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Quantification and Classification of Household Solid Waste in the City of Bukavu, DRC

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Abstract

This study focused on the management of solid household waste and its recovery in the form of organic fertilizer and took place in the three municipalities that make up the city of Bukavu. The objective of the study was to set up a management method for the fermentable fraction of waste emitted by the inhabitants of the city of Bukavu for the production of organic fertilizer. The method used consisted of a questionnaire survey coupled with laboratory experimentation and analysis. The results show that the city of Bukavu (1,021,540 inhabitants) produces 521 tons of household solid waste daily, or 0.51kg of waste per person per day. Of this waste produced, the fermentable fraction represents 50% of the overall mass and the other non-fermentable half is distributed in the following proportions: 19% plastic, 16% wood, 5% glass, 4% textile, 4% paper and 1% metal. In addition, the production of household solid waste is influenced by the standard of living of the inhabitants in the city of Bukavu. Waste management at household level by sorting into different categories is estimated at 44% compared to 56% for the 94 households from which the collection was carried out. This last percentage is essentially made up of households of avenues not having a subscription to sanitation structures in the municipality of Kadutu (avenues Boulevard Industriel, Ntwali-Tabora and ONL) as well as in the municipality of Bagira (avenue Nkubirwa). Considering the socio-economic context of the city of Bukavu, it was noticed that there is a waste management plan that is inconsistent with the socio-economic realities of its inhabitants. This work suggests the establishment, by political decision-makers, of a waste management plan which must take these

realities into account.

Subject Areas

Environment

Keywords

Household, Waste, Municipality, Standard of Living

1. Introduction

Today's consumer society is changing; the products and the waste resulting from their use are becoming more and more complex, by their nature and their chemical composition. In addition to this modification of the structure of the material composing the waste, the quantity produced is only increasing due to the constant increase in the population and to the modification of consumption habits [1].

Thus, between 1960 and 1990 in the European countries, such as France, it recorded an average increase in the specific production of household waste of 0.2% per year [2]. This increase would be much greater for industrial waste. In the cities of developing countries, the demographic evolution is very high and would be the main factor in the evolution of the waste flow. However, Nyenyezi *et al.* [3] reported that Bukavu city gradually expanded, going from 3 Km^2 to 58.26 Km^2 on the eve of independence. The current area is 60 Km^2. The city has seen the number of its inhabitants increase exponentially [4] between the periods from 1990 to 2020 from a density of 3000 in habitants/Km^2 to 16.191 in habitants/Km^2. Built on a chain of mountains, with an estimated population of more than 1.3 million inhabitants in 2022, the city of Bukavu, formerly called "The beautiful Bukavu" because of its green nature, is currently unclean due to the inefficiency of the system of waste management. Bukavu generates on a daily basis 898 tons per day (t/d) of waste. This poor waste management leads to an accumulation of uncollected waste in the city. The current situation is such that: bulging avenues of waste, waste burnt almost everywhere, the lake and rivers polluted. To remedy this situation, the Mayor of the city has set himself a mission called: "to transform waste into wealth" [5].

In addition to the "natural" population growth, the recent boom in the population of Bukavu is mainly due to three factors, including immigration from rural areas caused by conflicts and the activity of armed groups, commercial opportunities, and land-use problems in the outskirts of the city where people do not have access to water, electricity or roads. Contrary to this very widespread idea, on a continental scale, according to which the management of household solid waste (MSW) in African cities is a financial question, we are led, in view of the many investments made in this sector in recent years, to recognize that the

question of MSW in Africa is much less a financial problem than a question of organization or rather of management. At the level of the cities of the Democratic Republic of Congo and the city of Bukavu in particular, this question has not yet known a sincere commitment on the part of the municipal authorities and their inhabitants. In Bukavu, the landfills set up by non-profit associations do not meet any environmental standard [6]. Even if at the level of the town halls, the national administration provides for agents in charge of the sanitation of the cities, this work is not done for lack of the means allocated to this work on the one hand and on the other hand, to the lack of training officers responsible for this work. These so-called "wild" landfills become places of emission of greenhouse gases and leachate harmful to both the environment and human health [7]. This urban waste is, according to Aoun and Bouaoun [8], a major source of pollution that poses environmental and health problems. The garbage stored in these "wild" landfills is still found in circulation in the city by certain people who collect the rare reusable goods such as kitchen crumbs, plastic bags and bottles as well as cardboard boxes whose lifespan can be extended.

Urbanization and economic growth contribute to the improvement of the living conditions of the individual, but are accompanied by pollution of various kinds requiring appropriate measures to neutralize it despite all the consequences that these dumps and garbage "returning" to the city can have on the daily life of the population [9].

If, in industrialized countries, waste management is already a very important and coveted economic activity, in Bukavu on the other hand, the problem of residues is not yet taken care of. The problem of waste management in this city has attracted very little attention from scientists, authorities and investors [10]. The current difficulties can be attributed to multifaceted organizational, technical, institutional, educational factors and to a lack of information and awareness. The management of household waste should be ranked among the priorities if we want to ensure the conditions for sustainable urban development [11]. There are many recovery and recovery channels for better waste management. Some authors like Ngnikam and Tanawa (2000) cited by Temgoua *et al.* (2014) [12], highlight the importance of the fermentable fraction in the household waste of the countries of the South and others propose composting as one of the interesting techniques to valorize this organic matter [13]. Aoun and Bouaoun (2008) [8] define the double objective of composting: production of an organic amendment without negative impact on the environment and reduction of waste nuisances by contributing to the maintenance of the quality of the environment. According to several scientists [1] [14] [15], composting is the decomposition of organic matter and its transformation into humus by the action of a large number of microorganisms in a warm, humid and airy environment. This process makes it possible to transform organic waste into compost, an organic amendment very rich in nutrients. The composting of urban waste also offers very interesting solutions for transforming organic waste into a resource [16] [17]. The results of

Jaza Folefack (2008) [12] show that compost for lettuce production is the most productive input. However, farmers in many parts of the world, and especially in developing countries, are failing to utilize the potential offered by composting. Indeed, they have to deal with various constraints including a lack of awareness of effective and fast technologies that facilitate work [12] [18]. The aim of our study is to determine the quantity of solid household waste produced its physical categorization in Bukavucity.

2. Materials and Methodologies

2.1. Study Area

The city of Bukavu is located in the province of South Kivu. It was created and delimited since 1901. It was recognized as an urban district in 1925 and city in 1958. It has 3 communes, 20 districts, more than 400 avenues and a population currently estimated at approximately 1,021,540 with an average density of 16,191 habitat/Km^2 [19] over an area of 60 km^2. Its climate is humid tropical tempered by its mountainous relief with 2 seasons: dry with 4 months and rainy with 8 months). The soil is clayey and the average temperature is 20˚C. Our study will cover the three municipalities of the city of Bukavu (Bagira, Kadutu and Ibanda) with a population estimated at 148,135 in Bagira, 392,298 in Kadutu and 481,107 in Ibanda [19] (**Figure 1**).

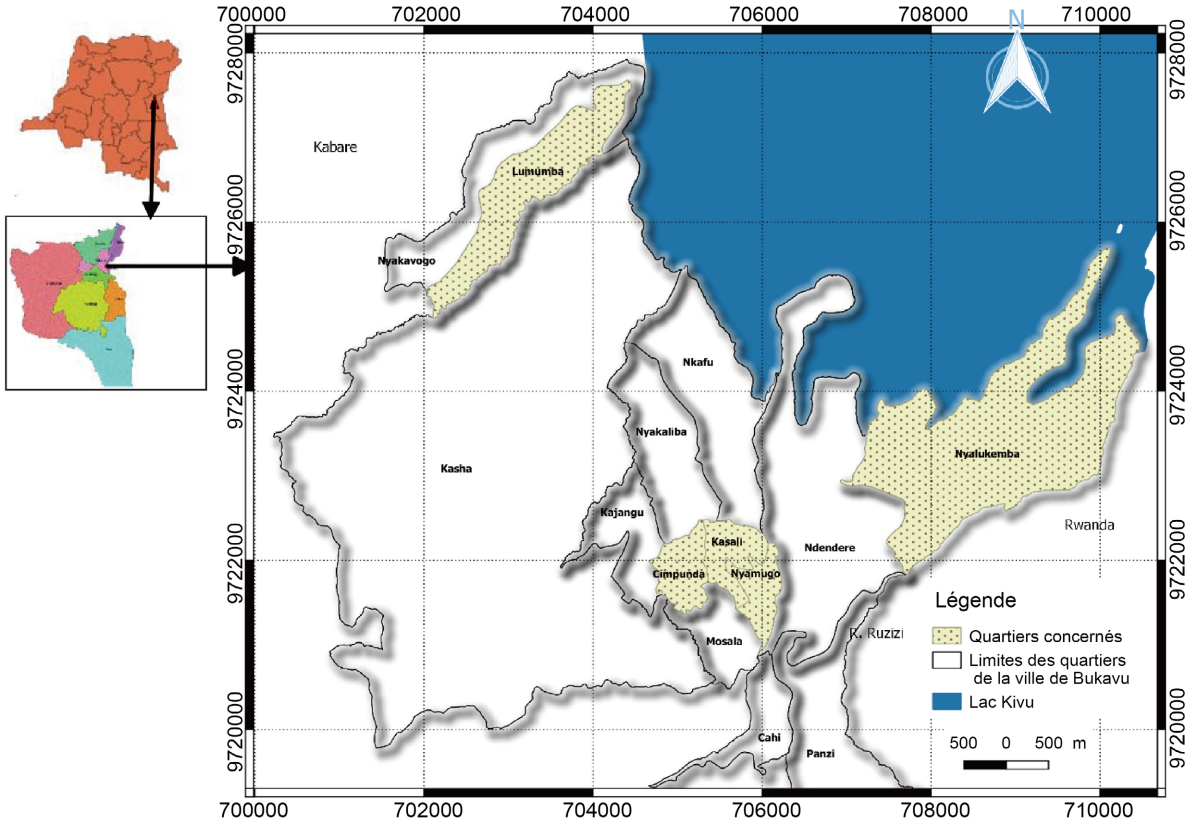

Figure 1. Map of the study area.

2.2. Data Collection

To carry out this task, the teams of investigators need 9 working days. The first and second days were for the sensitization of household managers and the possible deposit of garbage bags; waste storage takes place from the third to the eighth day and the collection of garbage bags takes place on the ninth day.

After the household manager joins the study, he answers the questions administered by the interviewer whose questionnaire is deployed on the tablets and smartphones [20] with the Kobo collect software. Two garbage bags with a capacity of 50 kg each are donated to each household, one for biodegradable waste and the other for other categories of waste.

Indeed, these two garbage bags made of polyethylene and galvanized by a sachet to avoid the loss of leachate are labeled and placed in each household that is part of our sampling for sorting different categories of waste in order to collect all household waste. One of the trash bags will contain organic waste and the other all other types of waste. Households/avenues are chosen according to their income level according to a report (2021) from the town hall which divides households into three categories: high standing, meddle standing and low standing.

At the end of the collection, these garbage bags are collected and brought to our landfill fitted out for the circumstance of this study, in Kabare, in the Cirhunga group at the Kabare Pilot Agricultural Farm. The garbage bags are emptied there, the sorting of the different categories according to their nature [21] is carried out in order to determine the physical composition of each garbage can and these different fractions are weighed by an electronic scale.

One hundred households in total are concerned by this study for the three communes in the proportions respectively of 14.5%, 38.4% and 47% for Bagira, Kadutu and Ibanda. After a review based on knowledge of these three municipalities and their avenues, the sampling is in clusters and should be random and representative according to the UN Habitat model (2020) which divides households into different social classes (LS: Low standing, MS: Middle standing and HS: High standing).

The avenues below by municipality were thus chosen, distributing the households as follows in **Table 1**.

Table 1. Avenues by municipality.

Municipality	Ibanda			Kadutu			Bagira	
Avenues	Muhumba	Kajangu	Pesage	Boulevard Industriel	Ntwali Tabora	ONL	Biega	Nkubirwa
Households	23	10	14	12	13	13	8	7
Social classes (standard of living)	HS	HS	HS	LS	MS	LS	MS	LS
Households total/Municipalities	More 47			38			15	

Cartography of companies working in the field of sanitation at the level of these three municipalities has been drawn up and it has been realized that only twenty-two companies carry out this work on the extent of the city of Bukavu (town hall report). To do this, with the exception of the avenues chosen at the level of the municipality of Ibanda and Biega Avenue in Bagira, there is no sanitation company on all the other avenues. This is why households that do not have a contract with any sanitation company have been made aware of the culture of sorting. All the households selected according to our survey step (10 households), should also be accessible to allow collection. This survey step could be enlarged depending on whether the garbage bags are not protected inside the plot.

The team of investigators is made up of 6 people, respectively 2, for Ibanda, 2 for Kadutu, 1 for Bagira and 1 supervisor.

2.3. Cartography

The data from the survey carried out on the ground as well as the data on the limited neighborhoods of the city of Bukavu [22] were used to make the different distribution maps of the households surveyed in the QGIS 2.18 software.

2.4. Statistical Analysis

Data were encoded in Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA) and R software (R Core Team, 2018) was used for analysis. One-way ANOVA was used at a significance level of 0.05. Tukey's multiple comparisons of means were also used at the 95% confidence level. Before the application of the analysis of variance, the verification of the normality of the hypothesis of distribution of the data was carried out using the test of homoscedacy (homogeneity of the variances) by the K-squared test of Bartlett. The former is used to examine whether two categorical variables are independent in influencing the test statistic. Also, Student's t-test was performed. The t-test is a test used for hypothesis testing. Descriptive results were expressed as means, percentage, standard deviation, graphs with standard error bars performed using Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA).

3. Results

3.1. Quantification of Household Solid Waste

3.1.1. Spatial Distribution of Surveyed Households

The maps below show the distribution of households that were the subject of our study across the three communes of the city of Bukavu. **Figure 2** illustrates the distribution of the surveyed households (in red dot) having been the subject of the study area.

3.1.2. Production of Solid Waste by Households

1) Production of biodegradable solid waste

i) Municipality of Ibanda

The production of biodegradable solid waste in the municipality of Ibanda is

21.844 Kg, 19.964 Kg and 10.911 Kg respectively in Muhumba, Kajangu and Pesage avenues (Figure 3).

Let us statistically analyze the results of Figure 3 and the summary of the analysis of variance (ANOVA) is presented in Table 2.

Table 2 shows a non-significant difference ($p = 0.102 > 0.05$); *i.e.*, the quantities of solid biodegradable waste produced by households are the same in the three avenues of the municipality of Ibanda.

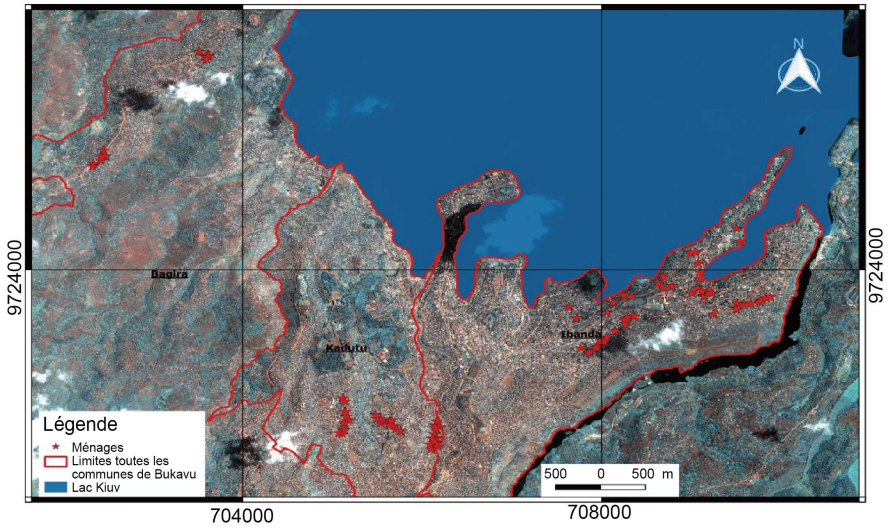

Figure 2. Distribution in the three municipalities of Bukavu city.

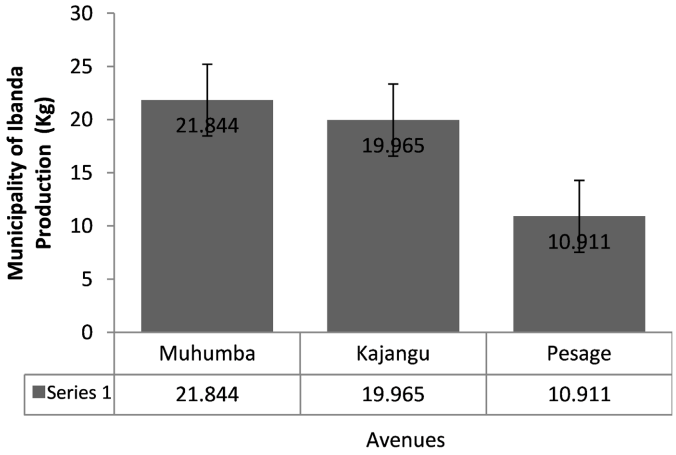

Figure 3. Production of biodegradable waste in Ibanda.

Table 2. Summary of the ANOVA of the production of biodegradable waste in Ibanda.

Source of variation	Degree of freedom	Sum of squares	Mean squares	F	Pr(>F)
Avenues	2	1033	516.7	2.418	0.102
Residual	40	8545	213.6		

ii) Municipality of Kadutu

Figure 4 below shows that the production of biodegradable waste in three chosen avenues of the municipality of Kadutu is respectively 8.120 Kg, 8.746 Kg and 12.182 Kg for Boulevard, Ntwali and ONL Avenues.

Let us statistically analyze the results of Figure 4 and the summary of the analysis of variance (ANOVA) is presented in Table 3.

A non-significant difference in the production of solid biodegradable waste in the three avenues of the municipality of Kadutu (p-value = 0.449 > 0.05) is observed in Table 3, *i.e.* the quantities of solid biodegradable waste produced by the households are the same in the three chosen avenues of the commune of Kadutu.

iii) Municipality of Bagira

Figure 5, below, distributes the production of biodegradable waste in the two chosen avenues of the municipality of Bagira as follows: Nkumbirwa avenue (street D) with 12.037 Kg and Biega avenue (district A) with 5,502 Kg. By applying the Student's t test, there is a non-significant difference in the production of solid biodegradable waste in the two avenues of the municipality of Bagira; *i.e.* the production of biodegradable solid waste on Biega Avenue is the same as that of Nkubirwa Avenue (t = −1.4517, df = 12, p-value = 0.1722 > 0.05).

2) Production of no-biodegradable waste

i) Municipality of Ibanda

Figure 6 shows that in the municipality of Ibanda, the production of non-biodegradable solid waste is 15.542 Kg in Muhumba Avenue, 15.482 Kg in Kajangu Avenue and 17.090 Kg in Pesage Avenue. Table 4 shows a non-significant

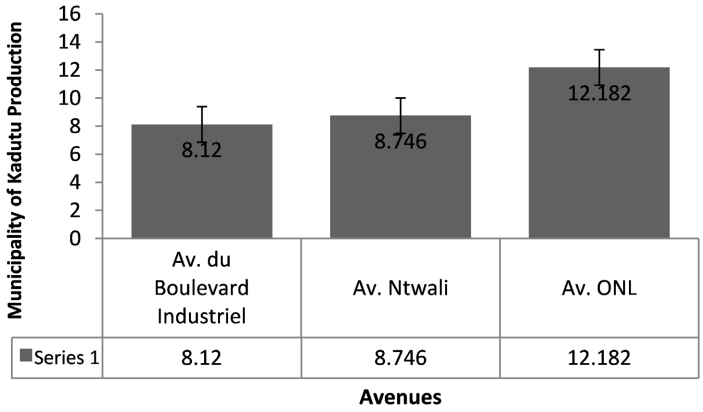

Figure 4. Production of biodegradable waste in Kadutu.

Table 3. Summary of the ANOVA of the production of biodegradable waste in Kadutu.

Source of variation	Degree of freedom	Sum of squares	Mean squares	F	Pr(>F)
Avenues	2	106.8	53.42	0.82	0.449
Residual	32	2084.5	65.14		

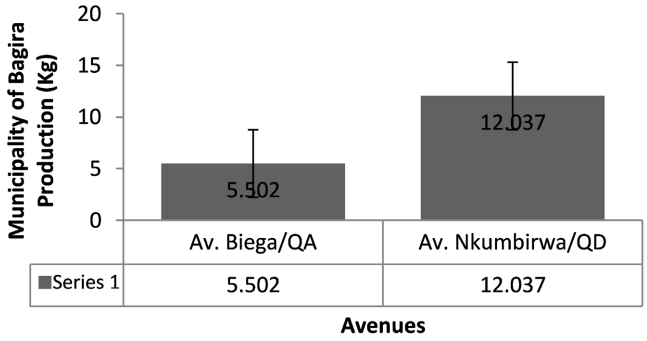

Figure 5. Production of biodegradable waste in Bagira.

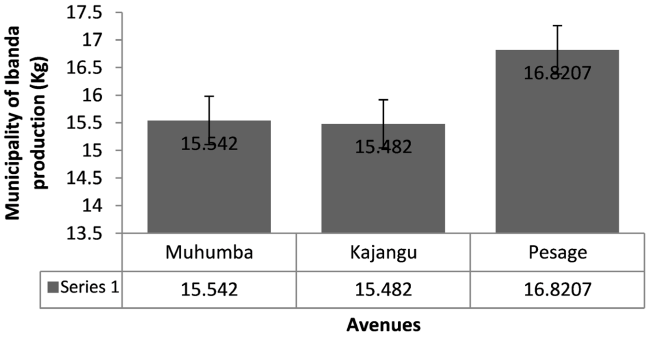

Figure 6. Production of non-biodegradable waste in Ibanda.

Table 4. Summary of the ANOVA of the production of non-biodegradable waste in Ibanda.

Source of variation	Degree of freedom	Sum of squares	Mean squares	F	Pr(>F)
Avenues	2	494	247.0	1.273	0.291
Residual	40	7765	194.1		

difference in the production of non-biodegradable solid waste in the three avenues of the municipality of Ibanda (p-value = 0.291 > 0.05); *i.e.*, the quantities of non-biodegradable solid waste produced by households are the same in the municipality of Ibanda.

Let us statistically analyze the results of **Figure 6** and the summary of the analysis of variance (ANOVA) is presented in **Table 4**.

A non-significant difference in the production of solid non-biodegradable waste in the three avenues of the municipality of Ibanda (p-value = 0.291 > 0.05) is observed in **Table 4**, *i.e.* the quantities of solid non-biodegradable waste produced by the households are the same in the three chosen avenues of the commune of Ibabda.

ii) Municipality of Kadutu

It appears in **Figure 7**, the municipality of Kadutu produces 13.490 Kg of non-biodegradable waste at Boulevard Avenue, 8.026 Kg at Ntwali Avenue and 12.803 Kg at ONL Avenue.

The analysis of variance (ANOVA) summary of the results in Figure 7 is presented in Table 5.

In view of the results of this analysis (Table 5), it appears that the difference is not significant, *i.e.* the quantities of no-biodegradable waste produced by households are the same in the municipality of Kadutu.

iii) Municipality of Bagira

Figure 8 below shows that the production of non-biodegradable waste in the municipality of Bagira is 7.896 Kg at Biega Avenue (street A) and 7.859 Kg at Nkumbirwa Avenue (street D). In view of the statistical analyzes with the Student's t test, there is a non-significant difference between the production of non-biodegradable solid waste in the municipality of Bagira. The production of biodegradable waste is the same in the two avenues of the municipality of Bagira (t = −0.043374, df = 12, p-value = 0.9661).

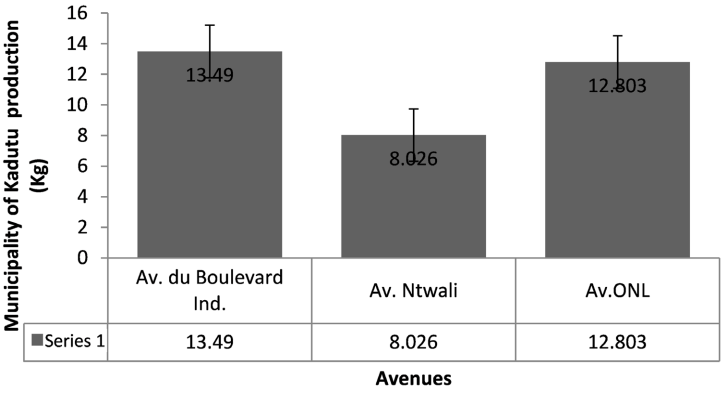

Figure 7. Production of non-biodegradable waste in Kadutu.

Table 5. Summary of the ANOVA of the production of non-biodegradable waste in Kadutu.

Source of variation	Degree of freedom	Sum of squares	Mean squares	F	Pr(>F)
Avenues	2	222.3	111.16	1.502	0.237
Residual	34	2515.7	73.99		

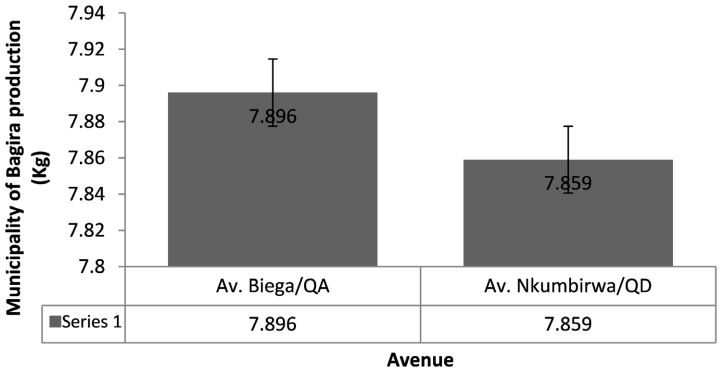

Figure 8. Production of non-biodegradable waste in Bagira.

3) Comparison of household waste production by municipality

i) Biodegradable solid waste

The production of biodegradable solid waste is distributed as follows (Figure 9) in Ibanda (17.573 Kg ± 5.846), Kadutu (9.683 Kg ± 2.187) and Bagira (8.769 Kg ± 4.620). The average production of the three municipalities per household for 6 days of collection of solid biodegradable waste is 12.009 Kg. It is 2.001 Kg per day and per household and 0.250 Kg per day and per person.

ii) Non-biodegradable solid waste

The production of non-biodegradable waste is distributed as follows (Figure 10): in Ibanda (15.948 Kg ± 0.756), in Kadutu (11.001 Kg ± 3.731) and in Bagira (7.878 Kg ± 0.026).

The average production of the three municipalities per household for 6 days of non-biodegradable waste is 11.609 Kg; it is 1.935 Kg per day and per household and 0.242 Kg per person and per day.

For 6 days, households produce an average of 24.89 kg, *i.e.* an average daily production of 4.15 kg. With a family size of 8, the average daily production per person is 0.51 kg.

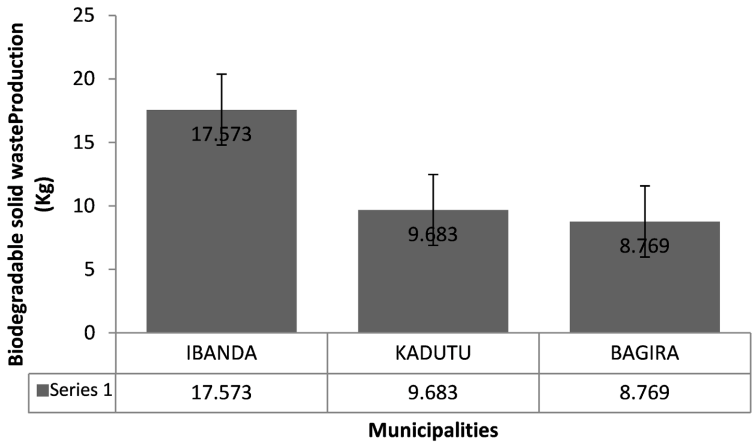

Figure 9. Biodegradable production of municipalities.

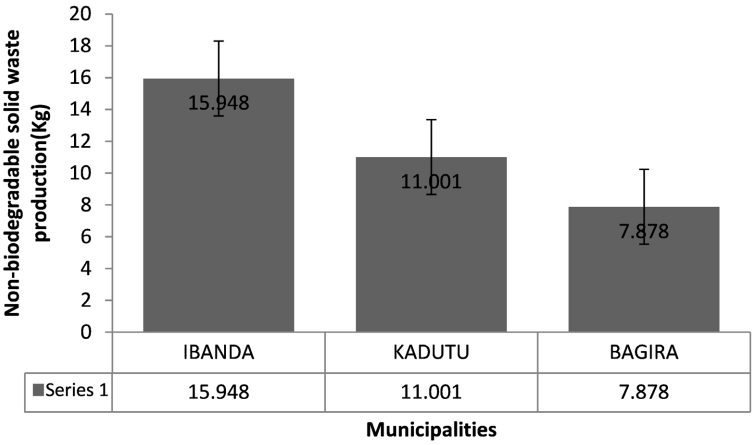

Figure 10. No-biodegradable production of municipalities.

4) Production of solid household waste/standard of living

The data in Table 6 below provides information on average household waste production according to standard of living.

From Table 6, it appears that a difference between the standard of living along the avenues HS Muhumba (37.292 Kg), HS Kajangu (35.097 Kg), HS Pesage (28.314 Kg), LS ONL (22.871 Kg), LS Nkubirwa (20.035 Kg), LS Boulevard Industriel (19.886 Kg), MS Ntwali Tabora (15.612 Kg) and MS Biega (13.441 Kg). The summary of the one-way analysis of variance (ANOVA 1) is summarized in Table 7.

P-value being less than 0.05, there is a significant difference; that is to say, the standard of living has an impact on the quantity of solid waste produced by the households of the avenues in the city of Bukavu. Let us compare the means two by two by the multiple comparison method of TukeyHSD (Table 8).

Table 6. Average household waste production according to standard of living.

N	Social classes(standard of living)							
	HS Muhumba	MS Kajangu	MS Pesage	MS Boulevard Industriel	MS Biega	LS Ntwali Tabora	LS ONL	LS Nkubirwa
1	48.4	17.796	7.36	26.825	7.345	12.47	7.51	25.3
2	12.63	74.08	21.42	8.68	19.44	5.99	6.09	50.665
3	53.24	36.285	4.7	19.78	21.27	29.315	16.47	7.715
4	49.79	76.89	5.06	21.39	15.895	21.43	11.21	13.79
5	49.2	37.37	19.93	10.82	10.745	15.14	2.44	9.8
6	25.695	11.43	21.86	33.82	17.93	4.4	20.715	12.94
7	14.17	2.63	37.96	27.445	8.76	1.72	51.63	0.00
8	24.03	23.14	79.85	45.4	6.1415	7.865	33.68	0.00
9	48.89	36.25	30.865	12.355	0.00	16.287	39.76	0.00
10	52.01	0.00	20.8	7.28	0.00	19.34	26.2	0.00
11	4.42	0.00	46.82	5.84	0.00	15.47	36.83	0.00
12	80.52	0.00	10.285	19.00	0.00	41.335	21.915	0.00
13	9.74	0.00	68.45	0.00	0.00	12.19	0.00	0.00
14	64.78	0.00	21.035	0.00	0.00	0.00	0.00	0.00
15	17.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	48.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	25.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	21.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	35.395	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	11.835	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Means	37.292	35.097	28.314	19.886	13.441	15.612	22.871	20.035

Legend: HS: High Standard, MS: Middle Standard, LS: Low Standard.

Table 7. Summary of the ANOVA of household waste production.

Source of variation	Degree of freedom	Sum of squares	Mean squares	F	Pr(>F)
Standard of living	7	5743	820.4	2.554	0.0194 *
Residual	86	276.5	321.2		

Codes Sign : 0 “***”0.001 “**” 0.01 “*” 0.05 “.” 0.1 “ ” 1.

Table 8. Multiple Comparison of TukeyHSD.

Avenues of three municipality of Bukavu city	Difference	Low limit	Upper limit	p-adj
MS_Ntwali/Tabora - BS_Nkubirwa	−4.4233077	−31.9054397	23.058824	0.9996343
LS_ONL - LS_Nkubirwa	2.8358333	−25.0055575	30.677224	0.9999833
HS_Muhumba - LS_Nkubirwa	14.8157500	−11.1031743	40.734674	0.6377763
MS_Biega - LS_Nkubirwa	−6.5941875	−36.6663266	23.477952	0.9972946
LS_Boulevard/Industriel-LS_Nkubirwa	−0.1487500	−27.9901408	27.692641	1.0000000
HS_Kajangu - LS_Nkubirwa	15.0617778	−14.2856250	44.409181	0.7522745
HS_Pesage - LS_Nkubirwa	8.2789286	−18.8914868	35.449344	0.9803594
LS_ONL - MS_Ntwali/Tabora	7.2591410	−15.0318115	29.50094	0.9714743
HS_Muhumba - MS_Ntwali/Tabora	19.2390577	−0.5986377	39.076753	0.0640165
MS_Biega - MS_Ntwali/Tabora	−2.1708798	−27.1924120	22.850652	0.9999944
LS_Boulevard/Industriel-MS_Ntwali/Tabora	4.2745577	−18.0163949	26.565510	0.9988502
HS_Kajangu-MS_Ntwali/Tabora	19.4850855	−4.6605885	43.630759	0.2065394
HS_Pesage-MS_Ntwali/Tabora	12.7022363	−8.7447913	34.149264	0.5950251
HS_Muhumba-LS_ONL	11.9799167	−8.3525604	32.312394	0.6013970
MS_Biega-LS_ONL	−9.4300208	−34.8456171	15.985575	0.9427563
LS_Boulevard/Industriel-LS_ONL	−2.9845833	−25.7169837	19.747817	0.9999062
HS_Kajangu-LS_ONL	12.2259444	−12.3278543	36.779743	0.7796916
HS_Pesage-LS_ONL	5.4430952	−16.4623939	27.348584	0.9941219
MS_Biega-HS_Muhumba	−21.4099375	−44.7037163	1.883841	0.0950220
LS_Boulevard/Industriel-HS_Muhumba	−14.9645000	−35.2969770	5.367977	0.3129867
HS_Kajangu-HS_Muhumba	−0.2460278	−22.1042883	22.596344	1.0000000
HS_Pesage-HS_Muhumba	−6.5368214	−25.9403791	12.866736	0.9656479
LS_Boulevard/Industriel-MS_Biega	6.4454375	−18.9701588	31.861034	0.9933441
HS_Kajangu-MS_Biega	21.6559653	−5.4010031	48.712934	0.2152281
HS_Pesage-MS_Biega	14.8731161	−9.8056392	39.551871	0.5733045
HS_Kajangu-LS_Boulevard/Industriel	15.2105278	−9.3432710	39.764327	0.5382067
HS_Pesage-LS_Boulevard/Industriel	8.4276786	−13.4778106	30.333168	0.9311875
HS_Pesage-HS_Kajangu	−6.7828492	−30.5731300	17.007432	0.9866176

It generally emerges that the avenues at High-Standing produce more than the avenues at Middle and Low-Standing; except for the Middle-Standing avenues which produce less than the Low-Standing avenues.

5) Production of biodegradable and non-biodegradable solid waste in Bukavu city.

The synthesis of the distribution of production of biodegradable and non-biodegradable waste (all fractions) of Bukavu city is presented in Figure 10. The latter shows an equal distribution of waste. The different fractions of waste are distributed as follows in Figure 11 below: 50% biodegradable, 19% plastic fuel, 16% wood fuel, 4% paper fuel, 4% textile, 6% glass inert and 1% metal inert.

3.2. Categorization of Household Solid Waste

Alongside biodegradable solid household waste, non-biodegradable solid household waste is in different fractions including inert (glass, metal) and combustibles (paper, wood, textile and plastic). These different fractions are produced in different proportions depending on the place of production.

3.2.1. Non-Biodegradable Waste

Regarding those inert waste, the glass waste in the three municipalities of the Bukavu city, Ibanda takes first place with 1.835 Kg ± 1.073 followed by Bagira (1.374 Kg ± 1.299) and Kadutu (0.883 Kg ± 0.179) in Figure 12. As for metal waste, the municipality of Ibanda produces 0.371 Kg ± 0.085 followed by Kadutu 0.337 Kg ± 0.186 and Bagira 0.16 Kg ± 0.034 (Figure 13).

The production of paper waste is (1.709 Kg ± 0.431) for Ibanda, followed by Kadutu with (0.62 Kg ± 0.227) and order (0.421 Kg ± 0.347) for Bagira (Figure 14). However, the production of textile waste is 1.204 Kg ± 0.361 in Ibanda, 0.990 Kg ± 0.394 in Kadutu and 0.691 Kg ± 0.117 in Bagira (Figure 15). Thus, the production of wood waste is 4.809 Kg ± 2.541 in Ibanda, 3.959 Kg ± 0.939 in Kadutu and finally 1.943 Kg ± 2.015 in Bagira (Figure 16). The production of plastic waste is 6.684 Kg ± 1.751 in Ibanda, 4.651 Kg ± 2.009 in Kadutu and 1.349 Kg ± 0.998 in Bagira (Figure 17).

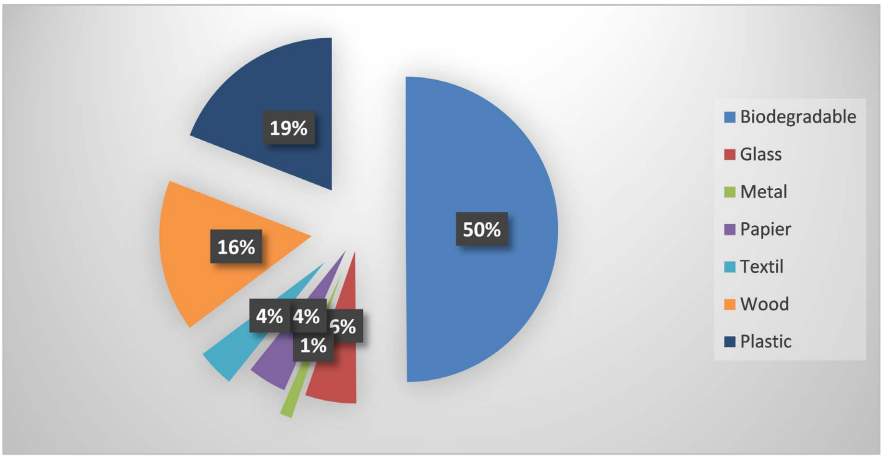

Figure 11. Generation of biodegradable and non-biodegradable waste (all fractions).

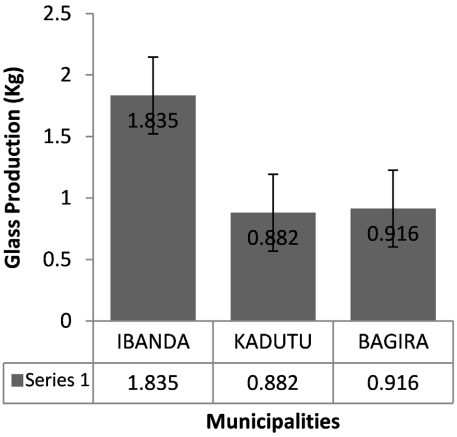

Figure 12. Glass Production.

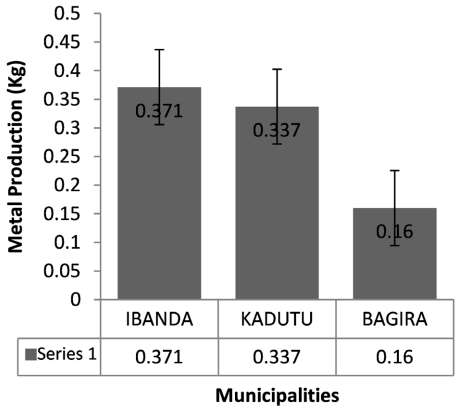

Figure 13. Metal Production.

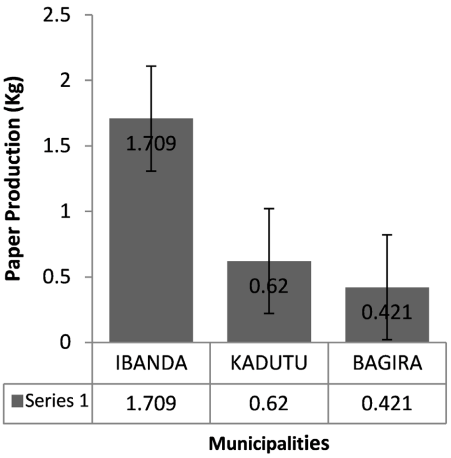

Figure 14. Paper Production.

4. Discussion of Results

Figure 2 shows how the surveyed households are distributed over the study area. Indeed, after the definition of the study area and in addition to the criteria that led to the choice of the households surveyed: accessibility, standard of living, "no

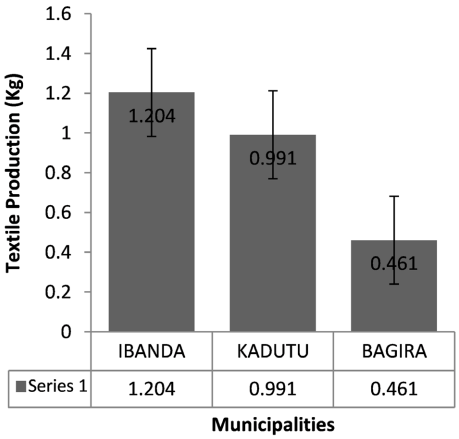

Figure 15. Textile Production.

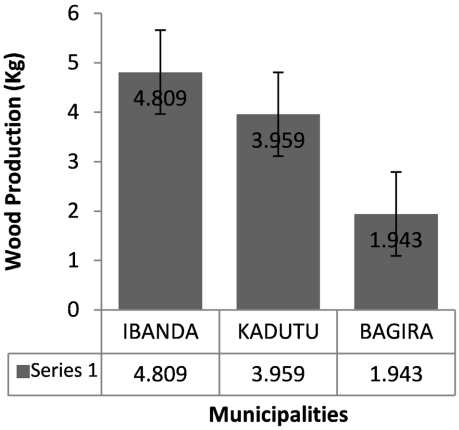

Figure 16. Wood Production.

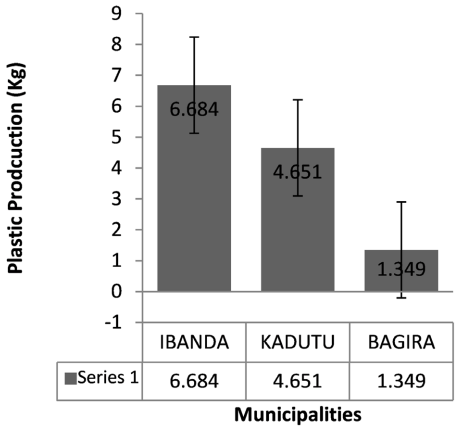

Figure 17. Plastic Production.

Survey" of 10 households on the same avenue; this "no sounding" was sometimes not respected on the avenues whose households are not fenced in order to avoid the loss of garbage bags (case of the avenues of the municipality of Kadutu and the avenue Nkubirwa in the municipality of Bagira). The spatial distribution

of the households surveyed was also a function of land use.

The production of two large fractions (bio and non-biodegradable) of the waste produced in the city of Bukavu is distributed in the proportion of 50-50, while [10] Bisimwa *et al.* (2012) and a study by [23] UN Habitat (2020) found percentages of the order of 92.35% and 58.52% respectively of the fermentable fraction for the same Bukavu city. [24] Tshala *et al.* (2017) found in their study on the recovery of household waste in the city of Kolwezi a value of 53% of the fermentable portion, while in the cities of European countries this percentage is relatively lower, this is the case of France where the rate of putrescible waste is 29% [25].

The average daily production of solid waste in the Bukavu city is 4.15 kg per household, or 0.51 kg per person per day for the family size of 8. This production is higher but close to that of 0.48 kg/pers/day found by [23] UN Habitat (2020) for the Bukavu city but lower than that found by [26] Mindele (2016) 0.91 kg/pers/day for the city of Kinshasa during the dry season, period during which our study has been done. For a population of 1,021,540 inhabitants [19] (DPS/ Sud-Kivu, 2020), this production is estimated at 520,985.4 kg, or 521 tons of waste generated by households in the city of Bukavu per day.

The fermentable fraction represents 50% against the non-fermentable fraction with different categories: Plastic (19%), wood (16%), glass (5%), textile (4%), paper (4%), and metal (1%). The values of the non-fermentable fraction are higher than those found in other African cities. This is the case of a study carried out by [27] Temgoua *et al.* (2014) in Cameroon in the city of Deschang where the percentages of plastic, textile, glass, paper and metal are respectively 3.97%, 3.5%, 0.38%, 0.8% and 0.30% while [28] Mbulingwe *et al.* (2014) found for the Dar Es Salaam city the percentage of 3.1%, 2.2%, 3.5% and 2% respectively for paper, plastic, glass and metal. The good organization of the metal recovery sector through the Bukavu city can explain this low rate of this fraction compared to the others.

In addition, the production of household waste depends on the standard of living of the inhabitants (Ojeda-Benitz *et al.,* 2003) cited by [29] Charnay, 2005. For this study, High-Standing avenues produce more than Middle and Low-Standing avenues and Middle-Standing avenues produce more than Low-Standing avenues; exception made for ONL (LS) Avenue where it was observed that 58% of the households surveyed organized wedding parties during the study period. For Biega Avenue (MS), the households surveyed have vegetable gardens where biodegradable waste is preferentially used for organic amendment.

5. Conclusions

At the end of this work, it was shown that the Bukavu city with its 1,021,540 inhabitants produces 521 tons of solid household waste daily, *i.e.* a quantity of 0.51 Kg of waste per person per day. Of this waste produced, the fermentable fraction represents 50% of the overall mass and the non-fermentable fraction takes the

other half distributed in the proportions of 19% for plastic, 16% for wood, 5% for glass, 4% for textile, 4% for paper and 1% for metal. It has also been shown that the standard of living has an impact on the amount of solid waste produced by households in the Bukavu city during the dry season.

Considering the socio-economic context of the Bukavu city where there is a waste management plan that is inconsistent with the socio-economic realities of its inhabitants, a management plan model that takes these realities into account should be adapted and put into effect.

Conflicts of Interest

The authors declare no conflicts of interest.

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