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REVIEW

Environmental Impact of Improper Solid Waste Disposal in San Pablo, Perú

Impacto Ambiental de la Disposición Inadecuada de Residuos Sólidos en San Pablo, Perú

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ABSTRACT

The study showed that inadequate solid waste management in the district of San Pablo represented a critical environmental problem, characterised by cumulative impacts on soil, water and public health. The absence of a technically designed landfill and the disposal of waste in an open dump without waterproofing or leachate treatment systems led to the continuous release of pollutants. These leachates, generated by the decomposition of organic matter and the percolation of rainwater, contained high concentrations of biodegradable organic matter, heavy metals (Pb, Cd, Cr, Hg, Ni) and pathogenic microorganisms, frequently exceeding Environmental Quality Standards. In the soil, leachate infiltration altered physicochemical properties, increasing electrical conductivity, decreasing pH and reducing natural fertility. From a biological point of view, a decrease in microbial diversity and an alteration of essential biogeochemical cycles were observed. This situation was aggravated by sociocultural factors such as hyperconsumption, low recycling rates and low environmental awareness, compounded by the limited technical and budgetary capacities of the local government. Comparative analysis with national and international studies showed that the case of San Pablo replicated a common pattern in localities without adequate infrastructure. The research highlighted the need to implement a sanitary landfill with leachate and biogas control, environmental monitoring programmes, community education campaigns and citizen participation mechanisms as comprehensive strategies to mitigate and prevent environmental and health risks, ensuring a healthy environment for the present and future population.

Keywords: Solid Waste; Leachate; Soil Contamination; Municipal Landfill; San Pablo.

RESUMEN

El estudio evidenció que la gestión inadecuada de residuos sólidos en el distrito de San Pablo representó una problemática ambiental crítica, caracterizada por impactos acumulativos sobre el suelo, el agua y la salud pública. La ausencia de un relleno sanitario técnicamente diseñado y la disposición de desechos en un botadero a cielo abierto sin impermeabilización ni sistemas de tratamiento de lixiviados provocaron la liberación continua de contaminantes. Estos lixiviados, generados por la descomposición de materia orgánica y la percolación de aguas pluviales, presentaron altas concentraciones de materia orgánica biodegradable, metales pesados (Pb, Cd, Cr, Hg, Ni) y microorganismos patógenos, superando con frecuencia los Estándares de Calidad Ambiental. En el suelo, la infiltración de lixiviados alteró propiedades fisicoquímicas, aumentando la conductividad eléctrica, disminuyendo el pH y reduciendo la fertilidad natural. Desde el punto de vista biológico, se observó una disminución de la diversidad microbiana y una alteración de los ciclos biogeoquímicos esenciales. Esta situación se agravó por factores socioculturales como el hiperconsumo, la baja tasa de reciclaje y la escasa conciencia ambiental, sumados a las limitadas capacidades técnicas y presupuestarias del gobierno local.

El análisis comparativo con estudios nacionales e internacionales demostró que el caso de San Pablo replicó un patrón común en localidades sin infraestructura adecuada. La investigación resaltó la necesidad de implementar un relleno sanitario con control de lixiviados y biogases, programas de monitoreo ambiental, campañas de educación comunitaria y mecanismos de participación ciudadana, como estrategias integrales para mitigar y prevenir riesgos ambientales y sanitarios, asegurando un entorno saludable para la población presente y futura.

Palabras clave: Residuos Sólidos; Lixiviados; Contaminación del Suelo; Botadero Municipal; San Pablo.

INTRODUCTION

Solid waste is a growing problem in municipal management in both urban and rural areas. Although there are similarities in general aspects, there are specific aspects to consider for each situation, which currently promote environmental pollution and ecological imbalance. This has caused growing concern in society, and the debate reaches all sectors of the community.

Although the problem of municipal solid waste has been identified for several decades, especially in metropolitan areas, the partial solutions that have been achieved so far do not cover all countries in the region or most medium-sized and small cities, becoming a permanent political issue that in most cases generates social conflicts. Municipalities are the entities responsible for the proper management of this solid waste, as they are primarily responsible for collection, transport, and final disposal. Solid waste is one of the most serious problems facing various municipal governments. This is due, among other things, to its cumulative nature, i.e., it accumulates year after year. This situation is even more problematic when one considers that populations are not stable but are increasing over time, with a consequent increase in the amount of solid waste generated.

In the District of San Pablo, there is no final disposal site for solid waste that can be classified as a sanitary landfill. Therefore, the inadequate final disposal of this waste leads to the generation of leachate derived from microbial decomposition processes and certain waste components. Due to its high toxicity, this can cause severe problems for the environment and soil resources, especially the soil where large amounts of solid waste accumulate, generating sources of infection for the population through infiltration, runoff, washing, or dragging, as these spread to different places as a result of leachate from the municipal landfill in the District of San Pablo.

DEVELOPMENT

Problem

The inadequate management of solid waste worldwide is a major problem for society, as it generates pollution when it accumulates or is disposed of improperly without taking into account the appropriate place where it should be deposited, especially considering that soil is the most affected, as it is the only place where solid waste from landfills can be deposited. Likewise, the decomposition of organic matter produces leachates, which damage the soil in the area, since these soils are the only receiving bodies, thus altering their normal composition, which translates into soil contamination.

In Peru, the proper management of municipal solid waste is one of the main and most serious problems affecting the environment. This problem is growing in the country as hyper-consumerism becomes increasingly ingrained in our culture. Added to this problem is a lack of environmental awareness and culture, as the habit in our society is to use and throw away. “In our country, around 23 000 tons of waste are produced every day and only 15 % is recycled. Furthermore, there are only 12 authorized landfills, meaning that 90 % of waste ends up in the approximately 1 250 illegal dumps that exist in Peru”.

In this context, the District of San Pablo is no stranger to this problem, as waste disposal is carried out in open dumps. This solid waste is generated by the population of the district of San Pablo and is sent to a municipal dump that does not have the necessary conditions to minimize environmental pollution, as provided for in “Legislative Decree No. 1278 - Legislative Decree Approving the Law on Integrated Solid Waste Management.” The dump is located 2 km from the Huingoyacu-Consuelo highway (San Pablo).

The problem lies in the possible contamination of the soil located in the area directly affected by the municipal landfill in the District of San Pablo. This project therefore aims to assess the level of soil contamination in order to propose and/or establish an alternative solution that minimizes soil contamination caused by leachates.

Previous work

Internationally

Álvarez in his research paper entitled: Diagnosis and proposal for improvement of the municipal landfill in Villa Victoria, State of Mexico. Undergraduate thesis. Autonomous University of the State of Mexico. Villa

Victoria – Mexico. 2016. The author concludes by saying that:

- After reviewing both the study area and the current legislation for the establishment of final disposal sites in municipalities, we have concluded that Villa Victoria, State of Mexico, does not have a final disposal site for urban solid waste that complies with the legislation.

Romero in his research paper entitled: Study of lead contamination in soils at a closed battery recycling plant in Freire, IX region. Undergraduate thesis. University of Chile. Santiago, Chile. 2017. He concludes by saying:

- The concentration of lead was determined in soil samples from both the site and baseline levels, finding statistically significant differences between the means of both groups. Lead concentrations at the site greatly exceeded baseline levels and the chosen reference standard (400 [mg/kg] EPA).

Sanchez In her research paper entitled: Heavy metal contamination in the Moravia landfill in Medellín: transfer to flora and fauna and evaluation of the phytoremediation potential of native and introduced species. Postgraduate thesis. Pontifical University Javeriana. Bogotá, Colombia. 2010. The author concludes by saying that:

- Despite the fact that 24 years have passed since its closure, the former Moravia landfill has high concentrations of Pb, Ni, Cr, Hg, and Cd in its surface layers, with values that exceed by a wide margin the permissible limits for agricultural soils, soil amendments, and even previous reports on sanitary landfills. It should be remembered that despite its closure in 1984, the waste matrix has been covered by houses for most of the time, so the infiltration and mobility of heavy metals has been almost nil.

Márquez[1] in her research paper entitled: Evaluation of Agricultural Soil Contamination by Leachates from a Municipal Landfill in Central Mexico. Undergraduate thesis. University of Toluca Valley. Mexico. 2010. The author concludes with:

- LX contaminates areas surrounding the disposal site, mainly the soil and adjacent vegetation. A tool for measuring the contamination potential of an LX is the Leachate Contamination Index (LCI).

Hernández[2] in his research paper entitled: Evaluation of the leachate index of open urban solid waste landfills in the city of Havana. Undergraduate thesis. Technological University of Havana, "José Antonio Echeverría," Cuba. 2009. I conclude:

- Provincial and municipal landfills have workers and supervisors. However, in special period landfills, controllers are not always present, even though they are required to be by regulation.

National level

Falcón[3] in her research paper entitled: Soil contamination as a result of municipal solid waste disposal in the Roma-Casa Grande landfill. Undergraduate thesis. Cesar Vallejo University. Trujillo, Peru. 2016. The author concludes by saying that:

- The inadequate final disposal of municipal solid waste causes the presence of heavy metals such as lead, cadmium, and chromium VI, whose concentrations exceeded the Environmental Quality Standards for soil, causing various negative impacts on the environment, society, production, and the economy at the local, regional, and national levels.

Champi[4] in their research paper entitled: Evaluation of Pollution from Solid Waste Disposal in the Population Centers of Pisac, Coya, Lamay, and Calca- Cusco Region. Undergraduate thesis. National University of San Antonio Abad del Cusco. Cusco, Peru. 2014. The authors concluded by saying:

- The physical-chemical analysis of the leachates generated by the final disposal of solid waste from the landfills in the towns of Pisac (Matara) and Calca (Kaytupampa) show a high content of suspended organic matter and, consequently, high BOD and COD values, making them a potential contaminant of soil and water resources. With regard to heavy metals in the leachates, trace amounts were found in the four landfills and below the Maximum Permissible Limits (MPL) proposed by MINAM. Bacteriological analysis of the leachates shows the presence of high levels of total coliforms in the Pisac, Coya, Lamay, and Calca landfills, exceeding the MPLs, indicating bacteriological contamination, which would therefore be affecting the soil resource.

Vivanco in his research paper entitled: Evaluation of soil contamination caused by the municipal landfill in Abancay and its negative impacts on the environment and human health. Undergraduate thesis. Alas Peruanas University, Abancay branch. Abancay, Peru. 2012. I conclude by saying that:

- The poor final disposal of solid waste, which is dumped in the municipal landfill, emits toxic gases

and produces leachates, leading to the release of dangerous pollutants, constituting a serious health problem and causing adverse effects on the soil and human health.

Rojas[5] in her research paper entitled: Evaluation of the physical and chemical quality of soil contaminated with leachates from the solid waste dump and its effects on the public health of the population in the area surrounding the Cancharani dump in Puno. Postgraduate thesis. Puno, Peru. 2016.

At the regional level

Ramírez[6] in his research paper entitled: Determination of Water Pollution Levels from the Final Disposal of Solid Waste Generated in the City of Moyobamba- 2014. Undergraduate thesis. National University of San Martin Tarapoto. Moyobamba – Peru. 2014. The author concludes by saying that:

- The El Paraíso ravine was found to be the most polluted, as evidenced by leachates from the municipal landfill, where low pH levels and high concentrations of total dissolved solids were found to be the most significant limiting factors.

Rojas[5] in her research paper entitled: Environmental and Economic Evaluation of the Final Disposal of Municipal Solid Waste in Moyobamba – 2015. Undergraduate thesis. National University of San Martin - Tarapoto. Moyobamba – Peru. 2016. She concludes by saying:

- Regarding the evaluation of the final disposal phase of municipal solid waste located on the Moyobamba-Yantaló highway, and according to the number of environmental impacts identified, the most affected environmental components are mainly soil, water, and air.

Vásquez[7] in his research paper entitled: Evaluation of the water quality index in the area of influence of the municipal landfill in Tarapoto, Yacucatina sector, San Martin, Peru. Postgraduate thesis. National University of San Martin, Tarapoto. Tarapoto, Peru. 2010. The author concludes by saying:

- All sampling points show contamination by total coliforms and thermotolerant coliforms, exceeding water quality standards.

Izquierdo[8] in his research paper entitled: Evaluation of the contamination of water sources located in the area of influence of the municipal landfill in the city of Yurimaguas. Undergraduate thesis. Yurimaguas – Peru. 2013. The conclusions were that:

- None of the parameters in the physical-chemical analyses exceed the values established in the ECAs for water, D.S. No. 015-2015. Therefore, this water is not contaminated for the use given to the water bodies investigated, except for total solids, which exceed the ECAs (Points 2.4).
- The water bodies studied contain traces of heavy metal contaminants (cadmium, chromium, and lead), the latter two exceeding the ECAs for the use of these water sources. It should be noted that there are small traces of cadmium, which may be due to the disposal of solid waste from electrical and electronic equipment and waste from batteries.

Theories related to the topic

What is soil?

Martinez[9] says that soil is the "upper layer of the planet's solid surface, formed by the weathering of rocks in which plants are or may be rooted and which constitutes a particular ecological environment for certain types of living beings."

"Another accepted definition of soil is: a mixture of small fragments of rock and organic materials, together with liquids and gases in varying proportions of their respective components, with a certain productive capacity".[9]

Soil composition

Solid phase

"The solid phase is responsible for the behavior of the soil. Within it, two types of components can be distinguished: the mineral fraction derived from the original material and the organic fraction from the remains of living beings that inhabit both the interior of the soil".[9]

"The solid mineral phase includes substances of a saline nature, which are soluble and therefore less stable than silicates, which are the primary constituents. The components of the solid phase are divided into:[9]

- Mineral components: "The mineral fraction of the soil derives directly from the original material and there are three main types: sand, silt, and clay".[9]
- Organic components: "The organic matter in soil comes from the remains of organisms that have fallen on its surface, mainly leaves and plant residues. This material is known as "fresh organic matter" and its quantity varies with the use or vegetation covering the soil".[9]

Liquid phase

"The liquid phase is known as 'soil water' and is so named because it comes from rainfall or high water tables. Once in contact with the solid phase, substances in solution and suspension from the liquid phase are incorporated into it".[9]

"It is in this phase that the processes of soil formation and evolution take place, with those relating to the solid-liquid interface being of particular importance. It also acts as a vehicle for transporting substances both within the soil and from the soil to the outside".[9]

Gaseous phase

"This phase consists of a gas qualitatively similar to air, but with different proportions of its components. It allows soil organisms and plant roots to breathe".[9]

"Gas exchange between the soil and the atmosphere occurs through diffusion between the two. The importance of organism respiration in the composition of the soil atmosphere is evident in the seasonal differences observed in carbon dioxide content".[9]

Soil pollution

"The most obvious environmental effect of inadequate municipal solid waste management is the aesthetic deterioration of cities and the natural landscape, both urban and rural. The degradation of the natural landscape caused by uncontrolled littering is on the rise; it is increasingly common to see open dumps or rubbish piled up anywhere".

"Another easily recognizable negative effect is the aesthetic deterioration of towns and cities, with the consequent devaluation of both the land where the dumps are located and the neighboring areas, due to neglect and the accumulation of garbage. In addition, soil contamination or poisoning is another of the harmful effects of these dumps, due to the discharge of toxic substances and the lack of control by the environmental authorities".

Sources of pollution and pollutants

Causes of soil pollution

According to Rodriguez[10] "There are various causes of soil pollution problems, some of which are difficult to control and cannot be classified systematically, such as accidental spills of hazardous substances and illegal dumping carried out clandestinely."

"Due to their quantitative significance, the most important sources of soil pollution include poorly maintained or abandoned industrial waste dumps, pipelines and deposits of hydrocarbons and chemicals in general, and mining and metallurgical activities. This is with regard to localized pollution".[10]

Main causes of pollution:

- "The improper disposal of hazardous waste in vacant lots, warehouses, storage facilities, and industrial installations."
- "Leaks of hazardous materials (especially hydrocarbons and their derivatives) from tanks, underground containers, pipes, and ducts."
- "The leaching of hazardous waste at storage sites and sites where hazardous waste management activities are carried out."
- "Spills of chemical substances due to transportation accidents."
- "The improper disposal of hazardous waste or solids contaminated with hazardous waste at final disposal sites for municipal solid waste."

Important functions of soil:

- "Acting as a regulatory filter during aquifer recharge and protection."
- "It is the place where biological, biogeochemical, and trophic network cycles take place."
- "It constitutes a biological habitat and reserve for the preservation of species and, therefore, of genetic diversity."
- "It is the physical basis for agricultural and livestock food production."
- "It is a producer of forest resources."
- "It is the physical basis for the construction of buildings and services."

Diffuse Pollution

According to [10] "Diffuse pollution, with agricultural soils as a typical example, constitutes another area of the problem, different both in its characteristics and in the nature of its possible solutions, which are basically limited to prevention, given the technical and economic unfeasibility of corrective solutions."

Loss of soil nutrients through leaching

According to Fernández "The concept of leaching is used to describe a phenomenon characteristic of humid climates, which causes the loss of nutrients in some soil layers by water carrying away basic substances from the soil such as clay, salts, iron, or humus."

"This concept is also used to indicate the movement of waste and other pollutants towards rivers and seas, and the process of washing away a layer of soil or geological layer by water."

"Vegetation, especially forest vegetation, serves as a natural protection against leaching, which is why, if it is destroyed, this process is considerably accelerated. The use of highly acidic fertilizers, excessive irrigation, and crops that retain many nutrients from the soil also contribute to this problem."

Soil quality

According to [10] "Soil quality encompasses the physical, chemical, and biological components of the soil and their interactions. Therefore, to capture the holistic nature of soil quality, or health, all parameters must be measured. However, not all parameters are equally relevant for all soils or situations."

Soil sampling

"Sampling is the activity of taking representative samples that allow the soil under study to be characterized, while the sample can be defined as a representative part that has the same characteristics or properties as the material being studied, and the samples that will be sent to the laboratory are those chosen to be analyzed according to the established objectives."

"The sampling technique to be applied depends, among other things, on the objective of the study, the edaphic, meteorological, geological, and hydrogeological conditions at the site, the depth and accessibility of the contamination under study, and the analytical requirements regarding the quantity and quality of the samples."

"For surface samples: For surface sampling (to a depth of approximately one meter), manual probing can be used. This system is relatively easy, quick to use, and inexpensive, but since the amount of soil that can be extracted with this technique is small, it will be necessary to obtain composite samples from several probes. Other alternative techniques for surface sampling include pits or trenches."

"For deep samples: At a potentially contaminated site, there may also be a spatial distribution of contaminants at depth. This may result from the interaction between the characteristics and properties of the soil along the profile and the characteristics and properties of the contaminants themselves. It is therefore essential that sampling also reflects the possible spatial variability of contaminants at depth. Otherwise, the decisions made may not be appropriate."

Solid waste and its impact on the environment

"It is known that the improper disposal of municipal solid waste in landfills has negative impacts on human health and the environment."

"The factors that determine the form and intensity of the impact are related to the predominant type of waste, the distance between populated areas and landfills, the depth of the water table, and the distance and characteristics of surface water sources that could be affected."

"Contaminants can arise as gases in the air and soil or as leachates in surface and groundwater. If contamination is not detected in the landfill area, it is important to define the route of movement of the contaminant, the path from the landfill to the point of detection".[12]

"In the case of surface water, the path is often a stream channel or an eroded surface; for groundwater, the path is usually the upper aquifer".[12]

"Once the path has been established, the common practice is to identify all activities, human and otherwise, along the path in order to complete an assessment of the impacts of the contaminants".[12]

"Equally important in controlling leachate movement is the management of all surface water, including rain, runoff, intermittent streams, and artesian springs," where these contaminate the soil along their path.[12]

"Environmental impact is a set of positive and negative effects that an economic activity, whether ongoing or planned, has on the standard of living and the physical environment of its area of influence".[13]

"The issue of waste affects all activities, people, and spaces in a general and horizontal way, becoming a problem not only because of what it represents in terms of abandoned resources but also because of the growing inability to find places that allow for its proper disposal from an ecological point of view".[13]

The negative effects occur on different environmental factors:

Water:

- "Production of leachates and runoff phenomena with the consequent danger of contamination of soils exposed to the source of pollution".[13]
- "Contamination from point source discharges affects surface soils used as receivers".[13]
- "Contamination by runoff to agricultural soils, etc".[13]

- "Leaching of chemicals, pesticides spilled from containers and residues left in containers spilled on the ground that affect surface and underground aquifers".[13]
- "Contamination of underground aquifers as a result of leachate percolation from uncontrolled landfills and dumps".[13]
- "Chemical contamination from industrial waste causes the loss of resources for human consumption or recreation, deteriorating the landscape and destroying the fauna on the earth's surface".[13]

Landscape deterioration:

- "Landscape pollution leads to a decline in quality of life in terms of space and horizon, as well as serious damage to the landscape, accentuated by the indiscriminate dumping of solid waste".[13]

Flora and Fauna:

- "Alterations to plant communities as a result of the indiscriminate appearance of uncontrolled landfills".[13]
- "Contamination of pastures and fodder for animal feed".[13]
- "Modification or reduction of vegetation cover and, therefore, risk of soil erosion".[13]
- "Generation of infection sites as a result of the accumulation of organic matter".[13]
- "Domestic animals fed with vegetable residues and waste in contact with industrial waste, with the consequent danger of pesticides and toxins entering the animal metabolism and subsequently being transmitted to humans through milk and meat".[13]
- "Increase in insect and rodent pests".[13]
- "Changes in the feeding patterns of certain animal species".[13]

Contamination by leachates

"Leachates are liquids generated by the release of excess water from solid waste and by the percolation of rainwater through the layers of solid waste in the composition phases. Leachate is considered the main and most significant pollutant generated in a landfill."

"Leachates are all liquids that have come into contact with landfill waste and are produced by the dissolution of one or more compounds in municipal solid waste in contact with the soil, or by the decomposition dynamics of the waste itself."

"In most landfills, leachate consists of liquid that enters the landfill from external sources (surface drainage, rain, groundwater, underground springs) and, where applicable, liquid produced by the decomposition of waste." This contaminates the soil indiscriminately.[12]

"The leachate generated in a landfill is the product of multiple factors, such as: composition of the waste, age of the landfill, water balance, design and operation of the landfill, solubility of the waste, microbiological and chemical conversion processes, and the interaction of the leachate with the environment."

"The flow generated varies according to the state of advancement and type of landfill operation, and the composition also varies over time."

Físicos	Constituyentes orgánicos	Constituyentes inorgánicos	Biológicos
Aspecto	Químicos orgánicos	Sólidos en suspensión (SS), sólidos totales disueltos (STD)S.	Demanda bioquímica de oxígeno (DBO).
pH	Fenoles	Sólidos volátiles en suspensión (SVS), sólidos volátiles disueltos (SVD).	Bacterias coliformes (total, fecal, fecal estreptococo).
Potencial de reducción oxidación	Demanda química de oxígeno (DQO).	Cloruros	Recuento sobre placas estándar.
Conductividad.	Carbono orgánico total (COT).	Sulfatos.	
Color	Acidos volátiles	Fosfatos.	
Turbicidad	Taninos, ligninas.	Alcalinidad y acidez.	
Temperatura	N-Orgánico.	N-Nitrato	
Olor	Solubles en éter (aceite y grasa)	N-Nitrito.	

Figure 1. Leachate composition
Source: [12]

Composition of leachate

"As water filters through decomposing solid waste, biological materials and chemical constituents leach into solution. This process gives rise to liquid streams characterized mainly by a large number of substances, often with extreme pH values, high organic load and heavy metals, as well as an intense odor".[12]

"Under normal conditions, leachate is found at the bottom of landfills. From there, it moves through the underlying strata, although some lateral movement also occurs, depending on the characteristics of the surrounding material and the shape of the soil supporting the fill (topography, slope, soil type, shape of the basin)".[12]

"There are marked differences between leachates from new landfills (less than 2 years old) and mature landfills (more than 10 years old), especially in the values recorded for BOD, COD, and suspended solids".[12]

Leachate quality

"It maintains that the quality of leachates is fundamentally determined by the biochemical reaction processes that take place in the landfill and by its environmental conditions. Soluble substances and substances that have been made soluble in water through biochemical processes, as well as the end products of biochemical reaction processes, fall spontaneously into the soil."

"As they filter through the decomposing solid waste into the soil, biological materials and chemical constituents leach into solution. Figure 2 presents representative data on the characteristics of leachates in new and old landfills".[12,13,14,15]

Constituyente	Valor en mg/L[b]		
	Vertedero Nuevo(menos de 2 años)		Vertedero maduro(mayor de 10 años)
	Rango[c]	Típico[d]	
DBO_5	2000 - 30000	10000	100 - 200
COT(carbono orgánico total	1500 - 20000	6000	80 - 160
DQO	30000- 60000	18000	100 - 500
Total de sólidos en suspensión	200 - 2000	500	100 - 400
Nitrógeno orgánico	10 - 800	200	80 - 120
Nitrógeno amoniacal	10 - 800	200	20 - 40
Nitrato	5 - 40	25	5 - 10
Fósforo total	5 - 100	30	5 - 10
Ortofosfato	4 - 80	20	4 - 8
Alcalinidad como Ca CO_3	1000 - 10000	3000	200 - 1000
pH	4,5 – 7,5	6	6,6 – 7,5
Dureza total como Ca CO_3	300 - 10000	3500	200 - 500
Calcio	200 - 3000	1000	100 - 400
Magnesio	50 – 1500	250	50 - 200
Potasio	200 - 1000	300	50 - 400
Sodio	200 - 2500	500	100 - 200
Cloro	200 - 3000	500	100 - 400
Sulfatos	50 - 1000	300	20 - 50
Hierro total	50- 1200	60	20- 200

Figure 2. Data on the composition of leachates from new and mature landfills
Source: [12]

CONCLUSIONS

This study has established, based on a review of the literature, empirical evidence, and contextual analysis, that the inadequate management of solid waste in the District of San Pablo is a high-priority environmental problem, characterized by its multi-causal complexity and cumulative impacts on the physical, chemical, and biological components of the environment. The lack of a technically designed and regulated final disposal system in accordance with the provisions of Legislative Decree No. 1278 has led to the use of an open-air dump lacking waterproofing, drainage and leachate collection systems, as well as control and monitoring mechanisms, which has generated an active and sustained source of environmental pollution.

The findings of previous studies, at the international, national, and regional levels, corroborate that the conditions observed in San Pablo reproduce a recurring pattern in localities that lack infrastructure for comprehensive solid waste management. In these scenarios, leachates—the product of rainwater percolation and the microbiological decomposition of the organic fraction of waste—have high pollutant loads, including biodegradable organic matter, heavy metals (Pb, Cd, Cr, Hg, Ni), and high concentrations of pathogenic

microorganisms. These parameters often exceed the Environmental Quality Standards (ECA) established for soil and water, representing a latent risk to the integrity of the edaphic resource, the quality of water resources, and the health of the population.

From the point of view of soil resources, the continuous infiltration of leachates causes significant alterations in their physicochemical properties, such as increased electrical conductivity, decreased pH, accumulation of soluble salts and heavy metals, as well as a reduction in their cation exchange capacity and natural fertility. In biological terms, the presence of toxic contaminants alters the structure and diversity of soil microbial communities, interfering with essential biogeochemical cycles and affecting the soil's ability to perform its ecosystem functions.

Furthermore, the lack of a comprehensive solid waste management system exacerbates the problem due to sociocultural and environmental governance factors. These include persistent patterns of hyperconsumption, low segregation and recycling rates, the absence of incentives for waste recovery, and limited environmental awareness among the population. Added to this is the lack of technical and budgetary capacity in local government to implement sustainable waste management practices, which contravenes the principles of prevention, minimization, and shared responsibility established in current regulations.

Consequently, assessing the level of soil contamination in the area directly affected by the municipal landfill is not only an essential methodological requirement for determining the magnitude of the environmental impact, but also a strategic tool for formulating policies and action plans aimed at mitigation and remediation. The following priority measures should be implemented:

Construction and implementation of a technically designed sanitary landfill with leachate impermeabilization, collection, and treatment systems, as well as biogas control.

Institutional and technical strengthening of local government through specialized training, budget allocation, and acquisition of equipment for collection, transport, and final disposal.

Establishment of a permanent environmental monitoring program for soil, water, and air, with quality indicators and parameters aligned with national and international regulations.

Design and implementation of community-based environmental education and awareness campaigns aimed at reducing waste generation, source separation, and increasing recycling rates.

Promotion of citizen participation in environmental monitoring and decision-making processes on waste management, under principles of shared responsibility and transparency.

Resolving the problems identified in the District of San Pablo therefore requires a comprehensive approach that integrates technical, regulatory, socio-educational, and institutional management dimensions. The implementation of a comprehensive solid waste management system, backed by scientific evidence and in line with current regulatory frameworks, will not only mitigate current negative impacts but also prevent future environmental and health risks. This will contribute to the conservation of natural capital, the strengthening of ecosystem resilience, and the fulfillment of national and international commitments on sustainable development, thus ensuring a healthy and safe environment for present and future generations.

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