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Residents' perception and environmental assessment of a waste recycling centre: a case study of Buenos Aires City (Argentina)

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Abstract

Urban waste management should ensure minimal environmental impact and local context adaptation. We present an assessment of the municipal Recycling Centre in Buenos Aires City (Centre), which processes recyclable materials, food waste, municipal tree pruning, and construction and demolition waste. To evaluate the Centre's socio-environmental performance, we conducted a study in an area of ~9 km^2 around the Centre. First, we surveyed nearby residents to gather their perceptions of the Centre and neighbourhood cleanliness. Second, we analysed indicators of air quality by dust traps, street cleanliness by applying an index evaluating street littering and provision of municipal waste containers, and vehicular and pedestrian traffic at the entrance of the Centre. About 80% of local residents had a negative perception of street cleanliness, largely due to litter scattered by neighbours around waste containers and pavements. Among residents aware of the Centre's existence, 60% reported negative perceptions, linked with dust emissions and heavy truck traffic. Positive perceptions were linked to the awareness about the Centre's role in waste recycling and employment. Air quality revealed the highest levels of dust particles near the Centre and on avenues, irrespective of their distance from the Centre. The cleanliness index was lowest in the Centre's immediate vicinity. Intense truck traffic was documented at the Centre's entrance, also reported as a negative issue in the surveys. These findings highlight negative environmental impacts on the well-being of residents in the Centre's surroundings, some of them associated with the Centre's operations. The study identifies opportunities for significant improvement to address these issues.

Keywords Recycling facilities · Construction and demolition waste · Integrated assessment · Socio-environmental impacts

Abbreviation

C&DW Construction and demolition waste

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1 Introduction

Sustainable solid waste management is a major challenge in urban areas worldwide, particularly where urban sprawl is intense (Mavropoulos, 2011). In these contexts, increasing population density is accompanied by both greater municipal solid waste generation and construction and demolition waste (C&DW) inherent to urban development (Fernández Colomina & Sánchez-Osuna, 2007; Kaza et al., 2018; Korhonen et al., 2018; Mavropoulos, 2011).

Waste management has been increasingly approached from a circular economy perspective (Mavropoulos, 2011) and is also considered as an important driver in urban programmes for the mitigation of climate change (Kirchherr et al., 2017). Circular economy has been proposed as an alternative to the unsustainable "take-make-dispose" model. It proposes a cyclical flow model to regenerate material cycles by orienting modern cities toward minimization of resource extraction, energy consumption, material transport, waste generation and eventually close the loop of materials through high value recycling (Geissdoerfer et al., 2017; Korhonen et al., 2018).

However, accomplishing an effective circular economy requires adaptation to specific local contexts and minimization of negative socio-environmental impact (Consejería de Medio Ambiente y Ordenación del Territorio de Madrid2018; MacArthur, 2013). In areas where waste treatment facilities are in close proximity to residential areas, implementation of a circular economy is particularly challenging as waste recovery plants can negatively impact their surroundings (Ulubeyli et al., 2017). Previous studies revealed that in cases where recycling facilities cannot be located in peri-urban or industrial areas, environmental and social conflicts require more exhaustive mitigation strategies and monitoring programmes than those currently in effect (Blengini & Garbarino, 2010; Central Public Health and Environmental Engineering Organisation of India, 2016; Lu & Yuan, 2012).

Among the different waste types, waste from construction and demolition (C&DW) is particularly important since it can be up to 50% of total solid urban waste and its management represents a major environmental problem (Kartam et al., 2004; Lawson et al., 2001; Poon et al., 2004; Thorin, 2020; Yeheyis et al., 2013). Its high recycling potential has allowed challenging recycling goals worldwide (Coronado et al., 2011; Mercante, 2005; Suárez-Silgado et al., 2018). During the last years waste segregation and valorisation have been receiving increasing attention among decision makers and C&DW has been already included in waste management plans of several cities (Faruqi & Siddiqui, 2020; Lu & Yuan, 2012; Tufaro et al., 2016). Thus, dust emission, noise and vehicular traffic are major challenges, particularly when recycling plants for different waste materials are located within residential areas as in the case of the City of Buenos Aires (AECOM, 2018; Dania et al., 2007; EPA, 2019).

Studies aimed at the development of instruments and guidelines to assess the performance of recycling centres based on environmental and public perception are scarce (Engkvist et al., 2010). Some studies focus on the perception of visitors, workers and residents (Engkvist, 2010; Lavoie & Guertin, 2001; Rahardyan et al., 2004; Zeiss & Atwater, 1991). It seems that residents living close to this type of facilities mostly complain about odour, noise, traffic, among other affections (Zeiss & Atwater, 1991). Other studies found that high concentration of airborne biological contaminants, volatile organic compounds (VOCs) and CO_2 emissions were common in waste facility surroundings (Coelho & de Brito, 2013; Gallego et al., 2012; Han et al., 2020; Marchand et al., 1995; Ortiz et al., 2010). In turn, health problems on workers and residents have also received attention (Aatamila et al., 2011; Poulsen et al., 1995; Raun et al., 2013; Sigsgaard et al., 1994). Previous studies documented odour-associated physical symptoms such as eye irritation and toothache (Aatamila et al., 2011) and asthma and bronchitis (Poulsen et al., 1995). However, the integration of environmental and social aspects in order to provide a comprehensive analysis of the impacts remains elusive.

Buenos Aires City is the capital of Argentina, the largest city in the country and the second in Latin America (Buenos Aires City Government—IGES, 2019). It has a total of 3 million inhabitants and an equivalent number of commuters (Buenos Aires City Government—IGES, 2022). From a total of approximately 7,300 t/day of waste (CEAMSE, 2018), 40% is processed in the Recycling Centre of the City (hereafter, Centre). The Centre is located in a complex area made up of residential zones, including formally urbanised areas and shantytowns, private recreational locations, and logistics and transport company facilities; the area crossed by high-traffic arterial roads (hereafter, Avenues, Fig. 1). Since its opening in 2014, the Centre has processed approximately 6 million tonnes of waste. In turn, it has received a number of complaints from nearby residents mainly due to dust emissions and truck circulation particularly linked to the C&DW plant, which motivated the present research.

The objective of this study was to carry out an integrated analysis of Buenos Aires City Recycling Centre in order to improve understanding of its performance. We specifically evaluated (1) residents' perception of the Recycling Centre and neighbourhood cleanliness and (2) air quality, street cleanliness, and vehicular and pedestrian traffic in the proximity of the Recycling Centre entrance.

2 Materials and methods

2.1 Study system and design

The Recycling Centre is located in the south of Buenos Aires City (34° 39′ 16.32'' S, 58° 26′ 31.56'' W), within a complex urban matrix that includes residential areas, clubs, schools,

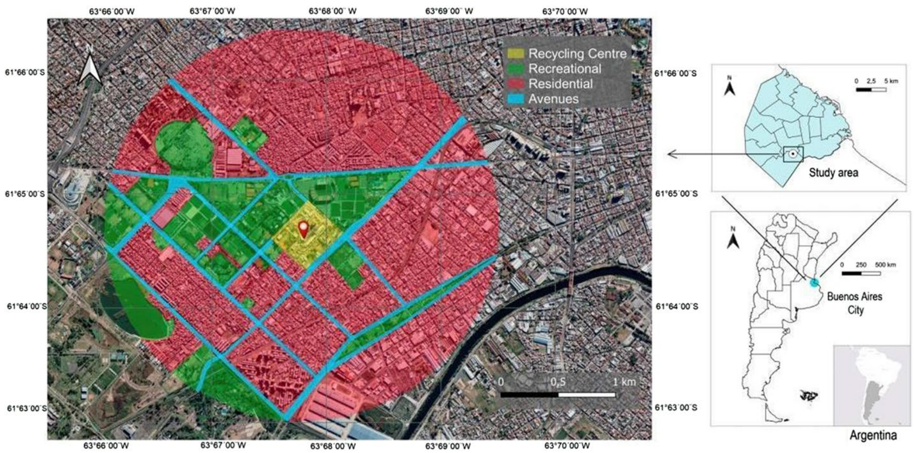


Fig. 1 Satellite image from Google Earth showing the circular study area (1.7 km radius). Colours denote the different land uses (key). The red mark represents the location of the Centre facilities

logistic facilities, shantytowns and arterial roads. The Centre occupies nearly 7 ha and is composed of five treatment facilities which process approximately 3,200 t/day of C&DW, municipal tree pruning, food waste and household and commercial recyclables (cardboard, paper, plastics, glass and metals) (López de Munain et al., 2021). The C&DW recycling plant is the most important of the Centre, since it processes about 95% of the incoming material. The Centre also houses an educational unit that receives the general public, school groups, non-governmental organisations, and other visitors. This unit offers guided tours of the different treatment plants and also includes thematic workshops for children, with a view to raising awareness of recycling, recovering, reusing and composting.

Based on previous observation of the neighbourhood, vehicular traffic and resident dynamics, the study area was defined as a radius of approximately 1.7 km around the Centre, with the aim of capturing both the areas most likely to be affected by the Centre's routine operations (i.e. the immediate surroundings) and those less likely to be affected (i.e. the less immediate surroundings). Then, the area was classified into four zones according to land use: (1) "Residential" included both formally urbanised areas and shantytowns, with logistics centres interspersed with houses within the residential matrix; (2) "Recycling Centre" included the Recycling Centre and a radius of up to approximately 100 m around it; (3) "Recreational" was composed of private clubs and public parks; and (4) "Avenues" included the main arterial roads of the area (Fig. 1). Impact assessment of the Centre considered both land use and proximity to the Centre. We carried out a survey to assess social perception of the Centre and neighbourhood cleanliness and established a set of indicators to evaluate street cleanliness, air quality and vehicular traffic.

2.2 Indicators studied

A random sample of 150 residents from the different zones of the study area was surveyed. Surveys were conducted during March 2019, in five different days (Monday to Friday, from 9 to 6 am). The other environmental measurements (street cleanliness, air quality and urban traffic) were obtained during the same period (March 2019). The final number of responses was 133, as 17 responses were discarded due to different technical flaws. The number of interviews complied with the theoretical saturation criterion, so we decided not to interview any more people when the last interview did not yield any novel insights into the study object (Sánchez-Arias et al., 2019). Given that the Centre zone consisted mainly of the Centre facilities and included very few houses, a smaller sample of residents was surveyed ($n = 10$). Briefly, the surveys consisted of short (~5 min) interviews. Interviewers introduced themselves as staff of the University of Buenos Aires and randomly invited neighbours passing through a public place within the study area to participate in a brief and anonymous survey on urban hygiene and waste management. To obtain their perception on the neighbourhood cleanliness and the Centre, we conducted a concise semi-structured personal questionnaire with two main sections ("Appendix 1"). In the first section, we assessed residents' perception of factors associated with local neighbourhood cleanliness and waste-related issues, and the responsibilities of the different stakeholders (government, residents, public services, etc.). In the following section, each participant was interviewed using a short list of questions specifically focused on the Centre. This interview included both open and closed questions, and participants' responses were coded to allow the data to be stored and analysed. Prior to the interviews, the questions were tested with a small sample of people and some of them were slightly modified to avoid misinterpretation. Those results were not included in the study.

Particles suspended in the air were measured with a contact methodology adapted from the Open Air Laboratories (Imperial College of London) and a sensing system developed by Kuznetsov et al. (2014). One hundred dust traps were randomly geolocalized throughout the entire study area ("Appendix 2"). Each trap consisted of a 4×2 cm fragment of transparent adhesive tape attached to a Petri dish. The traps were attached open to lampposts of the public lighting network, at a height of 3 m, and oriented vertically towards the Recycling Centre. They were exposed for a period of 30 days and then collected, covered and taken to the laboratory for processing and analysis. From a total of 100 traps 69 were recovered; 31 were lost through falls. In the laboratory, 2×2 cm fragments of the transparent adhesive tape were cut, stamped against a transparent acetate sheet and labelled. Tape fragments were scanned at high resolution and the images were analysed, registering the white (clean), and grey or black (with particles) pixels with the Python Open Source Computer Vision Library (OpenCV, 2015). The amount of particles in the air was expressed as the percentage of grey and black pixels of the total pixels on each tape. Before sampling, the methodology was calibrated by regressing the number of particles counted with the microscope and in the pixel output ($r^2=0.92$); these results were evaluated in terms of proximity to the Recycling Centre and the different zones of the study area (Residential, Recreational, Recycling Centre and Avenues).

A cleanliness quality index developed by the Secretary of Urban Hygiene of Buenos Aires City was used to obtain an objective assessment of street cleanliness in the study area (Observatorio de Higiene Urbana de la Ciudad, 2019). The Street Cleanliness Index included a number of indicators related to three main cleanliness criteria: (1) waste containers and bins availability and condition, which quantified the availability of facilities (rubbish and recycling containers, and litter bins), their fullness condition, odour emission, the presence of bulky waste (e.g. furniture, large home appliances) and waste scattered around them; (2) street littering, referring to the presence of waste bags and waste scattered along roads and pavements; and lastly, (3) street hygiene, which registered the presence of tree leaves and dog and bird faeces on the streets and pavements ("Appendix 3"). A total of 40 sample units were surveyed that included all the different zones of the study area. Each sample unit included the two opposing pavements of one 100 m-block, and each block was divided into three equal segments; each sample was therefore composed of six segments of approximately 33 m. Using an ad hoc application we assessed the state of each segment of the blocks according to the indicators of the cleanliness criteria. The indicators were weighted according to their importance for the cleanliness perception of the neighbourhood and each was given a score between 0 and 100, 0 corresponding to the worst cleanliness condition and 100 the best. The sum of the three criteria gave an overall score for the Index; thus, a general value (which also ranged from 0 to 100) was obtained for the hygiene of each sample unit.

Vehicular and pedestrian traffic was measured at the entrance of the Recycling Centre (Varela Avenue). We recorded the number of light vehicles (passenger cars, vans and small city delivery trucks), heavy-duty vehicles, motorbikes, bicycles and pedestrians circulating on pavements on both sides of the avenue. The heavy-duty vehicles included buses and trucks; the trucks were classified into two groups: those linked to the Recycling Centre and those not linked. In addition, every ten minutes we recorded the number of trucks that had stopped at the entrance of the Centre, awaiting entry. Records were kept on 5 different weekdays of different weeks (totalling 10 sampling hours): in the morning (from 7 to 11 am), at midday (from 11 am to 2 pm) and in the afternoon, (from 2 to 6 pm). Although the Recycling Centre operated during 24 h, recording was suspended during the evenings and nights (from 6 pm to 7 am) for safety reasons.

2.3 Statistical analyses

Particles suspended in the air and cleanliness indicators were analysed by one-way analyses of variance, with type of land use as the independent variable. Then, linear regression analyses were performed considering proximity to the Recycling Centre, in metres. When analyses of variance indicated significant differences, means were compared by Tukey tests. The data on particles suspended in the air were square root transformed to obtain homoscedasticity of residuals and then retransformed to original values in the figure. Analyses were performed by Infostat (Di Rienzo et al., 2012).

3 Results and discussion

3.1 Residents' opinions

Residents living close to the Recycling Centre had a more negative opinion of neighbourhood cleanliness than others, as 100% considered that it was between moderately clean and very dirty. In contrast, these categories were mentioned by only 16% and 24% of residents of the Residential or the Avenue zone, respectively (Table 1). Overall, most residents considered that neighbourhood hygiene was lower than that of the City as a whole ("Appendix 4", Fig. 6).

Participants identified multiple factors affecting the cleanliness of public areas: litter and waste scattered on pavements and around containers, and no street sweeping service were the most frequently mentioned factors (Fig. 2). In contrast, those living near the Recycling Centre were mainly affected by broken pavements and dog faeces, as well as no street sweeping ("Appendix 4", Table 3). Foul odour, no waste containers or bins, dust, piles of construction debris, truck circulation, bulky items or yard trimmings, annoying noises, lack of vegetation maintenance and standing water were less frequently mentioned (Fig. 2).

Approximately half the participants identified residents as being primarily responsible for the hygiene deficiencies, whereas 21% identified the sweeping service and 15% the waste collection service ("Appendix 4", Fig. 7). Fewer participants mentioned the Centre and the informal waste collectors (people who collect recyclable rubbish and sell it to the recycling industry).

Table 1 Residents' perception of neighbourhood hygiene

Perception (%)	Average ($n=133$)	Centre ($n=10$)	Avenues ($n=61$)	Residential ($n=62$)
Very clean	1.08	0.00	1.64	1.61
Clean	12.44	0.00	14.75	22.58
Medium	34.93	30.00	37.70	37.10
Dirty	32.40	50.00	26.23	20.97
Very dirty	19.14	20.00	19.67	17.74

Responses were classified according to the different land use types (Centre, Avenues and Residential). There are no responses for the Recreational category as nobody was living on that land. The five perception categories are shown on the left; n = number of responses for each land use

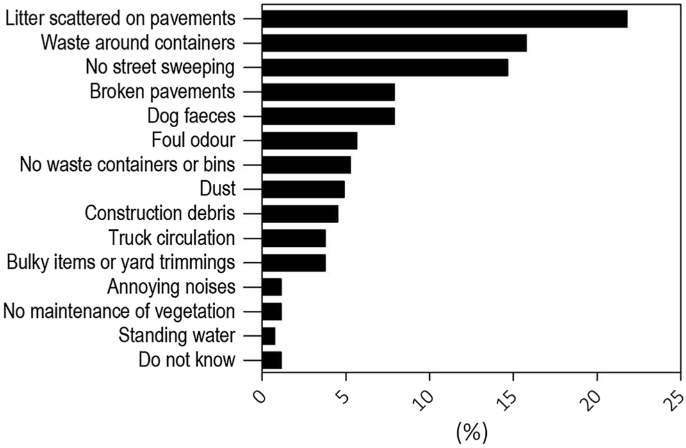


Fig. 2 Residents' perception of the factors affecting street cleanliness ($n=133$). Categories correspond to those mentioned by participants. Responses of residents from different land use types were pooled for clarity (individual responses for each land use type are presented in "Appendix 4", Table 3)

When specifically questioned about the Centre, 70% of participants reported that they were aware of it, particularly those living in the vicinity of the Centre. Among them, 60% expressed a negative opinion of the Centre and 40% expressed a positive opinion. Negative opinions were related to the unfamiliarity with this type of technology. When asked about the Centre, respondents demonstrated unawareness regarding the facility's role in recycling different types of waste. What is more, they were affected by the proximity of the Centre to their homes, which they associated with the presence of foul odour, dust, heavy traffic and lack of hygiene. Conversely positive perceptions highlighted the role of the Centre as a source of employment for local residents and its importance for waste recycling.

Several studies have already focused on residents' resistance toward waste treatment facility sites and the determinants of that attitude. Resistance is generally associated with the "not in my backyard" (NIMBY) phenomena, that is when people living near the place feel an imbalance between the benefits and the damages they will face from hosting the facility (Lober & Green, 1994). Different concerns have been reported about living near a waste treatment facility, which would result in that opposition. Residents living closer are usually more concerned about operational impacts such as odour, noise, dust, littering than other people (Che et al., 2013; Okeke & Armour, 2000). Also traffic impact (Furuseth & Johnson, 1988; Furuseth & O'Callaghan, 1991; Lima, 2004; Okeke & Armour, 2000), psychological impacts (Lima, 2004; Okeke & Armour, 2000; Sakawi et al., 2011) and economic impacts like property devaluation (Rahardyan et al., 2004) have been reported. However, perceived risk of the residents may be influenced by the level of familiarity with the facility (Lober, 1996). Coinciding with our results, other studies found that unknown facilities are more susceptible to opposition (Lober, 1996; Rahardyan et al., 2004; Zeiss & Atwater, 1991). Nevertheless, negative perceptions are likely to change if people have the opportunity to visit the sites and take part in the decision-making process (Elliott, 1984; Rahardyan et al., 2004). Also, public participation, information and transparency are likely to improve people's acceptance (Che et al., 2013). Therefore, in the case of the Centre, it is necessary to reinforce bonds with the community by strengthening the role of the educational centre of the Centre and informing local residents about the operation and management of the plant. Furthermore, residents pointed to the Centre as a source of dirt, but at the same time they blamed themselves for deficient cleanliness. Thus, the educational centre would also play an important role in raising residents' awareness of waste disposal (McKenzie-Mohr, 2002).

3.2 Air quality, street cleanliness and traffic

The Centre and avenue zones had the highest concentration of particles suspended in the air, while Recreational registered an intermediate value and Residential the lowest ($p=0.003$) (Fig. 3a). The suspended particles were not significantly correlated with proximity to the Recycling Centre ($r^2=0.014$ and $p=0.33$, Fig. 3b). Thus, these results indicate that not only the Centre but also other sources of air pollution could be affecting air quality such as vehicular traffic. Moreover, we found low values of particles even in the proximities of the Centre which can be associated with methodological limitations of the dust traps or other factors that limited particles capture efficiency of traps like natural barriers and prevailing wind direction patterns during the measurements.

It has already been documented that dust emissions are among the major impacts of C&DW facilities, being extremely hazardous for workers and nearby inhabitants (Coelho & Brito, 2013; Duan et al., 2015). Although in this case it was not possible to link health problems with the Centre, implementing more exhaustive mitigation and monitoring strategies should be a priority as the negative impact of suspended particulate matter on health has been widely reported (Gan et al., 2011; Krämer et al., 2010; Panasevich et al., 2009). In the case of avenues, the high values of particulate matter could be attributed to vehicular traffic, as they are usually a major source of air pollution in cities (European Commission, 2017; Ho et al., 2003; Karagulian et al., 2015). Specifically in Buenos Aires City, vehicular traffic contributes 94% of these emissions into the atmosphere (Venegas & Martín, 2004). Conversely, the lowest values of particulate matter were found in the Recreational zones which are characterised by their green infrastructure. Because urban vegetation contributes to removing air pollution and improving its quality, implementing green barriers around the Centre

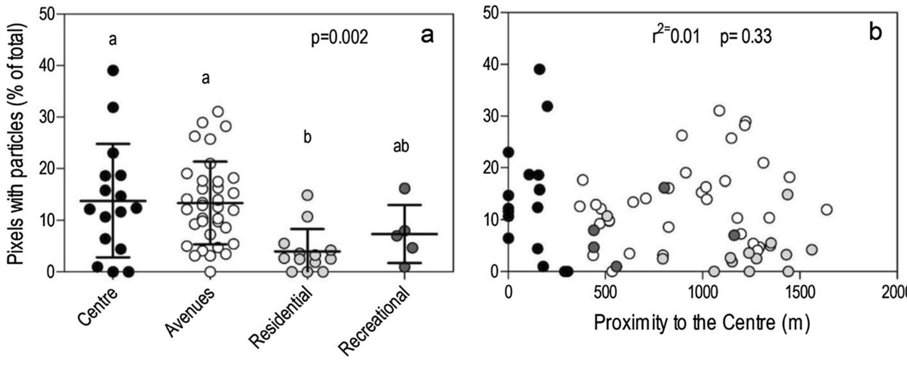


Fig. 3 Particles suspended in the air, estimated from the proportion of white, grey and black pixels on the adhesive tape fragments. The results are presented in relation to the different classes of land use (**a**) and proximity (in metres) to the Centre (**b**). The colour presented in panel b corresponds to the different classes of land and is the same as that of panel a. Different letters above the bars (a, ab, b) indicate significant differences ($p<0.05$) among classes of land use

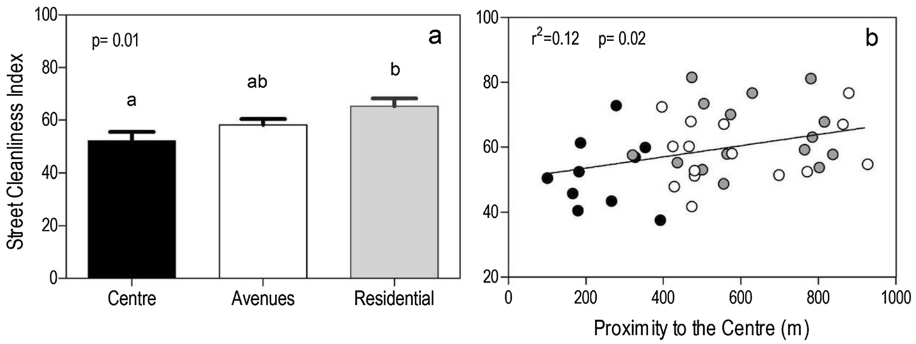


Fig. 4 The Street Cleanliness Index for the different types of land use (**a**) and proximity (in metres) to the Recycling Centre (**b**). Different letters above the bars (a, ab, b) indicate significant differences ($p<0.05$) among classes of land use. The lines above the bars indicate the standard errors of the data

Table 2 Results of the Street Cleanliness Index in the study area

Criteria	Average ($n=40$)	Centre ($n=10$)	Avenues ($n=17$)	Residential ($n=13$)
Container and bin condition	35.9 (3.28)	31.6 (9.59)a	28.8 (7.35)a	47.4 (8.41)a
Street littering	65.1 (3.28)	58.3 (2.71)a	63.1 (2.08)a	73.9 (2.38)b
Street hygiene	74.5 (3.28)	66.3 (4.54)a	82.6 (3.48)b	74.5 (3.98)ab

The criteria evaluated in the index are on the left. The table shows the score obtained for each of the criteria in each of the zones. The numbers in parenthesis indicate the standard errors and the letters on the right (a, ab, b) denote significant differences for each criteria ($p<0.05$) among land use categories (Centre, Avenues and Residential); n = number of responses for each land use

and increasing the public tree network would mitigate the impact of dust production by the plant, strengthening the current measures (Nowak, 2006; Yin et al., 2011).

On the Street Cleanliness Index we obtained a general score of 59/100 although this varied between land uses and proximity to the Recycling Centre (Fig. 4). The Centre obtained the lowest score, whereas the Residential area received the highest, and Avenues had intermediate values ($p=0.01$, Fig. 4a). In this case we detected a significant relationship between proximity to the Recycling Centre and the Street Cleanliness Index ($p=0.02$, Fig. 4b), demonstrating that the worst cleanliness conditions were found in the surroundings of the Centre. Of the three criteria, street hygiene obtained the highest score, followed by street littering, whose value was twice that of the container and bin condition criterion, which registered the worst performance (Table 2). The container and bin condition criterion did not differ significantly between land uses ($p=0.23$). In contrast, the street littering of the Centre and Avenues zone was significantly lower than that of Residential ($p=0.0002$); the street hygiene of the Centre had the lowest values of the study area ($p=0.02$) (Table 2).

The Street Cleanliness Index results were in line with residents' opinions finding that the poorest hygiene conditions were near the Recycling Centre; however, they showed some inconsistencies regarding the factors that impeded cleanliness. Although residents expressed their primary concerns about litter scattered on pavements and around containers, as well as the lack of street sweeping, the Centre zone received an acceptable score of 58 points from the Index for this specific criterion. In contrast, both the container and bin condition, as well as street hygiene criteria, exhibited significantly lower scores. Moreover, this mismatch between social perception and the objective assessment was found not only for the Recycling Centre zone but also for the other land use categories. This suggests that the Street Cleanliness Index should be improved in order to capture residents' perception.

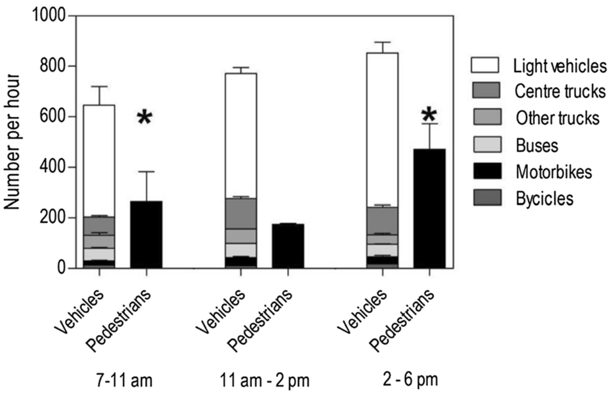
Vehicular circulation at the Centre entrance (Varela Avenue) averaged 756 vehicles h-1 (Fig. 5). Approximately 70% were light vehicles, followed by Centre trucks, which comprised 13% of the total. Buses and other trucks were similar in frequency, each accounting for 7% of total traffic. Motorbikes and bicycles represented only a minor fraction of the total (3% and 2%, respectively). The average number of Centre trucks stopped in Varela Avenue awaiting entry to the Recycling Centre was 2.5, with peaks of 8–10 trucks between 12 and 1 pm. Pedestrian traffic on the Avenue averaged 280 persons h-1 but increased sharply to 600 persons h-1 during specific moments of the morning and afternoon (indicated by black asterisks in Fig. 5), in coincidence with the peaks of the Centre trucks, linked to school start and finish times.

We recorded an intense traffic flow which was also reported by the residents living close by, particularly those from the nearby shantytown or along other avenues. Even though the traffic is very much lower than that registered in other avenues of Buenos Aires City (Tomino, 2014), the Centre entrance avenue has a number of important aspects to consider. On the one hand, the avenue connects the nearby shantytown with the clubs, schools, and important bus stops of the area; so it has an intense flow of people who have to deal with an inadequate pedestrian infrastructure. On the other hand, a major proportion of the traffic is heavy trucks, which accumulated on both sides of the avenue, hindering the circulation of other vehicles; they particularly increased average travel time, the number of other vehicles changing manoeuvres, and traffic incidents (Moridpour et al., 2015). In this sense, the implementation of a buffer area between the Centre and the neighbourhood might mitigate this impact; residents' safety should be protected by including separate travel channels for pedestrians and bicycles, and designing a truck-only lane for the Centre trucks (Lord et al., 2005; Nuworsoo & Cooper, 2013; Pucher & Dijkstra, 2003).

3.3 Limitations of this research and future perspectives

Air quality assessment will be improved by expanding the analysis to encompass different periods of the year. Moreover, future studies can incorporate other methodologies which

Fig. 5 Number of vehicles and pedestrians circulation at the Centre entrance per hour during weekdays as a function of time of day. The black asterisks represent the maximum peaks of pedestrians. Vertical lines indicate the standard errors of the data



differentiate among types of air pollutants in order to make it easy to associate them with their source, and which provide measures of suspended particles comparable to international guideline limits of health affection.

The research presented a set of environmental indicators which were useful to assess different environmental and social effects of the Recycling Centre; however, one limitation of the study was that we did not include other aspects such as noise and odour measurements, and devaluation of neighbouring properties, which could be incorporated in the future studies to provide a more complete assessment of the environmental impacts of the Centre.

4 Conclusions

An integrated assessment was made to analyse the environmental impacts of the Recycling Centre of Buenos Aires City. The environmental indicators revealed an association between the Centre and increased vehicular traffic, deficiencies in street cleanliness, and degraded air quality, which were also largely perceived by the residents. However, some impacts were not limited to the immediate vicinity of the Recycling Centre but extended to other areas within the study zone, indicating the existence of additional sources of environmental concerns beyond the Centre. In this sense, perception assessments revealed that residents themselves played a significant role in contributing to hygiene deficiencies. Furthermore, the surveys revealed a significant number of residents holding negative opinions about the Centre, mainly due to its close proximity to their homes and their lack of familiarity with this type of waste facility. Additionally, the comprehensive assessment helped identify infrastructural deficiencies in the surrounding areas of the Centre, which contribute to poor cleanliness conditions and significant traffic problems.

The integration of environmental indicators and residents' perception provides a comprehensive understanding of the major socio-environmental impacts of the Centre area and establishes the basis for the design of specific mitigation strategies to improve residents' well-being. To address these concerns effectively, Centre managers should focus on reducing dust generation and implementing buffer zones between the Centre and the surrounding neighbourhood. Simultaneously, local authorities need to enhance waste facilities and services, while also promoting community awareness of the City's waste management system through informative campaigns and educational initiatives to encourage proper waste disposal practices.

Appendix 1: Questionnaire on residents' perception

The following questionnaire aims to gather information about residents' perception of the Recycling Centre and factors associated with hygiene in the local neighbourhood and the City in general. The questions allowed open responses although we added comprehensive lists of potential options.

No	Section	Question	Possible answers
Q_1	Personal information	Where do you live?	Approximate address

No	Section	Question	Possible answers
Q_2	City hygiene	What is your opinion of Buenos Aires City hygiene?	Very clean; Clean; Medium; Dirty; Very dirty; I do not know
Q_3	Neighbourhood Hygiene	What is your opinion of local neighbourhood hygiene?	Very clean; Clean; Medium; Dirty; Very dirty; I do not know
Q_4		What factors mainly affect neighbourhood hygiene?[a]	Annoying noises; Broken pavements; Bulky items or yard trimmings; Dog faeces; Dust; Foul odour; No street sweeping; No waste containers or bins; No maintenance of vegetation; Others; Presence of construction debris; Standing water; Waste scattered around containers; Litter scattered on pavements; I do not know
Q_5		Who is mainly responsible for the hygiene condition of the neighbourhood? (*)	Rubbish collection service; Residents; Recycling Centre; Clubs; Street sweeping service; Informal waste collectors; No one; I do not know
Q_6	Recycling Centre	¿Do you know the Recycling Centre that is located in the neighbourhood? And, ¿What is it used for?	No, I do not know the Centre; Yes, I do, and I know its usefulness; Yes, I do but I do not know its usefulness; I do not know;
Q7		¿What is your opinion of the Recycling Centre?	open-ended question

[a]Respondents were asked to choose one or more options

Appendix 2: Satellite image from Google Earth showing the location of the 100 dust traps (red points). The yellow mark represents the location of the Centre. Traps were not located in the northern sector of the study area for safety reason

Appendix 3: Indicators conforming the three cleanliness criteria of the Street Cleanliness Index

Criteria	Indicators
Container and bin condition	In the segment… Are there any rubbish containers? Are there any recycling containers? Are there any litter bins? Have the containers or bins got recyclable materials in their surroundings? Have the containers or bins got bulky waste, branches or construction debris piles in their surroundings? Have the containers or bins got scattered waste in their surroundings? Is there any rubbish (dry, wet, aggregates) scattered around which Would cause you to complain about "collection of rubbish outside the container"? Do the containers or bins have a foul odour? Are the containers or bins full? Are the containers or bins dirty?
Street littering	In the segment… Are there bulky items or branches? Is there scattered recyclable waste? Is there scattered organic waste? Is there small scattered inorganic waste? Is there medium-sized scattered inorganic waste? Is there large scattered inorganic waste? Are there any rubbish bags outside the containers? Is there any construction debris?
Street hygiene	In the segment… Are there dog faeces? Are there pigeon faeces? Are there foul odours? Are there tree leaves?

Appendix 4

See Figs. 6, 7 and Table 3.

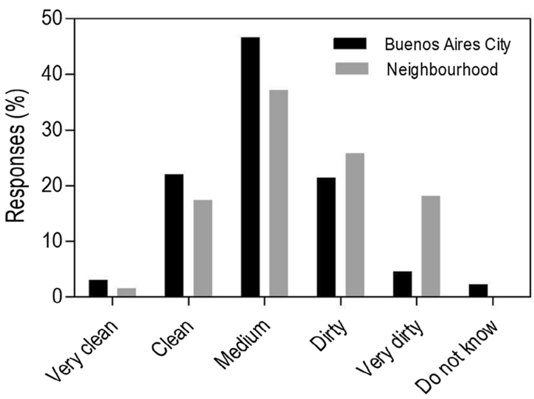


Fig. 6 Residents' perception of the cleanliness of the City and the neighbourhood ($n = 133$). The five categories correspond to those included in the questionnaire

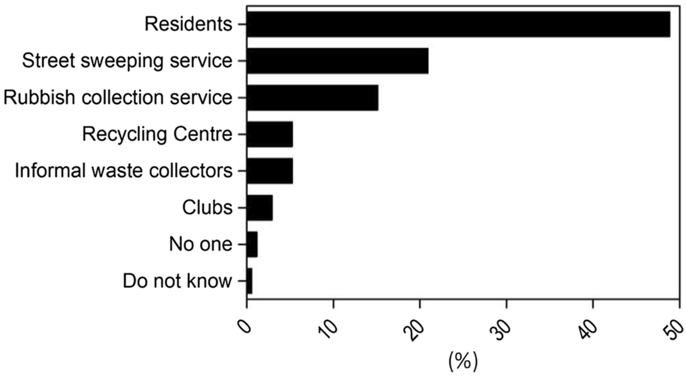


Fig. 7 Residents' perception of the parties primarily responsible for street hygiene. Categories correspond to those mentioned by participants. Responses referring to the different land uses were pooled for clarity ($n = 133$)

Table 3 Residents' perception of the main factors affecting the hygiene of the neighbourhood

Factors affecting hygiene (%)	Average ($n = 264$)	Centre ($n = 16$)	Avenues ($n = 133$)	Residential ($n = 115$)
Litter scattered on pavements	17.67	6.30	18.00	28.70
Waste around containers	13.03	6.30	12.80	20.00
No street sweeping	17.77	25.00	13.50	14.80
Broken pavements	12.77	25.00	9.00	4.30
Dog faeces	9.07	12.50	6.00	8.70
Foul odour	5.67	6.30	9.00	1.70
No waste containers or bins	3.70	0.00	6.80	4.30
Dust	5.43	6.30	3.00	7.00
Construction debris	4.93	6.30	6.80	1.70
Truck circulation	2.70	0.00	3.80	4.30
Bulky items or yard trimmings	4.43	6.30	5.30	1.70
Annoying noises	0.80	0.00	1.50	0.90
No maintenance of vegetation	0.80	0.00	1.50	0.90
Standing water	0.50	0.00	1.50	0.00
Do not know	0.80	0.00	1.50	0.90

On the left the factors are ordered by importance; n = number of responses for each land use

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Author contributions EG and MS designed the study and conducted the field work. EG, MS and LG analysed results and discussed their implications. LG contributed with technical and specific information of the Centre operative aspects. EG and MS wrote the article.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors state that there is no conflict of interest to declare that are relevant to the content of this article.

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