include education and awareness initiatives to ensure that residents understand how the system works and their role within it.

It is recommended that government and municipalities in developing countries recognise the value of including analyses of illegal dumpsites to be able to make appropriate integrated waste management decisions to manage waste they are ultimately responsible for. Illegal dumping can clearly not only be seen as the ‘bad behaviour’ of residents.

It is further recommended that we investigate the re-use practices of communities, including those practices that they might not even be aware of or explicitly define as re-use practices. These practices can be supported and strengthened, and additional re-use practices can be explored.

Finally, it is recommended that all levels of the South African government urgently prioritise waste management. Prioritisation should be reflected in budget allocations, policy development and law enforcement. Government must realise that we are dealing with communities struggling socio-economically in a developing country. We therefore need to start thinking differently about waste and waste management if we want to be role players in the goal towards a circular economy and achieving the United Nation’s Sustainable Development Goals to which South Africa is a signatory (De Medina-Salas et al., 2020).

Credit author statement

C Nell - data collection; data Formal analysis; writing; conceptualisation, C Schenck – data collection; conceptualisation; data Formal analysis; writing, D Blaauw – data collection; conceptualisation; writing, critical reader.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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