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Torrente, Jorge M.; Chifari, Rosaria; Ripa, Maddalena; [et al.]. «Robust information for effective municipal solid waste policies : identifying behaviour of waste generation across spatial levels of organization». Waste management, Vol. 103 (February 2020), p. 208-217. DOI 10.1016/j.wasman.2019.12.032

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Authors' Accepted Manuscript (AAM). The published version of this paper is available at the publisher's website: https://doi.org/10.1016/j.wasman.2019.12.032

Robust information for effective municipal solid waste policies: identifying behaviour of waste generation across spatial levels of organization

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Abstract

Existing studies have studied influencing factors of MSW generation behaviour at different spatial levels of organization, but always one at a time and not simultaneously. Income is a strong influencing factor, affecting MSW generation from the individual to the country level, capable of hiding the effects of the others. This study shows that when MSW generation behaviour is holistically analysed across multiple levels of organization (individuals, households, and communities) hierarchically organized as functional units of MSW generation within a specific study area, it is possible to identify influencing factors in addition to income (education, demographic, health, ethnic, economic activity and financial types) as explanatory variables. Increasing the number of influencing factors of MSW generation makes it possible to create a robust knowledge base for MSW management policies in fast-growing urban areas of developing countries, improving the information used to select proper policies and plans within their MSW management systems and avoiding overlapping policies causing legal gaps. Betania, an urban area of the Panama City district, has been chosen as a case study area. The results show that the household income explains 86% of its members´ MSW generation and the community indigenous population explains 21% of households´ MSW generation. It is concluded that MSW generation is not linear across levels, it has as many degrees of freedom as influencing factors shaping the levels of organization where functional units generating waste exist. Influencing factors appearing at each spatial level affects MSW generation in an interdependent manner in variable degrees of magnitude.

Keywords

Municipal solid waste generation; Multi-scale analysis; Influencing factors; Waste policies developing countries; Panama district.

Highlights

- Sudden changes in MSW generations behaviours are common to developing countries.
- Determined by social practices at multiple hierarchical spatial levels of organization.
- Different influencing factors of MSW generation behaviour appear at each level.
- Income is mostly the main influencing factor of MSW generation behaviour.
- Most studies conclude this from analyzing this link one spatial level at a time.
- Simultaneous analysis can reveal influencing factors others than income.

1. Introduction

Municipal Solid Waste (MSW) management is a major concern in developing countries experiencing uncontrolled rapid growth of urban areas (Zohoori and Ghani, 2017). Economic development in these countries is expected to further exacerbate the already high pressure on the MSW management system through increased consumption (and concomitant waste generation) and a change in waste composition (Adamović et al., 2017). Marked spatial heterogeneity in the socio-economic characteristics of urban dwellers presents further challenges as the disparity in income level and expenditure results in different behaviours of MSW generation -i.e., quantity and quality of waste outflows- and, hence, places spatially differentiated requirements on the MSW management system to implement.

Proper governance plays an important role in the MSW management system (Leal Filho et al., 2016) and requires a careful integration of physical/technological components (the “hardware”) with effective mechanisms of monitoring and control (the “software”) (Seadon, 2010). In developing countries, several public agencies, from the central to municipal governments, are involved in waste management. Their functions often overlap because they are unclear; there is no single agency designated to coordinate or assume responsibility for MSW management (Manaf et al., 2009; Periathamby et al., 2009). This has led to weak implementation and enforcement of laws and regulations of MSW management (Meidiana and Gamse, 2010) and hinders effective waste management planning (Mmereki, 2018). In general, at a given level of technology, it is the lack of pro-active policies, not considering the multiple factors influencing MSW generation, that most negatively affects the final performance of MSW management systems (Wilson et al., 2012).

In fact, understanding information on influencing factors of MSW generation is important for two reasons. Firstly, to create policies aimed at changing the materials´ resource consumption habits and MSW generation behaviour of urban dwellers in order to reduce the quantity of waste generated and enable the implementation of source-separated MSW collection to improve the quality of the waste received by the MSW management system (Liu and Wu, 2010). Secondly, to properly plan, develop and organize the processes and the infrastructures associated with an efficient MSW management, such as waste collection frequencies, human and technological resources, payment rates and treatment facilities (Cargo, 1978; Wertz, 1976).

Mazzanti and Zoboli (2008) point out that it is important not to wait to implement waste generation reduction policies until consumption levels and resulting MSW generation — both in quantity and quality— arrive at a point where they overwhelm the capacity of local MSW management systems. Hence there is an urgent need to benchmark the experiences of developing countries in MSW management and take adequate actions studying the influencing factors of MSW generation (Leal Filho et al., 2016; Wilson et al., 2015; Zaman et al., 2016) to anticipate future troubles, implement effective policies and plan for due processes and infrastructures. This requires the availability of useful data for characterizing relevant aspects of the process to be controlled.

Influencing factors, such as income, education, sociodemographic characteristics, health, ethnicity, and religion are widely used to correlate MSW generation behaviour and to try to anticipate future states of the MSW management system (Bandara et al., 2007; Barr, 2007; Matsumoto, 2011; Mohammed, 2018). However, results obtained are mostly biased because of the adoption of only one hierarchical level of analysis of the socio-economic organization -i.e., individual, household, community, town, district, province, country, etc.-; mostly the individual level (Hoornweg and Bhada, 2012), and per capita MSW generation average values are simply aggregated to obtain MSW generation figures at other hierarchical levels (Kawai and Tasaki, 2016). The lack of waste studies supporting updated data collection in developing countries, forces: (i) correlation results obtained at the individual level to be used at other levels without considering MSW generation behaviour constraints; and (ii) misconceived policies and technological improvements applied to hierarchical levels, others than the individual level for which correlations were obtained, thus misspending human, technical and economic resources.

Given the complexity of urban systems and the heterogeneity of cultural, economic and geographic contexts, an effective analysis of the influencing factors affecting the behaviour of MSW generation is challenging (Mazzanti and Zoboli, 2008). An assessment of the effects of an influencing factor studied at a specific hierarchical level of socio-economic organization cannot provide a useful description of the overall performance of complex MSW management systems (Seadon, 2010). Proper governance requires the analysis of an integrated set of criteria of performance. The study of influencing factors can only fulfil its purpose when it is simultaneously carried out at different spatial levels.

For instance, values describing MSW generation behaviour, obtained from correlations with influencing factors at the household level, provides useful information for policies regulating waste storage and separation (source-/post-separation) and collection (curb-side/drop-off) (Bing et al., 2014); correlations at community (or town) level provides useful information for determining collection routes, types and dimensions of collection vehicles, street sweeping routines and the balance between manual or automatic MSW management actions (Bras et al., 2009); correlations at district level can inform policies governing waste management subsystems functions used in centralized MSW management systems (-e.g. treatment options, final disposal choices, etc- (Chua et al., 2011; Desa et al., 2011).

The selection of a specific spatial level depends on the specific purpose of the analysis. For example, in Italy, the waste management tariff is calculated by pricing the full cost of MSW management services based on the total MSW generated at the provincial level, whereas the waste management tax is calculated based on the household living space (Mazzanti and Zoboli, 2008).

The complex nature of social-ecological systems, organized across different hierarchical levels, entails the expression of features and behaviours that can only be observed at the different hierarchical levels (Ahl and Allen, 1999; Allen and Starr, 1983). Depending on the pre-analytical choice of level, MSW generation can be measured per person (but will be different for different types of persons), per household (but will be different for different types of households), per community (but will be different for different types of communities), and so on. At any given level, the observed waste generation behaviour is the result of a combination of interactions and influences across processes, simultaneously taking place at higher and lower levels of socio-economic organization.

Individuals generating waste operate inside families that share a common boundary of the household. Households share a common boundary in the form of a building or community where they are located, and so on. The heterogeneous distribution of different typologies of households in space add further complexity: a given community can host different typologies of households, and a city can host different typologies of communities.

This paper presents results of a secondary analysis of existing data from a study on MSW generation in Betania, a culturally diversified urban area of Panama City, This study was commissioned by the Municipality of Panama City (MUPA, 2018a) with the specific aim to exploratorily study the degree of magnitude that influencing factors affect household MSW generation, and understand their simultaneous effect across multiple hierarchical levels of socio-economic organization. The broader scope of the paper is to create a robust knowledge base for MSW management policies in fast growing urban areas in Latin America and other developing areas.

2. Materials and methods

2.1. Conceptual framework

A multi-level analysis of the series of processes of waste generation and management taking place in a defined social-ecological system requires the definition of "functional units" (Garb and Friedlander, 2014; Kampis, 1987; Klerkx et al., 2012) identifying relevant agents at different hierarchical levels of organization inside the system. Two broad types of agent can be distinguished in a MSW management system: (i) "functional units of MSW generation" expressing behaviours of waste generation in space and time at different hierarchical levels (generating the throughput of waste to be processed); and (ii) "functional units of MSW management" (determined by a combination of workers and technology) such as collection, transport, valorisation and treatment (recycling, incineration, anaerobic digestion, composting, etc.) and final disposal (processing the throughput of waste in space and time).

Functional units of MSW generation can be defined across different levels of organization from “individuals” to “countries”. Obviously, the larger the size of the unit considered, the larger the heterogeneity of the waste generation behaviours it will contain. Individuals are the smallest identifiable functional unit of MSW generation given that, in biophysical sense, resources of the economic system are consumed by people (Burger et al., 2017). Measuring daily MSW generation at individual level would be the most rigorous way to obtain the real amount of waste generated from city dwellers but it is both impractical and does not provide relevant information for the functional units of MSW management. Other definitions of functional units of MSW generation are more useful to study predictable characteristics (expected behaviour) of MSW generation (Redko et al., 2004).

An important one is the household, which represents the constrained space of individuals, their nesting level of organization, and the immediate functional unit of their MSW generation (Kampis, 1987). It is possible to study and identify specific influencing factors for typologies of household associated with the typologies of individuals living in it and use them as independent variables in models that estimate behaviours of household MSW generation. In turn, larger boundary entities (communities) determine the functional unit of the households within. Indeed, the constrained-constrainer relationship between entities making up functional units of MSW generation can be repeated across multiple levels of organization: households—community, communities—town, towns—districts, etc.

From the point of view of hierarchy theory (Ahl and Allen, 1999), the functional units of MSW generation observed at their specific level -i.e. households generating solid waste (a problem) to be disposed- represent the final causes of the functional units of the MSW management system -i.e. those in charge of eliminating the problem-, but at the same time they represent the efficient cause -i.e. entities which MSW generation behaviour determines the pattern of MSW management- when considering the whole process of MSW metabolism (Wolfram, 2002).

Nested systems, like socio-economic systems, are affected by an 'extensional complexity' determined 'by the fact that at any local at any level in this hierarchy there could be a mixture of different kinds of information coming from different levels constraining the dynamics' (Salthe, 2012).

In the case of MSW management systems, functional units of *MSW management* have to guarantee the expected functions -i.e., the handling of wastes- for the functional units of *MSW generation*, that are operating at the lower level. Thus, there is an *impredicative* relation between the characteristic of the functional units of *MSW generation* and those of *MSW management*: functional units generating waste affect the characteristics of those managing waste by posing new challenges, and those managing waste constraint the possible generation of waste by setting limits to what can be managed (Clayton, 1996; Seadon, 2010). This chain of reciprocal influence operates across all the different hierarchical levels of organization and emphasizes the need for a multi-scale approach when trying to assess the factors influencing the behaviours of MSW generation across different levels of organization.

2.2. The case study

A case study is presented for Betania, an urban area (administrative level of *'corregimiento'* or town) of Panama City. With an estimated population of 59,765 inhabitants (INEC, 2010a, 2006), Betania accounts for approximately 1% of the country's total population. Although Panama City is one of the fastest growing urban areas of Latin America (IMF, 2018), Betania experienced a population growth rate of only 5% in the period 1980-2010 (INEC). Nonetheless, Betania was selected for study because of its location and cultural diversification, presenting widely varying resource consumption habits and MSW generation behaviours (JICA, 2003). Although other towns of Panama City have grown up to 541% in the same period -e.g., Pacora, Tocúmen, Las Cumbres, Juan Díaz-, they are located in the outskirts of the city as satellite or dormitory towns and exhibit limited cultural diversification. Betania, on the other hand, is located in the southeast part of the Panama district centre, surrounded by other towns with a considerably wide socio-economic diversity. The 33 communities that make up Betania combine traces of these socio-economic features -e.g. education, financial, demographic, ethnic, economic activity and health- that characterize Betania´s surrounding metropolitan towns. Household size in Betania increased from an average of 2.9 to 3.1 members in 8 years from 2010 to 2018.

The case study area has been carefully chosen to represent the socio-economic diversity of most communities in developing countries, which are well stratified and present different attributes on influencing factors of MSW generation behaviours within the same area (Jordan, 1982).

In the Panama district, of which Betania forms part, no source waste separation is formally implemented for collecting MSW. A small proportion of families use the recycling stations offered by the Zero Waste program of the Panama district to increase the material recovery of recyclable MSW (MUPA, 2018b). However, there are less than 10 stations and with insufficient capacity to receive MSW from the whole district, even from the few families that bother to segregate and carry their waste to the closer station. This fact is evident from the overflow of waste observed in some stations (EFE, 2019). This program runs more to foster recycling consciousness in population than to collect separately a significant quantity of MSW (MUPA, 2018c). In this sense, the term MSW generation refers to the combined waste fractions of materials present in the MSW streams.

MSW generated in the entire district is collected mainly mixed through a "Curbside" collection: in houses, it is collected in metal basket-like outer containers; in popular sectors, public containers are used; and in building apartments concrete structures with a metal door are implied (Linowes and Brown, 2006). MSW represents approximately 87% of the total waste generated in the Panama district and it is constituted by 53% of waste from households and 34% from commercial sector. Even if both waste flows are transported separately, at the end they are landfilled mixed without any previous treatment (AAUD, 2016) creating serious environmental consequences that could be limited if at least part of the organic fraction of MSW was first source separated and then valorized. In this paper, the focus is made on MSW generated from households in Betania town since it contains 58% of organic fraction (MUPA, 2018a) whose correct management requires urgent attention and novel approaches to improve the current status.

2.3. Data sources

A data set of MSW values per household and day, obtained from a study commissioned by the Municipality of Panama City (MUPA, 2018a), was used to represent the MSW generation of upper, middle-upper, lower-middle and lower income level communities –i.e. communities 30, 8, 3, 23- (see **Table A.1** of the Appendix for the identification (ID) indexes of the communities of Betania). MSW generation was measured (weighted) during one week for 600 randomly selected sample households in 4 out of the 33 communities that make up Betania (150 per community). Data was represented as observed median values per household and day of the 4 communities to which they belong $(\boldsymbol{diag}(\boldsymbol{Whh_{44}})_{\boldsymbol{hh-obs}})$ (see **Table A.2** of the Appendix for acronyms and variables description).

2.4. Statistical analysis

Given the correlation of MSW generation behaviour to resource consumption habits (Adamović et al., 2017), linear regression models were used to correlate the individuals’ functional unit of MSW generation with the IF of the households' functional unit, and household's functional unit of MSW generation with the IF of the community functional unit. IFs considered in this study (**Table 1**) were taken from the available database of the last National Census (2010) and Statistic Institute of Panama (INEC, 2010b) and classified by education, demographic, health, ethnic, economic activity and financial type of variables.

2.5. Correlation of functional units of MSW generation and the IF of their functional unit

An average value of MSW generated per individual per day was estimated from $(\boldsymbol{diag}(\boldsymbol{Whh_{44}})_{\boldsymbol{hh-obs}})$ divided by surveyed values of total individuals living in each household, as shown in **Equation 1**.

$$\boldsymbol{diag}(\boldsymbol{Wind_{44}})_{\boldsymbol{hh-est}} = (\boldsymbol{diag}(\boldsymbol{Whh_{44}})_{\boldsymbol{hh-obs}}) \times (\boldsymbol{diag}(\boldsymbol{Pind^{-1}}_{\boldsymbol{44}})_{\boldsymbol{hh-obs}})$$

(1)

A linear regression model (RStudio Team, 2015) was used to correlate individuals´ functional unit of MSW generation with the IF "household median monthly income" of the households´ functional unit to assess its effect size on the MSW generation at this level (**Equation 2**).

$$\boldsymbol{diag}(\boldsymbol{Wind_{44}})_{\boldsymbol{hh-est}} \sim \boldsymbol{diag}(\boldsymbol{Ihh_{44}})_{\boldsymbol{hh-ava}}$$

(2)

The MSW generation per individual and day for the other 27 communities was calculated ($diag(Wind_{133})_{hh-cal}$) and a value of MSW generation per household and day (**Equation 3**) has been inferred for all 33 communities with the aggregation of the MSW generation values per individual and day by the average total individuals per household, available as official data (INEC, 2010b).

$$diag(Whh_{133})_{ind-cal} = (diag(Wind_{133})_{hh-cal}) \times (diag(Pind_{133})_{hh-ava})$$

(3)

A linear regression model was used to correlate households'´ functional unit of MSW generation with the IFs "Community indigenous population", "Community median monthly income of active population", "Community population without social security", "Community population with less than 3rd grade of primary school approved" and "Community illiterate population" of the communities´ functional unit to assess their effect sizes on the MSW generation at the household level (**Equation 4**). The Stepwise method (Graham, 2015; RStudio Team, 2015) was used to select the most representative variables from **Table 1** with the application of the Akaike Information Criterion (AIC) (Akaike, 1974) by removing and/or adding at each step the variable that keeps the AIC value as low as possible. This process is iteratively repeated until it can no longer be reduced (Gallardo et al., 2012).

$$diag(Whh_{133})_{ind-cal} \sim diag(IND_{133})_{com-ava} + diag(Icom_{133})_{com-ava} + diag(NOSS_{133})_{com-ava} + diag(LTG_{133})_{com-ava} + diag(ILL_{133})_{com-ava}$$

(4)

The MSW generation per household and day for the other 27 communities was calculated $(\boldsymbol{diag}(\boldsymbol{Whh}_{133})_{\boldsymbol{com-cal}})$ and a value of MSW generation per community and day (**Equation 5**) then inferred for all 33 communities with the aggregation of the MSW generation values per household and day by the average total households per community, available as official data (INEC, 2010b). Consideration of functional unit IF was kept for the individual and household levels, the MSW generation at the community level has been calculated for illustrative purposes.

$$\boldsymbol{diag}(\boldsymbol{Wcom}_{133})_{\boldsymbol{hh-cal}} = (\boldsymbol{diag}(\boldsymbol{Whh}_{133})_{\boldsymbol{com-cal}}) \times (\boldsymbol{diag}(\boldsymbol{Phh}_{133})_{\boldsymbol{com-ava}})$$

(5)

Finally, **Equation 6** shows the total daily MSW generation per day for the town of Betania, which is a scalar value obtained with the trace –i.e. aggregation of values- of the diagonal matrix that represents the daily MSW generation of all its 33 communities of **Equation 5**.

$$(\boldsymbol{Wtown})_{\boldsymbol{hh-cal}} = \boldsymbol{Tr}(\boldsymbol{diag}(\boldsymbol{Wcom}_{133})_{\boldsymbol{hh-cal}}) \tag{6}$$

Equation 7 and 8 represent the correlation between the MSW generation of the individuals´ and households´ functional units obtained from the linear regression model with the IF of the households´ and communities´ functional unit.

$$\boldsymbol{diag}(\boldsymbol{Wind}_{ii})_{\boldsymbol{hh-reg}} = (\boldsymbol{\beta}_{\boldsymbol{o}}\boldsymbol{J}_{ii})_{\boldsymbol{hh}} + (\boldsymbol{\beta}_{\mathbf{1}})_{\boldsymbol{hh}}\, \boldsymbol{diag}(\boldsymbol{Ihh}_{ii})_{\boldsymbol{hh-ava}};\ \text{where } i = 1 \ldots, n$$

(7)

$$\boldsymbol{diag(Whh_{ii})_{com-reg}} = (\boldsymbol{\beta_o J_{ii}})_{com} + (\boldsymbol{\beta_1})_{com}\, \boldsymbol{diag(IND_{ii})_{com-ava}} + (\boldsymbol{\beta_2})_{com}\, \boldsymbol{diag(Icom_{ii})_{com-ava}} + (\boldsymbol{\beta_3})_{com}\, \boldsymbol{diag(NOSS_{ii})_{com-ava}} + (\boldsymbol{\beta_4})_{com}\, \boldsymbol{diag(LTG_{ii})_{com-ava}} + (\boldsymbol{\beta_5})_{com}\, \boldsymbol{diag(ILL_{ii})_{com-ava}}; \text{ where } i = 1 \ldots, n \quad (8)$$

P-values under the conventionally predefined level of significance 0.05 are desirable to validate statistical hypothesis tests (Bhattacharya and Habtzghi, 2002). *P-values* over 0.05 are a typical result for small sample size linear regressions (Ioannidis, 2005), as in our case. The effect size is used for statistical validation of the model instead of the *p-value* because null hypothesis significant testing is a dichotomous measure of evidence showing whether explanatory variables influence MSW generation or not, but not indicating the degree of magnitude explanatory variables are expected to influence MSW generation (Lee, 2016; Verhagen P et al., 2004). The absolute value of the Pearson's correlation coefficient is used as the effect size value, interpreted for the independent variable as explaining certain percentage (R^2) of the dependent variable response.

2.6. Clustering communities by MSW generation values´ similarities looking for IF causality

The double clustering methodology (Matuszewski, 2002) was used for the discovery of causality of MSW generation between communities by assessing their similarities at different levels of organization. Hierarchical Agglomerative Cluster (HAC) analysis (Kassambara, 2015), commonly used to associate relatively “natural” homogenous groups in a statistic population (Gentle et al., 1991), was used twice to cluster communities by their MSW generation values, first in the individual´s functional unit, then in the household´s. Hierarchical clustering is an algorithm that groups similar objects to create a set of clusters where each one is distinct from each other, while keeping the objects within each cluster the most similar to each other as possible.

The main output of Hierarchical Clustering is a dendrogram, a structured tree that shows the hierarchical relationship among clusters, where each leaf corresponds to an observation. As it is moved up the tree, observations that are similar to each other are combined into branches, which are themselves fused at a higher height. The height of the fusion, provided on the vertical axis, indicates the (dis)similarity between two observations. The higher the height of the fusion, the less similar the observations are. The *distance* between two clusters is computed based on length of the straight line drawn from one cluster to another; commonly referred to as the *Euclidean distance.* Results are presented as dendrograms formed according to MSW generation values of the 33 communities of Betania in order to show community affinity with the effect of causality.

Average distances of members within the same cluster were used in order to yield the highest Cophenetic correlation coefficients (CCC). The CCC is a measure of the extent at which a dendrogram preserves the pairwise distances between the original unmodeled data points (Sokal and Rohlf, 1962). A CCC value of 0.75 can be interpreted as acceptable (Mather, 1976). This analysis was performed using the package “stats” (RStudio Team, 2015).

2.7. *Clustered communities´ membership variation among the levels of individuals and households*

As MSW generation values change from the individual to the household functional unit due to different IF affecting the MSW generation at each level, membership of communities also does within cluster dendrograms at both levels. In order to understand the extent at which this variation is present, the quality of the alignment between both cluster trees was measured using the entanglement coefficient (Galili, 2018; RStudio Team, 2015; Ryota Suzuki, 2015; Soetaert, 2013). The entanglement coefficient is a measure between 1 (100% entanglement) and 0 (0% entanglement) interpreted as the correspondence of community´s arrangements by the MSW generation between the individual and household level. Less entanglement represents a good quality alignment, which means high correspondence between trees.

3. Results

The effect size that the variable *"Household median monthly income"* exerts over the MSW generation of individual functional unit is |0.93|, which means that it explains 86% of the MSW generation of the individual functional unit (see statistical results and coefficients values in **Table A.2**). The variable *"Community indigenous population"*, with the higher effect size (r = |0.46|), is the one better explaining the MSW generation of household functional units over the rest of independent variables, with 21% of the dependent variable response.

Columns 2 and 3 of **Table A.3** of the Appendix section show results of MSW generation of functional units 'individuals' and 'households' for the 33 communities that make up Betania. **Figures 2 and 3** show dendrograms of clustered communities performed according to the MSW generation values of the individual and household functional units from the **Table A.4** of the Appendix section, respectively. The CCC values for the clusters formed from the MSW generation of the individuals' functional unit is 0.80 and 0.78 for the MSW generation of households´ functional unit, which exceed the minimum acceptable of 0.75. Communities presented in each dendrogram were divided in 5 clusters (red framework) to emphasize the community membership as per the similarity of their MSW generation intervals at each level.

Figure 2 shows upper (La Alameda) and middle-upper (Condado del Rey) income level communities in the same cluster (cluster 4), and lower (La Gloria) and lower-middle (Villa Soberanía) income level communities in the same cluster (cluster 3).

Figure 3 shows the upper income level community (La Alameda) in cluster 4, the middle-upper-income level community (Condado del Rey) in cluster 5, the lower (La Gloria) and lower-middle (Villa Soberanía) income level communities in the same cluster (cluster 3). Whilst the double clustering methodology was used for the discovery of causality of MSW generation, the small sample size used for the linear regressions may alter the reliability of results interpretation, especially when more than one independent variable is present.

Figure 4 confronts the dendrograms of **Figure 2 and 3** to assess the alignment quality between both dendrograms with the entanglement coefficient. An entanglement coefficient value of 0.56 is obtained, interpreted as a 56% lack of alignment; which represents the overall change of community membership from one dendrogram to the other, leaving a remaining 44% alignment.

In **Figure 4,** left side dendrogram, community (9) is clustered alone (cluster 5) as the highest MSW generator per individual and day, far from other cluster MSW generation values. However, the same community is found in the right side dendrogram of **Figure 4** clustered with six communities (13, 26, 29, 27, 22, and 30), five (26, 29, 27, 22, 30) of which comes from cluster 4 of the left side dendrogram and one community (13) from cluster 3.

The integrated representation of MSW generation at multiple levels of organization is shown in **Figure 5.** This figure presents an integrated 3-dimensional profile picture of the MSW generation of the 33 communities that make up the town of Betania, to simultaneously assess the MSW generation picture at the levels of individuals, households and communities. This profile picture was built with MSW generation data of **Table A.3** and serves as a guiding tool to create appropriate policies at several levels of organization of the same community to yield successful interactions among them. The higher MSW generation per individual and day (1.09 kg) is from community (9), however community (8) has the highest MSW generation per household and day (2.98 kg). The fact that community (9) has a higher MSW generation rate per individual and day than community (8) does not mean that it will behave the same at the household level, since IFs shaping these levels are different. Community (31) has the highest MSW generation per community and day with 2564 kg.

4. Discussion and recommendations

Correlation of MSW generation was directly obtained simultaneously for individual´s and household´s functional units of MSW generation in function of the "*Household median monthly income"* and *"Community indigenous population"* IF, respectively. At the individuals' level, the income of the household, as a whole entity, affects the average MSW generation of its members beyond their individual incomes; the higher the household income, the larger is the MSW generation of its members. Household income is a stronger determinant of resource consumption habits than inhabitants´ individual incomes, and consequently better shows causality of their MSW generation behaviour (De Feo et al., 2017; Karlsson et al., 2004; Oribe-Garcia et al., 2015). However, at the household level, indigenous population of communities had a higher effect size over MSW generation of households than other IF. This can be directly interpreted as the more indigenous inhabitants in communities, the higher is the MSW generation of communities´ households because of higher consumption of organic waste derived from food scraps. Consumption habits of indigenous communities in Panama are well-known to be high in raw food goods (AAUD, 2016) and the organic fraction, mainly made up of food scraps, is commonly the most abundant of the MSW stream in DC (Taboada-González et al., 2011). However, a low 21% of dependent variable response shows that the causality interpretation entailed in this correlation maybe improved with the availability of more data to correlate variables.

A still remaining 44% alignment between dendrograms of communities clustered as per individual and household functional units is interpreted as the behavioural trace that the *"Household median monthly income"* IF (used to explain the MSW generation of the individuals´ functional unit) left over the MSW generation of the higher level, the households´ functional unit. "Household median monthly income" and "Community median monthly income of active population" may be the cause of this alignment remaining trace since both variables refer to income, which is a direct cause of resource consumption, each at their respective level of organization.

Community (9), as per its correlation with MSW generation, appears as an upper income level community at the individual level and as a middle-upper income level community at the household level. Community (13), as per its correlation with MSW generation, appears as a lower income level community at the individual level, and as a lower-middle income level community at the household level. The trending to cluster with same or similar communities from the lower level (26, 29, 27, 22, and 30) is a sign of the community "memory" when other functional unit IF, corresponding to the higher level, are shaping the new context of their MSW generation. Income, as a known IF of MSW generation at multiple spatial levels, varies not only among levels of organization but also within them. The memory of behavioural trend traces remains from one level to the other and are mixed together with the IF representing the context of the new level in unknown proportions that should be surveyed specifically according to the case study. Absolute income level apparently represented at each level, cannot be generalized to all the spatial level at which MSW generation is analysed.

Understanding the extent to which influencing factors simultaneously affect MSW generation allows for volumetric rather than linear representations at several spatial levels at a time. The integrated three-dimensional profile picture of the MSW generation offers a graphical understanding of the extent at which the *X* axis, representing the MSW generation per individual and day (kg/inhabitant*day), is chiefly the only dimension taken into account when policies are created and implemented at several levels. The *Y* and *Z* axis, representing MSW generation per household (Kg/household*day) and community (Kg/community*day) are normally imperceptible for policy makers. This simple graphical representation shows that the current view of MSW generation as a scalar value is insufficient for policymaking and novel vector and matrix representations are needed. The relationship between the MSW generation of functional units at different levels of organization is not linear, but most are differentiable to the extent that can be approximated with the aggregation of linear functions that are given per level and can be graphically represented with tensor-like figures. MSW generation has as many degrees of freedom as IF shaping each level where functional units exists, a tensor-like representation of MSW generation is a reliable way to understand how MSW generation behave at the many levels that are relevant (Jeffreys et al., 1969).

The use of the Principal Component Analysis (PCA) technique or similar is recommended in further studies to determine, not only MSW generation behaviour specific influencing factors, but also the extent at which they are a cause of municipal solid waste generation at higher hierarchical levels of organization, where functional units rely on more than one influencing factor.

The effect size parameter used in this paper shows the extent at which discrete independent variables explain the response of the dependent variable independently of the sample size. Larger sample sizes are recommended for further studies to understand interactions among independent variables and elaborate more reliable interpretation of results.

5. Conclusion

Existing studies have studied influencing factors of MSW generation behaviour at different spatial levels of organization, but always one at a time and not simultaneously. Income is a strong influencing factor, affecting MSW generation from the individual to the country level, capable of hiding the effects of the others. However, this study shows that when MSW generation behaviour is analysed across multiple hierarchical levels of organization, it is possible to identify influencing factors others than income as explanatory variables. In this way, by increasing the number of influencing factors of MSW generation become possible to improve the information used to select proper policies and plans in developing countries MSW management systems in a holistic manner.

When policies are not developed on a proper analysis of the complexity of the relation between units of MSW generation and units of MSW management across hierarchical levels of organization policy overlapping may cause legal gaps. In this situation by considering the influencing factors of the functional unit at each hierarchical level of organization we can generate a better assessment of the effectiveness of MSW.

The approach presented here could also be applied to individual fractions of the municipal solid waste stream –e.g. metal, plastic, paper, organic- so as to understand the extent at which influencing factors affects their generation at different levels in function of the materials composing the municipal solid waste stream. As source separation is not common in developing countries, waste characterization activities have to be performed first; otherwise local actions for policy creation are not viable.

Solid waste management systems of developing countries mostly use landfills in which all solid waste streams are mixed without previous treatment. The approach presented in this paper could be used to understand simultaneous generation behaviour at multiple hierarchical levels of spatial organization of other solid waste streams -e.g., commercial municipal solid waste, tires, clinical waste and construction & demolition waste- in order to be able to plan actions to improve their solid waste management systems.

6. Acknowledgements

This original work was supported by the Government of Panama, the Instituto de Formación y Aprovechamiento de Recursos Humanos (IFARHU), the Universidad Tecnológica de Panamá (UTP) and the Secretaría Nacional de Ciencia, Tecnología e Innovación (SENACYT) of Panama. Authors acknowledge financial support from the Spanish Ministry of Science, Innovation and Universities, through the “María de Maeztu” program for Units of Excellence (MDM-2015 0552). Authors are deeply grateful to Valēre Anna Espinal for her great contribution in statistical development of this paper, to the Zero Waste Program of the Municipality of Panama for valuable updated data, to Sandra Bukkens for reviewing English grammar and to the anonymous reviewers for their useful comments and suggestions. Authors declare no competing financial interests. This work reflects the authors’ view only, the funding agencies cannot be held responsible for any use that may be made of this work.

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Table. 1. Available independent variables as IF of the MSW generation at the household and community level from official data of the National Census and Statistic Institute of Panama (INEC, 2010b)

Type	***Independent variables***
Education	- Population with less than 3rd grade of primary school approved

	- Illiterate population - Average higher grade approved
Demographic	- Average inhabitants per household - Median age
Health	- Handicap population - Population without social security
Ethnic	- Indigenous population
Economic Activity	- Active population (from 15 to 64 years old) - Population employed in agricultural activities - Unemployed population - Not economically active population
Financial	- Community median monthly income of active population - Household median monthly income

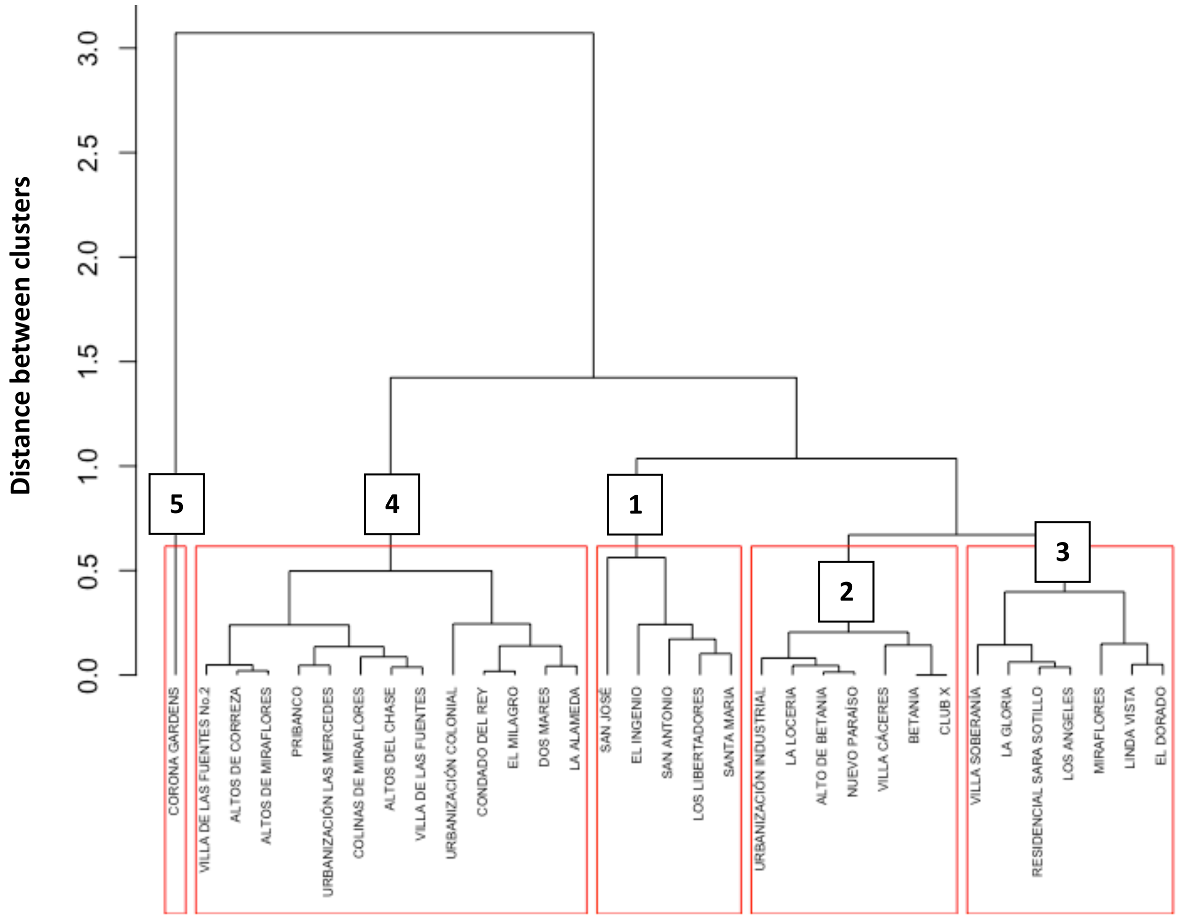

Figure 2. Dendrogram of communities obtained with the similarities of their MSW generation at the level of individuals. Statistical tools derived from several sources (Galili, 2018; RStudio Team, 2015; Ryota Suzuki, 2015; Soetaert, 2013)

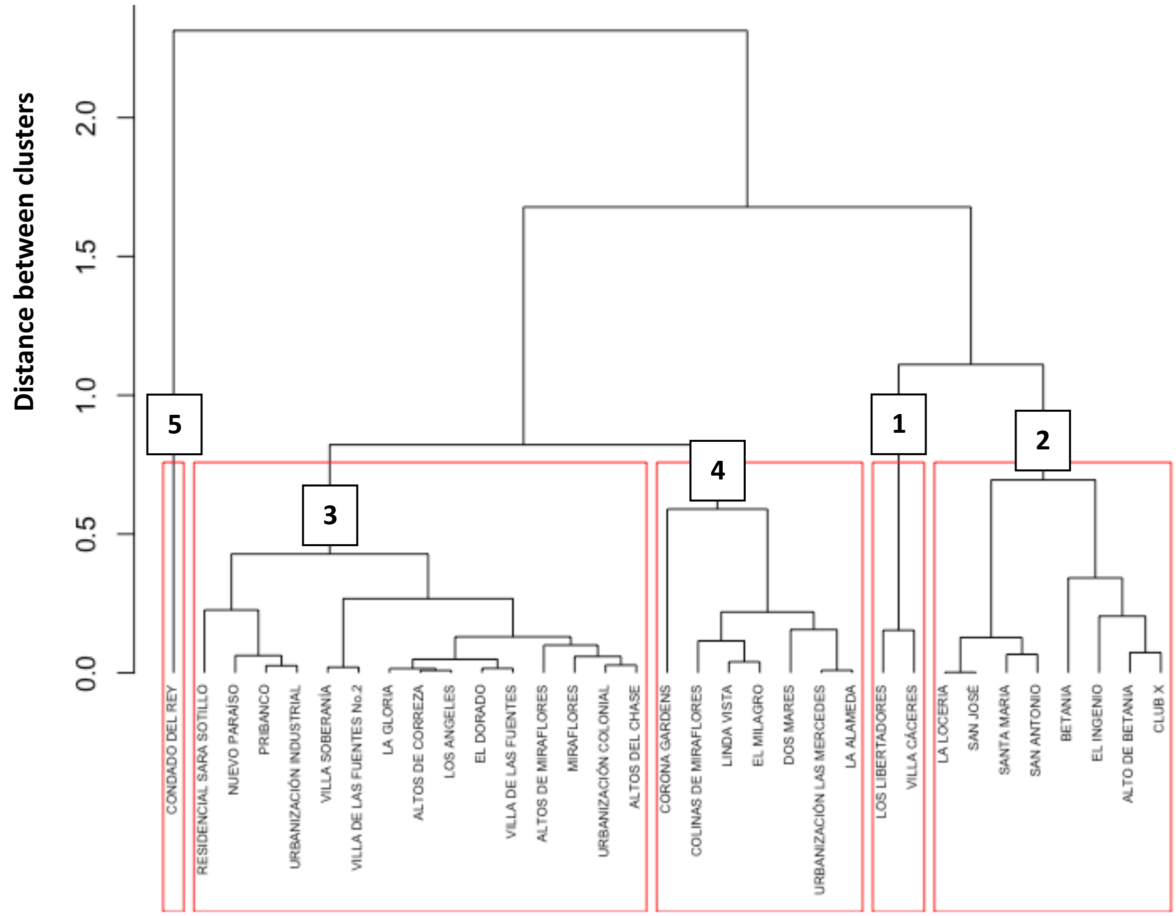

Figure 3. Dendrogram of communities obtained with the similarities of their MSW generation at the household level. Statistical tools derived from several sources (Galili, 2018; RStudio Team, 2015; Ryota Suzuki, 2015; Soetaert, 2013).

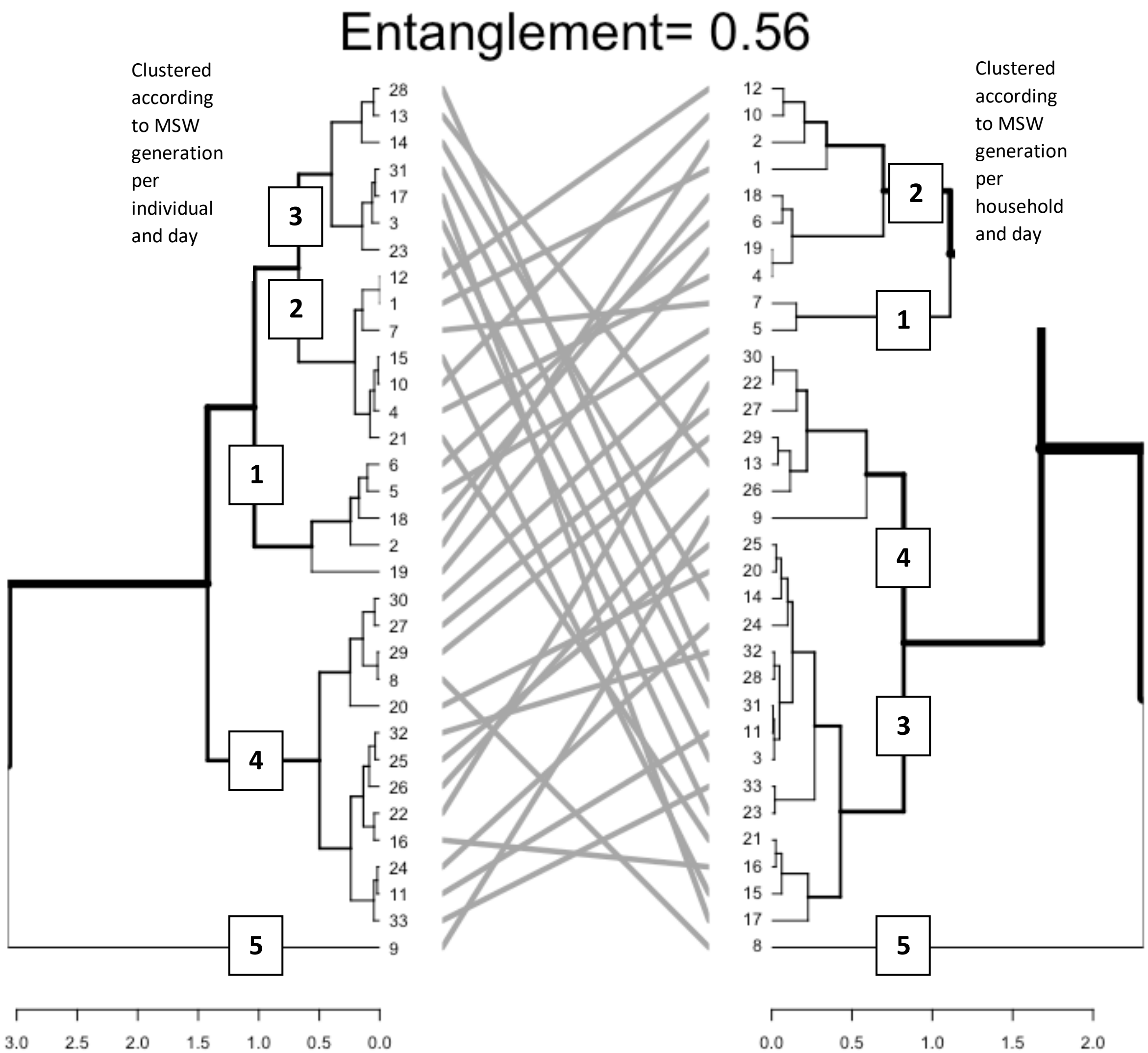

Figure 4. Community membership entanglement from the *individual – household* to the *household – community* functional unit relationship

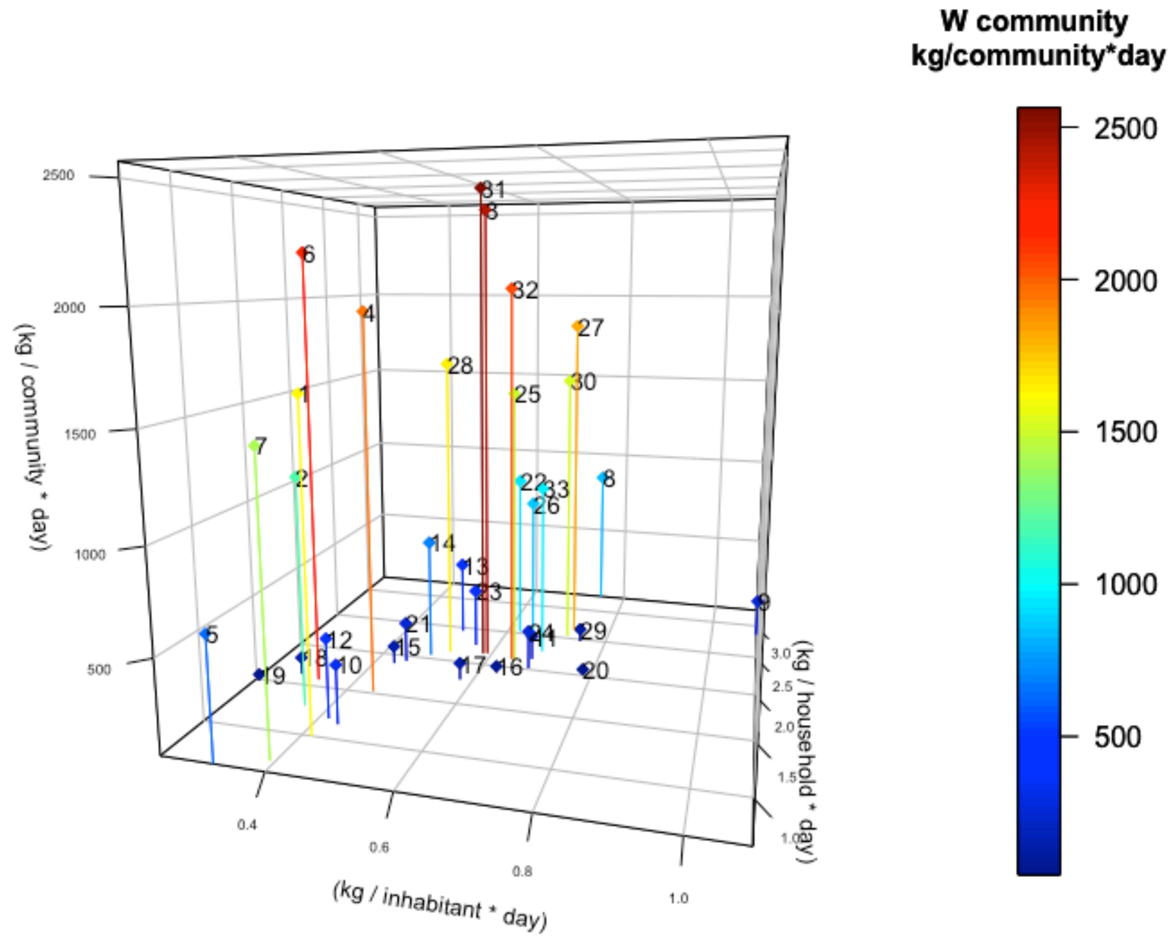

Figure. 5. Integrated three-dimensional profile picture of the MSW generation of the town of Betania composed by the MSW generation values in kg per day of its sub-levels of organization -e.g. inhabitant, household and community-.