Municipal solid waste treatment complex in small towns. Case study: San Andrés de Machaca.

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Abstract: The project to conceptualize the Urban Solid Waste Treatment Complex in the town of San Andrés de Machaca, has been designed to give final disposal to common solid waste and hospital waste generated in the urban area and part of the rural area, in addition to taking advantage of organic waste through the generation of compost, additionally contemplates the recovery of part of the potentially recyclable materials, which will be carried out in a recycling plant that will be located inside the complex. The proposed and requested design is intended not as a final disposal site, but rather as a complex that integrates all the units in order to take advantage of solid waste, so that in the long term the common waste cell reduces the waste it receives. and thereby increase its useful life.

Keywords: Complexes, towns, waste, WTC.

Introduction

In Bolivia, the management and handling of municipal solid waste is the exclusive responsibility of the Autonomous Municipal Governments (GAM), as stated in Article 32 of the Political Constitution of the State: "The autonomous municipal governments have exclusive responsibility for urban sanitation, management and treatment of solid waste within the framework of State policy".

According to data from the Ministry of Environment and Water, in Bolivia, only 6.87%, that is, 23 of the 339 municipalities in the country, have sanitary landfills, of which only 16 are in operation; the rest (316) continue to operate in open dumps due to the lack of economic resources and trained personnel; approximately 18% are located near riverbanks, generating water pollution that has not yet been quantified. (Opinión, 2017).

Of the total number of municipalities "*60% are small, with a population range of 2,000 - 10,000 inhabitants*" (INE, 2015); for this reason, it is necessary to attend the management of solid waste in small towns and not only focus on medium and large ones.

Dumps and areas contaminated by waste must enter into processes of closure, technical closure and environmental sanitation, in compliance with current regulations and health protection, within a maximum period of five years, according to the planning issued by the Ministry head of sector (Bolivia, 2015).

Until the closure of landfills is achieved and authorized sites, sanitary landfills, are implemented, it is necessary to have a landfill adequacy plan, in which mitigation and management measures will be established, this document must be approved and supervised by the departmental government in accordance with the provisions of Article 40 of Law 755 of 2015. (Bolivia G. O., 2015)

In San Andrés de Machaca, there are only dumps, which do not have any type of environmental permit or license. The municipality subsidizes the sanitation service with its own resources and generates 40 tons/year, which has four uncontrolled disposal sites near the community.

The conceptualization of the San Andres de Machaca Urban Solid Waste Treatment Complex considers: the morphology of the terrain, topographic conditions, soil structure and composition, water table, availability of cover material, characterization or composition, waste quantification, and the planned useful life of the landfill.
The purpose of this work is to demonstrate that it is also possible to have a Solid Waste Treatment Complex in small municipalities (localities), and in this way be able to make use of the waste and a disposal in the common waste cell,

less and less; also that the integral and adequate management of waste is not only for large or medium-sized localities; pollution is mainly caused by the sum of several small sites due to poor or non-existent waste management.

Study Area

The Katari Basin is home to approximately 10% of the total national population, making it one of the most populated basins in the country, which in recent decades has presented a series of problems related to the management of natural resources, such as the deterioration of surface and groundwater quality. These problems, aggravated by the effects of climate change, have affected the ecosystem, livelihoods and biodiversity of Lake Titicaca.

The Bolivian sector of Lake Titicaca corresponds to the area of Lake Titicaca, and is made up of 6 provinces, of which 5 are located on the shores of Lake Titicaca and one that does not have coastline, there are several Bolivian municipalities that are relevant to carry out its sanitation San Andrés de Machaca is one of them. This has been marked by the growth of its local economies, which are dominated by agriculture, fishing, livestock, dairy farming and tourism, all of which have a significant impact on the Lake Titicaca basin~~.~~ (UNESCO, 2013).

San Andrés de Machaca, is located in the Ingavi province of the La Paz Department (Figure 1), the municipality has an area of 1,575.91 km², an average annual temperature of 8°C and the town is located 116 km west of the city of La Paz, which is the capital of the country (SENAHMI, 2012).

The municipality is formed physiographically by a set of mountains and hills, so its altitude varies from 3,810 meters above sea level in the area of Lake Titicaca to 4,381 meters above sea level at Cerro Pacocahua. Most of its territory is made up of the plains of the Bolivian Altiplano; San Andrés de Machaca is an agricultural/commercial municipality.

Ordinary waste is taken to one of the municipality's official dumps located about 300 meters away.

Figure 1. Geographical location of the municipalities in the study (Google Earth)

Materials and Methods

Burning waste in the open air is an ancestral practice that reduces the infectious health risk of waste, limits the proliferation of vectors, flies and mosquitoes, as well as dogs, birds and rabbits, limits the dispersion of bags and reduces the volume of waste, which has been promoted by non-governmental organizations (NGOs) in the municipalities, particularly in the case of San Andrés de Machaca. However, this practice also has negative impacts such as air pollution and health risks due to the emission of toxic gases during burning and contamination of water sources and soil.

The burning pit is widely used by municipalities that produce little waste. The municipal backhoe digs a pit whose volume can measure between 5 and 20 m³.

In San Andres de Machaca, where the main activity is cattle ranching, less than 5% live in the capital of the municipality (total population approximately 6,100), so the project's focus should be on the rural sector. Likewise, according to the PTDI, there is a strong rural influence in the composition of municipal authorities. In this sense, rural input and contributions to the decision-making process in the municipality are important (Gobierno Autónomo Municipal de Jesús de Machaca, 2016b).

Improper waste management increases the presence of pests and animal vectors that cause disease, such as rats, pigeons, cockroaches, flies, etc.

Many micro dumps and dumps are located very close to farmland causing volatile elements to be carried by the wind and contaminating crops. In several cases animals eat plastic bags causing serious problems and even death.

The physical composition of the waste obtained in a previous characterization carried out by the Municipal Government of San Andres de Machaca is presented in Table 1 (Gobierno Autónomo Municipal de Jesús de Machaca, 2016a).

It is important to have secondary information or to carry out field work in order to have data on waste characterization.

Table 1. Physical composition of waste obtained from primary information.

Materials	**San Andres de Machaca**
Paper	2.5%
Cardboard	4.1%
Glass	0.1%
Plastic	13.2%
Multilayer - Tetra Pak	0.1%
Ferrous scrap	10.7%
Non-ferrous scrap	0.8%
Food and food waste	18.2%
Sanitary waste (toilets)	7.9%
Gardening	7.9%
Sweep	25.4%
Textiles	2.5%
Wood	2.0%
Others	4.5%
TOTAL	**100%**

(Gobierno Autónomo Municipal de Jesús de Machaca, 2016a)

Organic matter predominates in the waste composition, followed by plastic waste and others, cited in Table 2. The data used were:

Table 2. Waste generation data

Growth Urban PPC	
Growth Rural PPC	0%
Waste density	0.55
% sweep w/r RSM* % sweep w/r RSM* % sweep w/r RSM	
% sweep w/r RSM**	

(Gobierno Autónomo Municipal de Jesús de Machaca, 2016a)
*Year 1 to 5 generation of 3% c/r urban generation is contemplated,
**A generation from year 6 of 2% c/r urban generation is contemplated, due to the fact that collection coverage reaches 100%.

It should be noted that the latter category includes waste such as Tetrapak, sanitary, sweepings, textiles, wood and construction and demolition waste, the summary results are shown in Table 3.

Table 3. Physical composition of waste recorded from primary and secondary information.

Materials	Organic Matter	Plastics	Paper and Cardboard	Metals	Glass	Others	TOTAL
San Andres de Machaca	26.1 %	13.2 %	6.6 %	11.5 %	0.1 %	42.4 %	100.0%

(Gobierno Autónomo Municipal de Jesús de Machaca, 2016a)

The general waste composition is shown in Table 4.

Table 4. Waste composition

Materials	Organic Matter	Other (Garbage)	Recyclables	Total
San Andres de Machaca	26.10%	42.40%	31.40%	100%

(Gobierno Autónomo Municipal de Jesús de Machaca, 2016a)

Waste data are summarized in Table 5. The waste density (also called specific weight) is directly related to the physical composition of the waste, showing that the values oscillate within the common range for municipal solid waste (MSW), between 40 and 200 kg/m³.

Table 5. Per Capita Production and Density of Waste

Municipality	PPC (kg/inhab/day)	Specific weight (kg/m³)
San Andres de Machaca	0.38	127.00

(Gobierno Autónomo Municipal de Jesús de Machaca, 2016b)

Population data, is shown in Table 6:

Table 6. Population and production per capita

Population	Growth rate PPC	Urban PPC	% Pop.
6,124	Urban 0.92% Urban Rural	0.38	100% urban Rural 0.0% 0%

(Gobierno Autónomo Municipal de Jesús de Machaca, 2016b)

The population of San Andres de Machaca totals 6,124 inhabitants and considering that the coverage of the sanitation service will reach 50%, the same percentage is considered for final disposal.

Generation data are summarized below:

1. Generation

To obtain waste generation data:

Generation (ton/day) = Population (hab.) x PPC (kg/hab.-day)

Sweep (ton/day) = Generation (ton/day) x 3% (Year 1 to year 5)

Sweep (ton/day) = Generation (ton/day) x 2% (From year 6 onwards)

Generation from years 1 to 5 is expected to be 3% of urban generation (where solid waste management is in place; rural areas are dispersed, which is why the system includes them), a percentage that drops to 2% as of year 6, since collection coverage reaches 100%, as shown in Table 7.

Table 7. Waste generation

Year	Population	Urban	Rural	Urban PPC	Rural PPC	Urbana Ton/day	Rural Ton/day	Sweep Ton/day	Total Ton/day	Total Ton/year
2019	3,062	3,062	0	0.380	-	1.05	0.00	0.03	1.08	394.20
2020	3,057	3,057	0	0.380	-	1.05	0.00	0.03	1.08	394.20
2021	3,037	3,037	0	0.384	-	1.05	0.00	0.03	1.08	394.20
2022	3,026	3,026	0	0.388	-	1.06	0.00	0.03	1.09	397.85
2023	3,015	3,015	0	0.392	-	1.06	0.00	0.03	1.09	397.85
2024	3,004	3,004	0	0.395	-	1.07	0.00	0.03	1.10	401.50
2025	2,993	2,993	0	0.399	-	1.20	0.00	0.02	1.22	445.30
2026	2,982	2,982	0	0.403	-	1.20	0.00	0.02	1.22	445.30
2027	2,971	2,971	0	0.407	-	1.21	0.00	0.02	1.23	448.95
2028	2,960	2,960	0	0.411	-	1.22	0.00	0.02	1.24	452.60
2029	2,949	2,949	0	0.416	-	1.23	0.00	0.02	1.25	456.25
2030	2,938	2,938	0	0.420	-	1.23	0.00	0.02	1.25	456.25
2031	2,927	2,927	0	0.424	-	1.24	0.00	0.02	1.26	459.90
2032	2,916	2,916	0	0.428	-	1.25	0.00	0.03	1.28	467.20
2033	2,905	2,905	0	0.432	-	1.26	0.00	0.03	1.29	470.85
2034	2,894	2,894	0	0.437	-	1.26	0.00	0.03	1.29	470.85
2035	2,883	2,883	0	0.441	-	1.27	0.00	0.03	1.30	474.50
2036	2,872	2,872	0	0.446	-	1.28	0.00	0.03	1.31	478.15
2037	2,850	2,850	0	0.450	-	1.28	0.00	0.03	1.31	478.15
2038	2,839	2,839	0	0.455	-	1.29	0.00	0.03	1.32	481.80
2039	2,828	2,828	0	0.459	-	1.30	0.00	0.03	1.33	485.45

2. Utilization

For utilization, the following data come from Table 7, which are the result of urban and rural generation, and subtracting the amount of daily sweeping, we have the generation data by type of waste in Table 8.

Table 8. Generation by type of waste

Generator	Generation		
	Ton/day	Ton/day	% share
Domiciliary	1.08	1.08	100.00%
Sweep	0.03	0.00	0.00%
Total		1.05	100.00%

Waste composition, which comes from the characterization results, is the input for the results in the following table:

Table 9. Percentage Share of Waste by Type

Recyclables	Organic	Garbage	Total
31.40%	26.10%	42.40%	99.90%
		100.00%	100.00%
31%	26%	42%	99.90%

To obtain the results of Table 10, the household waste data (1.08 ton/day), recorded in Table 8, must be multiplied with the percentage of recyclable and organic waste recorded in Table 9 (31.4 and 26.1%, respectively), and also the remaining percentage (42.4%) that is garbage; in the same way for the projection of year 20, in this way the amount in (ton/day) according to typology will be obtained.

Table 10. Waste by Type Ton/day

	Recyclables	Organic	Garbage	Total
Domiciliary	0.34	0.28	0.46	1.08
Sweep	0.00	0.00	0.00	0.00
Total (year 20)	0.43	0.35	0.55	1.33

Quantity to be used S/PMR	1.00	ton/day
Quantity Total waste	2.00	ton/day
Target Utilization	50%	With respect to urban population
Quantity to be Utilized Project	0.5	ton/day

With the results obtained in Table 10 and according to the proposed composting goals, the amount of waste to be composted in tons/day is shown in Table 11.

Table 11. Year 1 Composting Goals

Sector	Organics	Target Utilization	Waste for composting
	ton/day	%	ton/day
Domiciliary	0.28	50%	0,140
Total Year 1			0.140

With the results obtained in Table 10 and according to the recycling goals set, we can have the amount of waste to be recycled in ton/day, as shown in Table 12.

Table 12. Recycling Goals Year 1

Sector	Organics	Target Utilization	Waste for recycling
	ton/day	%	ton/day
Domiciliary	0.34	50%	0,170
Total Year 1			0.170
Total composting + recycling	= 0.140 + 0.170		
Total Utilization Year 1 (ton/day)			0.310

Proposed goals

It is necessary to set goals that define a reasonable growth in the use of organic waste and recyclable waste, such goals are given by the conditions that the municipal government has at the moment, ideally if there were data on recycling in some neighborhoods of the municipality, it would help to be able to project these data.

With these growth rates, the target is met over the life of the project.

Growth rate Composting 5.0% per year
Recycling Growth Rate 8.0% annual

Having calculated the amount of waste to be used, the % for composting and recycling should be obtained for each, with respect to the generation (recorded in Table 7), the amount of waste to be composted is divided by the total generation, in the same way for the waste to be recycled, the results in Table 13.

Composting (%) = Amount of composting (ton/day) / Total generation (ton/day)
Recycling (%) = Recycling quantity (ton/day) / Total generation (ton/day)

Table 13. Percentage of usable waste

Year	Quantity of waste to be used		% With Respect to Urban Generation		
	Composting Ton/day	Recycling Ton/day	Composting %	Recycling %	Total
2019	0.14	0.17	12.9%	15.7%	28.6%
.....					
2039	0.36	0.77	27.6%	59.2%	86.7%

3. *Waste flow within the complex*

To complete the waste flow, we must include the percentage of rejection, the percentage that is estimated, but that is given by the experiences of utilization, both for recycling and composting is 5%, percentage to the amount of ton/day of both (recycling and composting), so that we finally obtain the amount that would go to the landfill.

Recycling scrap material 5%.
Composting scrap material 5%.

Composting rejection = Amount of waste to be composted x Composting scrap material (5%)
Recycling rejection = Amount of waste to be composted x Recycling scrap material (5%)

Table 14. Waste flow within the complex

Year	Generation ton/day	Composting ton/day	Recycling ton/day	Rejection ton/day	Landfill ton/day
0	1.08	0.14	0.17	0.02	0.80
1	1.08	0.14	0.18	0.02	0.78
.....					
20	1.33	0.36	0.77	0.06	0.26

4. *Common waste cell*

With the values obtained in Table 14, the waste projection is made for the common waste cell.

Table 15. Common waste cell

Year	Income Residues			Compacted waste			Material Coverage			Waste + Coverage	
	Diary ton/day	Annual ton/year	Accumulated ton	Diary m^3/day	Annual m^3/year	Accumulated m^3	Diary m^3/day	Annual m^3/year	Accumulated m^3	Annual m^3/year	Accumulated m^3
2019	0.80	292.0	292.0	1.45	530.9	530.9	0.22	79.6	79.6	610.5	610.5
2020	0.78	284.7	576.7	1.42	517.7	1,048.6	0.21	77.7	157.3	595.3	1,205.9
2021	0.76	276.9	853.6	1.38	503.5	1,552.1	0.21	75.5	232.8	579.0	1,784.9
2022	0.75	272.2	1,125.9	1.36	495.0	2,047.1	0.20	74.2	307.1	569.2	2,354.1
2023	0.72	263.3	1,389.2	1.31	478.8	2,525.8	0.20	71.8	378.9	550.6	2,904.7
2024	0.71	257.4	1,646.6	1.28	468.0	2,993.9	0.19	70.2	449.1	538.2	3,443.0
2025	0.80	291.0	1,937.6	1.45	529.1	3,523.0	0.22	79.4	528.4	608.4	4,051.4
2026	0.77	280.1	2,217.7	1.40	509.2	4,032.1	0.21	76.4	604.8	585.6	4,637.0
2027	0.76	275.6	2,493.3	1.37	501.1	4,533.3	0.21	75.2	680.0	576.3	5,213.3
2028	0.73	266.7	2,760.0	1.33	484.9	5,018.2	0.20	72.7	752.7	557.7	5,771.0
2029	0.70	256.9	3,016.9	1.28	467.1	5,485.3	0.19	70.1	822.8	537.2	6,308.1
2030	0.66	242.5	3,259.4	1.21	440.9	5,926.2	0.18	66.1	888.9	507.0	6,815.2
2031	0.63	230.7	3,490.1	1.15	419.5	6,345.7	0.17	62.9	951.9	482.4	7,297.6
2032	0.62	225.1	3,715.2	1.12	409.3	6,755.0	0.17	61.4	1,013.2	470.7	7,768.2
2033	0.58	211.0	3,926.2	1.05	383.6	7,138.6	0.16	57.5	1,070.8	441.2	8,209.4
2034	0.53	192.0	4,118.2	0.96	349.0	7,487.6	0.14	52.4	1,123.1	401.4	8,610.8
2035	0.48	175.2	4,293.4	0.87	318.6	7,806.2	0.13	47.8	1,170.9	366.4	8,977.1
2036	0.44	160.6	4,454.0	0.80	292.0	8,098.2	0.12	43.8	1,214.7	335.9	9,313.0
2037	0.38	137.2	4,591.2	0.68	249.4	8,347.6	0.10	37.4	1,252.1	286.8	9,599.8
2038	0.32	115.6	4,706.8	0.58	210.2	8,557.8	0.09	31.5	1,283.7	241.8	9,841.5
2039	0.26	95.9	4,802.7	0.48	174.4	8,732.2	0.07	26.2	1,309.8	200.5	10,042.0
		4.510,7			8.201,3			1.230,2		9.431,5	

Loose density kg/m^3	0.25ton/m^3
Compacted density kg/m^3	0.45ton/m^3
Stabilized density kg/m^3	0.55ton/m^3
Covering material	15%

Leachate

Leachate is calculated as follows:

$$Q = \frac{1}{t * (P * A * k)} \quad \textbf{(1)}$$

where: Q is the average leachate flow rate in L/seg; P is the average annual precipitation; A is the surface area of the landfill cells in m^2; t is the number of seconds in a year; and k is the coefficient that depends on the degree of compaction of the garbage (0.35-0.50).

Table 16. Leachate Flow

Municipality	Average rainfall (mm)	Surface area of landfill (m^2)	Average leachate flow (L/s)	Average leachate flow (m^3/d)
San Andrés de Machaca	490	1700	0.019	0.8

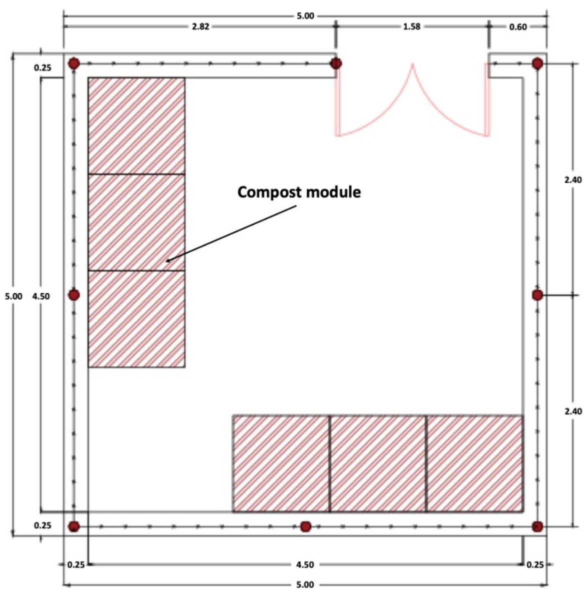
A capacity of 71.89 m³, stores leachate 895 L/day, the tank has a capacity of 12 days, and then goes to the evaporation pool, with a capacity for 90 days (3 months). The solar radiation values are high since the location is in the altiplano; Bolivia is one of the countries that receives the most solar radiation in the world. 66% of Bolivia has one of the highest levels of solar intensity on the planet, the highest annual average daily solar radiation is present in the altiplano (Solón, 2017)

Among the main climatic parameters that affect evapotranspiration are radiation, air temperature, atmospheric humidity and wind speed (ALLEN, 1994)

Compost

The composting area is a site with a fence made of callapos, its dimensions 5.0 x 5.0 m, the modules are arranged inside as shown in image 28, dimensions 1.0 x 1.0 x 1.0 x 1.2 m.

Density 500 kg/m³



(a)

(b)

Figure 2. (a) Compost area; (b) final disposal site Tiahunacu.

The volumetric calculations are detailed in Table 17 below.

Table 17. Compost volumetric calculations

Year	**Composting** ton/day	**Composting** kg/day	**Composting** ton/year	**Compost volume** (m³) day	**Compost volume** (m³) year
2019	0.14	135.00	49.28	0.27	98.55
…….					
2039	0.36	358.20	130.74	0.72	261.48

The Table 18 details the dimensions of the compost module.

Table 18. Compost module dimensions

Ítem	Length (m)	Width (m)	Height (m)
Dimensions (composting area)	5.00	5.00	2.00
Dimensiones (compost module)	1.00	1.20	1.00
Module capacity (m^3)		1.20	

One module covers the capacity of 4 days of organic waste generation.

Recycling

The sorting area for recycling will be a shed, where recycling techniques can be implemented as this practice grows in the municipality.

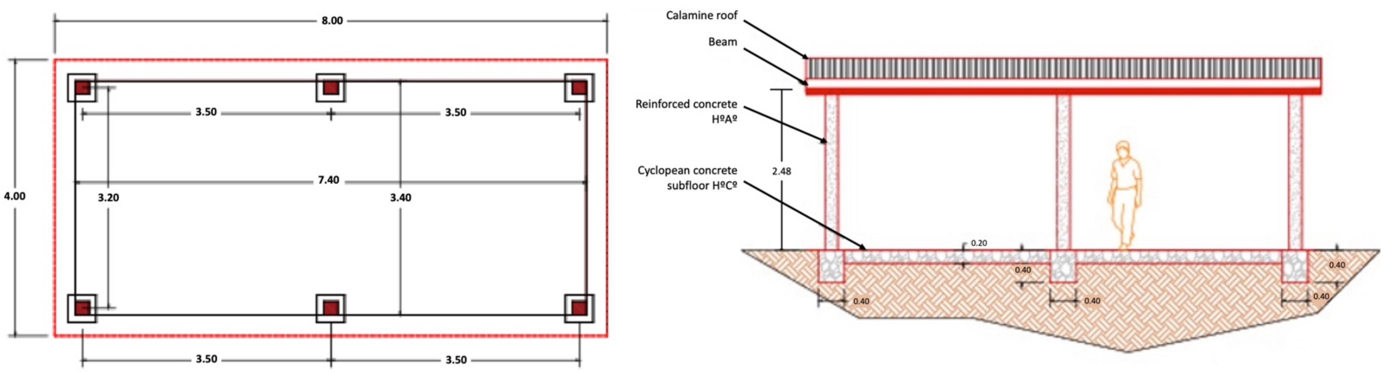


Figure 3. Selection area

The Table 19 details the dimensions of the selection area.

Table 19. Selection area dimensions

Ítem	Length (m)	Width (m)	Height (m)
Dimensions (selection area)	5.00	5.00	2.00

The volume calculations are detailed in Table 20, considering a density of 900 kg/m³, the monthly capacity is 5.5 m³ (according to the proposed goals).

Table 20. Volumetric calculations for the selection area

Year	Recycling T/day	Recycling kg/day	Recycling T/year	Recycling volume m^3/day	Recycling volume m^3/year
2019	0.17	165.00	60.23	0.18	66.92
…….					
2039	0.77	769.06	280.71	0.85	311.90

Supply - Demand Balance

From the comparison of demand and supply, the future deficit was established if the current conditions in the municipality are maintained.

The projection of the deficit between current supply and demand is shown graphically in Figure 4, which shows the lack of a final disposal site for solid waste. The generation of solid waste in the municipality will increase 37% by the year 2040, assuming that per capita production remains the same, and it is projected that the percentage of collection coverage will decrease from 100% to 77% in the same of time. Taking into account the above, it is evident that there is a deficit between the growing demand and the current supply in the municipality in terms of waste management.

As shown in the Figure 4, the final disposal site in the municipality of San Andrés de Machaca should have a capacity of approximately 1,042 tons in order to store the total amount of waste generated in the municipality. The landfill will dispose of an average of 45 tons of waste per year.

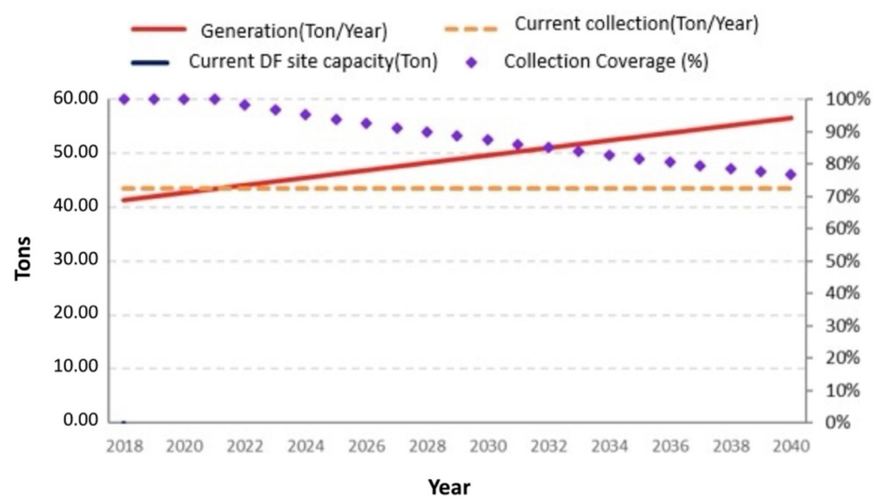


Figure 4. Current Supply vs. projected Demand

It is estimated that approximately 83 tons of waste will be used, according to the proposed use percentages.

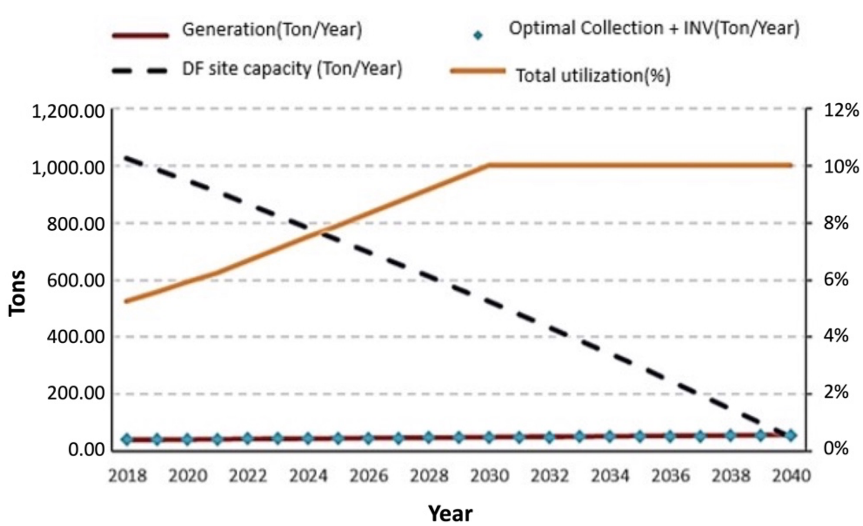


Figure 5. Supply with investment vs. projected demand

The projection of the deficit between current supply and demand is shown graphically in the Figure 5. As can be seen in the graph, the lack of a final disposal site for solid waste is evident. The generation of solid waste in the municipality will increase by 37% until 2040, assuming that per capita production remains the same, and it is projected that the percentage of collection coverage will decrease from 100% to 77% in that period of time.

Taking into account the above, it is evident that there is a deficit between the growing demand and the current supply of the municipality in terms of waste management.

Results and discussion

According to the calculations performed, the following results are obtained, for the 20 years projection:

Composting Area: 360 kg/day
Recycling Area: 770 kg/day
Landfill:
Waste: 8.732.2 m^3
Coverage: 1,309.8 m^3
Total: 10,042.2 m^3
Leachate:
Capacity of the Storage tank 895 L/day, the tank has a capacity of 12 days.
Evaporation pool capacity 50 m^3

The Flow Diagram of the Complex is shown in the Illustration of Figure 6, the values that are presented are those projected at 20 years, it is important to highlight the reduction of waste that enters the WTC, which starts with 800 kg/day and at year 20, reduces to 260 kg/day, thanks to the use.

The solid waste treatment and disposal complex consists of a common waste cell, an emergency cell and a safety cell (bioinfectious), each of which includes adaptation works such as excavations, landfills, roads, a leachate drainage system, chimneys for gas management and rainwater management ditches.

The San Andres de Machaca Waste Disposal and Treatment Complex (WTC) includes eight key processes:

- Waste registration and inspection;
- Organic waste composting;
- Recycling in the selection area
- Final disposal of household solid waste and assimilable waste in a common waste cell;
- Final disposal of household solid waste and similar waste in an emergency cell
- Final disposal of hospital waste in a safety cell;
- Hazardous waste storage
- Leachate storage
- Leachate treatment (evaporation pool)

The main activities to be developed within the Complex are as follows:

- Reception, inspection and registration of waste entering the center.
- Waste discharge by type and handling.
- Final disposal of household and similar solid waste in a common waste cell.
- Final disposal of hospital solid waste in a safety cell
- Temporary disposal of household and similar solid waste in an emergency cell
- Leachate collection, conveyance and treatment
- Biogas chimney
- Organic waste utilization through composting

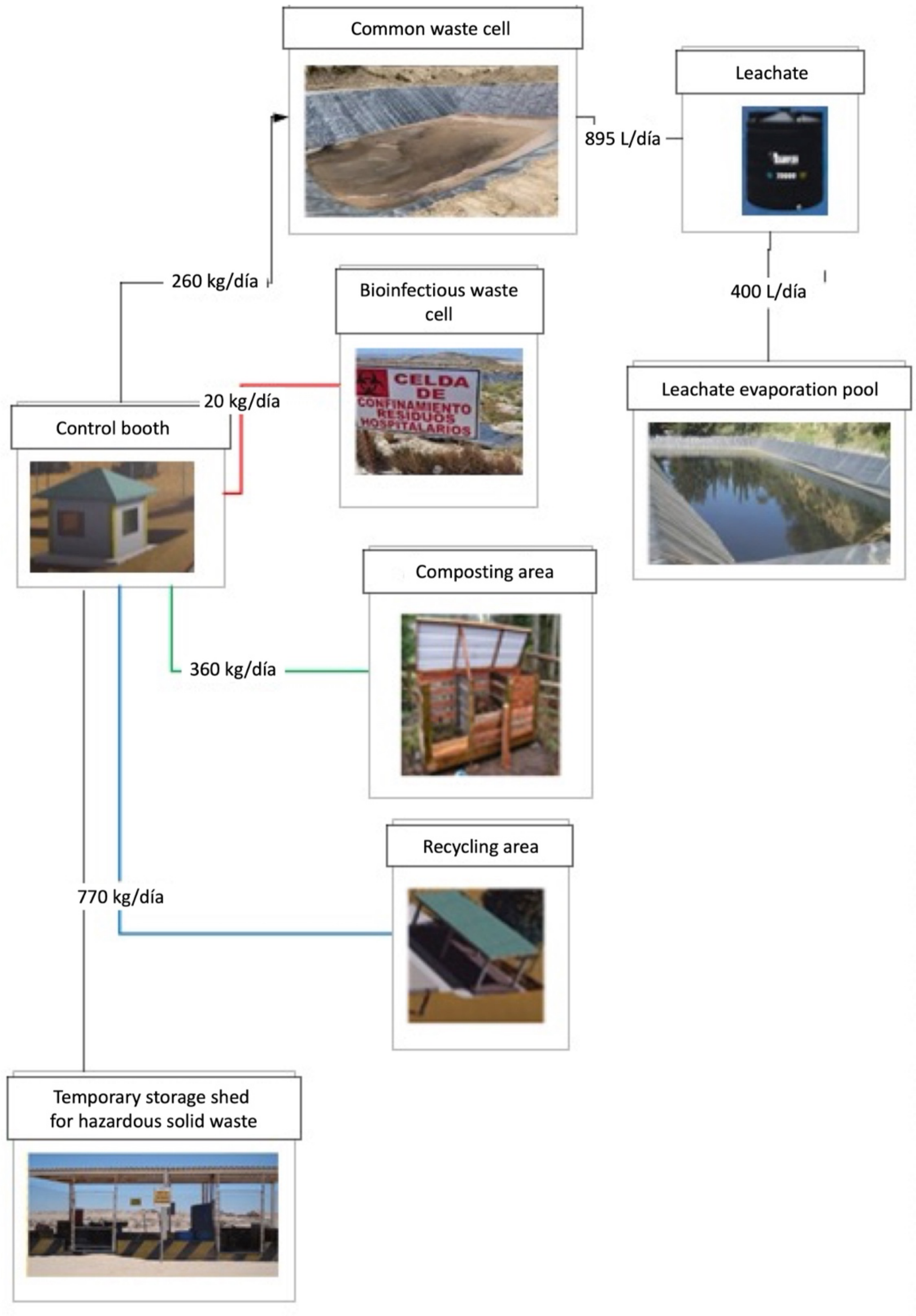


Figure 6. Complex flow diagram

The following Illustration - Layout (arrangement of the units of the Solid Waste Complex)

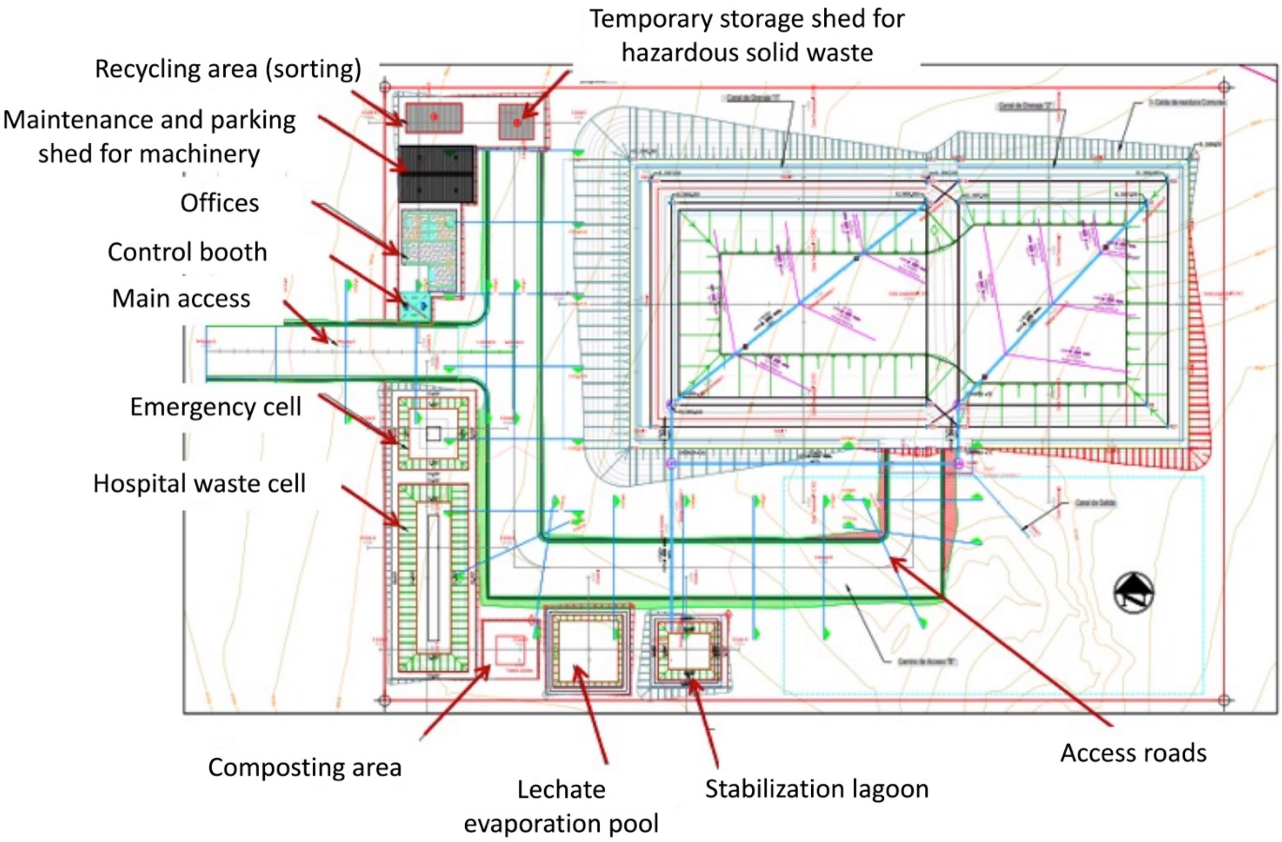


Figure 7. Layout of the Solid Waste Complex Units

The useful life of the complex is 20 years, a period for which all facilities have been designed. Both the design of the Complex and all activities or works related to its construction, operation and closure have been carried out in accordance with current Bolivian regulations (Agua, 2012).

The following is a detail of the surface areas of the aforementioned areas

Table 21. Location of Project Surfaces

Sector	Surface	Unit
Total area of the property	1.02	has
Surface of the Complex	1.02	has
Administrative office, personal sanitary facilities, dining room	75.0	m^2
Maintenance and machinery shed	128.0	m^2
Control booth	7.5	m^2
Landfill	1904.0	m^2
Hospital waste safety cell	105.0	m^2
Emergency cell	49.0	m^2
Stabilization pond	30.0	m^2
Evaporation pool	72.30	m^2
Hazardous waste shed	16.0	m^2
Composting area	25.0	m^2
Recycling area	32.0	m^2

The Figure 8 shows the virtual model of WTC San Andrés de Machaca

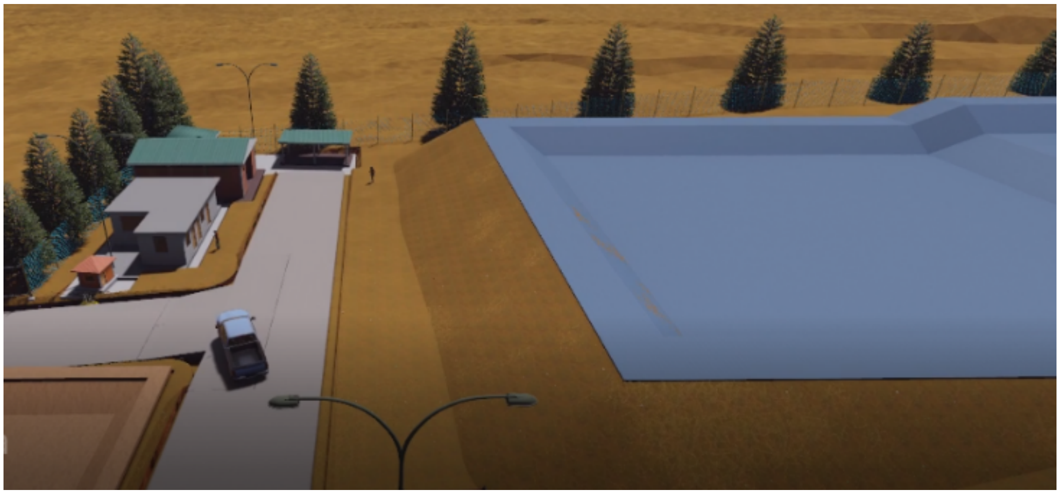


Figure 8. Virtual model of WTC San Andrés de Machaca

The required area data for the first year of operation are as follows:

Table 22. Calculation of the area required for the first year of operation.

Item	Value	Unit
Percentage of coverage: 15 % of the volume of waste disposed	15.00	%
Specific weight of compacted waste on site	0.55	ton/m^3
Daily average depth of compacted waste	0.9	m
Covering layer thickness	0.1	m
Daily cover cell height = Average depth of compacted waste + Cover material	1.1	m
Total population. Year of project start 2017	3.062	hab.
Average per capita production of solid waste (PPC)	0.38	Kg/inhab/day
Generation rate (net)	1.08	ton/day
Generation rate (with utilization) (start year)	0.80	ton/day
Daily volume of waste = Generation rate / Specific weight of waste	1.27	m^3
Daily waste area required = Daily volume of waste / Average height of compacted waste	1.30	m^2
Daily volume of coverage = Daily volume of waste * Percentage of coverage	0.20	m^3
Total daily volume = Daily volume of waste + Daily volume of coverage	1.47	m^3

The budget was developed, starting with the design, metric computations, unit price analysis and finally the total budget.

Conclusions

The Waste Treatment Complex - WTC, has a cost of US$350,000.00, with a useful life of 20 years.

The solid waste treatment and disposal complex consists of a common waste cell, an emergency cell and a safety cell (bioinfectious), each of which includes adaptation works such as excavations, landfills, roads, a leachate drainage system, chimneys for gas management and rainwater management ditches.

The proposed design is not intended as a final disposal site, but rather as a complex that integrates all the units in order to make the best use of solid waste, so that in the long term the common waste cell will reduce the waste it receives and thus increase its useful life.

We always focus our attention on medium and large localities, leaving aside the small ones, which are usually the majority, therefore the proposed study aims to solve these small localities, in a comprehensive manner, with an adequate budget considering the projection for 20 years.

Likewise, these localities are the ones that occupy sites close to water sources, contaminating in a great way a whole region.

The volumetric requirements for the design of the landfill were estimated for 20 years, using the total annual and accumulated volumes of both solid waste and cover material, using the waste generation projection and the volumetric weights of the confined waste.

It is important to mention that the projection of waste to be disposed of in the Solid Waste Complex was made considering that the municipality will adopt the utilization programs proposed in this study, and without taking into account volume losses due to decomposition of organic matter and loss of natural moisture.

The project to conceptualize the Urban Solid Waste Treatment Complex for the town of San Andrés de Machaca has been designed to provide final disposal of urban solid waste and hospital waste generated in the urban area and part of the rural area, as well as to take advantage of organic waste through the generation of compost; it also contemplates the recovery of part of the potentially recyclable materials, in which a recycling plant will be built.

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Author contributions: N.M.-F.: Analysis and interpretation of data, conceptualization, design, edition.

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