Evaluation of Water Contamination Caused by Cemeteries in Central Ecuador—A Warning for the Authorities

Aldás Sandoval María Belén, Guevara García Paulina Valeria, Jaramillo Merino Stephany Belén, Ocaña Garzón Edwin Marcelo, Ponce Arguello Mariuxi Fernanda, Toulkeridis Theofilos y Vizuete Freire Diego Francisco

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Article

Evaluation of Water Contamination Caused by Cemeteries in Central Ecuador—A Warning for the Authorities

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Abstract: Although cemeteries are sacred sites where decomposing bodies are permanently deposited, until now relatively little attention has been paid to the possibility that they constitute a source of water contamination. The present research intends to evaluate the levels of physico-chemical contamination of rivers near ten cemeteries in central Ecuador by analyzing a variety of physicochemical parameters in the field and laboratory during dry and rainy periods. A statistical analysis was conducted, demonstrating that the majority of variables are lacking for regular patterns or homoscedasticity to be demonstrated. Subsequently, an analysis was performed using the Kruskal–Wallis test, concluding that there was no significant difference between sampling sections and periods, but there was between pre-established categories, so for that reason it was decided to work only in the dry season and the results were compared with the EPA regulations, depending on the use of water from each river. It was concluded that there is a high probability of environmental contamination in the river by the cemeteries termed "Not suitable" because they registered greater non-compliance with the maximum permissible limits, while cemeteries categorized as "Completely adequate" had a lower probability of contaminating the water. It is suggested that a normative, globally applicable criterion for the optimal location of cemeteries or final disposal sites be established.

Keywords: cemeteries; leachate; river; environmental contamination; Kruskal–Wallis

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1. Introduction

Cemeteries are constructions intended to house human remains and, in turn, are influenced by the religious beliefs and perspectives of the communities [1,2]. However, these spaces are part of an ecosystem that may contain tree species and water reservoirs, which may be affected by pollution from leachate released during the human decomposition process [3–6]. The overall process of corpse treatment, from initial autopsy and embalming to final disposal in burial sites [7], generates several potential contaminants capable of dispersing into the environment [8,9]. Such contaminants come from the body and most likely include chemicals applied during embalming (e.g., arsenic, formaldehyde and methanol), makeup (e.g., cosmetics, pigments and chemicals), as well as various additional items, such as fillings, paints, pacemakers, dental amalgams, varnishes, among many others [2,10].

In the same way, during the cadaveric decomposition process, progressive physical, biological and chemical reactions are generated, the duration of which is determined by a combination of internal factors, such as the presence of chronic diseases, muscle mass, body size and weight of the corpse, and external factors such as environmental temperature, humidity and precipitation [11].

The human body, on average, is composed of 64% water, 20% proteins, 10% lipids, 1% carbohydrates and 5% minerals [12], which are transformed into simpler compounds during the decomposition process [13], and such transformation develops in two main phases: the first is autolysis, which consists of the enzymatic self-digestion of the cells, and the second is putrefaction, which is made up of transformative and destructive processes, involving the progressive disintegration of the organic compounds of the tissue to form gases, liquids and salts [14,15]. During this process, different volatile compounds are released, such as ammonia, hydrogen sulfide, sulfur dioxide, putrescine, cadaverine, among others, that determine specific odors [7].

Similarly, during the decomposition process of a human body, 0.4–0.6 L of leachate are produced per 1 kg of body weight [16]. Such leachate contains 60% water, 30% salts in the form of ions and 10% degradable organic substances, fungi and viruses, which represent a high degree of toxicity and pathogenicity [17,18]. The leachate generated is characterized by high values of conductivity, pH, biochemical oxygen demand (BOD) and its specific fishy odor [19].

Furthermore, a rapid urbanization and environmental degradation also occurs in urban areas due to accelerated population growth [20]. This situation puts territorial pressure on cemeteries, even more so if one considers that the population faced a pandemic in which the mortality rate increased significantly [21,22]. Therefore, the denser urban populations and the need to expand cities have caused new housing to be established in the areas around urban cemeteries, which indirectly causes an environmental problem [2,23].

According to Neckel et al. [24], leachates are able to be transported through the soil, specifically the unsaturated soil zone, since it functions as a filter and adsorbent. Therefore, it is responsible for the eventual release of chemicals and micro-organisms. Furthermore, edaphic conditions may favor the leaching of hazardous elements through different soil layers, allowing contamination of groundwater and underlying aquifers [25].

In this way, it increases the radius of contamination and leads to the water in these aquifers having inappropriate characteristics for different uses, mainly agricultural use, irrigation and human consumption [26]. This situation compromises the quality of the water and, in turn, becomes an environmental problem of great impact for the inhabitants located around the cemeteries [27]. The research undertaken by Neckel et al. [18,22,24,28] demonstrated that the contamination of cemeteries produces an alteration in microbiological components and increases the prevalence of toxic organic contaminants (TOC) in groundwater.

This pollution issue is intensified in urban cemeteries due to the absence of management and treatment of the liquid effluents emitted by decomposing bodies, which when attached to the soil are known as necroleachate [29,30]. This compound is a grayish liquid with a bad odor [1]. It is characterized by having a density greater than that of water, which allows it to achieve good dispersion and mobility capacity, and, in turn, facilitates its infiltration into underground wells and its spread to larger areas, thus increasing contamination [31,32].

In twelve cemeteries in Germany, drainage systems were installed at a depth of 2.6 to 3 m in order to characterize their drainage systems with respect to the concentration of compounds from leachates [33]. The water samples were taken from the wells closest to the drainage area and from the respective surface waters located upstream of the cemeteries. The results indicated the existence of high concentrations of nitrates (NO_3), ammonium (NH_4), phosphates (PO_4) and dissolved organic carbon (DOC), as well as an electrical conductivity greater than 1127 µS/cm. On the other hand, Lautz et al. [33] found that the amounts of NO_3 in cemeteries' groundwater were considerably higher than residential groundwater, i.e., from 6.2 mg/L to 0.05 mg/L, respectively. In turn, NO_3 concentrations in streams increase between 1.4–1.9 mg/L upstream and downstream of cemeteries, which represents a risk to the environment and human health.

In several Latin American countries, the poor management of human corpses has been a serious problem, since the lack of public policies, standards and procedures that regulate the handling of this type of waste directly results in a high probability of environmental contamination [16,34–36]. Consequently, they represent a danger to populations near to and far from cemeteries, given that aquifers contaminated by leachate can meet surface sources, and thereby disperse the contaminant load [17,37].

In Ecuador, more advanced studies have not been implemented that would demonstrate whether cemeteries constitute a source of contamination for the population [38]. Likewise, state and municipal environmental agencies have not updated the technical parameters that allow the environmental impacts caused by the decomposition of human corpses to be controlled. Consequently, there is a lack of suitability criteria and appropriate policies to guide the implementation of cemeteries [39].

In the research developed by Crisanto-Perrazo et al. [38], in order to explain the probability of environmental contamination due to the presence of a cemetery, they analyzed ten qualitative and quantitative variables such as water table, distance to water sources, precipitation, slope of the terrain, type of soil, age of the cemetery, temperature of the site, number of graves, geological fault and population density. They subsequently established different levels of impact for each variable and assigned relative values that covered all the probabilities of contamination based on the environmental and geographic conditions of the cemetery, from the least probable to the most probable. In this way, they evaluated the suitability of a site, resulting in five traffic light categories:

- Unsuitable: the site contributes significantly to environmental contamination due to the geographic and environmental conditions of the cemetery. High probability of contamination in water and soil.
- Slightly suitable: the site has a considerable impact on environmental contamination of water and soil.
- Moderately suitable: the site has a moderate impact on environmental pollution. Medium probability of contamination in water and soil.
- Highly suitable: the site has a low impact on environmental pollution of water and soil.
- Fully suitable: the site minimizes or completely eliminates environmental contamination. Minimal likelihood of contamination in water and soil.

In a complementary manner, Flores Gómez et al. [40] analyzed the physicochemical parameters in soil and water in the cemeteries considered critical within the categorization set out by Crisanto-Perrazo et al. [38], with the aim of proposing an environmental and territorial solution to the problems generated by the poor management of cemeteries in Ecuador, as well as land use compatibility studies in the study area. Among the most relevant results, it stands out that the analysis of the physicochemical parameters indicated a tendency towards environmental contamination caused by cemeteries located in unsuitable areas.

Therefore, the current study focuses on determining the probability of contamination in the rivers near cemeteries located in the cantons of Quito, Mejía and Rumiñahui in Ecuador through the analysis of physicochemical parameters, such as pH, temperature, conductivity, dissolved oxygen (DO), chemical demand of oxygen (COD), biochemical oxygen demand (BOD_5), NO_3 and PO_4 in the field and laboratory during the dry and rainy periods.

2. Materials and Methods

The research was performed in a variety of phases, which included (a) the calculation of the representative sample, (b) the verification of accessibility to a river, (c) the water sampling during dry and rainy periods, (d) the analysis of physicochemical parameters, (e) the comparison of results with international regulations and (f) the corresponding statistical analysis of the results.

2.1. Calculation of the Representative Sample

Within the cantons of Quito, Mejía and Rumiñahui in Ecuador, there is a total of 70 cemeteries. For the present study, the representative sample size was chosen statistically by cemetery categories, and the statistical formula (Equation (1)) was applied with a confidence level of 95%. It was detected that the size of the cemetery population in each category (N) was small, so the calculation of the required sample was practically the same. Therefore, a minimum of three samples per category was used, except in the "Completely adequate" category in which two cemeteries were used to construct the population size. In this way, a statistical trend was established and it was adjusted to the available economic resources.

$$\text{Sample Size Formula } = \frac{\frac{\left[z^2 \times \text{ p}(1-\text{p})\right]}{e^2}}{1 + \frac{\left[z^2 \times \text{ p}(1-\text{p})\right]}{e^2 \times \text{ N}}} \quad (1)$$

- N is the population size
- z is the z-score
- e is the margin of error
- p is the standard deviation

The result of applying Equation (1) is the number of cemeteries by category. The selection of the cemeteries was conducted by applying the Analytical Hierarchy Process (AHP), which is a pairwise comparison procedure that allows the importance of each of the criteria in relation to the others to be established, based on the assignment of weights [41,42]. Among the qualitative and quantitative variables that were considered are accessibility to a river (a_1), burial time in years (a_2), form of burial (a_3), quantity of buried population (a_4), affected population (a_5), distance to a river (a_6) and distance from the cemetery to the town (a_7).

The experts of the research group considered that the proximity to a river was more important in relation to the other variables, assigning it a value of 9. This is because the cemetery's distance to a river maintains a directly proportional relationship with contamination of the water [43]. Followed by this was the form of burial, which can be a niche or earth, with a weight of 8, and burial time was given a value of 7. Values were given to the variables as follows: amount of buried population 6, affected population 5, distance from the cemetery to the population 4 and, finally, accessibility to a river was given a value of 3.

Subsequently, the coefficients of each variable were generated using the pairwise comparison matrix. Once the weights were obtained, the weighted linear sum expressed in Equation (2) was proposed for the selection of the optimal cemeteries of each category.

$$C_{\text{optimum}} = 0.07 \times a_1 + 0.17 \times a_2 + 0.19 \times a_3 + 0.14 \times a_4 + 0.12 \times a_5 + 0.21 \times a_6 + 0.10 \times a_7 \quad (2)$$

The result of applying Equation (2) was to determine the sampling cemeteries by category, with those that reached results closest to 1 being selected for the present study.

2.2. Verification of Accessibility to a River

Once the optimal cemeteries for each category were obtained, field accessibility was verified for sampling to 500 m upstream and downstream of the river with reference to the location of the cemetery. It should be noted that, in certain cemeteries, it was not possible to comply with this distance due to the difficulty of accessibility. However, during the visit, it was confirmed that there was difficulty in taking water samples in the following cemeteries: Descanso Eterno, Bellavista and General de Puellaro. The General de Puellaro cemetery is in the "Completely adequate" category, so only one cemetery was sampled within this category. Subsequently, the total number of cemeteries sampled was 10.

Figure 1 indicates the geographical location of rivers near cemeteries selected for this research.

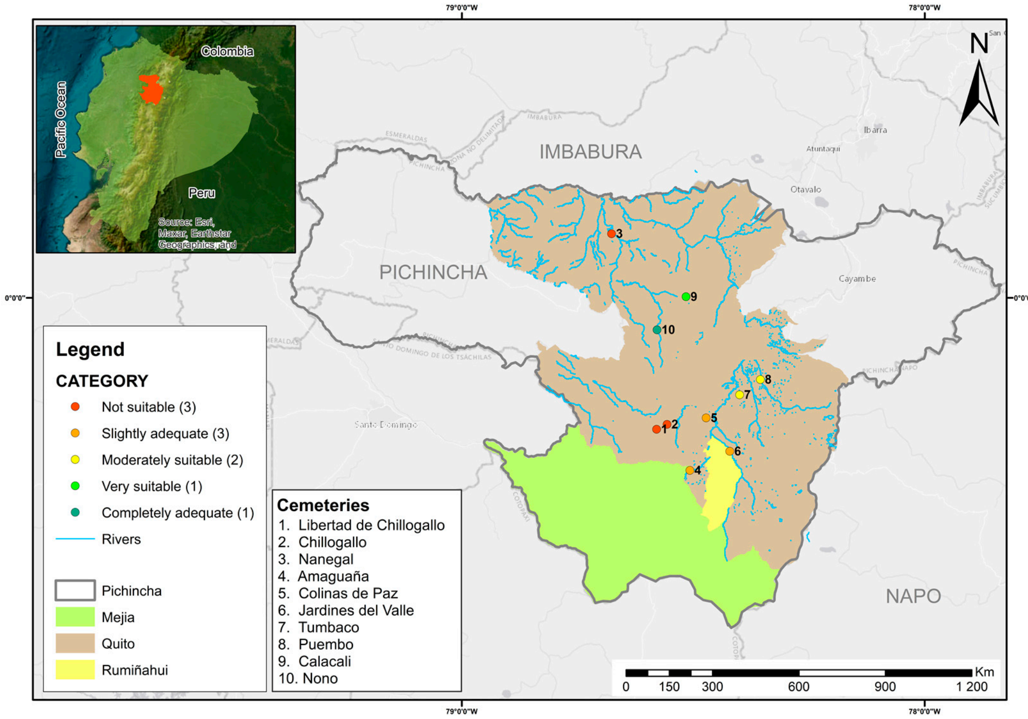

Figure 1. Location of the ten cemeteries in the study area within the three cantons, labelled with the corresponding category.

2.3. Water Sampling during Dry and Rainy Periods

Surface water sampling consisted of three sections, namely upstream, parallel and downstream of the cemetery during the dry and rainy periods. Sampling for the dry period was performed during the months of July and August, while the rainy period sampling was undertaken in the months of November and December of 2023. During this phase, physicochemical parameters were measured in situ. Using a HACH HQ40D multiparameter meter, the measured parameters included pH, temperature, conductivity and dissolved oxygen. For the measurement of the parameters COD, BOD_5, NO_3 and PO_4, the water samples were stored in plastic containers, with their corresponding labeling. A 2L plastic container was used for laboratory analysis of BOD_5, NO_3 and PO_4. To preserve the COD sample, a 125 mL plastic container and sulfuric acid (H_2SO_4) were used. The plastic containers were placed in a cooler with ice in order to maintain a temperature below 4 °C, thus ensuring correct storage and transportation [44]. Finally, the water samples were sent to the Environmental Research and Control Center (CICAM) belonging to the National Polytechnic School in Ecuador for the respective analysis.

The data pertaining to climatic conditions, sampling time and results of in situ parameters were attached to a control sheet for each cemetery. It should be noted that the sampling for those rivers that presented interference from wastewater was conducted in the early morning so that the sample remained representative of the present study [44].

2.4. Analysis of Physicochemical Parameters

The analysis of the water samples was realized by CICAM. Each parameter was analyzed with a respective measurement method. COD was analyzed with the PE-V-01 method | SM Ed. 23 5220D/VIS Spectrophotometry, BOD_5 with PE-V-06 | SM Ed. 23 5210B/Barometric, NO_3 was measured with the PE-V-20 method | SM Ed. 23, 2017, 4500-NO_3-B/UV and PO_4 spectrophotometry with PE-V-53 | SM Ed. 23, 2017, 4500-P C/VIS Spectrophotometry [45].

2.5. Comparison of Results with International Regulations

The results of the analyzes of the physicochemical parameters were compared with the maximum permissible values according to the use of the river water established in the U.S. Environmental Protection Agency (EPA) [46]. During the field visit, the use of water from the river near each cemetery was verified, as listed in Table 1 [47].

Table 1. Maximum permissible values for uses of river water established by the EPA.

Uses	Quality Criteria							Cemeteries
	DO	pH	EC	PO_4	NO_3	BOD_5	COD	
Agricultural water	-	6.5–8.4 [48]	<700 µS/cm [48]	10 mg/L [49]	<30 mg/L [46]	30 mg/L [49]	120 mg/L [49]	Libertad de Chillogallo (LC) Calacalí (CL) Nanegal (NA) Amaguaña (AM)
Environmental water	>5 mg/L [50]	6.5–8	-	0.1 mg/L [51]	10 mg/L [50]	10 mg/L	-	Chillogallo (CH) Colinas de Paz (CP) Puembo (PM) Jardines del Valle (JV) Nono (CN) Tumbaco (TB)

2.6. Statistical Analysis

The statistical analyzes were performed between sampling periods (Dry and Rainy), sections (Upstream (U), Parallel (P), Downstream (D)) and categories (Not suitable, Slightly adequate, Moderately suitable, Very suitable and Completely suitable), working with results that had more or fewer than 50 data points. Initially, the normality of the data was analyzed, so when the dataset contained fewer than 50 data points applied in the statistical analyzes of the sampling sections and categories, the Shapiro–Wilk Test was used in the R programming language. Conversely, when the dataset contained more than 50 data points applied in the statistical analysis of sampling times, the Kolmogorov–Smirnov Test was used [52]. The normal distribution refers to a symmetrical, bell-shaped distribution that is essential for the application of statistical tests such as ANOVA [53]. The null hypothesis of the Shapiro–Wilk Test and the Kolmogorov–Smirnov Test was that the data would follow a normal distribution. Therefore, the p-value associated with the test was analyzed, and it was less than a level of defined significance, i.e., 0.05, so the null hypothesis (H_0) was rejected, indicating that the data did not follow a normal distribution [54].

Subsequently, the analysis of the homoscedasticity of the data was conducted with the Levene Test Statistic using R software (version 4.3.2) [55,56]. This test was applied for the statistical analyzes between sampling periods, sections and categories. The statistical test implied that the variances of the different groups to be compared were approximately similar, that is, the dispersion of the data was constant at all levels of the independent variable [57,58].

Finally, for the dataset that met the assumptions of normality and homoscedasticity, the ANOVA statistical test was applied using the R programming language [59–61]. While, for the dataset that did not meet the assumptions of normality and homoscedasticity, the non-parametric Kruskal–Wallis test was used in R software (version 4.3.2). Both statistical tests allowed us to determine if there were statistically significant differences between two or more independent data groups, that is, between the results of the sampling periods, sections and categories. In turn, the null hypothesis of the tests predicted that there would be no significant difference between the set of results analyzed (sampling periods, sections and categories), while the alternative hypothesis (Ha) suggested that at least one set of results would show a different distribution [62].

It is fundamental to note that these statistical tests aim to determine whether there are statistically significant differences between the results of the sampling periods, sections and categories.

3. Results

3.1. Statistical Analysis of the Results

3.1.1. Analysis between Sampling Periods

The statistical analysis used to evaluate the differences in the concentration of contaminants between sampling periods indicated that all the results of the different physicochemical parameters did not comply with the assumptions of normality and homoscedasticity, since the *p*-value was greater than 0.05 in all cases. Therefore, the results of the physicochemical parameters were analyzed using non-parametric tests (Kruskal. Test), in which it was determined that the results of the pH and conductivity (EC) parameters presented a significant difference between sampling times (Table 2).

Table 2. Differences in pollutant concentrations between sampling periods.

Parameter	Mean		χ^2	*p*-Value
	Dry Period	Rainy Period		
DO (mg/L)	6.58	6.75	0.78	0.37
pH	7.26	8.00	17.69	$\mathbf{2.592 \times 10^{-5}}$
EC (µS/cm)	711.83	295.88	14.13	**0.0001**
PO_4 (mg/L)	1.42	1.01	3.59	0.06
NO_3 (mg/L)	7.75	6.55	0.21	0.65
BOD_5 (mg/L)	6.84	4.90	0.42	0.52
COD (mg/L)	31.91	24.29	3.36	0.07

Notes: The bold values indicate that the *p*-value of pH and EC were less than 0.05, therefore H0 was rejected, that is, for these parameters there was a significant difference between the dry and rainy periods.

Figure 2 illustrates the box plot of the pH (A) and EC (B) parameters, which presented a difference between sampling periods, and the distribution of the results in their corresponding period is displayed.

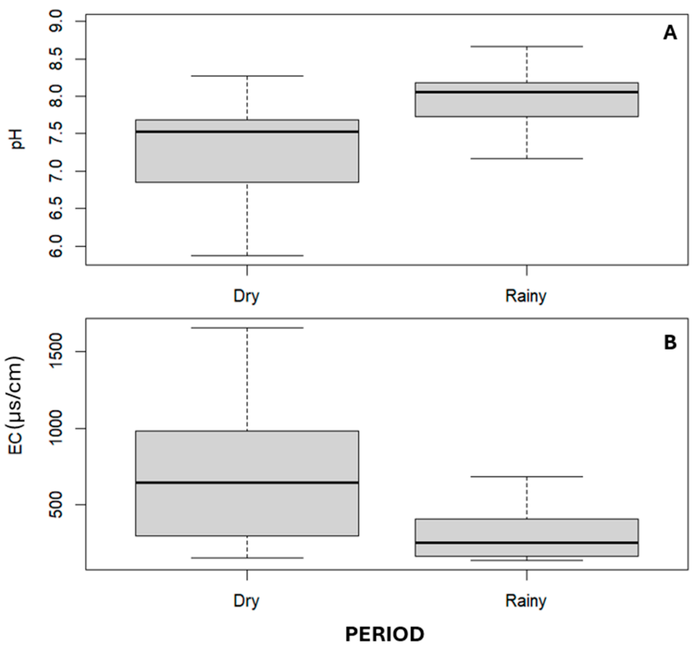

Figure 2. Box plot of the pH (**A**) and EC (**B**) parameters, which showed differences between sampling periods. (**A**: represents pH levels, with the vertical axis ranging from 6.0 to 9.0. **B**: represents EC in µS/cm, with the vertical axis ranging from 0 to 1500 µS/cm).

Once it was determined that there was no significant difference between sampling periods, statistical analyses were performed for categories and sections exclusively with the results from the dry season because environmental criteria indicated that during this period a higher concentration of pollutants is recorded compared to during the rainy season.

3.1.2. Analysis between Sampling Sections

The results were compared between sampling sections (Upstream, Parallel, Downstream) from the dry period. The analysis used was the Kruskal–Wallis test for all physicochemical parameters, and it indicated that no parameter presented significant differences between sampling sections (Table 3).

Table 3. Kruskal–Wallis analysis for study parameters between sampling sections during the dry season.

Parameter	**Mean**			**X^2**	***p*-Value**
	Upstream (U)	**Parallel (P)**	**Downstream (D)**		
DO (mg/L)	6.60	6.7	6.43	0.46	0.79
pH	7.11	7.38	7.31	1.65	0.44
EC (µS/cm)	683.68	634.82	828.67	1.21	0.55
PO_4 (mg/L)	0.97	1.56	1.76	3.35	0.19
NO_3 (mg/L)	9.85	6.88	6.38	0.09	0.96
BOD_5 (mg/L)	4.80	5.52	10.57	0.19	0.91
COD (mg/L)	28.48	28.79	39.19	0.18	0.90

Notes: The *p*-value was greater than 0.05 in all the parameters analyzed, which indicates that there was no significant difference between sampling sections.

3.1.3. Analysis between Categories

The results were compared between categories, and the analysis used the Kruskal–Wallis test for all parameters (DO, pH, EC, PO_4, NO_3, BOD_5, COD) and it indicated that DO, EC, PO_4 and BOD_5 presented significant differences between previously established categories, while the remaining parameters did not present differences, as indicated in Table 4.

Table 4. Kruskal–Wallis analysis for study parameters between sampling categories during the dry season.

Parameter	**Mean**					**X^2**	***p*-Value**
	Not Suitable	**Slightly Adequate**	**Moderately Suitable**	**Very Suitable**	**Completely Adequate**		
DO (mg/L)	6.43	7.08	6.36	6.30	6.21	16.41	**0.002**
pH	7.47	7.16	7.08	7.71	7.01	8.83	0.07
EC (µS/cm)	524.35	903.11	847.70	991.50	242.23	13.58	**0.009**
PO_4 (mg/L)	1.85	1.45	1.39	0.90	0.47	10.54	**0.03**
NO_3 (mg/L)	7.03	9.39	6.27	12.3	<5	7.92	0.09
BOD_5 (mg/L)	14.80	3.18	6.02	<0.1	<0.1	13.98	**0.007**
COD (mg/L)	46.99	36.99	17.3	16	11.27	9.31	0.053

Notes: The bold values indicate that the *p*-value of DO, EC, PO_4 and BOD_5 were less than 0.05, therefore, H0 was rejected, that is, there was a significant difference between categories.

Figure 3 illustrates the box plot of the DO (A), EC (B), PO_4 (C) and BOD_5 (D) parameters, which demonstrated a difference between categories.

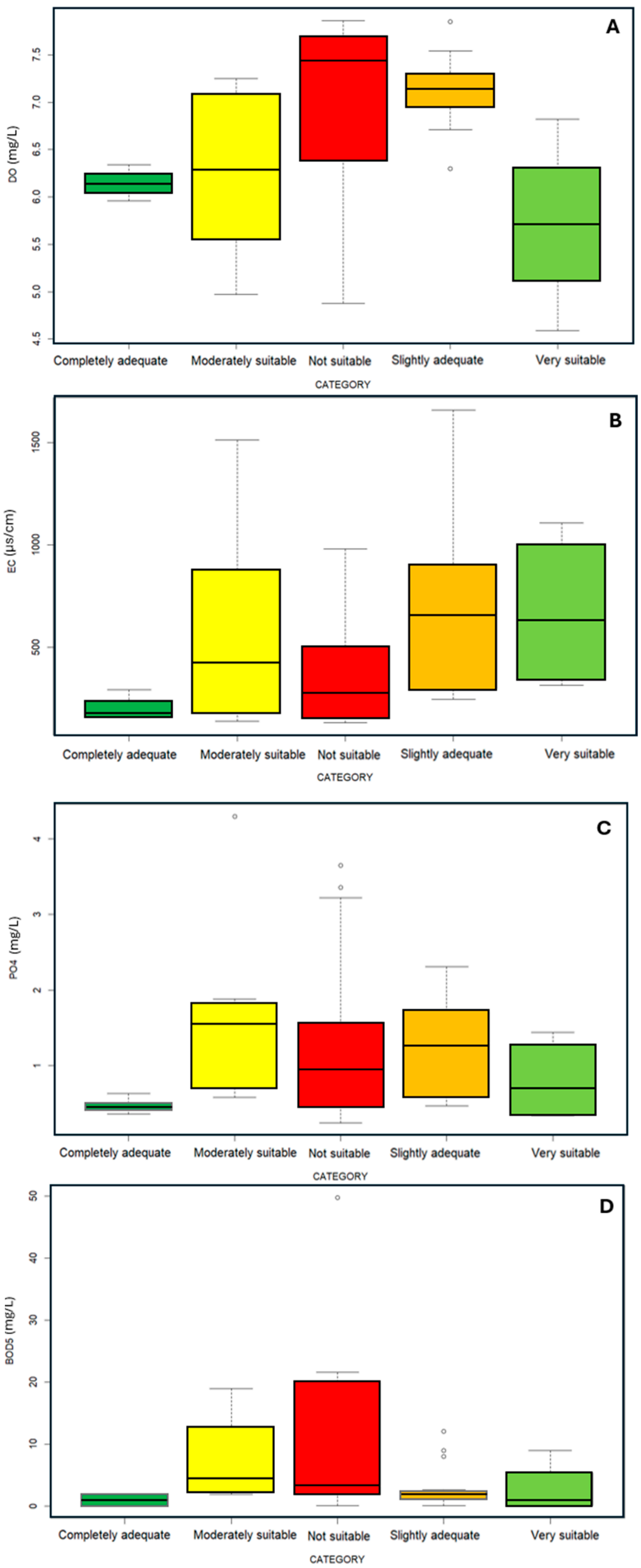

Figure 3. Box plot of the parameters DO (**A**), EC (**B**), PO_4 (**C**) and BOD_5 (**D**) that demonstrated differences between sampling categories during the dry season.

3.2. Comparison of Results with EPA Regulations

Once the results of the physicochemical parameters of the dry season (environmental criteria) had been compared with the quality criteria for the corresponding use, it was established that certain physicochemical parameters of the rivers near the cemeteries did not comply with the maximum permissible limits of the EPA regulations, as listed in Table 5.

Table 5. Comparación de parámetros fisicoquímicos en época seca versus límites permitidos por la normativa EPA (Comparison of physicochemical parameters in dry season versus limits allowed by EPA regulations).

Category	Cemetery	Section	River	Field Parameters			Laboratory Parameters			
				DO (mg/L)	pH	EC (μS/cm)	PO_4 (mg/L)	NO_3 (mg/L)	BOD_5 (mg/L)	COD (mg/L)
Not suitable	CH	U	Grande	5.2	7.75	794	**1.04** *	8.8	3.5	20
		P		**4.8** *	7.36	426	**2.94** *	9.4	**21.6** *	38
		D		5.1	7.68	566	**3.36** *	9.8	**20.8** *	48
	LC	U	Rundobalin	6.4	6.64	171.02	0.83	<5	17.1	79
		P		7.4	7.54	494	3.22	9.3	20.1	56
		D		5.7	7.24	310	3.65	6.4	**49.8** *	**147** *
	NA	U	Alambi	7.7	7.59	152.1	0.25	<5	<0.1	12
		P		7.6	7.79	**981** *	0.76	<5	<0.1	13
		D		7.5	7.66	**825** *	0.6	<5	<0.1	<10
Slightly adequate	JV	U	Pita	7.8	**5.87** *	1658	**0.55** *	<5	0.4	22
		P		7.4	**6.35** *	1321	**0.47** *	6	1.5	22
		D		7.5	**6.11** *	1477	**0.59** *	5.4	0.8	<10
	CP	U	Unnamed	7.0	7.59	293	**2.26** *	5.4	9	54
		P		7.1	7.61	307	**1.60** *	<5	2.6	58
		D		6.3	7.53	1128	**1.83** *	<5	**12.1** *	61
	AM	U	San Pedro	6.8	7.61	655	1.41	**33.9** *	2	29
		P		6.9	7.9	643	2.31	11.2	<0.1	38
		D		6.7	7.87	646	1.99	7.9	<0.1	39
Moderately suitable	TB	U	Quebrada	6.1	**6.08** *	1512	**1.57** *	6.2	**13** *	36
		P		6.3	6.57	908	**1.62** *	7.1	5.2	20
		D		5.4	6.17	1434	**1.85** *	7.9	9	14
	PM	U	Guambi	7.1	7.46	198.7	**0.79** *	<5	2.7	<10
		P		6.3	7.93	201.5	**0.9** *	6.2	3.8	14
		D		7.0	**8.27** *	832	**1.6** *	5.3	2.4	<10
Very suitable	CL	U	Unnamed	5.8	7.52	**1108** *	0.35	19.7	<0.1	13
		P		6.8	7.9	**875** *	1.44	<5	<0.1	19
Completely adequate	CN	U	Charguayacu	6.1	6.95	295	**0.63** *	<5	<0.1	<10
		P		6.2	6.85	191.7	**0.36** *	<5	<0.1	<10
		D		6.3	7.23	240	**0.41** *	<5	<0.1	14

Notes: Interpretation of abbreviations: Upstream (U), Parallel (P), Downstream (D), Dry period (DS), Rainy period (RS) * Values in bold exceed the permissible limits of the regulations. Sampling in the downstream section of the river near the Calacalí cemetery was not possible due to difficulty of access.

4. Discussion

The data collected for the study parameters DO, NO_3, PO_4, COD, BOD_5, pH, EC were subjected to the ANOVA statistical test between seasons, sections and categories, which was not achieved since the data did not comply with homoscedasticity or normality. The Kruskall–Wallis test was then applied. The results yielded showed a significant difference between categories, while there was no statistically significant difference between seasons and sections, so for subsequent analyses only the results from the dry season were used. This decision was made based on the environmental criterion that establishes that the highest concentration of the pollutant load from leachates is reflected during the dry season.

The results obtained between sections and categories were compared with the EPA maximum permissible limits for agricultural and environmental uses (Table 5) in which it was observed that there are parameters such as pH, BOD_5 and PO_4 that register values outside the norm. The highest value was observed in the section parallel to the cemetery, while downstream there were lower values due to the dispersion and degradability of the pollutants studied [8,9].

In the case of BOD_5, there was an increase of approximately 15% in the water sample taken parallel to the cemetery compared to upstream. Similarly, in the PO_4 parameter, the water sample from the river parallel to the cemetery indicated an increase of 35% compared to the upstream sample (see Table 3). This trend was recorded in the water samples taken parallel to the cemetery, mainly in the rivers near Chillogallo, Jardines del Valle and Puembo, which may mean that there is a greater amount of organic matter derived from human decomposition.

In the case of the Chillogallo cemetery, it is evident that the COD curve increased as a function of the sampling section. This may mean that the organic matter is being decomposed by micro-organisms, which has an impact on the considerable increase in the amount of oxygen available to other organisms present in the aquatic ecosystem, which may then lead to environmental eutrophication.

On the other hand, in the water sample taken downstream from the river near the Libertad de Chillogallo cemetery, a higher value of PO_4 was recorded, which may be due to the use of water in activities related to agriculture (see Table 1), mainly crop irrigation. Agricultural fertilizers contain PO_4 to benefit the growth and development of crops, however, due to the action of water movement and topographic conditions, the concentrations of this compound may increase downstream [33].

The cemeteries classified as "Not suitable" (Chillogallo (CH), Nanegal (NA), Libertad de Chillogallo (LC)) mostly record values outside the norm with respect to the parameters PO_4, NO_3 and EC, indicating a high probability of environmental contamination of the water bodies near the cemeteries. The cemeteries classified as "Completely suitable" mostly complied with the values declared in the EPA regulations, and they indicated a low probability of water contamination [39,40]. For example, the river near the Calacalí cemetery (CL) met environmental compliance standards, therefore, the water quality was favorable for protecting aquatic ecosystems.

In several cases, it was observed that the values of the blank sample parameters did not correspond to the standard, but were instead lower than those recorded in the sample parallel to the cemetery, which means that the river water was contaminated before it reached the cemetery. However, it can be observed that there was a contribution from the cemetery that mostly caused the values to increase in the section parallel to and after the cemetery, and that in any case they do not correspond to the standard. Therefore, they do not meet the minimum values necessary to guarantee the quality of the water in the river near the cemetery under study, according to its respective use. On the other hand, in Table 5, it is observed that at point D the contamination values were lower than those recorded at point P because the study focused on non-conservative substances that degrade based on distance and time.

The statistical analysis between categories indicated that there were significant differences in the parameters of DO, EC, PO_4 and BOD_5, while there were no significant differences in the rest of the parameters analyzed. In turn, the regulatory compliance of each category in reference to the EPA established that the "Completely adequate" category had greater compliance with respect to the rest of the categories. Therefore, according to the studies conducted by Crisanto-Perrazo et al. [38], these cemeteries, being located in these areas, have a lower probability of environmental contamination in the water, which is why the classification carried out in this study is correct.

The distances at which the samples were taken were 500 m because at that distance there was already dilution and accessibility. However, even if the distance were different, the pollutants would behave in the same way because the parameters are non-conservative substances (degradation over time and distance).

Due to water pollution caused by poorly located cemeteries, it is highly likely that it also affects human health, so it is imperative that authorities consider offering the population alternatives to traditional burial, where the body is not subjected to embalming processes, thus avoiding the introduction of unwanted chemical substances that later filter into the environment, as well as systems for containment and treatment of necrolixivids [6]. Finally, it is crucial to promote research into liquid waste from cemeteries for subsequent treatment in order to prevent the spread of diseases [28], conserve water resources and protect the environment.

Thus, this study constitutes a starting point for the authorities worldwide to issue environmental regulations and policies focused on the optimal location of these spaces and any other final disposal.

5. Conclusions

The analysis of the parameters DO, pH, EC, PO_4, NO_3, BOD_5 and COD indicates that, depending on the category in which the study cemeteries are located, the contamination of the water resource is evident since the values of the parameters analyzed were outside the maximum permissible limits established by the EPA.

Cemeteries in the "Not Adequate" category had a high probability of contamination of nearby rivers, since the parameters analyzed exceeded the limits established by international standards. Meanwhile, cemeteries in the "Completely Adequate" category demonstrated a low probability of contamination of water resources.

The analysis using the Kruskal–Wallis test confirmed that the established categories were correct since there is a statistically significant difference between them.

In several cases, the river studied shows contamination in the blank sample (U), which indicates that the study parameters did not correspond to the standard. However, the contribution made by the cemetery is evident since the values measured in P (parallel to the cemetery) were higher than in U.

The values measured downstream (D) on several occasions were lower than those at point P. This is explained from the point of view of non-conservative substances, that is, those that dilute and degrade over time and distance.

Finally, leachates from human decomposition must be treated technically to ensure the quality of the water resource. It is essential to formulate more demanding regulations, establishing criteria for the optimal location of cemeteries to ensure the protection of public health and the environment.

6. Recommendations

The high costs associated with collecting water samples and laboratory analysis of the parameters studied restricted the scope of this study, therefore, it is recommended that the sample be expanded to different regions, climates and parameters to obtain more evidence of cemetery-related contamination in water resources.

It is suggested that all rivers near cemeteries be monitored in order to control environmental water pollution and thus ensure the protection of public health. Additionally, it is important that local authorities pay attention to this issue by proposing policies and regulations that allow for the regulation and management of the ideal location of cemeteries, considering the possible effects that they may cause to the population surrounding them. These policies and regulations could be extended to manage landfills and wastewater treatment plants worldwide.

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