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Incidence of the Leachates from the Quevedo Emerging Cell on the Water Quality of the Limón Stream, San Cristóbal Parish, Quevedo Canton

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ABSTRACT

The present study aimed to assess the impact of leachates from the emerging cell on the water quality of the Limón stream in Ecuador. Five sampling points were selected as references using the NTE INEN 2176:2013 standard. Subsequently, these samples were analyzed in a laboratory using the standard methods for the examination of water and wastewater for the respective physicochemical analysis. The analysis results were compared with the Unified Text of Secondary Legislation of the Ministry of the Environment, and the water quality index (WQI) was determined according to the National Sanitary Foundation (NSF). Additionally, an environmental diagnosis was conducted based on the cause-effect matrix by Leopold to propose a strategy for the restoration and ecological recovery of the affected components. According to the obtained results, the sampling points closer to the leachate discharge showed high concentrations of dissolved oxygen, iron, fecal coliforms, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS), which exceeded the maximum permissible limits according to legislation. This resulted in a "fair" water quality index classification according to the WQI classification. These findings highlight the importance of considering and assessing the environmental impacts. A total of 24 impacts were identified on physical, biotic, and anthropic components, with 4.76% being highly significant, 42.86% significant, and 52.38% negligible. In conclusion, the results indicate a scenario of environmental deterioration at the leachate discharge stations, urging the urgent implementation of corrective measures to address the detected high contamination.

Keywords: pollution, WQI factors, legislation, environmental impact, water resources, landfill.

INTRODUCTION

In the current era of the Fourth Industrial Revolution and globalization, the health of surface water bodies faces an urgent challenge due to the wide range of human activities that generate pollutants. This phenomenon is manifested in the form of direct and indirect discharges of industrial, agricultural, domestic, and landfill wastewater, creating constant pressure on water quality worldwide (García et al., 2021). Environmental pollution, in this context, emerges as a globally impactful concern, where the increasing production of urban solid waste intertwines with natural environment degradation (Pozo et al., 2020).

The concern for water bodies and their relationship with solid waste holds a significant place on the environmental agenda. In Ibero-American countries and on a continental scale, solid waste is managed through landfills and dumpsites, which can give rise to leachates or percolated liquids as a result of the degradation of organic waste in the presence of precipitation (Pozo et al., 2020). Leachate plays a crucial role in the transport of refractory pollutants, toxic substances, and heavy metals, putting groundwater levels at risk and consequently affecting water quality, human health, and the surrounding ecosystems (Bautista et al., 2018).

Previous research highlights the complexity of the situation, showing that the leachates from landfills can significantly alter the physicochemical parameters of water as well as increase the presence of heavy metals and other contaminants (Montalvo and Quispe, 2018). In this context, it is essential to understand the composition of leachates, which depends on multiple factors, such as waste typology and climatic conditions (Morales, 2022).

In this context, Ecuador stands as an example where solid waste management and its effects on water bodies pose tangible challenges. Approximately half of the Municipal Decentralized Autonomous Governments (GAD) have landfills (National Institute of Statistics and Censuses, 2021). In the province of Los Ríos, specifically, solid waste management is carried out through a consortium management approach, with various emerging cells under municipal administration. However, the Quevedo emerging cell, the largest in the Mundo Verde Consortium, has experienced serious environmental problems and has generated negative effects, such as the damming of the Limón stream and the deterioration of its quality due to leachates (Anchundia et al., 2020; Quinsaloma, 2019).

From a methodological perspective, this study adopted a rigorous scientific approach, employing recognized methods and tools to formulate a restoration strategy for the direct influence of the Limón stream. The proposal focused on improving water quality for the benefit of both the population and the environment. Through this approach, the aim was to provide a concrete response to the issue raised and advance the technical management of leachate discharge into the Limón stream.

From a legal standpoint, this research is grounded on various national regulations, including the Constitution of the Republic of Ecuador, which recognizes the population's right to a healthy and balanced environment (CRE, 2008). The Organic Environmental Code (COA, 2017) and the Unified Text of Secondary Legislation of the Ministry of the Environment (TULSMA, 2017) provide the essential legal framework for this study and its environmental implications. Finally, this project also explored the social impact, as the proposal for treating leachates in the Quevedo emerging cell goes beyond the purely technical aspects. The research aimed to provide a viable and sustainable solution for leachate management, thereby preserving water quality and the well-being of downstream communities of the Limón stream.

This research aimed to determine the repercussions of leachates from the Quevedo emerging cell on the water quality of the Limón stream, specifically in the San Cristóbal parish, Quevedo Canton. The study represents an opportunity to identify the physical, biotic, and social dimensions affected by the leachates and establish a baseline that allows discerning critical points requiring attention (United Nations [UN], 2019). Additionally, it sought to generate socio-economic and environmental information to the propose holistic solutions that counteract the adverse impacts of leachates on the Limón stream.

METHODOLOGY

The present research was conducted in Limón stream, located in the San Cristóbal parish, Quevedo canton, Los Ríos province, where the coordinates of the sampling perimeter were taken as shown in Table 1. Using the geographic information from the DATUM WGS84 reference system, with UTM projection zone 17 South (Table 1).

Water quality of Limón stream

To determine the water quality, 5 sampling points were established within Limón stream, each consisting of materials mentioned in Table 2. The water sampling was carried out following the NTE INEN 2176:2013 standard, which specifies sampling techniques. Subsequently, the samples were evaluated in the laboratory using the standard methods for the examination of water and wastewater for the respective physicochemical

Table 1. Location of the Quevedo emergent cell

No.	X	Y
1	674525	9886139
2	674689	9886065
3	674522	9885888
4	674393	9885981

Table 2. Description of sampling points

Points	Description
1	100 meters upstream from the discharge of the old landfill
2	Discharge from the old landfill
3	Discharge from the first leachate treatment plant
4	Discharge from the second leachate treatment plant
5	100 meters downstream from point 4

analysis. The results of the water parameters were compared with the TULSMA standard, Book VI, which sets the water quality standards for the preservation of flora and fauna in freshwater and marine, and estuarine waters.

Furthermore, the water quality index was calculated using the National Sanitation Foundation (NSF) method (2006), as studied by García et al. (2021). This index conforms to Ecuadorian regulations, as it has a higher slope value. Additionally, it takes into account the weighted arithmetic average of nine variables and is determined through the following equation:

$$QWI = \sum_{i=i}^{i=n} Q_i \times W_i \tag{1}$$

where: W_i – importance factor or weighting of variable (i) relative to the other variables that make up the index;
Q_i – scaling factor of the variable, dependent on its magnitude, and independent of the others;
i – variable or parameter under consideration.

The parameters considered and their weights according to NSF are indicated in the Table 3. The water quality index rating scale was proposed by Brown, which indicates the following results present in Table 4.

Table 3. Weighting of quality parameters according to NSF

Parameters	NSF weight
Dissolved oxygen	0.17
Fecal coliforms	0.15
pH	0.12
BOD_5 (biochemical oxygen demand)	0.1
Nitrates	0.1
Phosphates	0.1
Temperature	0.1
Turbidity	0.08
Total dissolved solids	0.08

Table 4. Water quality classification according to QWI values

Description	Range
Excellent	91–100
Good	71–90
Fair	51–70
Poor	26–50
Very poor	0–25

Diagnosis of the current situation of the treatment plant and leachate discharges

Through direct observation, a baseline was established during a field visit to assess the state of environmental elements and the conditions in which they exist, including the physical, biotic, and social aspects. On the basis of this information, environmental impacts were identified using the cause-and-effect matrix (Leopold Matrix), which allows for a qualitative assessment of environmental factors.

The Leopold matrix consists of a two-entry table, where the upper part determines the magnitude of the impact (M), and the lower part indicates the intensity or degree of impact incidence (I). Depending on the assessment for M, the Impact Magnitude is measured on an ascending scale of 1 to 10, preceded by the + or – sign to indicate whether the impact is positive or negative, respectively. Depending on the assessment for I, the Impact Incidence is measured on an ascending scale of 1 to 10. The sum of the values in the rows will indicate the incidences of each environmental factor as a whole, while the sum of the column values will provide a relative assessment of the effect that each action will have on the environment (Merladet, 2016).

Restoration and recovery of sites affected by leachate discharges in Limón stream

Following the analysis of the information, a plan of action has been developed to mitigate the potential environmental impacts resulting from leachate discharges in municipal landfills.

RESULTS AND DISCUSSION

Water quality of Limón stream

The detailed observation of Table 5 reveals a concerning picture regarding the average water analysis at each sampling station. Specifically, it is noteworthy that at the leachate discharge points (P2, P3, and P4), significantly elevated concentrations of various parameters have been recorded, including dissolved oxygen, iron, fecal coliforms, BOD, COD, and TSS.

This finding indicates that the values obtained at these discharge points exceed the limits established by TULSMA as acceptable quality criteria. These criteria are outlined in Table 3, which delineates the quality standards necessary to preserve the health of flora and fauna in various types of water bodies, whether freshwater, cold, warm, marine or estuarine.

According to the analysis conducted by Du et al. (2019), elevated levels of BOD are influenced by the toxicity generated by metals. Similarly, it is observed that the removal of these metals is hindered by BOD, as the latter facilitates the dissolution of metals, making their effective elimination difficult and restricted. Some metals, such as lead, cadmium, and mercury, are toxic to microorganisms that decompose organic matter, which can inhibit or slow down their activity, reducing BOD (Igiri et al., 2018).

Both physical and chemical parameters must be favorable to allow the action of microorganisms in degrading contaminants, so they should be properly managed within the leachate emergent cells before being discharged into effluents to prevent negative impacts on the environment and water quality (Table 5) (Vasistha & Ganguly, 2020).

According to the NSF water quality index shown in Table 6, it has been determined that the water quality at all sampling points is classified as fair. This assessment is based on a series of rigorous parameters that ensure water safety for human consumption (Cesar and Saravia, 2017). However, it is essential to carefully analyze the results obtained at each sampling point to better understand the environmental situation and the possible influence of external factors on water quality.

In the case of point 2, corresponding to the discharge from the old landfill, a higher value of 61.03 units has been recorded compared to other points, in addition to those located in areas further away from the landfill (P1-P5), they also had an index high quality. This discrepancy in values

Table 5. Water quality monitoring matrix

Parameters	Units	P1	P2	P3	P4	P5	AM 097-A. Table 3
Temperature	ºC	24.3	24.8	24.1	24.7	23.9	-
Electrical conductivity	-	168.5	118.8	135.8	138.5	136.3	-
pH	-	7.7	8.36	7.61	7.71	7.62	-
Dissolved oxygen	mg/L	3.3	4.4	5.4*	5.5*	5.1	<5
Turbidity	UNT	4.5	3	4.2	3.8	3.3	-
Aluminum	mg/L	0.2766	3.697	0.7463	49.003*	0.307	5.0
Arsenic	mg/L	<0.0031	0.0034	<0.0031	<0.0031	<0.0031	0.1
Cadmium	mg/L	<0.0004	0.0011	<0.0004	<0.0004	<0.0004	0.02
True color	UCIPt dill 1:20	-	56*	-	20	-	1:20
Copper	mg/L	<0.0037	0.0455	0.0086	0.0277	0.005	1.00
Phosphate	$MgPO_4/L$	<0.072	<0.083	< 0.105	< 0.095	<0.065	-
Iron	mg/L	0.8925	84.749*	18.701*	63.718*	13.622*	10.00
Mercury	mg/L	<0.00002	<0.00002	-	<0.00002	<0.00002	0.005
Total coliforms	NMP/100 mL	>2419	>241970	>2419	>241970	>2419	-
Fecal coliforms	NMP/100 mL	>2419*	>2419*	>2419*	>2419*	>2419*	2000
Nickel	mg/L	<0.0004	0.0903	<0.0004	0.028	<0.0004	2.00
Nitrates	$MgNO_3/L$	0.84	0.33	0.42	0.68	0.56	
Lead	mg/L	0.0104	0.0106	0.0117	0.0138	0.0187	0.2
Oils and greases	mg/L	<0.44	54*	0.85	37.5	<0.44	30
BOD	$mg0_2/L$	25.95	1110*	44.4	153.6*	30.45	100
COD	$mg0_2/L$	51.2	1165.1*	76.67	348.32*	68.98	200
Phenols	mg/L	<0.023	0.04	0.03	0.048	<0.023	
Sulfates	mg/L	1	0.99	1	0.99	0.99	1000
Total suspended solids	mg/L	3	235*	11*	37*	14*	5.00
Zinc	mg/L	0.5745	0.9059	0.5399	0.6406	0.536	5.00
Mercury	mg/L	-	-	<0.00500	-	-	0.005

Note: * Does not comply with the maximum allowable limits according to Table 3 of TULSMA.

Table 6. Water quality index results at different sampling points

Sampling points	Σ ICA	Classification
1	58.28	Fair
2	61.03	Fair
3	54.31	Fair
4	55.92	Fair
5	59.65	Fair

could be indicative of a specific situation where the source of contamination is not only the landfill itself, but there may be other sources of contaminants that enter the water before reaching the leachate discharge (Caho and López, 2017).

The "fair" classification obtained in the overall results should not be interpreted as a guarantee of optimal water quality. Rather, this pattern of values at the sampling points indicates the presence of contaminants in the water that exceed natural and healthy levels. This situation can have significant implications for both human health and the surrounding aquatic ecosystem (Hredoy et al., 2022).

The contaminants remaining in the treated landfill leachate can have an adverse impact on the environment once discharged into receiving waters (Qi et al., 2017). Among these are contaminants of emerging concern (CECs), which are a potentially significant issue concerning suspected risks to human health and the environment (Verlicchi et al., 2012).

CECs include, among others, pharmaceuticals and personal care products (PPCP), perfluorinated compounds (PFCs), persistent organic pollutants (POPs), and nanomaterials (Chen et al., 2017; Petrie et al., 2015). In recent decades, traces of various CEC compounds have been identified in multiple environmental samples, such as influents/effluents from wastewater treatment plants, soils (Song et al., 2018), sediments (Bu et al., 2013), sludge (Meng et al., 2016), biota (Barrett et al., 2010), surface water (Sousa et al., 2018), groundwater (Sui et al., 2015), and drinking water (Glassmeyer et al., 2017).

The presence of contaminants in the discharge from the old landfill, as well as at points farther away from it, suggests a concerning dispersion of harmful substances in the environment. These contaminants could originate from various sources, such as industrial discharges, untreated urban wastewater, or runoff from contaminated surfaces in the area (Palomeras et al., 2021). It is vital to investigate and determine the exact source of these additional contaminants to implement appropriate corrective and preventive measures.

Diagnosis of the current situation of the treatment plant and leachate discharges from the Quevedo emergent cell

Quevedo has a population of 173,575 according to the census data from the National Institute of Statistics and Censuses (2010), with a daily production of 190 tons of garbage, according to the studies reported by Anchundia et al., (2020). According to the collected information in the study area, it was established that the area is considered rural, with residential agricultural land use according to LOOTUGS (2016). The land area is approximately 5.3 hectares, with an average annual precipitation of 10.119 mm per year according to a study by Espinosa (2013).

According to on-site information, there are approximately 100 rural residents distributed in 26 houses. They identify as mestizos, with income levels averaging $180 per month, which is $6.00 per day. The housing is of mixed construction, using cement, bricks, and wood. The education level of the population is concentrated with 40% having completed only primary education, 55% completing secondary education, and only 5% at a higher level of education or having completed it.

The landfill has an impact, whether positive or negative, on the environmental factors it comes into contact with. Therefore, it is necessary to identify each of these factors to implement the corrective measures that reduce their effects. Table 7 shows the cause-and-effect matrix for the identification of environmental impacts in the perimeter of the study area, which revealed 24 environmental factors affected by the improper management of the emergent cells.

According to Figure 1, of the number of affected environmental factors, 4.76% were highly significant, indicating that these factors had a substantial impact on the environment. 42.86% were significant, signifying that a substantial part of the identified effects is related to the factors that have a moderate impact, although they are important for the environment. Lastly, 52.38% were noticeable impacts, and while these impacts have a recognizable effect, their influence on the environment may be relatively smaller compared to other factors (Juan Pérez, 2017).

Table 7. Cause-effect matrix for the identification of environmental impacts

Environmental factors			Environmental effects					
			C1	C2	C3	C4	C5	
Component	Factor	Subfactor	Contaminants in the water (heavy metals, organic substances, bacteria)	Species of aquatic animals and plants present, genetic diversity, density, and biomass of the aquatic community	Emissions of toxic gases, and foul odors	Levels of contaminants in the soil near the watercourse	Diseases associated with exposure to water or air	Number of actions
Physical	Air	Quality of ambient air			X		X	2
Physical	Soil	Soil quality		X		X		2
Physical	Water	Hydrography and water quality	X	X		X		3
Biotic	Fauna	Faunal species		X		X	X	3
Biotic	Flora	Plant species in the area		X		X		2
Anthropogenic	Population	Socioeconomic activities	X		X		X	3
Anthropogenic	Employment	Hiring of unskilled labor			X		X	2
Anthropogenic	Visual perception	Landscape	X	X	X	X		4
Anthropogenic	Quality of life	Public health	X		X		X	3
Number of affected factors:			4	5	5	5	5	24

According to the studies conducted by Qi et al. (2017), conventional treatments and membrane treatment are not capable of effectively removing refractory organic and inorganic contaminant residues in leachate. Therefore, landfills have become a significant issue in the context of environmental conditions and occupational safety for those handling such waste. This is because the decomposition of the matter generates toxic gases and leachate products that directly affect the immediate ecosystem and its surroundings, as well as the health of human communities located in the vicinity (Quintero, 2017).

Proposal for a strategic plan for ecological restoration and recovery of sites affected by leachate discharges in Limón stream

Basic principles:

- Implement solid and liquid waste management systems in the landfill to minimize the generation of leachate.
- Control the sources of leachate through proper waste compaction, impermeable layer covering, and the design of drainage systems to collect leachate.

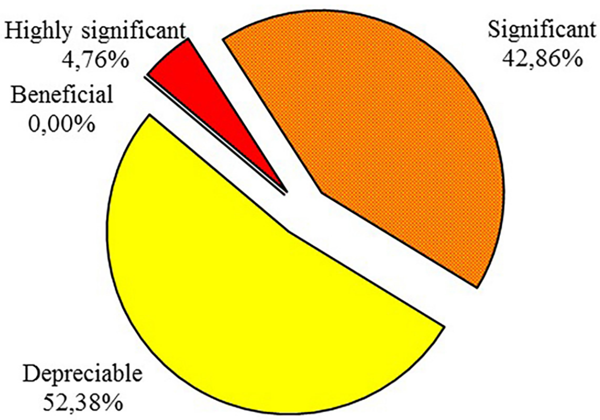

Figure 1. Percentage of environmental impacts caused by leachate discharges into Limón stream

- Establish on-site treatment systems to treat leachate at the point of generation before releasing it into the environment.
- Use technologies such as evaporation systems, filtration, and bioremediation to remove or reduce contaminants present in leachate.
- Employ appropriate transport systems to prevent spills and leaks during the transfer of leachate to treatment facilities.
- Consider technologies such as coagulation-flocculation, advanced oxidation, adsorption, and desalination to eliminate specific contaminants.
- Implement a continuous monitoring program to assess water quality on-site and in receiving sources.
- Conduct regular analyses of leachate and nearby groundwater to ensure contaminant levels are within allowable limits.
- Ensure compliance with environmental regulations and water quality standards established by local and national authorities.
- Educate the local community about the risks associated with leachate and the importance of proper waste management.
- Promote the adoption of sustainable and responsible practices among residents and businesses near the landfill.
- Research and consider emerging and developing technologies to enhance the efficiency and effectiveness of leachate treatments.
- Continuous innovation can lead to more effective and sustainable solutions.

General objective:

Establish a strategy for restoring water quality affected by landfill leachate discharge.

Strategic objectives:

- Reduce the generation of leachate in the landfill.
- Improve the quality of leachate on-site.
- Minimize the release of leachate.
- Evaluate the effectiveness of actions.
- Ensure compliance with regulations.
- Raise the awareness about proper waste management.
- Innovate for better solutions.

Strategic formulation

In Table 8, a matrix of strategies with objectives and indicators is presented to restore the water quality of Limón stream, San Cristóbal Parish, Quevedo Canton.

CONCLUSIONS

At the leachate discharge points, there are significantly high concentrations of various water quality parameters, such as dissolved oxygen, iron, fecal coliforms, BOD, COD, and TSS. These values exceed the allowable limits established by TULSMA to preserve the health of the aquatic ecosystem. The evaluation through the NSF water quality index rates the water quality at all points as "regular", although it is encouraged

Table 8. Strategic formulation matrix

Objectives	Strategy	Indicators
Reduce the generation of leachate in the landfill	Leachate prevention and control	✓ Volume of leachate generated per ton of waste ✓ Percentage of waste compacted correctly ✓ Control of toxic and hazardous waste ✓ Efficiency of drainage and collection systems
Improve the quality of leachate on-site	On-site treatment	✓ Levels of contaminants before and after treatment ✓ Efficiency of on-site treatment technologies ✓ Frequency of equipment maintenance and operation
Minimize the release of leachate	Efficient collection and transport	✓ Volume of leachate infiltrated into the soil ✓ Number of spills or leaks during transport
Evaluate the effectiveness of actions	Continuous monitoring and evaluation	✓ Contaminant levels in groundwater ✓ Compliance with regulations and standards ✓ Frequency and consistency of sampling and analysis
Ensure compliance with regulations	Regulatory compliance	✓ Compliance with allowable contaminant limits ✓ Absence of sanctions or fines for non-compliance
Raise awareness about proper management	Education and sensitization	✓ Community knowledge level about leachate ✓ Participation in environmental education programs
Innovate for better solutions	Research and development	✓ Implementation of new technologies or approaches ✓ Improvements in the efficiency and effectiveness of treatment

to carefully analyze the results to better understand the situation.

According to the diagnosis of the current situation of the leachate treatment and discharge plant from the emerging cells, it was determined that this activity directly or indirectly affects 24 environmental factors, such as the physical components (quality of water, soil, and air), biotic (flora and fauna), and anthropogenic (diseases of the nearby population). These results have allowed the detailing of strategies to address pollution and protect both human health as well as aquatic and terrestrial ecosystems.

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