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Open Dumps Closure and Rehabilitation in Municipalities With Less Than 10,000 Inhabitants in Bolivia

Sergio Mauricio Morales, and Daza von Boeck Mariana
Zero Waste in Bolivia Project, Helvetas Swiss Intercooperation, Bolivia

Abstract: In Bolivia, Law 755 on integrated waste management establishes the obligations of different levels of government. Regarding final disposal, there are 26 municipalities in the country with sanitary landfills and 308 municipalities still have open dumps, being one of the main challenges, and by 2026 all of the country's municipalities must close dumps and set up sanitary landfills in compliance with national regulations. This work has consolidated the experience of the landfill rehabilitation process in the municipalities of Lagunillas, Boyuibe and Cuevo, which was developed in 2022, with a perspective of sustainability, replicability and scaling up. The methodological design applied has considered the methodology of the Roadmap for the progressive closure of landfills in Latin America and the Caribbean of the Environment Program. The interventions have considered: Stage 1 (Diagnosis and historical evaluation of landfills; social work with informal segregators; identification of closure alternatives); Stage 2 (technical project, actions required for the work); Stage 3 (operation of facilities and environmental control of landfills). With the rehabilitation of the Cuevo, Boyuibe and Lagunillas landfills, a transformation of the sites was achieved, guaranteeing the protection of the environment, in addition to generating jobs for the inhabitants of the territories. The document was prepared within the framework of the Basura Cero Project in Bolivia, financed by the Swedish International Development Agency and implemented by Helvetas Swiss Intercooperation, Swisscontact and Aguatuya Bolivia.

Key words: open dump, rehabilitation, sustainability, replicability, landfill

1. Introduction

It is essential to progressively eliminate landfills and replace them with efficient waste management practices and disposal methods [1]; within this framework, this work has become a priority for several countries in Latin America and the Caribbean. Correct and safe disposal of solid waste is a very important component of integrated waste management, since it contributes to environmental protection and adequate resource management [2].

Therefore, landfill closure is not an easy task and requires overcoming several challenges; however, the multiple impacts associated with open dumps make the opportunities and benefits resulting from proper closure even greater [1].

In the Bolivian case, with the enactment of Law No. 755 in October 2015, integrated solid waste management regains importance and visibility in the public agenda, establishing a series of obligations of the different levels of government and other actors in the framework of co-responsibility. Among these responsibilities, the Autonomous Municipal Governments in charge of urban sanitation services must develop actions for the closure of open dumps [3].

The final disposal of solid waste is one of the stages of operational management that presents the greatest challenges due to the persistence of open dumps. In view of this situation, the Ministry of Environment and Water has approved the planning for the closure of

Corresponding author: Sergio Mauricio Morales, Environmental Engineer; research areas: solid waste management. E-mail: sergio.morales@helvetas.org.

dumps in 2021, establishing the possibility of closure and subsequent rehabilitation of dumps as an alternative for municipalities to comply with the regulation [4].

This document addresses the process of closure and rehabilitation of open dumps in the municipalities of Lagunillas, Boyuibe and Cuevo in the Chaco Cruceño, Cordillera Province of the Department of Santa Cruz in the Plurinational State of Bolivia.

It is one of the first experiences in the application of the National Planning for the Technical Closure of Landfills developed by the Ministry of Environment and Water, approved in May 2021.

Fig. 1 Open Dump in the Municipality of Cuevo, before intervention.

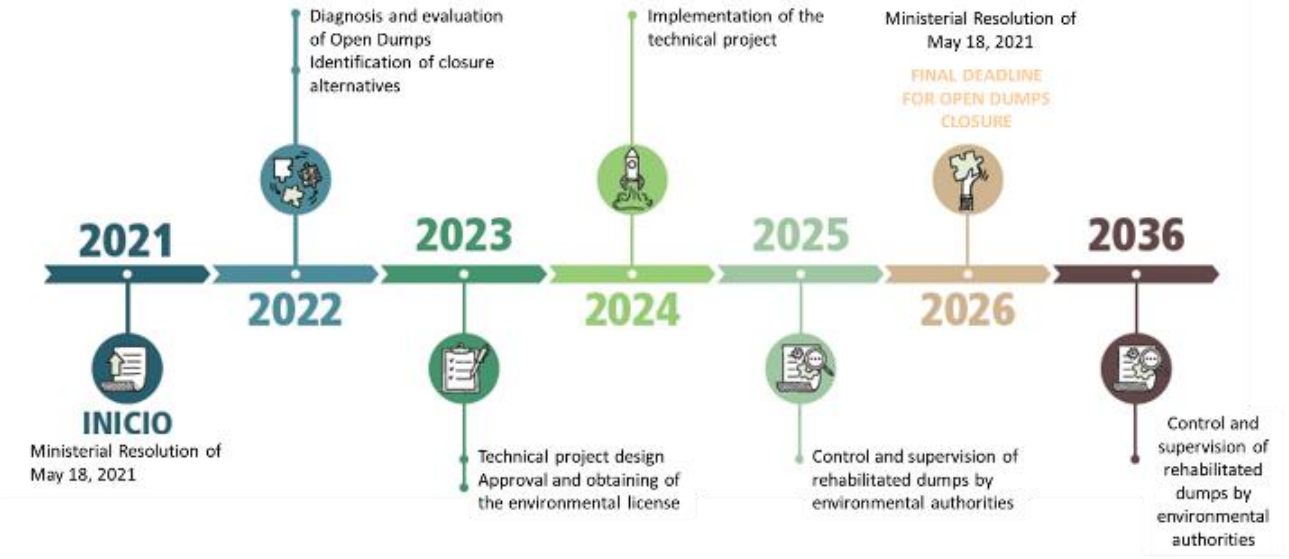

Fig. 2 Timeline for the technical closure of open dumps in Bolivia.

2. Material and Methods

2.1 Methods

According to UNEP (2021) [1], there is an overview of the different elements and practical measures that should be considered to carry out landfill closure; including a diagnosis, identification of alternatives, elaboration of the required actions and their implementation.

Therefore, the methodological design applied in the study has considered the methodology of the Roadmap for the progressive closure of landfills in Latin America and the Caribbean of the Environment Program developed by UNEP 2021.

It also considered a mixed quantitative-qualitative approach where the initial characteristics of these facilities were identified and technical aspects were specified through direct observation and soil analysis in order to identify the best alternatives for closure and rehabilitation.

2.1.1 Study Area

The municipality of Lagunillas has a population of 5,664 inhabitants and a per capita production of municipal waste (PPCM) of 0.565 kg/inhabitant/day, accumulating an annual generation of 315.46 t/year. Organic waste accounts for 56.6%, usable waste

(plastics, glass, paper, cardboard, and metals) for 12.3%, non-usable waste for 30.4%, and special and hazardous waste for 0.7%. Final disposal takes place in an open dump located 1.09 km from the town center, occupying an area of one hectare and has been in operation for 4 years, accumulating 941.16 tons of waste [5].

The municipality of Boyuibe has a population of 6,154 inhabitants and the PPCM is 0.482 kg/inhabitant/day, making a total of 723.78 t/year. Organic waste accounts for 54.61%, usable inorganic waste 14.84%, special and hazardous waste 0.41%, and non-usable waste 30.15%. Final disposal takes place at a municipal dump located 2.8 km from the town center, covering an area of three hectares, and has been in operation for 12 years, accumulating 10,419.01 tons of waste [5].

Finally, the municipality of Cuevo has an area of 1,082.5 km^2 and a population of 5,358 inhabitants, the PPCM is 0.5 kg/inhabitant/day, making a total of 653.35 t/year. Regarding the composition of solid waste, the organic fraction is predominant with 55.7%, usable inorganic waste is 13.1%, non-usable waste is 30.4% and special and hazardous waste is 0.8%; final disposal is done in an open dump of approximately one hectare, located 1.2 km from the town center and has been in operation for 11 years, accumulating 6,667.60 tons of waste [6].

2.1.2 Data Used

• Territorial Diagnoses of the Municipalities of Cuevo, Boyuibe and Lagunillas, Helvetas Swiss Intercooperation

• Closure and Rehabilitation Plans for the Cuevo, Boyuibe and Lagunillas Open Dumps. Helvetas Swiss Intercooperation.

• Technical Closure and open dumps Rehabilitation, Lessons Learned and Best Practices in the Municipalities of Lagunillas, Cuevo and Boyuibe in the Chaco Boliviano; Helvetas Swiss Intercooperation Bolivia.

2.2 A Conceptual Method Description: Closure and Rehabilitation Process of the Open Dumps

The development period for the closure and rehabilitation process of the open dumps in the municipalities of Lagunillas, Boyuibe and Cuevo in Bolivia has considered the periods 2021-2022, and is based on the measures described above, according to the following organization of stages:

Stage 1: which considers the development of the Diagnosis and historical evaluation of dumps; social work with informal segregators and identification of closure alternatives.

Stage 2: which considers the Technical Project, additional actions required for the work to be carried out.

Stage 3: Identifying the best measures for the operation rehabilitated dumps into landfills and environmental control of the rehabilitated dumps.

3. Results and Discussion

3.1 Results

3.1.1 Stage 1: Diagnostic and Historical Evaluation of Dumps; Social Work With Informal Segregators and Identification of Closure Alternatives

During the diagnostic stage, soil analyses were carried out to determine the suitability of the rehabilitation sites for landfill. The following results were obtained from the field analysis of the sites:

- The Lagunillas Open Dump is located on a site with a water table 1.55 meters above the surface; based on topographic analysis, satellite and geological images of the area, it is evident that there are no geological faults in the Lagunillas Open Dump area, meaning that the location of the landfill is not exposed to geological risk.
- In the case of Boyuibe, topographical, satellite and geological analyses indicate that there are no geological faults in the dump area. After an exploration of the site, it has been verified that

the water table is not found up to 3.3 meters from the surface to the base of the creek.

- In the municipality of Cuevo, based on a topographic survey, it was determined that the area occupied by the dump is 0.97 hectares, and that the water table is more than 3.3 meters deep. Based on topographic analysis, satellite and geological images of the area, it has been shown that there are no geological faults within the dump area.

Having applied the analysis of factors and parameters of the Guide for the Design, Construction, Operation and Closure of Landfills of the Ministry of Environment and Water (2014a) [7] it has been identified that the three landfills to be rehabilitated are located in an acceptable terrain and meet the criteria for rehabilitation. However, given the specific and particular conditions of each of the disposal sites, the actions carried out must be specified separately.

On the other hand, in compliance with the provisions of the Ministry of the Environment (2014b) [8], an environmental impact assessment has been carried out for each of the dumps, obtaining the following results:

- The impact weighting obtained for the Lagunillas Open Dump was 137, which places it within the range of 0 to 150, and it is considered a low-risk landfill, with the possibility of rehabilitation.
- The impact weighting obtained for the Boyuibe Open Dump was 184, placing it within the range of 150 to 200. It is considered a moderate risk landfill, with the possibility of rehabilitation as long as the site meets the requirements of the standard for landfill location.
- Finally, the impact weighting obtained for the Cuevo Open Dump reached a value of 137, therefore, it is within the range of 0 to 150, and is considered a low risk landfill, with the possibility of rehabilitation.

Another essential criterion when rehabilitating a landfill is political commitment. In the case of the municipalities of Lagunillas, Boyuibe and Cuevo, the support of the Municipal Executive and Legislative was important for the legal consolidation of the land, the technical follow-up of the actions and the financial and in-kind counterpart that was monetized for these tasks. Once the closure and rehabilitation process were completed, the municipal authorities appointed personnel to operate the rehabilitated sites, thus materializing the commitment to waste management.

3.1.2 Stage 2: Technical Project, Additional Actions Required for the Work to Be Carried Out

The activities related to the technical project design and its implementation are as follows:

Dissemination of the technical proposal to be implemented began in the 2020 management, including all waste management stakeholders in the three municipalities. Traditional means of communication and information were used in each place (e.g., radio, press, etc.) and the strategy was reinforced with local environmental volunteers. The latter were key in disseminating the closure of the dumps and in providing information to the population on the characteristics of the technical alternative, achieving a favorable response and the commitment of the individual generators.

To rehabilitate the open dumps in the municipalities of Boyuibe, Cuevo and Lagunillas, the following technical measures were proposed to transform them into a model sanitary landfill, applying the guidelines established in the National Planning for Landfill Closure and the methodology described in Ministry of the Environment (2021) [4].

Each of the landfill rehabilitation projects includes the implementation of the referential modules shown in Fig. 3.

The M1 macrocell for technical closure has a final cover system consisting of a 30 cm soil cover, a 20 cm impermeable layer and a 30 cm vegetative layer. The closure cell in the municipality of Lagunillas is 23 × 15

Fig. 3 Reference modules of the landfill closure and rehabilitation process, example Boyuibe.

meters, in the case of Boyuibe it is 20.5 × 65 meters and in Cuevo the dimensions are 42 × 55 meters.

On the other hand, the M2 macrocell for landfill operation uses the mixed method (trench and area) to optimize the available land at each of the sites; at the beginning the calculated useful life of the landfills was five years, due to an increase in selective collection of inorganic waste and composting at source, the useful life is now for 10 years. The total volumetric capacity of the Lagunillas landfill operating cell is 2,916.7 m^3. In the case of Boyuibe, the volumetric capacity of the cell during operation is 9,997.6 m^3. Finally, in Cuevo, the volumetric capacity of the cell is 6,978.9 m^3.

One of the most important aspects of the proper operation of a waste disposal site is related to the control of the by-products that will be generated by the degradation of the waste itself.

Regarding leachate, drainage systems have been implemented that conduct these liquids to a storage unit called a geotank (M^3) for subsequent treatment through recirculation and natural evaporation. It is important to mention that closed storage systems (geotanks) have been chosen to minimize the impact of odors.

The spatial distribution of these collection systems is every 25 meters and is closely related to the topography and morphology of the macrocells implemented.

Finally, the implementation of complementary actions to ensure the safety and care of the facilities includes signage, fencing, and the establishment of roads, among others necessary for buffering (M5).

3.1.3 Stage 3: Identifying the Best Measures for the Operation of the Facilities and Environmental Control of the Rehabilitated Dumps

Continuing with the closure and/or rehabilitation of the open dumps, the operation of the new cell began, for which training and operational support was scheduled in the three municipalities. The municipal governments of Lagunillas, Cuevo and Boyuibe were responsible for this activity, which began with the designation of municipal personnel to manage these sites.

The designated personnel were trained in the final disposal sites and exchanges of experiences with other Bolivian municipalities were promoted. With this training, the personnel acquired the skills to manage the landfills and took ownership of the method. Final waste disposal follows the process described in Fig. 4.

An indispensable criterion for the start of operations of a sanitary landfill is the planning and setting of dates in advance (scheduling) for the use of temporary cells (subcells) or final cells, which must ensure an adequate, orderly and sequential disposal and operation until their closure is consolidated. The procedure for this planning is the pre-dimensioning of the cells according to the amount of waste generated. In the case of the reference municipalities, subcells have been planned for a monthly or bimonthly operation, these have been schematized and located starting from the highest elevation.

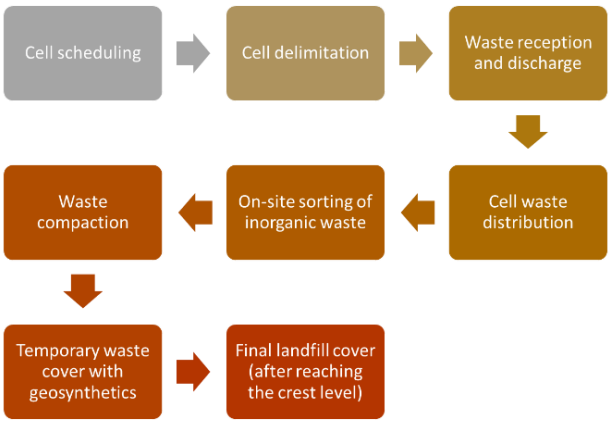

Fig. 4 Solid waste disposal process at the rehabilitated sites.

At the beginning of the use of each sub-cell, a staking out and delimitation in the field must be carried out, according to the calendarization, in this way the work area is identified for the foreseen period of time; a useful life of at least two months per sub-cell is recommended. For example, the size of the Cuevo sub-cell is 90 m^2, which is enough space to house the waste for two months of generation.

Reception consists of registering the number of vehicles and the volume of waste transported at the time of entering the landfill. Once the registration is completed, the waste is unloaded into the delimited sub-cell. This activity must be controlled at all times by the landfill operator to ensure that the waste is only disposed of in the sub-cell.

The distribution of solid waste refers to the dispersion of the material so that it has a uniform or even height in the sub-cell, respecting the width and length of the sub-cell for better compaction. Likewise, the shape and the slope must be considered with the appropriate inclination of 1:3 at the time of raising levels, this methodology allows to take maximum advantage of the volume of each sub-cell and reduce the area of disintegrated waste within the waste cell.

When the waste is distributed in the sub-cell, the inorganic waste is uncovered: PET bottles, aluminum cans, glass bottles and cartons, among others, at which time it is separated at the side of the cell so that the collection truck can take it to the municipality's collection point for recyclable inorganic waste. This task is carried out at the same time as the distribution.

Once the waste has been matched and the inorganic materials have been removed for recycling, the volume is reduced by means of a manual mechanical compactor that is easy to handle. This is an essential task when operating a waste disposal site, since proper compaction eliminates voids and extends the useful life of the waste discharge cells. The compaction height is defined according to the compaction characteristics of the equipment used.

According to the operation at each site, three to four passes are made, depending on the presence of subsidence of the waste mass, more passes can be applied for greater densification. With the use of the compactor, values of 0.35 to 0.40 T/m^3 were achieved.

A key aspect to consider is the care of the growth and shape of the waste mass. The following recommendations should be taken into account:

- Slope combing: consists of placing the sealing and profiling layer on the slopes.
- Height: shape and height of the body of the shaped embankments, to avoid settlements or correct them in a timely manner.
- Inclination: the slope inclination is permanently optimized to avoid destabilization of the slope, managing a maximum of 10%.

One of the aspects that "directly influence the useful life of landfills is the amount of cover material placed in their operation. Considering that space must be optimized, an operation modality was designed that replaces the use of soil in intermediate coverings with the use of reusable geo-synthetics" [7](Morales, 2022).

The methodology of covering the intermediate waste layers with a geo-synthetic (agro-film) to improve performance with respect to soil cover had a positive impact on the operation time of the subcells, reducing up to 40% of the hours of dedication of the personnel. In general terms, a manual landfill requires a lot of work on the part of the operators, with the transport of cover material being one of the most tiring activities; for this reason, replacing the intermediate cover with a lighter material that also guarantees the impermeability of the waste reduced the workload of the operators by up to 5 hours. In addition, this material provides temperature conservation properties inside the cell, facilitating its decomposition, the evaporation of leachates that may be generated and the stability of the waste mass.

Once the crest level is reached, the disposal stage is closed by trenching, to continue with the next sub-cell, repeating the steps described above. This method of vertical growth is more efficient since it forces the

closure of one cell to start another, reducing the surface area of exposed waste and therefore the presence of odors, vectors and minimizes the generation of leachate to the maximum. The method consists of manually moving soil from the nearby borrow bank to the operating sub-cell with a coverage of 20 cm. This can be considered as a partial closure since, if the final disposal method is mixed, once all the subcells are closed at the crest level, the final disposal will proceed with the area method.

The area operation will follow the same steps as the trench operation, from scheduling, delimitation, to the final closure of the landfill at the end of its useful life.

3.2 Discussions

The main challenge once a landfill has been rehabilitated is to ensure its proper operation. Therefore, from a technical point of view, it is imperative to generate local capacities for the management of a final disposal site through the development of an operations manual and the follow-up of the operators for a period of time that contemplates work during the dry and rainy seasons.

Given the climatic conditions of the Chaco region of Santa Cruz and the waterproofing measures of the subcells, after one year of operation there has been no evidence of leachate generation, showing that the waterproofing systems with geosynthetics and the operation of the subcells is efficient.

The absence of leachate generation is also explained by the use of the organic fraction at source through home composting and the feeding of farm animals at the family level.

One of the main problems faced by the municipalities when starting the operation of a final disposal site is to find the land for its operation; in this sense, the sites where they were already located have been optimized, establishing a closing cell and an operation cell.

In the case of the Chaco region of Santa Cruz, the three municipalities have managed to perfect their property rights, which has facilitated the development of the works.

4. Conclusions

The methodological design applied in the study was based on the methodology of the Roadmap for the progressive closure of landfills in Latin America and the Caribbean of the Environment Program. It also considered a mixed quantitative-qualitative approach where the initial characteristics of these facilities were identified and technical aspects were specified through direct observation and soil analysis in order to identify the best alternatives for closure and rehabilitation.

The closure and rehabilitation of the Cuevo, Boyuibe and Lagunillas open-pit dumps transformed the sites, generating technical, social, environmental and financial benefits.

The ordered work in subcells allows for better control in the operation of the final disposal site; likewise, the replacement of earth cover with geo-synthetics prolongs the useful life of the site and improves the compaction of the waste mass, optimizing the process and the performance of the personnel.

The methodology of covering the intermediate layers of waste with a synthetic geo-synthetic (agro-film) helps to improve performance with respect to ground cover, and has had a significant positive impact on the operation time of the subcells, reducing by up to 40% the hours of work dedicated by the personnel, allowing them to use the time available for other tasks inherent to the cleaning and utilization services.

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