

Composition and quantification of the anthropogenic and natural fractions of wastes collected from the stormwater drainage system for discussions about the waste management and people behavior

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Abstract A study was made of the composition of wastes collected from the pipes of the stormwater drainage system of Sorocaba, SP, Brazil (600 thousand inhabitants). A total of 10 samples weighing at least 100 kg each were sorted into 19 items to determine the fraction that can be considered natural (earth/sand, stones, organic matter, and water, the latter determined after oven-drying the samples) and the anthropogenic fraction (the remaining 15 items, especially construction and demolition wastes and packaging). Soil/sand was found to be the main item collected (52.5 % dry weight), followed by the water soaked into the waste (24.3 %), which meant that all the other wastes were saturated in mud, whose contents varied from 6.4 % (glass) to 87.2 % (metalized plastics packaging). In general, 83 % of the collected wastes can be classified as “natural,” but the remaining 17 % represent 2,000 kg of the most varied types of wastes discarded improperly every day on the streets of the city. This is an alarming amount of wastes that may clog parts of the drainage systems, causing troubles for all the population (like flooding) and must be strongly considered in municipal solid wastes management and in environmental education programs.

Keywords Stormwater drainage systems · Composition of wastes · Final disposal · Gravimetric characterization · Anthropic waste

1 Introduction

Urban agglomerations cause numerous environmental impacts. Large-scale soil sealing is a common feature in the formation of urban neighborhoods and cities, creating the need for vast and complex stormwater drainage systems consisting of curbside catch basins

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(openings under street curbs that lead to storm sewers), stormwater conduits, curbside storm drains, infiltration galleries, and pipes to drain off stormwater. In many cases, one finds that improperly discarded solid wastes end up being carried into these systems, causing serious problems for communities and the environment.

According to the latest National Survey of Basic Sanitation, only about 43 % of Brazilian municipalities discard their solid wastes in final disposal systems considered suitable, such as landfills (IBGE 2010a). Even in municipalities that discard their solid wastes correctly, one finds improper disposal of waste in public areas. If this waste is not collected in a timely manner, it may prevent the stormwater drainage system from working properly. This leads to potentially severe consequences (flooding, contamination of rainwater by the wastes themselves, reduction in the drainage capacity of stormwater conduits, rivers and urban lakes, and siltation of water bodies) and may even affect the population that discards wastes improperly on public streets (Allison et al. 1998; Neves 2011; Tucci 2002).

According to official data, in 2010, only 62 % of the Brazilian population was served by a network of storm water drainage (SNSA 2012a). In 2008, 75 % of Brazilian cities reported periodic sweeping and cleaning of streets, which helps in the preservation of the drainage system. However, in that same year, only 42 % of cities had services of cleaning and clearing the stormwater drainage systems. Still, 45 % of municipalities that reported cases of flooding in urban areas over the past 5 years (which represents more than 40 % of Brazilian cities) stated that one of the causes was the obstruction of stormwater pipes and curbside catch basins (IBGE 2010a).

Despite the significant impact thus generated, relatively few studies have attempted to gain an in-depth understanding of the discarded solid wastes (types and quantities) that end up in stormwater drainage systems, which could serve to underpin public awareness campaigns. In this regard, therefore, it would be interesting to determine and quantify the natural and human (anthropogenic) fractions of the wastes discarded improperly that are carried into stormwater drainage systems. The natural fraction can be considered the one that comprises soil, stones, branches, and leaves, while the anthropogenic fraction is composed of the most varied types of wastes discarded improperly by the population. Both fractions can be pushed into stormwater galleries by the population, intentionally or unintentionally, or be carried into stormwater drainage systems through the action of water, wind, and/or gravity.

According to Allison et al. (1998), one of the first studies on the characterization of wastes in stormwater drainage systems was conducted in Australia in 1989. Later, studies on the subject were conducted in New Zealand (ICNZT 1996), South Africa (Armitage 2007; Armitage and Rooseboom 2000; Marais and Armitage 2004), and Brazil (Brites et al. 2004; Neves and Tucci 2008; Neves 2011; Salles et al. 2012). All these teams of researchers sampled wastes collected from drainage water using devices such as nets that tend to allow small size wastes such as soil and sand to enter the drainage system. The wastes were generally sorted into organic matter, plastics, paper, metals, glass, construction and demolition waste, and others. No subdivisions were found that could determine the exact fraction of these wastes that is undeniably of human origin, distinguishing it from the naturally generated fraction.

The purpose of this paper is to present the results of the characterization, on dry and wet basis, of solid wastes found in the stormwater drainage system of Sorocaba, SP, Brazil, highlighting and differentiating the possibly natural and anthropogenic origin of these wastes.

Sorocaba, among more than 5,500 existing cities in Brazil, is in the 152nd place in relation to Human Development Index, according to a study of the United Nations Program

for Development. According to the same study, when evaluating only education in Brazil, Sorocaba is in the 92nd place. The index values for the city are, respectively, 0.828 and 0.915 (UNDP 2003). In 2008, the city had the 32nd largest gross domestic product in the country, just over US \$ 8 billion (IBGE 2010b). In 2010, the municipal administration revenue was approximately US \$ 640 million, the 25th highest amount among all Brazilian municipalities (FNP 2011).

Regarding the largest hundred cities of the country, Sorocaba was the sixth best in terms of sanitation, according to a study that considered only water and wastewater services in 2010 (TRATA BRASIL 2012). It also has drainage system for rainwater (underground and surface), with periodic cleaning and clearing of pipes and curbside catch basins (SAAE 2012).

The city has domestic solid waste collection for the entire population at least twice a week. Containers are distributed all over the city, so that the population does not leave the bags with waste on the curbside while the collection truck does not pass. The collection with container exists only in 243 Brazilian cities (SNSA 2012b). All waste collected (average of 411.4 t/day) is disposed in landfill (CETESB 2012). There is still a selective collection system that diverts only 1.5 % of the solid waste from the landfill (CETESB 2011; Simões et al. 2011).

So, in relation to the parameters presented, Sorocaba is in general above average of the majority of the Brazilian cities, despite registered cases of flooding in recent years (Araújo 2013). Thus, a study of the solid waste in the drainage system of the city can be considered comprehensive for the whole country and many cities in the world that are in similar or even worse conditions. This is because it is reasonable to assume that the situation in these cities, related to the presence of solid wastes in stormwater drainage systems and their removal, is at least similar to that recorded in Sorocaba in this study. For example, the city of Duque de Caxias, in the metropolitan region of Rio de Janeiro, was the one in the country that suffered most in early 2013 with floods and landslides caused by heavy storms, typical of the season. Three months before the heavy storm period started, the city began to experience problems related to the lack of garbage collection, leading to an accumulation of wastes in the streets that contributed to the tragedy, according to the municipal administration (Pita et al. 2013).

2 Materials and methods

This study evaluated wastes collected from stormwater conduits and curbside catch basins of the city of Sorocaba (population 600,000), in the state of São Paulo, Brazil. SAAE (Autonomous Water & Sewage Service of Sorocaba) is the municipal department responsible for urban drainage and is also in charge of cleaning and unclogging stormwater pipes and curbside catch basins, and taking the collected wastes away to the final disposal site. During this work, the covers of the curbside catch basins are removed and a worker puts a device that makes the suction of the wastes or, more commonly, shovels off the wastes that are obstructing the catch basin and/or the pipes that are connected with it. Even when no rain was registered several days before this work, the wastes are removed visually wet.

According to SAAE, about 12 tons of wastes are removed daily from stormwater conduits and curbside catch basins in the city, and are dumped in landfill (Silvério 2010). This information was based on the values paid for the landfill that charges SAAE per weight.

The research procedure involved sorting the different types of materials and/or the products of samplings taken randomly from piles of solid wastes newly removed from the stormwater drainage system by SAAE. A total of ten samplings were made between October 2010 and June 2011, and at least 100 kg of waste was sorted in each sample. This amount was therefore similar to that sorted in a previous study (Mancini et al. 2007) and followed the ASTM D5231 standard (2008), which recommends quantities of 91–136 kg of mixed wastes for sorting purposes.

The 10 samplings were taken so as to include all the different geographic regions of the city. To this end, the city's three macro-regions established by the municipality were followed. Four samplings were carried out in region 1, three in region 2, and three in region 3 (Fig. 1). Because the city, which covers an area of 456 square kilometers and has a population of about 600 thousand, is divided into only 3 macro-regions, estimates about the socioeconomic profile of the population generating these wastes could not be made, since each of the macro-regions contains high-income, middle-income, and low-income neighborhoods.

At the request of the research team, the wastes collected by the municipality in a given region were dumped onto the ground. No fewer than two barrels were filled with at least 100 kg of wastes each and taken to the sorting site. All these sampled wastes were sorted according to their relative presence and to the physical and chemical properties of each material, and divided into at least 17 items. The items comprised construction and demolition waste, stones, fabrics, bones, organic matter, wood, aluminum, ferrous metals,

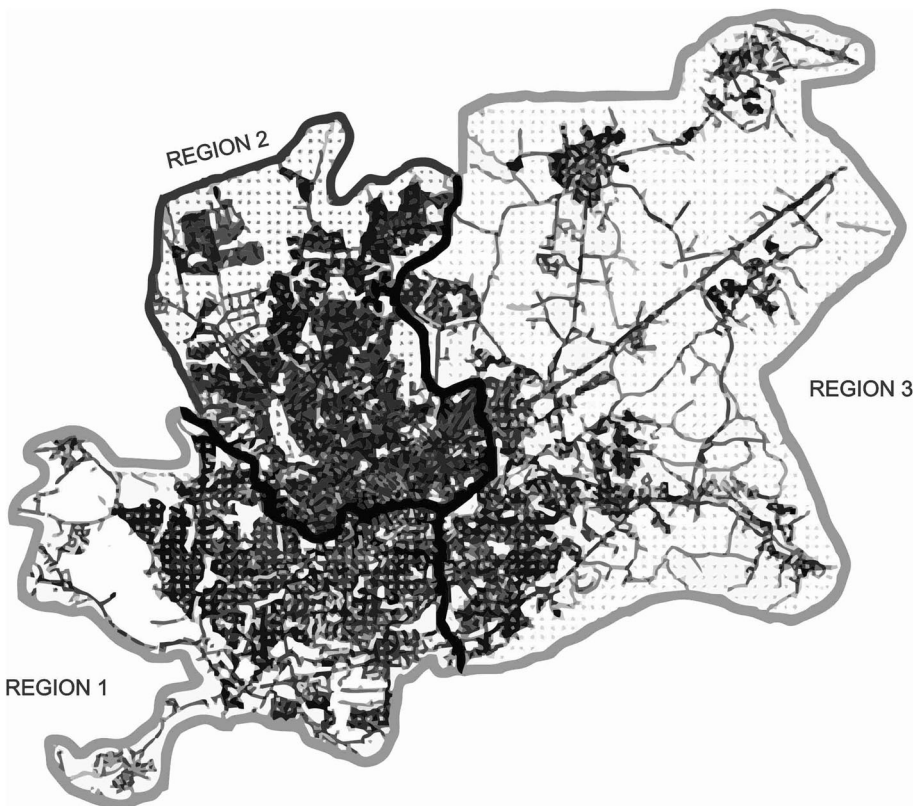


Fig. 1 Sorocaba's regions—geographic distribution

metalized plastics packaging (generally polypropylene with a layer of aluminum), glass, paper, PET (polyethylene terephthalate), expanded polystyrene (EPS or styrofoamTM), plastic films (plastic bags), other plastics, rubber, and other eventual items (wastes that were not frequent in any of the samplings, such as clay, foam, plaster, batteries, charcoal, and shoes). The remainder of this sorting process was earth and/or sand, which was added to the quantity of this material obtained by sieving (2 mm sieve) each of the 17 separate items. After screening the different classes of materials, they were weighed on a Micheletti MIC-100 electronic scale.

Because the main objective of this research was to quantify the fraction of wastes in the stormwater drainage system due to their inappropriate disposal by the population, the researchers were interested in sorting the organic matter into food scraps and plant debris. The reason for this is that the former would typify incorrect waste disposal while the latter could be attributed to natural causes, such as falling leaves, branches, and fruits in general. However, the absence of food scraps in the samples (except for a few bones that were properly sorted) led to the item “organic matter” representing only the remains of plants (e.g., leaves and branches).

For the same reason, i.e., quantification of the fraction of natural waste found in the stormwater drainage system, there was a division between “construction and demolition waste” and “stones.” The wastes identified as “stones” did not show any similarity with wastes such as pieces of tiles, bricks, concrete, and mortar, which were classified as “construction and demolition waste.” However, it was impossible to determine whether soil and sand particles were originated from construction sites (anthropogenic) or from rain runoff from exposed soil (natural). It was also impossible to distinguish whether the water, which was quantified in the laboratory according to a procedure described later herein, was present in the wastes due to natural or anthropogenic factors.

Therefore, the sum of these items—“stones”, “organic matter”, “soil/sand”, and “water” was considered the fraction that was carried “naturally” into the stormwater drainage system by gravity, wind, and rain.

After each measurement, a sample of each type of sorted waste was analyzed in the laboratory. When the waste was present in large quantities, representative samples (at least 300 g) were obtained according to a specific standard (ABNT 2004). However, a good part of the wastes was brought entirely to the laboratory. Each waste sample was placed on a tray and weighed on a semi-analytical balance (Marconi AS 1000C), after which it was oven-dried at 70 °C for 50 h to remove its moisture content. After obtaining the dry mass, each piece of waste was cleaned mechanically (by intensive shaking and scraping) to remove the soil and sand adhered to it. The purpose of this procedure was to determine, as close as possible, the real amount of the material. The average soil/sand content adhered to each waste generated an amount that was added to the quantity of “soil/sand” obtained in fieldwork, aiming to determine its total amount and final composition.

3 Results and discussion

Table 1 presents the average, wet basis, of the segregation of the 10 waste samplings found in the stormwater drainage system of Sorocaba, as well as the error associated with each item.

The average values listed in Table 1 were calculated from the results that, for some items, varied considerably from one sampling to another, as indicated by the relatively high associated error. It was the case of stones, bones, and eventual items, whose error values

Table 1 Total collected and average composition of samples sorted from the wastes found in the stormwater drainage system of Sorocaba, as well as the associated error (wet weight)

Items	Total collected (kg)	%	Error* (%)
Soil/sand	692.4	67.7	2.0
Construction and demolition waste	130.8	12.0	1.0
Stones	73.5	6.8	0.9
Fabrics	4.8	0.4	0.0
Bones	1.6	0.1	0.1
Organic matter	12.6	1.2	0.1
Wood	11	1.0	0.1
Aluminum	0.7	0.1	0.0
Ferrous metals	4.5	0.4	0.0
Metalized plastics packaging	5	0.5	0.0
Glass	1.9	0.2	0.0
Paper	2.7	0.3	0.0
PET	1.6	0.2	0.0
Expanded polystyrene	0.2	0.0	0.0
Plastic film	29.7	2.7	0.1
Other plastics	12.9	1.2	0.1
Rubber	2.9	0.3	0.0
Eventual items	53.9	5.0	1.2
Total	1,042.7	100	–

* Error = $\frac{t_{\alpha/2} \times SD}{\sqrt{n}}$, where

$t_{\alpha/2} = t_{0.05} = 2,262$,

SD = standard deviation, $n = 10$

were, respectively, 13, 100, and 24 % of the average values. This may be due to the intrinsic heterogeneity of the wastes or to the geographical and socioeconomic differences in the neighborhoods of each region, as well as weather variations. However, the confidence interval (mean \pm error) provides a good safety margin. For example, the results indicate, with 95 % confidence, that the content of discarded plastic films in the stormwater drainage system of Sorocaba during the period of this research was 2.6–2.8 %.

During the sorting, a wide variety of items was found, some of them rather curious and unlikely to occur in stormwater drains. Boxes for electronic devices, auto parts, pacifiers, toys, condoms, clothes, shoes, and medicine, as well as syringes and other vestiges of drug use were found. Whenever possible, each product was classified according to the material it was made of (such as the boxes and toys composed of “other plastics”) and when this was not possible, the product was classified as an eventual item.

Table 2 shows the average moisture and soil/sand content adhered to each item sorted from the samples obtained from wastes collected in the stormwater drainage system of Sorocaba, SP.

The moisture in the materials contributed to the impregnation of soil/sand, which caused all the sorted waste to have mud adhered to it, which was at least partially removed after drying and mechanical cleaning. As can be seen in Table 2, the water-to-“soil/sand” ratio is not proportional, which implies that the amount of saturated mud appears to be more related to the density of the waste. In general, metalized plastics packaging and plastic films, due to their high surface area in relation to their mass, were the materials that held the highest quantity of impurities, 87.2 and 74.4 %, respectively. Thus, for example, only 12.8 % of the weight attributed to the metalized plastics packaging actually represents the

Table 2 Average moisture and soil/sand content in each item sorted from waste samples collected in the stormwater drainage system of Sorocaba-SP and their respective error

Items	%		Error* (%)	
	Water	Soil/sand	Water	Soil/sand
Soil/sand	25.4	–	12.8	–
Construction and demolition waste	15.9	2.7	11.0	1.6
Stones	10.0	6.9	2.7	3.5
Fabrics	34.3	31.2	6.1	5.3
Bones	27.5	1.0	7.4	0.7
Organic matter	38.7	20.6	12.0	7.4
Wood	45.1	8.6	8.4	4.7
Aluminum	13.0	15.3	2.8	9.2
Ferrous metals	8.7	14.8	5.3	9.3
Metalized plastics packaging	29.3	57.9	11.7	12.3
Glass	1.9	4.5	1.0	2.0
Paper	32.9	23.0	9.5	9.1
PET	9.3	13.4	4.2	8.1
Expanded polystyrene	38.0	24.8	14.8	18.6
Plastic film	28.8	45.6	5.5	11.7
Other plastics	26.4	32.7	14.5	13.1
Rubber	38.8	5.5	25.5	6.3
Eventual items	19.0	12.3	11.3	10.8

* Error = $\frac{t_{\alpha/2} \times SD}{\sqrt{n}}$, where $t_{\alpha/2} = t_{0,05} = 2,262$, SD = standard deviation, $n = 10$

material, the remainder being added mainly after its incorrect disposal. Note, also, that the materials showing the least amount of impurities adhered to them were glass, PET, and ferrous metals, with indices of 6.4, 22.7, and 23.5 %, respectively. Again, it should be considered that the results for some items varied considerably from one sampling to another, as indicated by the high associated error.

The findings listed in Table 2 show that the inappropriately discarded waste ending up in the city's stormwater sewers tends to contain a minimum of 6.4 % (glass) and a maximum of 87.3 % (metalized plastics packaging) of water and soil/sand. Thus, any recovery of the materials contained in wastes collected from stormwater sewers should be analyzed carefully, taking into account the intrinsic difficulties of separating each type of material and recycling it (with or without impurities adhered), as well as legal and market aspects.

The relatively large amount of soil/sand adhered to the wastes hinders recycling processes, because it must be removed completely to ensure the best possible quality of the recycled product. Moreover, it should be noted that the mechanical removal of soil/sand from discarded products performed in this research cannot be considered 100 % efficient, since many materials were still clearly dirty after this procedure.

Likewise, the amount of water in the wastes is also a matter of concern, despite the fact that water is normally used in the recycling of some materials because it is necessary for the process (e.g., in the case of paper and organic matter) or as a cleaning agent (as in plastics). This use of water in recycling cannot be seen as a favorable aspect for the discarded waste found in stormwater drainage systems, because in this case, moisture carries other impurities with it, which end up impairing the quality of the final product.

Moreover, it is present in amounts and at times other than those considered ideal for each process, and increases the cost of transport to the recycling facility. In short, for all the potentially recyclable wastes listed in Table 2, water is considered a factor of difficulty and a deterrent. The presence of moisture is also a problem to the incineration of some solid wastes collected from stormwater sewers (such as organic matter, paper, textiles, and plastics). The fact that all the materials are coated with relatively large amounts of soil/sand, which hinder combustion reactions, contributes to this scenario.

In addition to the technical aspects of recycling, which are hampered by the presence of soil/sand and water in the wastes under study, one must wonder whether the recycling of these wastes can be considered environmentally advantageous. This is because the recovery of materials contained in wastes retrieved from stormwater sewers would probably require more energy and generate more solid waste, and liquid and gas effluents than the recovery of materials contained in other urban solid wastes, such as those from household or industrial selective wastes collection. Such wastes usually contain lower quantities of adhered impurities (Mancini et al. 2008).

This reinforces the need for sorting at the source and for selective wastes collection, which are actions that make the recycling of materials much more feasible from the technical, economic, and environmental standpoints. In the case of wastes in stormwater drainage systems, an even more basic action is needed: the correct disposal of waste (sorted or not) instead of its disposal on public streets.

Table 3 presents the average composition of the sorted waste, minus the moisture (dry mass) and soil/sand. It also gives the total percentage of water (sum of all the water contained in the sorted wastes) and soil/sand (sum of “soil/sand” contained in all the sorted wastes, along with the “soil/sand” that was separated from the wastes during the field work). Together with stones and organic matter, these items comprise the “natural” fraction of the wastes. The quantity of each type of waste daily sent to the landfill is also presented, considering an average weight of 12 tons a day, according to the municipality’s data (Silvério 2010).

As can be seen in Table 3, more than half of the 12 tons of wastes removed daily from the city’s stormwater galleries and pipelines due to blockage in the water drainage systems consists of soil and sand. More than 6,300 kg of particles is sent to the landfill every day. The waste that is not collected because it has not clogged the pipes or is not in locations where preventive maintenance has been done very likely represents a huge amount of sediment urban spaces that is carried into water bodies, accelerating their siltation.

As mentioned earlier, the fraction carried into Sorocaba’s stormwater drainage system by natural forces (i.e., sediments of urban soil and wastes impelled by the action of rain, wind, and gravity) was considered the total sum of water, soil/sand, organic matter, and stones. However, it cannot be stated that the entire quantity attributed to each of the items was present due to natural causes, given the impossibility of quantifying the real natural fraction (especially the item “soil/sand”). Despite the “inevitable” nature of these wastes, it is clear that they impact the stormwater drainage system, whether or not they are collected, indicating that measures are needed to reduce them (e.g., by sweeping the streets more frequently).

Thus, according to Table 3, of the 12 tons collected daily from stormwater pipes and curbside catch basins (and then sent to landfills), at least 2 tons of wastes per day is discarded in the streets by citizens (17 % of total) and end up in the stormwater drainage system. When not removed in time by the public water and sewage service, these wastes undoubtedly contribute to flooding and other urban problems.

From Table 3, one can also see that about 5 kg of metalized packaging, 620 kg of rubbers, metals, wood, paper, glass, fabrics, bones, and other eventual items, as well as

Table 3 Gravimetric composition of the wastes collected in the stormwater sewers of Sorocaba, and the estimated quantity of each item discarded daily into them

Items	Total samples collected in (kg)	Gravimetric composition (%)	Error* (%) \pm	Quantity referred to landfill (kg dia ⁻¹)
Soil/sand	548.5	52.5	1.6	6,310
Water	253.3	24.3	1.3	2,915
Construction and demolition waste	106.4	10.2	0.8	1,225
Stones	61.1	5.9	0.7	705
Fabrics	1.7	0.2	0.0	20
Bones	1.1	0.1	0.0	15
Organic matter	5.1	0.5	0.1	60
Wood	5.1	0.5	0.0	60
Aluminum	0.5	0.1	0.0	5
Ferrous metals	3.4	0.3	0.0	40
Metalized plastics packaging	0.6	0.1	0.0	5
Glass	1.8	0.2	0.0	20
Paper	1.2	0.1	0.0	15
PET	1.2	0.1	0.0	15
Expanded polystyrene	0.1	0.0	0.0	0
Plastic film	7.6	0.7	0.1	85
Other plastics	5.3	0.5	0.1	60
Rubber	1.6	0.2	0.0	20
Eventual items	37.0	3.5	1.0	425
Total	1,042.7	100	–	12,000

* Error = $\frac{t_{\alpha/2} \times SD}{\sqrt{n}}$, where $t_{\alpha/2} = t_{0,05} = 2,262$, SD = standard deviation, $n = 10$

160 kg of plastics (films, other plastics, PET, and polystyrene) are collected daily from the city's stormwater drainage system. More than half of this last item are plastic bags which stores use to package the consumers' purchases.

Besides the quality of waste sent for recycling and/or incineration (see discussions of Table 2), another aspect that should be taken into account in these cases is the amount of each residue. It can be seen in Table 3 that the individual amounts are too small to make the recycling of each material feasible. The daily volume consists of approximately 15 kg of PET and paper, 60 kg of organic matter (for composting), 40 kg of ferrous metals, 5 kg of metalized packaging, and 5 kg of aluminum. The remaining wastes (plastic film, other plastics, rubbers, glass, and other eventual items) should preferably be sorted into various subtypes to make recycling more attractive, and the predicted quantity of each subtype is also small. For an idea of scale, small PET recycling plants work with up to 1,000 kg of wastes per day (Mancini et al. 2007). The small amount of raw materials, allied to the difficulty of sorting and the dirt impregnated in these wastes, makes it highly unlikely that anyone would be interested in collecting, sorting, marketing, and recycling of these wastes. It should also be taken into account that part of these recyclable wastes, such as rubbers, metalized packaging, and eventual items, can be considered "administrative trash," that is, they have no value for the recycling market and their management must be done by the city administration (Fehr 2009).

All these aspects (difficulties in sorting and marketing, associated impurities, and small amount) make the wastes collected from drainage systems less attractive even for informal waste management systems, as the ones formed by scavengers that sell sorted wastes for recyclers (Nas and Jaffer 2004). Apart from recycling, the other idea would be to incinerate these wastes in order to generate energy. This would require a simpler sorting procedure involving only burnable wastes such as fabrics, organic matter, wood, metalized packaging, paper, and polymers. However, this quantity is also small: the sum of all these materials represents only 2.8 %, i.e., about 340 kg/day, of the 12 tons of waste that are carried daily into Sorocaba's stormwater drainage system. For comparison, each of the 24 incineration plants in Taiwan burned an average of more than 695 tons of waste daily in 2009 (Chen and Chen 2012). Another aspect that must be considered in the decision of incinerating wastes is the cost associated with the transportation of waste to the plant, which could undermine the process (Ferreti and Pomarico 2012).

Also of interest in Table 3 are the 1,225 kg of construction and demolition wastes in the form of pieces of tiles, bricks, mortar, and concrete carried daily into the city's stormwater sewers. This reflects the practice of leaving construction and demolition wastes on streets and pavements, from where they are washed or swept into curbside catch basins and stormwater conduits, instead of discarding it correctly in the city's Inert Waste Landfill (Prestes et al. 2012). This finding is corroborated by the fact that most of the paper (not quantified) found in the samplings comes from cement packaging bags.

In general, the population of Sorocaba discards over 2 tons of the most varied types of wastes improperly on the city's streets every day, and this garbage ends up in stormwater conduits and curbside catch basins. Again, it should be noted that these wastes are the ones collected by the municipal water and sewage service when the drainage system becomes clogged or during preventive maintenance. However, an unquantified amount of wastes passes from the streets through pipes that are not clogged and ends up directly in the streams and river that run through the city, contributing to its pollution and siltation.

Thus, the results presented in this study can be considered complementary to those reported by other authors, such as Armitage (2007) and Salles et al. (2012), who made separations of wastes collected from catchments or water bodies using perforated litter traps, which allow that small particles as soil/sand be carried by water. As expected, the aforementioned authors did not record the presence of soil and sand in the collected wastes, which is precisely the most representative fraction collected from curbside catch basins and stormwater conduits of Sorocaba. These authors also reported that organic matter (especially garden debris) accounted for 36–85 % of the wastes, while in the present study involving Sorocaba's stormwater drainage system, organic matter represented only 1.2 % (Table 1—when soil/sand is excluded, this percentage increases to 3.7 %). Because they are usually small and common on the streets, leaves and branches are carried into storm drains as soon as it begins to rain. When bulkier items such as plastics, paper, and wood (the latter consisting primarily of pieces of wood from construction) reach curbside catch basins, they increase the probability of stormwater pipes becoming clogged, damming all the other wastes, including much smaller items. In this sense, the study of Neves and Tucci (2008) describes the composition of wastes from street sweeping and of those collected from a catchment basin. Waste from street sweeping presented about 77 % sand, branches and twigs, stones, leaves, and organic matter, while no mention was made of these items in the waste collected from the catchment.

Figures 2 and 3 show the relationship between the average rainfall in the city of Sorocaba during the months when this study was conducted (INMET 2012) and the sum of water and soil/sand, respectively, contained in all the wastes from each sampling.

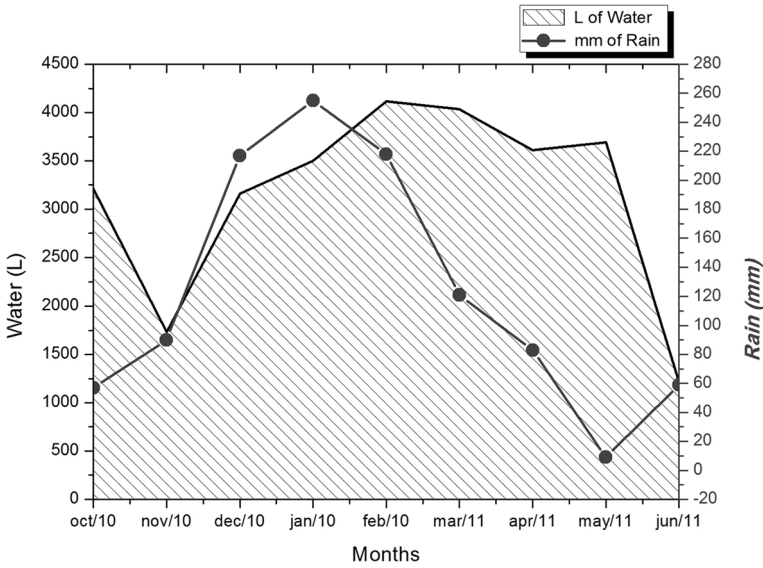


Fig. 2 Amount of water contained in all the sampled wastes and the average rainfall in the city of Sorocaba during the months when this study was conducted

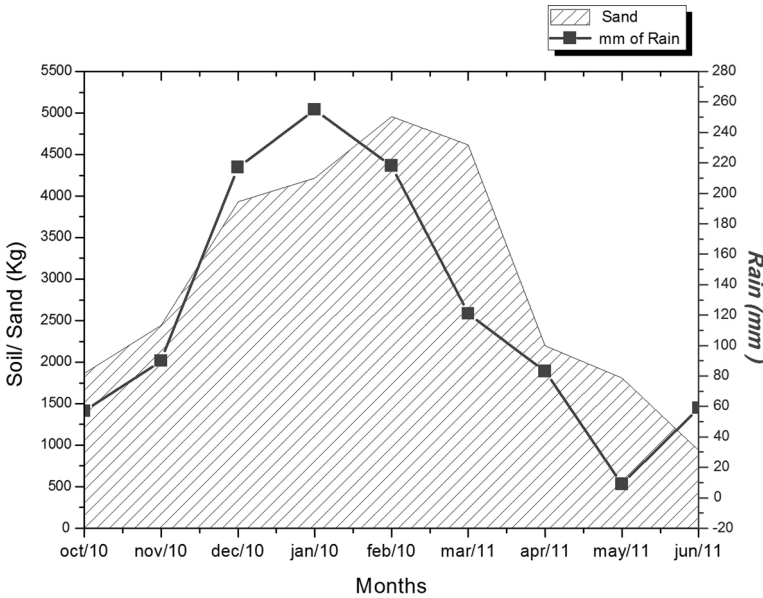


Fig. 3 Amount of soil/sand (separated plus adhered to all the sampled wastes) and the average rainfall in the city of Sorocaba during the months when this study was conducted

As can be seen in Fig. 2, there is no direct correlation between rainfall and the water contained in the wastes. However, there was a tendency for increasing the water contained in all the sampled wastes starting in November 2010, which remained stable in the March/

May 2011 quarter. The heaviest rainfall in Brazil occurs in summer (December–January–February), suggesting that during this period, the wastes accumulated in the stormwater drainage system tend to be more waterlogged. However, during this period, the teams that clear out stormwater conduits and curbside catch basins usually attend to emergencies, in order to meet the natural increase in demand and to prevent floods. Between March and May, when the rains subside, the teams return to more routine work, removing the wastes accumulated in the stormwater drainage system not only during these months, but also in previous months.

Figure 3 shows the soil/sand curve, whose shape resembles that of adhered water (Fig. 2), especially from November to March, which confirms their correlation demonstrated in Table 2. Like the adhered water curve (Fig. 2), the soil/sand curve (Fig. 3) appears shifted to the right with respect to rainfall. This suggests that the soil/sand dragged into the stormwater sewers and that adhered to the wastes is not directly correlated with the average rainfall, since the sewer clearance scheme works on an emergency basis during the period of heavy rains.

Also worth mentioning is that the nuisance caused by improper waste disposal represents costs that need to be minimized. Although there are no specific calculations, it is obvious that removing wastes from stormwater sewers (which requires operators removing the grates of curbside catch basins and entering them to remove garbage manually or with pumps) is more expensive than the ordinary collection of household garbage. The costs of transportation and final disposal are similar, since the former is done in similar vehicles and both wastes may be destined for the same landfill. If the wastes are not removed from stormwater sewers rapidly and/or with sufficient frequency and problems such as flooding occur, these problems also represent costs, such as the removal of affected families, hospitalizations due to waterborne diseases, desilting of water bodies, etc.

As already discussed, Sorocaba presents reasonable conditions of sanitation, economic development, and education, so that the average of 2 tons per day of solid waste going to the drainage system can be considered worrisome. Even with sweeping system and regular containerized garbage collection across the city, as well as a selective collection (despite incipient), it is observed the lack of environmental awareness on part of the inhabitants, since this behavior harms the population itself. The city environmental sustainability and the waste management accounts for the constant improvement of the services provided by the municipality within its area of jurisdiction, in particular, with respect to the existence of a more efficient environmental education program that raises population awareness regarding the need for a behavior change (Karani and Jewasikiewitz 2007).

4 Conclusions

Solid wastes collected from stormwater conduits and curbside catch basins were composed mostly of soil/sand (67.7 % wet weight and 52.5 % dry weight). The second most frequent item in the solid wastes was saturated water (24.3 %), which was determined by oven-drying samples. When these wastes were collected, all of them were soaked in mud, particularly the bulkier items such as metalized plastics packaging, 87.2 % of whose weight was attributed to soil/sand and water.

A correlation, albeit indirect, was found between the amount of water and soil/sand in the waste and the rainfall that occurred in the city. This was likely due to the fact that these wastes are collected from the stormwater drainage system during the period of heavy rains, when emergencies are prioritized.

Considering data provided by the municipal department responsible for draining the city, which indicates that an average of 12 tons of wastes is removed daily from curbside catch basins and stormwater conduits, about 83 % of the collected wastes can be classified as “natural.” It should be noted that many of these wastes, especially “soil/sand,” could not be identified as either of natural or anthropogenic origin; hence, these values are probably overestimated.

However, it was estimated that the population discards at least two thousand kilograms of wastes in the streets each day (17 % of the total collected), which are carried by water, wind and/or gravity to the stormwater drainage system, increasing the chance of clogging and urban problems such as flooding and others. Construction and demolition wastes, paper, and plastics stood out among the wastes.

The possibility of recycling and/or incinerating these wastes is practically nil, due to the need of careful sorting and the presence of impurities and saturated water in each waste item, as well as the small amount of the sorted waste and marketing difficulties for some items.

One must consider that the anthropogenic wastes that are collected from drainage system clogged parts are just a fraction of the total quantity that ends up going to water bodies. So, the sum of the quantity clogged in the pipes with the one that is freely carried by rainwater to the water bodies (possible to be estimated with perforated litter traps) would give more precise and certainly higher figures about the anthropogenic wastes that are in the streets and curbsides of the city.

In this sense, the constant improvement of the services provided (urban drainage, sweeping, garbage collection, and selective collection), coupled with the existence of an efficient environmental education program, could contribute to the reduction in problems associated with improper behavior of the population (as flooding) and to a more sustainable waste management, with, at least, a proper discard.

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