Green World Journal
ISSN: 2737-6109

CaMeRa Editorial

RESEARCH ARTICLE

Domestic Solid Waste Management in Rural Areas - case study of the Waorani Nampa Community, Ecuadorian Amazon

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DOI/URL: https://doi.org/10.53313/gwj61058

Resumen: This study focused on the proposal of an integrated solid household waste management system in the rural community of Waorani Nampa belonging to the Waorani indigenous nationality in the Ecuadorian Amazon. In this community, the burning of domestic solid waste is the only man-agement strategy commonly used, which has generated diverse environmental and health im-pacts on the population. Therefore, here we focused on diagnosing the socio-environmental con-dition of the community through surveys in order to determine the average daily per capita pro-duction of domestic solid waste. This was done through a characterization applying the method-ology of the Pan American Health Organization (PAHO) and the development of a proposal for a management model appropriate to the current demographic characteristics, from environmental education to final disposal. The results obtained determined that the average PPC of the commu-nity is 0.343 kg/person/day and the predominant category was the organic fraction with 64.20% of a total of 31.15 kg of solid waste produced. Finally, as initiatives for adequate management and use, it was proposed that an area be adapted to generate compost and a recycling system to obtain economic resources for the benefit of the population.

Keywords: Solid waste, Indigenous rural communities, Management system, Waorani Nationality

Cita: Jaramillo, J., Chacha, A., Herrera-Feijoo, R. J., Peñafiel-Arcos, P., & Cazares, K. (2023). Domestic Solid Waste Management in Rural Areas - case study of the Waorani Nampa Community, Ecuadorian Amazon. Green World Journal, 6(1), 58. https://doi.org/10.53313/gwj6105

Received: 03/Feb /2023
Accepted: 15/Apr /2023
Published: 20/Apr /2023

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Editor-in-Chief / CaMeRa Editorial
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1. Introducción

Solid waste management (SWM) originated from the need to improve people's quality of life[1,2]. Since ancient times, solid waste lacked of the necessary importance, based on the fact that the population was very small [3], as there was not much generation of these or in many cases, the way of collection until its final disposal was very efficient due to the territory size[4]. Due to the increase in the world population[5], people's lifestyle[6] and industrial growth[7], currently, household solid waste (HSW) has become one of the biggest problems at the health and environmental level throughout the world[8–10]. Currently, of the 2010 million tons of HSW generated worldwide, only 67% is collected and an adequate management system is conducted. According to the appreciations, it is projected that by the year 2050, the production of HSW will increase up to 3400 million tons[11]. Based on the chemical composition of these residues, the vast majority of them are impossible to biodegrade. In addition, a high amount of waste releases greenhouse gases (GHG) into the environment. Currently it is estimated that HSW's contribute with 5% of all GHG emissions generated worldwide[12].

The current volumes of HSW generation have become a major drawback in public health, due to their poor management, leading to the spread of diseases and the appearance of vectors [13,14]. In developing and underdeveloped countries, the impact on health and the environment is more acute, since solid waste management is performed using techniques considered inadequate. This occurs for example, with the use of open-air dumps and the uncontrolled incineration of waste[15–17]. The aforementioned practices are very common due to the lack of financial and management commitment on the part of the authorities in charge[18,19] .Under this premise, Ecuador is no exception, since in the different rural Amazonian communities there has been a substantial increase in the per capita production of daily solid waste generated [19].

The adequate management of domestic solid waste in rural areas of the Ecuadorian Amazon region has become a very important aspect for municipal governments, since in these areas there is no road available for the collection of HSW by truck collectors[20]. This situation is further aggravated due to the minimal environmental education that the inhabitants of these areas have regarding the management and management of solid waste [21]. As a consequence of the aforementioned, a significant increase in open-pit HSW has been generated without control by the municipal and environmental authorities [12,18]. According to previous studies coducted in rural areas that have the aforementioned characteristics, some emphasis could be placed on the A'I Dureno Cofán millennium community located in the Dureno canton, 27 km from the Lago Agrio canton, in northeastern Ecuador. This community is made up of 129 inhabitants, who represent the Cofan indigenous nationality. Due to the proximity that this community has with urban areas, it produces a large number of HSW when compared to neighboring indigenous communities [19].

The direct repercussions of the inadequate management of HSW are visual contamination, due to the presence of solid waste in open areas, as a consequence of this, there is landscape deterioration[22–24], and therefore the decline in tourism, without leaving aside the contamination that originates in the soil and water bodies[25,26]. As a rudimentary solution, the communities incinerate the HSW in the open air, but do not consider that this operation generates significant air pollution due to the combustion process that occurs. In these chemical reactions, substances harmful to living beings such as PM10, PM25, carbon monoxide (CO), persistent organic pollutants, such as polycyclic aromatic compounds (PACs), dioxins, furans and heavy metals are released into the atmosphere[27,28]. Apart from the affectation of these chemical compounds in the air, the health of the community members is seriously affected[19,29]. All the practices that have been mentioned can be reduced through the execution of environmental education programs for the community. But in addition to this, it is extremely important to focus resources on the implementation of techniques that allow HSW to be put to new use[21]. These strategies should contribute to improving the quality of life of the inhabitants and the environment[30–32]. A further potential solution to this problem is to propose and execute a comprehensive SWM plan that starts from the analysis of the generation of solid waste, its management and reuse[32,33].

Solid waste management must be executed based on the 17 sustainable development goals (SDGs), which are considered in the 2030 agenda for sustainable development agreed upon by UN member countries[34]. Given that the 12 objectives are directly related to solid waste management, it is important to analyze them[35], as the proper handling and management of solid waste is essential for sustainability[36]. Similarly, national environmental regulations promote the management of non-hazardous solid waste and waste, from a circular economy and inclusive recycling approach, both in urban and rural areas, according to the Organic Environmental Code (OEC) and the Regulations to Organic Environmental Code (ROEC)[37]. In this scenario, the public institutions in charge of managing these products are the Autonomous Decentralized Municipal Governments (GADs), which must generate policies that seek to fulfill all the objectives set, seeking a sustainable development of the society.

In this sense, the main objective of this research is to design an integrated solid waste management system by characterizing the domestic solid waste generated and defining proposals for each stage of the management system focused on the socioeconomic reality of the Waorani Nampa community belonging to the Waorani indigenous nationality in the Ecuadorian Amazon located in the Mera Canton, Pastaza province. This will serve as a guide for decision makers and will benefit the community's population through sustainable management of these resources.

2. Materiales y métodos

2.1 Study area

The community is located 10 km from the city of Puyo in the province of Pastaza and has 141 inhabitants living in 33 houses (Figure 1). The community has all the basic services, both electricity and potable water. Its population has a minor agricultural activity and most of its children and young people attend educational institutions[38].

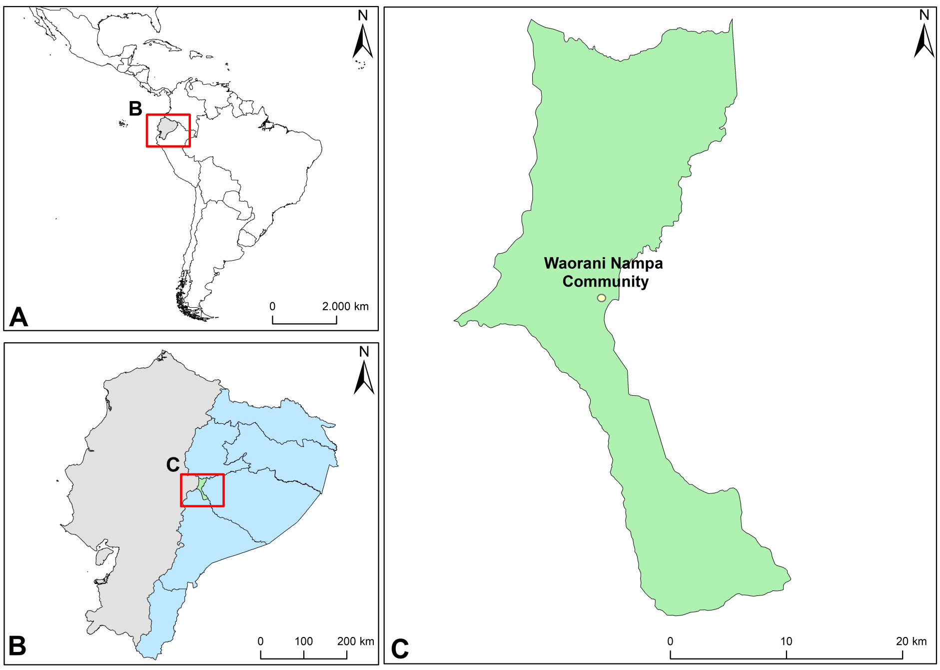

Figure 1. Study area; (a) Ecuador; (b) Mera Canton; (c) Waorani Nampa Community.

2.2 Diagnosis of the current situation of HSW generation and management in the Waorani Nampa community

The quantitative and qualitative diagnosis of the HSW generation in the community was developed by applying a descriptive survey based on open and closed questions, in the 33 inhabited houses. The topics consulted in the survey were discussed by a panel of teachers from the Environmental Engineering career of the Amazon State University of Ecuador, which was used as a validation system. Likewise, these topics were previously socialized with the target population in order to obtain their approval and commitment to the development of this work. In accordance with Ecuadorian regulations, in the Organic Environmental Code (COA) in its article 231 and in the Organic Code of Territorial Organization, Autonomy and Decentralization (COOTAD) articles 55 and 136, the administrative managers in the integral management of solid waste non-hazardous and sanitary waste, are the Autonomous Decentralized Municipal Governments, which are obliged to promote management alternatives in generators, promote environmental education programs and/or projects in their territorial constituency, organization and citizen oversight of environmental rights and nature. In the particular case of this study, those directly responsible for solid waste management should be the Municipal GAD of the Mera canton. This obligation is currently partially fulfilled due to the lack of planning, economic resources and personnel to conduct these activities, which in turn determines the need for a self-management model to solve this problem.

2.3 Characterization of HSW

In order to achieve the characterization of the HSW, the methodology of the Pan American Health Organization (PAHO) was used, which implies knowing the characteristics of these solid wastes in relation to their generation, composition, and density. This statistical methodology is applied in different solid waste characterization studies in the countries of the Latin American and Caribbean Region[39]. The study was carried out in the 33 houses present in the locality.

2.3.1 Solid waste collection in sampled homes

Each house was labeled and georeferenced. The collection of the HSW was developed for eight successive days, leaving aside the results of the first day as indicated by the previously mentioned methodology. The collection schedule was established collectively around the possibilities of the community. Solid waste was collected daily in 50 x 55 cm black polyethylene bags and its weight was taken in kg.

2.3.2 Calculation of daily average per capita production (PPC) of HSW

The weight of the waste that was collected daily in each of the dwellings is repre-sented by the abbreviation (Wt). Based on all the data collected, on the number of peo-ple per dwelling, the total number of people was determined, which in this case is rep-resented by the abbreviation (n). To obtain the daily PPC, Equation (1) was used.

$$PPC = \frac{daily\ waste\ weight\ (Wt)}{person\ number\ (n)} \quad (1)$$

2.3.3 Determination of the physical composition of solid waste

The collected solid waste was classified into the categories paper and cardboard, plastics, metals (including cans), glass, organic matter, sanitary waste and others. Afterwards, the percentage of each component was calculated, applying Equation (2), considering the data of the total weight of the waste collected in one day (Wt) and the weight of each category (Pi).

$$Percentage(\%) = \frac{Weight\ of\ each\ component(Pi)}{daily\ waste\ weight(Wt)} \quad (2)$$

2.4 Statistical analysis

For the execution of the corresponding calculations, the EXCEL software was used in the tabulation of the survey results and in the determination of the characterization parameters, which served to perform the analysis of the results of the activities. Likewise, the statistical package STATISTICA was used to generate mean, minimum, maximum and standard deviation values of the results of the production and characterization of the HSW generated in the community, within a basic analysis of descriptive statistics.

3. Results and Discussion

3.1 Diagnosis of the current situation of HSW generation and management in the Waorani Nampa community

The results of the survey allowed to determine that 46% of families in the community are composed of five or more individuals. This result is similar to that established in a previous study, where it is mentioned that indigenous households are larger because they have a higher amount of children[40]. Regarding the current management of domestic solid waste, 75% of the families surveyed do not perform any classification or use, so only 25% conduct a basic classification of the organic fraction to use it as fertilizer. This value is significantly lower than that determined by Peñafiel et al. [19], where 77% of families classify their solid waste. This fact may be due to the fact that in the study locality of this work, there is a collection service that simplifies the responsibility with these products by the generator, which does not occur in the community of comparative work, generating the search for alternative uses.

On the other hand, when asked if any type of treatment and/or revaluation of solid waste is known, 70% of the people surveyed mentioned composting. This coincides with the results of Vélez et al. [41], developed in an Amazonian indigenous community of Ecuador. All this allows to determine that the production of biofertilizers through techniques such as composting and vermicomposting, would have a successful opening in rural areas. In turn, in the locality it was possible to establish that all the families would be willing to contribute to an integral management of domestic solid waste, a fact that is repeated in the works[19,41], developed in the same way in rural areas.

3.2 Waorani Nampa Community PPC

The daily results obtained from the PPC can be seen in Table 1. These determina-tions were obtained from June 03 to 10, 2022 (8 successive days) with the exception of the first day, according to the aforementioned methodology. It is observed that the av-erage HSW PPC in the community is 0.343 kg/inhab/day.

Table 1. Average daily PPC of the Waorani Nampa community

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Average
Daily weight (kg)	29.50	45.70	75.65	39.30	18.90	56.40	73.20	48.38
PPC (kg/inhab/day)	0.209	0.324	0.537	0.279	0.134	0.400	0.519	0.343

This result can be compared with those obtained in works obtained in other rural communities of the country, such as [42], where a PPC of 0.330 kg/inhab/day was determined. In turn, there are investigations conducted in rural Amazonian areas, such as those realized by [43,44] in the province of Sucumbíos, in which average PPP values of 0.51 kg/inhab/day and 0.42 kg/inhab/day are obtained, respectively. Another investigation is the one presented by Vélez et al. [41] where it was determined that the daily PPP for a community of Waorani nationality in the Ecuadorian Amazon is 0.260 kg/inhab/day. Similarly, there is work conducted in a Cofán community [19], in which the result was 0.346 kg/inhab/day. These data indicate the significant variability of generation that exists in this type of population settlements, which could be marked mainly by the socioeconomic and cultural conditions of each community[45], and in a second plane by the level of accessibility to the conditions of a urban lifestyle. All this raises the need to develop a greater amount of social research, where the prevailing factors that condition the generation of HSW can be analyzed and determined. At the international level, there is the work developed by Llapapasca [46], where the results obtained in the determination of the PPC in a Peruvian rural community are established. The calculated value was 0.310 kg/inhab/day, which is similar to the Ecuadorian conditions described previously.

3.3 Physical constitution of the HSW of the Waorani Nampa community.

Community waste was characterized according to its physical constitution ac-cording to its type and composition (Table 2) and its quantity and percentage (Table 3).

Table 2. Physical constitution of the HSW of the Waorani Nampa community

Type of waste	Composition
Paper and paperboard	Sheets of paper, notebook sheets, newspapers, magazines, brochures, cardboard, food packaging.
Organic remains	Food scraps, egg shells, vegetable peels, bones, leaf debris and grass.
Plastics	Plastic covers, wrappers, bottles of drinks and oils.
Metals	Tuna and sardine cans, preserves.
Glass	Beverage bottles.
Domestic sanitary waste	Toilet paper, sanitary napkins.
Others	Rubber, leather, remains of textiles and ceramics.

Table 3. Quantity and percentage of the HSW of the Waorani Nampa community.

Days	Paper and paperboard		Organic remains		Plastics		Metals (cans)		Glass		Others		Domestic sanitary waste	
	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
2	2.00	6.78	19.75	66.95	3.50	11.86	1.10	3.73	0.65	2.20	0.10	0.34	2.40	8.14
3	4.20	9.19	28.40	62.14	4.60	10.07	3.10	6.78	0.50	1.09	1.80	3.94	3.10	6.78
4	5.30	7.01	52.40	69.27	4.75	6.28	2.10	2.78	0.40	0.53	3.50	4.63	7.20	9.52
5	1.40	3.56	26.30	66.92	2.70	6.87	6.10	5.2	0.30	0.76	0.70	1.78	1.80	4.58
6	2.30	12.17	12.10	64.02	1.20	6.35	0.60	3.17	0.10	0.53	0.40	2.12	2.20	11.64
7	6.10	10.82	29.50	52.30	8.40	14.89	2.40	4.26	0.00	0.00	2.80	4.96	7.20	12.77
8	3.80	5.19	49.60	67.76	6.90	9.43	3.60	4.92	2.50	3.42	2.30	3.14	4.50	6.15
Average	**3.59**	**7.82**	**31.15**	**64.20**	**4.58**	**9.39**	**2.71**	**5.88**	**0.64**	**1.22**	**1.66**	**2.99**	**4.06**	**8.51**

The percentage of organic waste generation is similar to that found in [19,41,43,44] for rural Amazonian localities, where an average value of 66% was determined. This could indicate an acculturation process in the area, as has been investigated in similar works[46].

3.4 Statistical analysis

To complement the analysis of the results referring to the determination of the PPC and characterization of the HSW, a descriptive statistical diagnosis was devel-oped that has been listed in Table 4. Based on these results, it was determined that all the parameters present a low variability of production each day of analysis.

Table 4. Quantity and percentage of the HSW of the Waorani Nampa community.

	# of samples	Arithmetic average	Minimum value	Standard deviation
PPC	7	0.343	0.134	0.152
Organic remains	7	31.15	12.10	14.82
Paper and paperboard	7	3.59	1.40	1.76
Plastic	7	4.48	1.20	2.45
Glass	7	0.64	0.00	0.85
Metal (including cans)	7	2.71	0.60	1.82
Others	7	1.66	0.10	1.29
Sanitary waste	7	4.06	1.80	2.32

3.5 HSW management system proposal for the Río Blanco community

For the correct design of the proposal for the integral management of the HSW, the population of the community was projected based on the corresponding population growth index, at a horizon of 15 years from the execution of this study, that is, to the year 2037. The growth rate of the Mera canton 2.80% was used, considering the last census carried out corresponding to the year 2010[38], since there is no information in the National Institute of Statistics and Censuses (INEC) specifically of the study community. For the year 2037 the population would be of about 185 inhabitants. With these results, the projected HSW production values that served to design the different stages of the proposal are presented in Table 5.

Table 5. HSW management system proposal for the Waorani Nampa community

Population	Current (n=141)		Future (n=185)	
	Weekley (kg)	Monthly (kg)	Weekly (kg)	Monthly (kg)
Organic remains	218.05	934.50	286.09	1226.12
Paper and paperboard	25.10	107.57	32.93	141.14
Plastic	32.05	137.36	42.05	180.22
Glass	4.45	19.07	5,84	25,02
Metal (Including cans)	19.00	81.43	24.93	106.84
Others	11.60	49.71	15.22	65.23
Sanitary waste	28.40	121.71	37.26	159.70
Total	**338.65**	**1451.35**	**444.32**	**1904.27**

3.6 Environmental Education Phase

The proper functioning of the integral management of solid waste requires great shared commitments between the inhabitants of the community and the local authorities, since, the complexity that this procedure covers exceeds the responsibility of the Decentralized Autonomous Governments. The aforementioned complexity begins with the conviction of the community's inhabitants of the need to separate organic waste into at least three categories, being organic, recyclable, and waste. This categorization is based on what is proposed by the Regulations to the Organic Code of the Environment (RCOA)[37]. To achieve this objective, the training schedule listed in Table 6 is proposed.

Table 6. Environmental education topics.

	Day 1	Day 2	Day 3
Training topics	Opening Classification of solid waste.	Welcome presentation Waste management and its social problems.	Welcome presentation Domestic organic waste composting method.

Recycling of organic content. Recycling of recyclable content.	Recycle help. Recycling protects the environment.
Unusable HSW disposal.	Biosecurity measures for the management of HSW of sanitary origin

3.7 Temporary Storage Phase

For this stage, the selective storage of HSW in each home is proposed in three categories, being organic (food scraps, fruit peels and vegetable waste), recyclables (plastic, cardboard, paper, glass and metal) and waste (sanitary waste and others). Each family need to be provided with three containers of 30 liters each.

3.8 Collection and Transport Phase

This stage is divided into three parts that coincide with the number of categories previously raised. It is proposed that the collection of organic waste be carried out daily due to the faster degradation that these suffer, and because it is the category with the highest production. Therefore, it is proposed that, within the community, a person or a group of people who work in a rotational manner be assigned, who will have the responsibility of moving the organic matter from each inhabited house, to the place destined for the system of composting. For the recyclable fraction, in the same way it will be allocated to a person or a group of people who are in charge of collecting this waste, twice a week, and its accumulation in a container of adequate dimensions considering the generation with the projected population. Subsequent to this, on a monthly basis, these materials will be transported to a recycling center "Puyo Recycles", which is closest to the Waorani Nampa community, via Shell-Puyo. The monthly cost for these activities will be USD 7.00. While, the profits from the sale of these products have been estimated through interviews with the owners of the recycling centers, and are presented in Table 7. Finally, the fraction considered as waste must be disposed of so that it can be collected by the collection service provided by the municipal GAD of the Mera canton.

Table 7. Estimated earnings from the sale of recyclable waste from the Waorani Nampa community.

Type of waste	Monthly profit (USD)	
	Actual	Projected
Paper-cardboard	12.91	16.94
Plastic	75.55	99.12
Glass	1.53	2.00
Metal (Including cans)	16.29	21.37
Total	106.27	139.43

3.9 Solid waste utilization and final disposal

3.9.1 Phase of use of the organic fraction

For this phase, an area of 42 m^2 will be allocated for the application of a treatment system for the organic fraction generated in the study area. It is proposed that this location be built with the labor of the community itself and with materials from the area. It must be covered for proper maintenance of the batteries. The formation of two piles will be considered, each of which will receive the daily organic fraction for a month. Complementary products could be pruning material or remains of vegetation cut from the community itself as nitrogenous material, and diluted panela blocks as energy input. In the present investigation, the determination of the C/N ratio was not performed, but the research work generated in the Amazonian indigenous community Limoncocha[44]. has been taken as a reference. Therefore, it is estimated that the average C/N ratio is 158. This relatively high value is due to the fact that almost all the residues are of vegetable and not animal origin. To reduce this ratio to the optimal range (25-35), the incorporation of poultry manure is proposed in a 1:1 ratio with the HSW of the community, which increases the percentage of nitrogen and thus the C/N ratio decreases. up to adequate values[47,48]. The cost of the sack of poultry manure in the city of Puyo, Pastaza is USD 5.00. In addition, a monthly sack of agricultural lime will be needed to control odors, the cost of which is USD 3.95, and a person will be assigned to be in charge of the activity of turning the piles. This process requires approximately 2-3 hours per week. Knowing that the generation of organic solid waste is currently 934.50 kg per month, that the addition of poultry manure would go in the same amount, that 30 to 50% of the total weight is transformed into compost[49] and taking a referential value of 30%, 5 bags of 35 kg of organic fertilizer would be obtained monthly, which could be marketed at USD 6 each. This value was taken based on the reference in the Pastaza Province, where the Pastaza Canton GADM, through the Pastaza Recycles program, generates compost from solid vegetable waste produced both in markets and in homes. The current monthly profit would be USD 30 and with the projected generation in 15 years of USD 42.

At the time of applying the entire proposed management system, it would be possible to take advantage of approximately 83% of all HSW generated and only 17% (waste, metals and others) would reach the Sanitary Landfill of the Mera canton. The generation of hazardous waste in the locality is practically nil. The only hazardous waste generated is that of sanitary origin, which is arranged for collection by the public service.

3.9.2 Summary of costs and income

The total monthly cost that would be generated by applying the proposed management system would be USD 18, considering the costs of transporting recyclable waste, agricultural lime, poultry manure and a 10% safeguard. Whereas, the profits that could be obtained under the current conditions of the number of inhabitants would be approximately USD 136.27, obtaining a net monthly income of USD 118. The economic resources obtained could be administered in the same community, through the designation of a commission responsible for managing monthly accounts. It is worth mentioning that in the environmental education phase, the entire community should be made aware of the socio-environmental and economic importance of the application of this proposal, which achieves the commitment of the participation of all disinterestedly in the collection, transport and construction of the composting area, knowing that the economic gains can be used for the well-being of the entire community.

4. Conclusiones

It was determined that the average daily HSW PPC in the Waorani Nampa community, located in the Ecuadorian Amazon, is 0.343 kg/inhab/day, while the total daily generation is approximately 48.32 kg. In comparison with the rural Amazonian communities of Ecuador, the study is related to the results obtained from the Cofán A I Dureno community in the province of Sucumbíos (0.346 kg/inhab/day) and are higher than the Waorani Gareno community in the province of Tena (0.26kg/inhab/day), this variability of results depends on socioenvironmental, economic, cultural and educational conditions, through the access that indigenous rural communities have to urban areas, although it is necessary to be able to carry out more studies of this type, to confirm this conclusion.

In turn, the organic fraction constitutes the type of waste that is generated in the greatest amount, 64.20% of the total. This presents an important opportunity for the application of composting processes, which has been very well received by the community. Given the lack of adequate management of the HSW generated, a management alternative is presented that is based on phases of environmental education, selective storage, collection, transport and use of organic and recyclable fractions. This contributes to environmental conservation, through a circular economy approach and citizen empowerment.

Author Contributions: Conceptualization, J.J., P.P.A and R.J. H.F.; methodology, P.P.A. and R.J.H.F.; validation, P.P.A. and R.J.H.F.; formal analysis, J.J. and P.P.A.; investigation, J.J., P.P.A. and R.J.H.F.; data curation, K.C. and A.C.; writing—original draft preparation, J.J., P.P.A and R.J.H.F.; writing—review and editing, P.P.A. and R.J.H.F.; visualization, K.C. and A.C; supervision, R.J.H.F and P.P.A; project administration, J.J. ; funding acquisition, R.J.H.F., P.P.A. and K.C.

Funding: This research received no external funding

Conflicts of Interest: The authors declare no conflict of interest.

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