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RESEARCH ARTICLE

Management of domestic solid waste in rural communities – a case study of the Río Blanco community, Ecuador

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Abstract: The current study focused on the proposal of a comprehensive management system for domestic solid waste in the rural community of Río Blanco belonging to the indigenous Ecuadorian Kichwa nationality. In this community, the burning of domestic solid waste is the only management strategy commonly used, which has generated various environmental and health impacts on the population. Therefore, here we focused on diagnosing the socio-environmental condition of the community through surveys in order to determine the average daily per capita production of domestic solid waste. This occurred through a characterization applying the methodology of the Pan American Health Organization (PAHO) and in the development of a proposal for a management model appropriate to the present demographic characteristics, from environmental education to its final disposal. The results obtained determined that the average DPCP of the community is 0.205 kg/person/day and the predominant category was the organic fraction with 45.84% of a total of 23.62 kg of solid waste produced. Finally, as appropriate management and use initiatives, we proposed the adaptation of an area for the generation of compost and a recycling system that allows obtaining economic resources for the benefit of the population.

Keywords: Solid waste, Indigenous rural communities, Management system

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1. Introducción

Solid waste management (SWM) arises from the need to solve the current needs of humanity in order to improve their livelihoods and well-being. In past decades, SWM was not considered a major problem because the world population was smaller [1] and the form of management was efficient thanks to the accessibility of the territory for its final disposal [2]. However, currently, household solid waste (HSW) is one of the environmental problems of greatest global concern due to the exponential increase in population [3], urbanization [4] and industrial growth [5]. Of the 2010 million tons of HSW produced annually in the world, only 67% is harvested and its production is estimated to increase to 3.4 billion tons by 2050 [[6]. In addition, the biodegradation of these residues releases a large amount of greenhouse gases (GHG) into the atmosphere, estimating a 5% contribution to total GHG emissions in the world [7].

The current volume of inadequately managed HSW production represents a public hygiene problem because it generates a focus of infectious diseases, generating problems in the health of the population [8,9]. In low-income countries, health risks are often exacerbated by the implementation of inappropriate SWNs such as open landfills and uncontrolled burning of solid waste [10–12]. These practices are common due to the lack of management and leadership of municipal authorities in terms of financial resources and public management [13,14]. In this context, Ecuador is not the exception, as in rural Amazonian communities a significant increase in the daily per capita production (PCP) of generated HSW has been evidenced [15].

The correct SWN in rural Amazonian areas is one of the needs of greatest current interest, due to the fact that a large part of rural areas do not have road infrastructure or access by land, which hinders waste collection [16]. On the other hand, this situation is aggravated by the little or no environmental education available to the inhabitants of rural areas about the proper management and handling of waste generated in their territories [17,18]. All this has generated waste accumulation practices in open spaces where waste is discarded without control or corresponding legal authorization [8,9,13,14]. This scenario is similar to what is currently evidenced in the Río Blanco community located in the Baños de agua santa canton, Tungurahua province in Ecuador. The community is composed of 109 inhabitants, all of whom are indigenous of the Kichwa indigenous nationality. This community is located a few kilometers from the urban area, generating a transformation in the food culture in the inhabitants of this indigenous nationality, producing as a consequence a higher generation of HSW than in other surrounding communities [15].

Furthermore, among the negative consequences to the natural environment generated by poor SWN, the contamination of water and soil resources stands out [19–22], visual contamination which is related to the deterioration of the landscape and economic effects on local tourism [23,24]. In addition, when HSW is incinerated in the open air, its combustion process releases harmful substances such as PM10, PM2.5, carbon monoxide (CO), heavy metals and persistent organic pollutants such as polycyclic aromatic compounds (HAPS), dioxins, polychlorinated and polybrominated furans [25–28]. This release of pollutants directly influences air pollution, increasing the incidence of serious health problems in the surrounding inhabitants of rural Amazonian communities [15,29]. In this sense, in the Río Blanco community there is currently no SWM in force, which has led to inadequate management of HSW, as it has been buried, burned, accumulated in public spaces or directly disposed into rivers.

These practices could be mitigated through the application of strategies included in environmental education programs [17]. However, it is essential to focus efforts and resources on the implementation of techniques and processes that make it possible to dispose, manage and reuse HSW [30–32]. Subsequently, an alternative needs to use a comprehensive SWM approach that considers everything

from generation to possible reuse, which could help safeguard the public health of citizens and sustainability [32,33]. In relation to sustainability, SRM must be performed in line with the 17 Sustainable Development Goals (SDGs) considered in the 2030 Agenda for Sustainable Development, agreed by 193 UN member countries in 2015 [34]. It has been identified that 12 SGDs contain within their goals a direct relationship with the HSW [35]. HSW is a critical need for sustainability in both urban and rural areas [36].

Similarly, national environmental regulations promote the management of waste and non-hazardous solid waste, from a circular economy and inclusive recycling approach, both in urban and rural areas, according to the Organic Environmental Code (COA) and the Regulations to the Organic Environmental Code (RCOA). In this scenario, the public institutions in charge of the management of these products are the Municipal Decentralized Autonomous Governments (GADs), which must generate policies that seek the fulfillment of all the objectives outlined, seeking a sustainable development of society.

In this context, the current research is mainly focused on the design of a comprehensive management system for domestic solid waste. This has been based on the socioeconomic characteristics of rural community of Ecuador, and in particular for the Río Blanco.

2. Materiales y métodos

2.1 Study area

The study area is located in the Río Blanco Community of the province of Tungurahua, Baños de agua santa Canton, Ulba Parish, in the center of the Ecuadorian highlands (Figure 1). The town has 109 homes, with public electricity and drinking water services. Currently only 37 homes are inhabited with a total of 115 people. This figure was taken as a reference of the target population. Río Blanco it is part of a predominantly agricultural sector, with a majority presence of people belonging to the mountainous Kichwa nationality.

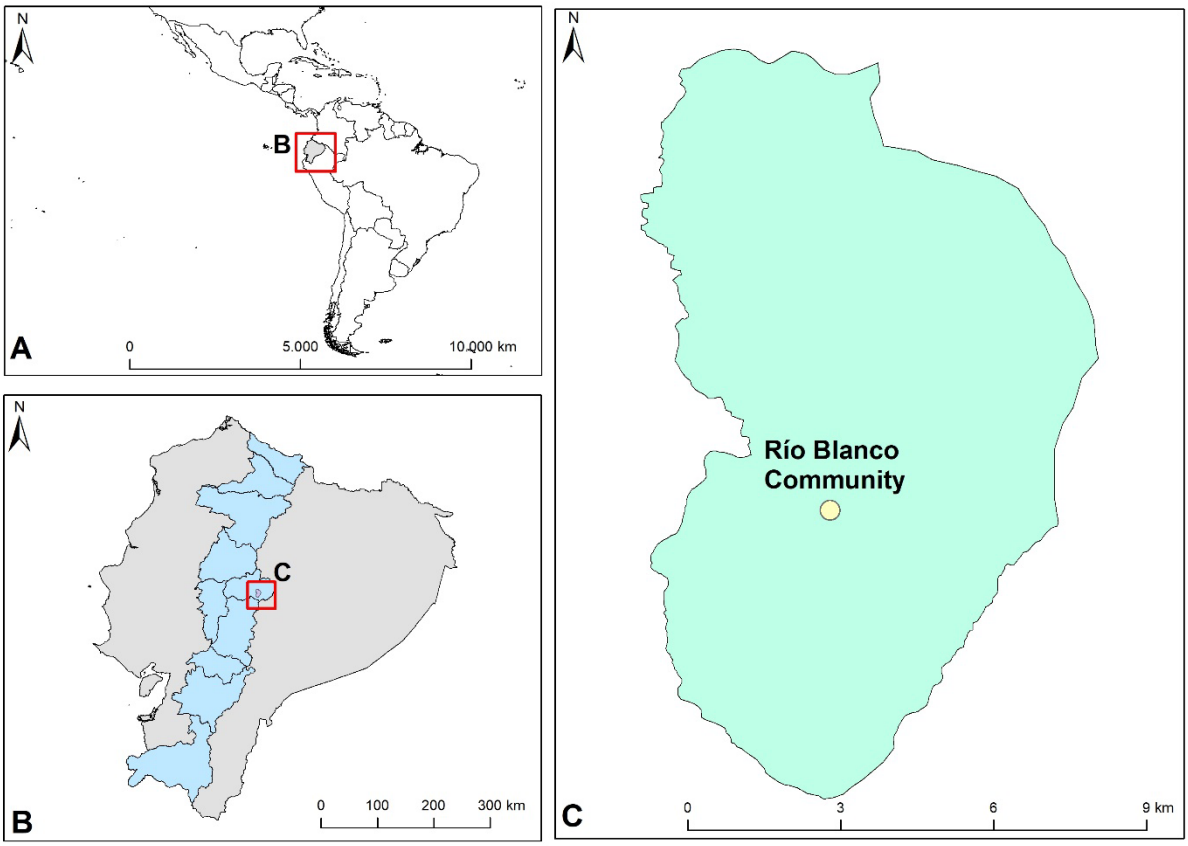

Figure 1. Study area; (a) Ecuador; (b) Ulba Parish; (c) Río Blanco Community.

2.2 Diagnosis of the current situation of HSW generation and management in the Río Blanco community

The quantitative and qualitative diagnosis of the HSW generation in the community was developed through the application of a descriptive survey based on open and closed questions, in the 37 inhabited dwellings. The topics consulted in the survey were discussed by a panel of teachers from the Environmental Engineering career at the Amazon State University of Ecuador, which was used as a validation system.

Likewise, these issues 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 Municipal Decentralized Autonomous Governments, which are obliged to promote management alternatives in the generators, promote in their territorial district programs and/or projects of environmental education, organization and citizen surveillance of environmental rights and nature [17].

In the particular case of this study, those directly responsible for solid waste management should be the Municipal GAD of the Baños de Agua Santa 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 domestic solid waste

To achieve the predominant aim of the study, 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 the different solid waste characterization studies in the countries of the Latin American and Caribbean Region, based on an established design [37], which consists of a standard procedure. Such methodology was applied in the 37 inhabited houses of the community, with a total of 115 inhabitants.

2.3.1 Solid waste collection in sampled homes

Each dwelling 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 aforementioned 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 their weight in kg was taken.

2.3.2 Calculation of daily average per capita production of domestic solid waste

The weight of the waste that was collected daily in each of the houses is represented by the abbreviation (Wt). Based on all the data collected, on the number of people per dwelling, the total number of people was determined, which in this case is represented by the abbreviation (n). To obtain the daily capita production, 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 solid waste collected was classified into the categories paper and paperboard, plastics, metals (including cans), glass, organic material, sanitary waste and others. The percentage of each component was calculated, applying Equation (2), taking into account 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 results of the survey and in the determination of the parameters of the characterization, which served to carry out the analysis of the results of the activities developed. Likewise, the STATISTICA statistical package 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.

2.5 HSW management system proposal for the Río Blanco community

Based on the results determined in the study of the production and characterization of the HSW generated in the Río Blanco community, proposals were developed for the management of the organic and inorganic part produced, ranging from environmental education to its final disposal, considering customs and availability of human and economic resources of the population.

3. Resultados y Discusión

3.1 Diagnosis of the current situation of HSW generation and management in the Río Blanco community

The results of the survey allowed to determine that 50% of families in the community are made up of 3 or more individuals. This result is similar to that indicated in the document "Ecuador Family in figures 2016" developed by the Private Technical University of Loja -UTPL, the Latin American Institute of the Family (ILFAM) and the Corporation for the Development of the Family-ORIENTAR, where states that the average number of members per household in Ecuador is 3 to 4 [38]. Regarding the current management of domestic solid waste, 45% of the families surveyed do not carry out any classification or use. The rest classifies and recycles organic matter and products such as plastic and paper. This value is significantly lower than that determined by [15], where 77% of families classify their solid waste. This data may be due to the fact that in the locality of study of this work, there is a collection service that simplifies the responsibility with these products on the part of the generator, which does not occur in the community of the compared work, generating the search for alternatives of use.

On the other hand, when asked if some type of treatment and/or revaluation of solid waste is known, 77% of the people surveyed mentioned composting. This coincides with the results of the work [39], developed in an Amazonian indigenous community in 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 families would be willing to contribute with an integral management of domestic solid waste, a fact that is repeated in the works [15,39], developed in the same way in rural areas

3.2 Characterization of domestic solid waste

3.2.1 Production per capita (PPC) of the Río Blanco community

The daily results obtained from the PPC are listed in Table 1. These measurements were obtained from May 31 to June 07, 2021. It is observed that the average PPC of HSW in the community is 0.205 kg/inhab/day.

Table 1. Daily average PPC of the Río Blanco community

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Average
Daily weight (kg)	23,65	23,11	20,86	23,34	23,95	23,45	26,97	23,62
PPP (kg/person/day)	0,206	0,201	0,181	0,203	0,208	0,204	0,235	0,205

This result can be compared with those obtained in works performed in other communities of the Ecuadorian highlands, such as that of [40], where a PPC of 0.330 kg/inhab/day was determined. In turn, there are investigations conducted in rural Amazonian areas, such as those performed by [41,42] in the province of Sucumbíos, in which average PPC values of 0.51 kg/inhab/day and 0.42 kg /inhab/day respectively. Another investigation is that presented by [39] 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 a study generated in a Cofán community [15], in which the result was 0.346 kg/person/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 [43], and in the background 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 predominant factors that condition the generation of HSW can be analyzed and determined.

At an international level, there is the work developed by [44], where the results obtained in the determination of the PPC in a community of the Peruvian highlands are established. The calculated value was 0.310 kg/person/day, which is similar to the conditions in Ecuador described previously.

3.2.2 Physical composition of solid waste

The community waste was characterized according to its physical constitution according to its type and composition (Table 2) and its quantity and percentage (Table 3).

Table 2. Physical constitution of the HSW of the Río Blanco community.

Type of waste	Composition
Paper and paperboard	Sheets of paper, notebook sheets, newspapers, magazines, brochures, cardboard, cardboard, food packaging.
Organic remains	Food scraps, eggshells, vegetable skins, bones, leaf and grass scraps.
plastics	Plastic covers, wrappers, beverage and oil bottles.
metals	Tuna and sardine cans, preserves.
Glass	Beverage bottles.
Domestic Sanitary Waste	Toilet paper, sanitary towels.
Others	Rubber, leather, remains of textiles and ceramics.

Table 3. Number and percentage of HSW in the Río Blanco community.

Days	Paper and paperboard		Organic remains		plastics		Metals (cans)		Glass		Others		Sanitary waste	
	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
2	2,67	11,29	10,43	44,10	4,32	18,27			0,57	2,41	1,67	7,06	3,99	16,87
3	2,24	9,69	11,65	50,41	3,32	14,37			0,84	3,63	2,33	10,08	2,73	11,81
4	1,54	7,77	10,46	52,77	4,04	20,38					0,53	2,67	3,25	16,40
5	2,73	12,09	9,9	43,84	3,76	16,65	0,32	1,42	0,14	0,62	0,76	3,37	4,97	22,01
6	2,97	12,40	10,73	44,80	4,97	20,75			0,43	1,80	0,28	1,17	4,57	19,08
7	3,75	11,97	12,83	40,94	5,54	17,68	0,77	2,46	0,77	2,46	2,79	8,90	4,89	15,60
8	2,14	9,15	10,3	44,04	4,16	17,79			0,17	0,73	1,65	7,05	4,97	21,25
Average	**2,58**	**10,62**	**10,90**	**45,84**	**4,30**	**17,98**	**0,55**	**1,94**	**0,49**	**1,94**	**1,43**	**5,76**	**4,20**	**17,58**

The percentage of organic waste generation is similar to that found in [40], where a value of 48% was determined, and it also corresponds to a rural community in the Ecuadorian highlands. However, in rural Amazonian localities [15,39,41,42], the average percentage is 66%. This fact can be explained due to the greater presence of urban customs by the communities of the highlands, in comparison with the localities studied in the aforementioned works. This, in turn, could evidence a process of acculturation in the area, as has been investigated in similar works [44].

3.3 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 developed that are 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. Descriptive statistics of the production and characterization of the HSW of the Río Blanco community.

	# of samples	Arithmetic average	Minimum value	Standard deviation
PPC	7	0,205	0,181	0,016
Organic remains	7	10,90	9,9	1,01
Paper and paperboard	7	2,58	1,54	0,70
Plastic	7	4,30	3,32	0,74
Glass	7	0,49	0,14	0,30
Others	7	1,43	0,28	0,94
Sanitary waste	7	8,34	6,73	0,90

3.4 HSW management system proposal for the Río Blanco community

For the correct design of the integrated HSW management proposal, the population of the community was projected based on the corresponding population growth rate, at a horizon of 15 years from the execution of this study. That is, to the year 2037 The growth rate of the Baños canton 2.40% was used, considering the last census carried out corresponding to the year 2010, since there is no information in the National Institute of Statistics and Censuses (INEC) specifically from the study community. For the year 2037 the population would be 164 inhabitants. With these results, Table 5 presents the projected HSW production values that were used to design the different stages of the proposal.

Table 5. Projected HSW production of the Río Blanco community.

Population	Current 115		Projected at 164	
	Weekly (kg)	Monthly (kg)	Weekly (kg)	Monthly (kg)
Organic remains	76,30	305,20	108,80	435,24
Paper and paperboard	18,06	72,24	25,75	103,02
Plastic	30,10	120,40	42,93	171,70
Glass	3,43	13,72	4,89	19,57
Others	10,01	40,04	14,28	57,10
Sanitary waste	29,40	117,60	41,93	167,71
Total	**167,30**	**669,20**	**238,58**	**954,34**

3.5 Environmental Education Phase

The proper functioning of the comprehensive management of solid waste requires great shared commitments between the inhabitants of the community and the local authorities, since the complexity involved in this procedure 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 Regulation of the Organic Code of the Environment (RCOA) [45]. To achieve this objective, the training schedule documented in Table 6 is proposed.

Table 6. Environmental education topics.

	Day 1	Day 2	Day 3
Training Topics	Opening	Welcome presentation	Welcome presentation
	Classification of solid waste.	Waste management and its social problems.	Household organic waste composting method.
	Recycling of organic content.	Recycle helps.	
	Recycling of recyclable content.	Recycling protects the environment.	
	Unusable HSW disposal.	Biosafety measures for the management of HSW of sanitary origin	

3.5.1 Temporary storage phase

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

3.5.2 Collection and Transportation 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 they suffer, and because it is the category with the highest production. For this reason, it is proposed that, within the community, a person or a group of people be assigned to work in a rotational manner, who will have the responsibility of moving the organic matter from each inhabited dwelling, to the place destined for the system of composting.

For the recyclable fraction, in the same way, it will be assigned 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. After this, on a monthly basis, these materials will be transported to a recycling center in the city of Baños de Agua Santa, province of Tungurahua. The monthly cost for these activities will be 7.00 USD. Meanwhile, the profits from the sale of these products have been estimated through interviews with owners of recycling centers, and are presented in Table 7.

Table 7. Estimated earnings from the sale of recyclable waste from the Río Blanco community.

Type of waste	Monthly profit (USD)	
	Current	projected
paper-cardboard	15,17	21,63
Plastic	20,47	29,19
Glass	1,10	1,57
Total	36,74	52,39

Finally, the fraction considered as waste must be disposed of to be collected by the collection service provided by the municipal GAD of the Baños de Agua Santa canton.

3.5.3 Phase of Use of the organic fraction

For this phase, an area of 42 m2 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 roofed 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 carried out, but the research work generated in the Amazonian indigenous community Limoncocha [42] 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 plant and not animal origin. To reduce this ratio to the optimal range (25–35), the incorporation of poultry manure in a 1:1 ratio with the HSW of the community is proposed, which increases the percentage of nitrogen and thus the C/N ratio decreases. up to adequate values [46,47].

The cost of a sack of poultry manure in the city of Baños is 1.50 USD. In addition, a monthly sack of agricultural lime will be needed for odor control at a cost of 12 USD, 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 305.20 kg per month, that the addition of poultry manure would be in the same amount, that 30 to 50% of the total weight is transformed into compost [48] and taking a reference value of 30%, 5 bags of 35 kg of organic fertilizer would be obtained monthly, which could be marketed at 6 USD each. This value was taken based on the reference in the Province of Pastaza, where the GADM of the Pastaza Canton, through the Pastaza Recicla program, generates compost from solid vegetable waste produced both in markets and in homes. The current monthly profit would be 30 USD and with the generation projected for 15 years it would be 42 USD.

3.5.4 Final Disposal Phase

At the time of applying the entire proposed management system, it would be possible to take advantage of approximately 76% of all HSW generated and only 24% (waste, metals and others) would reach the Sanitary Landfill of the city of Baños de Agua Santa.

3.5.5 Hazardous waste management

There is little hazardous waste generation in the locality. Sanitary waste is disposed of for collection by the public service. There is agricultural waste, such as plastic agrochemical containers, which are returned to the commercial companies as part of the extended responsibility process.

3.6 Summary of costs and income

The total monthly cost that would be generated by applying the proposed management system would be USD 23, considering the transportation costs of recyclable waste, agricultural lime, chicken manure and a 10% safeguard. While, the earnings that could be obtained in the current conditions of number of inhabitants, would be approximately 66.74 USD, obtaining a monthly net income of 43.74 USD. The economic resources obtained could be managed in the community itself, 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 in a disinterested way in the activities of collection, transport and construction of the composting area, knowing that the economic gains can be used for the welfare of the entire community.

4. Conclusiones

It was determined that the daily average PPC of HSW in the Río Blanco community, located in the Ecuadorian highlands, is 0.205 kg/person/day, while the total daily generation is approximately 23.62 kg. These values are similar to those of other localities in the region, but lower than those found in the Amazonian indigenous communities. The causes of this particularity could be the socioeconomic and cultural conditions of each community, although it is necessary to be able to conduct more studies of this type, in order to ratify this conclusion.

In turn, the organic fraction constitutes the type of waste that is generated in greater quantity, 45.84% 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, transportation and use of organic and recyclable fractions. This contributes to environmental conservation, through a circular economy approach and empowerment of citizens.

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