Article

Proposal of an Initial Environmental Management and Land Use for Critical Cemeteries in Central Ecuador

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Abstract: Cemeteries are sites for the final disposal of human bodies that constitute a source of contamination of soil and water as a result of the cadaveric decomposition generated. The current research performed an initial study on the contamination of soil and water due to the influence of cemeteries and verified compliance with the legislation regulating land use and occupation of Central Ecuador (PUGS) with the aim of proposing an environmental and territorial solution to the problems generated by the mismanagement of cemeteries, through the physicochemical analysis of soil and water and studies of land use compatibility. The results indicate the tendency of contamination caused by the studied cemeteries, since the samples taken in both the rainy and dry season for the measurement of parameters BOD₅, COD, DO, pH and electrical conductivity fail to meet the established requirements of the Ecuadorian and international environmental regulations. In addition, land use conflicts were encountered in the cemetery grounds. It is concluded that the existing cemeteries should be subjected to more detailed environmental analysis and subsequently should be treated as security landfills in the closure and post-closure stage. Also, it has been concluded that the cemeteries should not be located in urban or peri-urban areas.

Keywords: cemeteries; polluted environment; urban planning; soil use; cadaveric decomposition; Ecuador

1. Introduction

Once a person dies, their body may become a potential source of contamination due to migrating leachates generated by decomposition. This becomes even more evident when the body is buried in a cemetery within an unregulated or critical location, often being close to water fountains [1,2]. Due to the sanitary problems that caused the exhumation of corpses inside churches at the beginning of the nineteenth century, the creation of cemeteries far from the urban limits of the capitals began [3]. Globally, a disturbing reality is being experienced due to rapid urbanization and environmental degradation in urban and rural areas [4–6]. As the urban sprawl increases, the disposal of human bodies becomes a critical environmental problem [7–9] as the cemetery is the main funerary form still currently used in the world [10]. However, the previous treatment of human corpses varies according to the beliefs and idiosyncrasies of each region or state, which implies a variety of different environmental effects [11].

The efficient management of cemeteries is a key element to control environmental, social and also ecological impacts [12,13]. Incompatible land uses are a major source of potential degradation at urban level. The implementation of cemeteries in residential areas is often rejected by the resident population [14,15]. However, the areas near the cemeteries have been inhabited, becoming residential due to urban sprawl [16,17]. Thus, these resting places imply a long-term occupation of quality soils that are a basic natural resource. Unsustainability is beginning to be felt due to the exponential increase in the human population [9,18]. The implementation of cemeteries has the potential to impact health and is capable of affecting suburban areas. Therefore, preventive measures and even mitigation may be necessary [19]. The inappropriate location of cemeteries causes problems and disagreements such as bad odor, risk of disease, and aesthetic impact, among others [16]. Furthermore, land use policies and planning are based on demographic projections, which are reliable for fifteen or twenty years; that is, they are transitory and are constantly evolving according to social preferences and requirements [20,21]. Generally, cemeteries are a requirement within a community as part of the unavoidable equipment for society and, as such, these are spaces designed and built based on the criteria and technical knowledge of a given period [22].

It takes 15 to 25 years for a human corpse to reach ideal or complete decomposition [23]. The decomposition rate of buried corpses is highly dependent on burial depth and ambient temperatures [24]. When the ambient temperature is between 16 and 20 °C the decomposition of the bodies will be accelerated, while with low temperatures, −5 to 6 °C, the bodies will take longer to decompose [25]. Furthermore, soil moisture influences decomposition due to its effect on soil microbial activity, since microorganisms are the primary decomposers in soils [26]. The human body is a source of organic matter that, being in suitable environmental conditions and with the influence of scavengers, insects and decomposing microorganisms, the disintegration process could be accelerated to an estimated time of two to five years [27,28]. The decomposition of inhumed bodies results in leachates, typically composed of water, proteins, fats, mineral salts, and carbohydrates, and as they are not retained by vegetation they will infiltrate and are able to generate eutrophication [29,30], in addition to possible microbial pathogens, i.e., bacteria and viruses [31]. An adult human body weighing 70 kg generates up to 40 L of leachate, in other words, 0.4 to 0.6 L of leachate is produced per kg of body weight [32], which represents 62% of the mass of decomposed material [33]. Those, which are composed of 60% water, 30% mineral salts and 10% of substances such as putrescine, cadaverine and heavy metals [34], as well as chlorine and formaldehyde, which are used in funeral practices [35,36], can reach groundwater and surface water. Pollution due to cemeteries is directly proportional to the size of cemeteries and the number of burials [31]. There is a potential risk that sources of drinking water may be contaminated with fecal matter from corpses. Carcasses frequently leak feces that are able to contaminate rivers or other water sources and cause intestinal diseases [37].

In European countries, physicochemical soil analyses were performed in areas near ancient cemeteries, reaching high levels of bacteriological contamination, which demonstrated the influence of cemeteries on groundwater contamination [38]. In turn, an increase in typhoid fever cases was found in people whose residence was close to the analyzed cemetery. These studies indicated that the concentration of this bacterium was sixty times higher than the concentration found in natural water detected 0.5 m from groundwater from the alluvial substrate, whose concentration decreased depending on the depth of the sampling [32]. In China, South Africa and Nigeria, soil quality analyses were conducted in representative cemeteries, finding contamination associated with burial practices, indicating an increase in the concentration of trace metals due to the use of coffins with painted metal ornaments or processed wood [39,40].

There is also further contamination issues within graveyards and cemeteries: excavating a modern cemetery in the United States is similar to excavating a toxic waste site [41]. Each year the bodies buried, along with chemicals and complementary materials, comprise

a total of 30 million feet of hardwood, 2700 tons of copper and bronze, 104,272 tons of steel and 1,636,000 tons of reinforced concrete, in addition to 827,060 gallons of embalming fluid or formaldehyde [41].

In Latin America, the environmental impact caused by cemeteries was exposed, finding 35 ways they impacted upon the physical environment. These included quality of air, soil and surface water, with a percentage of 49.3% of environmental impact, and they had visibly altered the quality of water and soil in the nearby sector [42]. In addition, negative consequences were observed in the population and local commerce due to the presence of waste, sewage and sediment discharge [29]. In the soil analysis of three representative cemeteries, elevated concentrations of copper, zinc, iron, manganese, lead and chromium were found with respect to soils located outside the study area [29]. Furthermore, since 2020, there has been a global saturation of funeral services as a result of the increase in deaths during the COVID-19 pandemic. Due to contextual and socioeconomic factors, it has been difficult for Latin America to cope with this epidemic [43–45].

Based on the aforementioned information, the main objective of the current study has been to propose a solution to the environmental and territorial problems generated by the mismanagement of cemeteries located in so-called critical areas. Thus, we decided to base this proposal in central Ecuador in order to minimize the environmental impacts that are generated in the sectors surrounding the cemeteries in the chosen study area, through the analysis of previous studies, the physicochemical characterization of the water and soil in the area of study and analysis of compliance with current environmental and territorial regulations.

2. The Local Case of Ecuador

With the current Ecuadorian regulations in force, technical parameters are not considered which mitigate the environmental impacts caused by the decomposition of human corpses. As with land use plans, cemeteries are not regulated seriously enough considering the importance and impact they have on their location. There are few or no policies that govern them, and this causes their presence in residential areas to only be regulated by permits from the administration and under compliance with the law [46]. The regulation for funeral establishments and corpse management in Ecuador was issued in 2018 [47]. This regulation is limited to the management of corpses prior to exhumation or burial, ignoring the subsequent process, which needs a long-term analysis, including the environmental part [45]. Management policies need to be applied according to the nature and reality of each cemetery, as the treatment that needs to be given will depend on the characteristics of each area, being environmental, geographical and social [20].

Of the 72 cemeteries located in Central Ecuador, 32 were identified as poorly located as the result of a spatial analysis [48]. Hydrography criteria, soil texture, population density, slope, green areas, distance to the historic center, precipitation and temperature were introduced in a subsequent analysis, determining that there is a possibility of environmental contamination due to the equivocal location of nine cemeteries [46]. In the latter, classified as potentially polluting, a field study was performed that included determination of the water table, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), electrical conductivity, pH and temperature, furthermore, to the addition of variables such as distance to the body of water, type of soil, number of graves, age of the cemetery and geological fault. Therefore, we concluded the potential that these nine (9) graveyards are very likely sources of environmental contamination, they also lacked any completely adequate areas for the location of cemeteries [11].

Currently, Ecuador does not have an analysis of environmental parameters that allows us to know with any certainty whether or not cemeteries are sources of environmental contamination. Therefore, it is urgent to generate environmental and territorial management plans for cemeteries, which are based on technical analyses such as environmental quality standards, physical-chemical and bacteriological parameters of water and soil, electrical conductivity, exchange capacity, and infiltration rate among others. These may

allow us to establish, in an optimal way, the determination of the carrying capacity of the cemeteries to their correct location, from planning to closure, in addition to setting the most appropriate land use for the areas near them, thus mitigating environmental impacts and health effects on the population. The situation worsened in Ecuador as in this country there has also been an excess of mortality due to COVID-19 since the beginning of 2020, like in so many other countries [49–51]. The pollution generated by a cemetery is proportional to the number of graves and the age of the cemetery [11], so the cemeteries of Nanegal with approximately 500 graves, Cutuglagua with 10,000, Chillogallo with 40,000 and Pintag with 8000, are attractive for the present study, which together with other criteria such as distance to the body of water, slope, and water table among others, made these potential areas of contamination.

3. Study Area, Materials, and Methods

The study area focused on the cemeteries located in the central highlands of Ecuador, within the province of Pichincha. This area was selected as it is adjacent to Quito, the capital of the Republic of Ecuador, which has the second highest population density in the country [52]. There have been four specific cemeteries within three different cantons, which are particularly the cemeteries of: 1. Nanegal; 2. Chillogallo; 3. Pintag; and 4. Cutuglagua (Figure 1). The extensions of these four sites are between 960 and approximately 9600 m² and their nearest distance to rivers range between 2 and 143 m. They were determined in a preliminary study as critical in environmental terms [11].

Figure 1. Inlet illustrates position of study area within Ecuador and main map locates the studied cemeteries as indicated in the corresponding legend.

The physicochemical parameters of water and soil from cemeteries Nanegal, Chillogallo and Pintag were analyzed, while we performed only soil analyses of the Cutuglagua cemetery. No analysis was performed on water samples from the Cutuglagua cemetery since it was determined that the soil in the area is silty loam, which implies that the contaminants are retained on the surface coast of the soil [53,54]. In the same way, a highway was found between the body of water and the slope that limits the cemetery, in addition to the inaccessibility of the sample point, so it was decided that the water sample did not contribute to the current study.

For further control of our study, simple and random soil samples were taken in the dry season, within each cemetery for the laboratory analysis of organic matter, pH, and electrical conductivity at three different depths, being superficial (0.50 m), medium (1.50 m) and deep (2.50 m) resulting to a total of 12 soil samples. We decided to take the samples at the depths mentioned above as the research team verified in the field that the maximum burial depth is 2 m, despite the fact that the regulations dictate that burials must be at a depth of 2.5 m. The main reason for non-compliance with the norm is the result of the norm having only been in force since 2013, whereas the cemeteries have been in operation for more than forty years. [11].

Regarding the soil parameters analyzed, all were determined in the laboratory of Universidad de las Fuerzas Armadas—ESPE in Sangolquí, Ecuador. The AS-02 method of the Mexican standard NOM-021-SEMARNAT-2000 used to determine pH [55]. For the determination of electrical conductivity in soils, the procedure proposed by ISO 11265.1994 Soil quality was used [56]. For both parameters, the multiparametric Hach model HQ40d and probes of the same brand whose models were CDC401 and PHC101, respectively, and duly calibrated, were used [57]. For the determination of organic matter, the loss on calcination method proposed by TMECC Method 05 July 2001 [58] was used as well as the method of Sadzawka [59]. Subsequently, a comparison was made with the Unified Text of Ecuadorian Secondary Environmental Legislation (TULAS) [60].

With regard to the data measured in soil, such as pH, electrical conductivity and organic matter, a comparison was realized with NOM-021-SEMARNAT-2000 [61], using Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health [62] and with TULAS [60].

Two series of water samples were conducted: the first being in the rainy season (June 2021) and the second during the dry season (August 2021) with a total of 30 simple random water samplings; 12 samples in the rainy season and the residual 18 samples in the dry season. Water parameters were measured in situ such as DO, pH, electrical conductivity, and temperature. In the laboratory, BOD₅ and COD were analyzed as given control points upstream and downstream of each cemetery. All samples were taken 200 m upstream and downstream, (taking upstream samples as control points).

The determination of BOD₅ was performed using the MAM-38/APHA 5210 B Modified test method [57]. The determination of COD was conducted using the M-GO-AM-23 assay method/Merck oxidative and colorimetric method 28, 29, 112, 132 [61]. Both tests were realized in the accredited laboratory of Central University of Ecuador. For the measurement of DO concentration, saturation percentage (% sat), and temperature (°C). The multiparametric Hach model HQ40d was used, calibrated and coupled with an LDO probe of the same brand and model LDO101 [57]. Electrical conductivity and pH were determined with equipment and properly calibrated Hach probes, whose models were CDC401, and PHC101, respectively.

For the territorial analysis, a comparison was performed with the Land Use Management Plan (PUGS) [63], current Ecuadorian regulations [47], preliminary studies [13] and field observations, including remote sensing, drone measurements and multi-criteria analysis [11,48], thus determining the differences and limitations existing between the practice and the current territorial regulations, which are generating land use conflicts [13]. The area of Pintag, Chillogallo and Nanegal cemeteries were obtained through the metropolitan regulation report [64]. Despite the fact that Cutuglagua is included in the municipal administration of Mejía canton, the information was taken from the PUGS of Metropolitan District of Quito [63] as the PUGS of the canton it belongs to is not up to date and the cemetery is on the border with Metropolitan District of Quito.

Finally, for the analysis of land use a comparison was used, in which the PUGS was legally declared as the property of each cemetery. Therefore, according to observations made during the fieldwork, it needed to be established if there is a conflict of compatibility.

4. Results and Discussion

In Figure 2a, the pH values of the Chillogallo, Nanegal, Pintag and Cutuglagua cemetery soil samples are illustrated, respectively. We observed that the values are outside the quality range and in turn tend to acidity [55]. On the other hand, the pH values obtained in the Chillogallo soil are within the quality range imposed by TULAS and Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health (6–8) [60,62]. Similarly, it was observed that the soil tends to be neutral [55].

Figure 2. Physicochemical parameters of the soil samples taken in superficial profile (0.5 m), medium (1.5 m) and Deep (2.5 m), (a) pH, (b) electrical conductivity and (c) % organic matter.

The electrical conductivity values of the soil samples from the four cemeteries are presented in Figure 2b. These are within the permissible values for residential, commercial, industrial, and agricultural use imposed by the Ecuadorian Technical Standard [65] and Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health [62,66] (2 dS/m), despite the fact that the electrical conductivity values of Cutuglagua and Chillogallo are at the limit of such a range.

As indicated in Figure 2c, the organic matter in the Nanegal and Cutuglagua cemeteries tend to decrease according to the depth. On the other hand, Pintag presents an increase in organic matter according to the depth of sampling and in Chillogallo constant values are observed in organic matter, except in the medium depth profile.

The soil parameters of the Nanegal and Cutuglagua cemeteries display the behavior one would expect [67,68], unlike the soil of Chillogallo and Pintag. In Chillogallo, unexpected values were obtained in the physicochemical parameters in the soil sample of the medium profile where a higher percentage of organic matter and acid pH were observed, which rather than being attributed to the influence of the cemetery, was due to a previous movement of the soil. On the other hand, in Pintag the directly proportional increase in organic matter with respect to depth was found, and could be attributed to leachate infiltration [1].

The soils of Nanegal, Cutuglagua and Pintag tend to be acidic, except for Chillogallo, whose pH values together with the values of the surface and deep samples of Pintag are within the ranges established by national and international regulations [62,66]. All the soil samples analyzed presented electrical conductivity values within the established range of the Ecuadorian [66] and Canadian environmental regulations [62]. The soils have characteristics between light and moderately saline soil [55], which could affect the presence of sensitive vegetation [69].

Regarding the content of organic matter and according to the classification imposed by the Mexican regulation SERMANAT [55], the superficial and deep samples of the Chillogallo cemetery have a low content of organic matter concentration, while the medium depth sample contains an average organic matter content. The surface soil sample from the Nanegal cemetery presents a medium concentration of organic matter, unlike the medium and deep samples, which presented low content. On the other hand, the soil of the Cutuglagua cemetery presented a high content of organic matter in the superficial and medium profiles, unlike the deep profile, which indicated low concentration. The samples from the Pintag cemetery yielded medium organic matter content, with an increase in this in the deep profile, taking it to be at the limit of the medium to high classification range (10.9%).

Table 1 documents the values obtained from the physicochemical parameters both in situ and in the laboratory of the water samples from rivers near the critical cemeteries, allowing a comparison of upstream with downstream in the dry and rainy season. The amounts in parentheses represent the standard values of the Ecuadorian legislation (TULAS) for water, except the electrical conductivity value which is a bibliographic value [60,70]. According to the parameters measured in situ, the water from the Alambí river, which is close to the Nanegal cemetery, has an adequate electrical conductivity value for agricultural use. However, the electrical conductivity values for the Grande and Sanganchi rivers near the Chillogallo and Cutuglagua cemeteries, respectively, have values between 250 and 280 $\mu\text{S}/\text{cm}$ of electrical conductivity. However, their use is conditioned by the type of salts they contain.

Figure 3 illustrates the averages of the BOD, COD and DO values obtained from the water samples taken near the critical cemeteries, compared with the standard value given by TULAS [61], which are equal to bibliographical references [71], for agricultural use. The values of the measured parameters (BOD₅ and COD) should be higher in the dry season than in the rainy season, due to the dissolution caused by precipitation [72,73]. Even so, the opposite effect was observed in the Chillogallo cemetery, which may be attributed to anthropogenic activity (in addition to the fact that the sewage for domestic use goes directly

to the body of water, wastes caused by the artisanal production of dairy products were observed) observed in the rainy season sampling that was conducted on Saturday from 9 to 11:30 AM, while the dry season sampling was conducted on Saturday from 4:30 to 6:00 AM.

Table 1. Physicochemical parameters obtained in samples from water bodies near critical cemeteries.

Cemetery:		Chillogallo									
Season:		Rainy n = 4					Dry n = 6				
Location Respect to Cemetery:		Upstream		Downstream			Upstream		Downstream		
Parameter	pH (6–9)	7.4	7.05	7.05	7.16	7.45	7.7	7.8	6.2	7.78	7.86
	Cond. us/cm (280)	399	170.6	962	183.2	252	253	268	249	289	302
	DO mg/L (5)	4.75	6.75	4.34	7.04	6.97	6.88	6.8	6.45	6.43	6.44
	BOD ₅ mg/L (20)	77	20	163	10	14	14	17	16	20	28
	COD mg/L (40)	141	26	266	68	36	31	41	54	51	51
Cemetery:		Nanegal									
Season:		Rainy n = 4					Dry n = 6				
Location Respect to Cemetery:		Upstream		Downstream			Upstream		Downstream		
Parameter:	pH (6–9)	6.86	6.5	7.01	6.48	7.15	7.28	7.33	7.27	7.42	7.42
	Cond. us/cm (280)	73.9	106.45	71.1	103.04	125.6	123.4	114	114.9	110.6	120.8
	DO mg/L (5)	7.71	8.3	7.97	8.12	8.16	8.31	7.74	8.02	8.3	7.99
	BOD ₅ mg/L (20)	<5	<5	<5	7	<5	<5	<5	<5	<5	7
	COD mg/L (40)	<8	<8	<8	57	14	<8	18	19	<8	51
Cemetery		Cutuglagua									
Season:		Rainy n = 4					Dry n = 6				
Location Respect to Cemetery		Upstream		Downstream			Upstream		Downstream		
Parameter:	pH (6–9)	6.87	6.6	7.11	6.9	7.19	6.84	7.2	7.33	7.37	7.3
	Cond. us/cm (280)	273	228	283	223	246	250	255	247	260	257
	DO mg/L (5)	4.78	5.74	5.81	6.5	4.61	4.61	4.72	5.74	5.77	5.86
	BOD ₅ mg/L (20)	34	19	33	21	33	31	31	28	26	27
	COD mg/L (40)	75	46	57	68	65	86	71	46	47	51

The values obtained from the samples from the Chillogallo cemetery in the dry season may be the most representative for this research, since they were sampled at dawn to eliminate the possible anthropogenic interferences detected in the sampling during the rainy season. Even so, it was not possible to eliminate the interference generated by the existence of a discharge pipe at the height of the upstream sample point. This implies that the contamination expelled from such an installation would not be homogenized at the time the sample was taken, which explains the higher pollution values upstream compared to downstream, which is observed in Figure 3d.

The water from the Alambí (Nanegal) river can be used for all the uses silver plated by the TULAS [60] except for human and domestic consumption. The BOD₅ values in the C.hillogallo and Cutuglagua water bodies do not meet quality parameters for any use. The difference between the upstream and downstream COD ranges can only be observed in the body of water near the Nanegal cemetery, which ranges from excellent quality upstream to acceptable downstream in the rainy season. In the dry season it passes from good to acceptable quality. The ranges used are those established by SERMANAT [60].

Figure 3. Comparison of BOD₅, COD, DO values obtained in water samples taken before and after critical cemeteries in the rainy season (a,c,e) and the dry season (b,d,f).

Although the water from the Chillogallo and Cutuglagua rivers are used for agricultural use, further analysis is required to determine if this use is adequate, since, due to the values obtained for electrical conductivity, BOD₅ and COD initially in this investigation, they indicate these bodies of water have a high level of contamination compared to the limit value imposed in the TULAS [60]. In the samples of the body of water near the Cutuglagua cemetery, it was observed that in the rainy season the values tend to be constant and in the dry season the values of BOD₅ and COD decrease. This could be attributed to the self-cleaning nature of the water since the sample was taken 200 m downstream, where the water's path witnessed rocks and vegetation, allowing the oxygenation process with the hit of the water current [74,75]. Therefore, it could not be confirmed that the existing contamination of the river is due to the influence of the cemetery. On the other hand, the Chillogallo and Nanegal cemeteries demonstrate an increase in electrical conductivity, BOD₅ and COD values, which could be attributed to the filtration of pollutants from those cemeteries.

Furthermore, a land use conflict was documented in the Chillogallo cemetery, since the PUGS establishes the prohibition of low-impact industrial economic activity in that area.

Hereby, a discharge of dairy waste was observed in the field and the existence of a park neighborhood 20 m away, which is in conflict as the PUGS [63] rules that neighborhood-scale facilities have a radius of influence and coverage between 400 and 800 m.

In the Pintag cemetery, a conflict was encountered with the restriction for religious establishments since the PUGS establishes a maximum capacity of 500 people in the church. However, the main church in the sector is located a few meters from the cemetery and has a greater influx than that established in days of holidays and other festivities. Both, Nanegal and Cutuglagua, do not present compatibility conflict imposed by the PUGS. Although the cemeteries were created before the new PUGS guidelines were issued, nowadays none meet the minimum area established for the implementation of cemeteries, which is of about 20,000 m² zonal cemeteries and 50,000 m² metropolitan cemeteries [63]. However, no regulations or legislation were found in force that restrict or regulate the construction of houses or equipment near cemeteries. None of the cemeteries studied meets the minimum required distance of 200 m to any body of water [47].

The results of the environmental analyses obtained indicate a trend towards environmental contamination caused by cemeteries, and therefore, all existing or planned cemeteries must have a radial buffer zone with native vegetation of the place; the same one that retains the pollutants of the infiltrated leachates. The radius of the buffer zone will depend on the needs of the sector [76–78]. Cemeteries that have critical characteristics [48] with a notable tendency for contamination or saturation, and those located in urban or residential sectors that do not have a buffer zone should be treated as a security landfill in the closure phase. Furthermore, post-closure protocols [79] should be applied with the environmental monitoring required by this type of establishment [80]. The use of land equipment may only be close to the cemetery in the event of the existence of the buffer zone or, failing that, being the buffer zone as long as it has the necessary amount and species of vegetation to avoid affecting the health of the population or the environmental quality of the sector. Cemeteries should not be implemented in urban or peri-urban areas [81]. The creation and use of sustainable alternatives such as green cemeteries [39], which can be located in multifunctional land uses [82], should be promoted. The circular economy can be incurred by using the skeleton of tombs that have been abandoned for more than ten years in the industry as a source of catalyst providing economic benefits and environmental protection, thus reducing dependence on non-renewable natural resources [83].

5. Conclusions

The values obtained in the physicochemical analyses of soil and water reveal that the cemeteries analyzed in this study, except Cutuglagua, could be potential sources of environmental contamination. Therefore, a more exhaustive analysis of environmental parameters would be required and, if contamination is confirmed, they should be treated as landfills in closure and post-closure stages. For the construction of new cemeteries, it must be ensured that environmental, territorial, and geographical criteria are met for proper implementation.

Land uses change according to the development of the population in conjunction with urban sprawl, which implies that cemeteries that were once considered to be in rural areas are now in urban areas; ones that could be converted and represent a risk to the health of the inhabitants of the surrounding sectors. Cemeteries should not be implanted in urban or peri-urban areas due to the generation of conflicts in the compatibility of land use.

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