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WASTE MANAGEMENT

SUSTAINABILITY AND EVALUATION OF THE IMPACT CAUSED BY THE LANDFILL OF THE MUNICIPALITY OF CARMEN, CAMPECHE, MÉXICO

SUSTENTABILIDAD Y EVALUACIÓN DEL IMPACTO OCASIONADO POR EL RELLENO SANITARIO DEL MUNICIPIO DE CARMEN EN CAMPECHE, MÉXICO

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Abstract

The sustainability indicators allow the evaluation of the environmental impacts related to the sustainable development strategy. The research was conducted in ciudad del Carmen, Campeche, which is considered a barrier island located at the southeast of Mexico. The municipality channels the final disposal of solid urban waste (MSW) through a sanitary landfill which is located in a mangrove area, having a negative impact on the environment, negatively affects the sustainable development. This research identified a sequence of carbonated sands by means of subsoil sediment analysis, which allowed to define a porosity of 20.2 to 40.1 % and a permeability of $\pm\ 10^{-2}$-$10^{-4}\ ms^{-1}$, i.e., the sediments have good porous and high permeability. On the other hand, and with respect to water quality, concentrations of BOD_5 and COD in the mangrove were 63.06 and 1338.13 mg L^{-1}, respectively, as well as the presence of trace concentrations of some heavy metals. These values allowed to classify it as a strongly contaminated body of water.

Keywords: Mexico, sustainability, waste, leachate, pollution, water, sediments.

Resumen

Los indicadores de sustentabilidad permiten evaluar los impactos ambientales relacionados con la estrategia del desarrollo sustentable. Este estudio se realizó en Ciudad del Carmen, Campeche, que es considerada una isla de barrera que se localiza al sureste de México. El municipio canaliza la disposición final de los residuos sólidos urbanos (RSU) a través de un relleno sanitario el cual se encuentra ubicado en una zona de manglar, teniendo un impacto negativo en el medio ambiente lo que incide negativamente en el desarrollo sustentable. Mediante el análisis sedimentológico del subsuelo, se obtuvieron resultados que identificaron la dominancia de arenas carbonatadas, lo que permitió definir un rango de porosidad del 20,2 al 40,1 %, y permeabilidad de $\pm\ 10^{-2}$-10^{-4} ms^{-1} darcys, es decir, los sedimentos presentan una buena porosidad y una permeabilidad alta. Por su parte, mediante un análisis de la calidad del agua se detectaron concentraciones de Demanda Bioquímica de Oxígeno (DBO_5) y Demanda Química de Oxígeno (DQO) de 63,06 y 1338,13 mg L^{-1}, respectivamente, así como la presencia de concentraciones de trazas de algunos metales pesados. Estos valores permitieron clasificarlo como un cuerpo de agua fuertemente contaminado.

Palabras clave: México, sustentabilidad, residuos, lixiviados, contaminación, agua, sedimentos.

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1 Introduction

Ciudad del Carmen, Campeche, is a barrier island of sedimentary origin of Quaternary age (2.58 Ma. approx.) (SGM, 2005; CONABIO, 2012; ICS, 2018) located in the southeastern Mexico (Figure 1). The island is part of Mexico's largest and most valuable estuarine lagoon system: Laguna de Términos (Escudero et al., 2014). This system has an ellipsoid shape with a length of 70 km and a width of 30 km, and covers an area of 2500 Km^2, with an average depth of 3-3.5 m. The main rivers that deposit sediments in this lagoon system are the Palizada River (240 m^3 s^{-1}), the Candelaria River (35 m^3 s^{-1}) and the Chumpán River (2 m^3 s^{-1}), which provides a significant discharge of fresh water of 400 m^3 s^{-1} (Magallanes-Ordóñez et al., 2015).

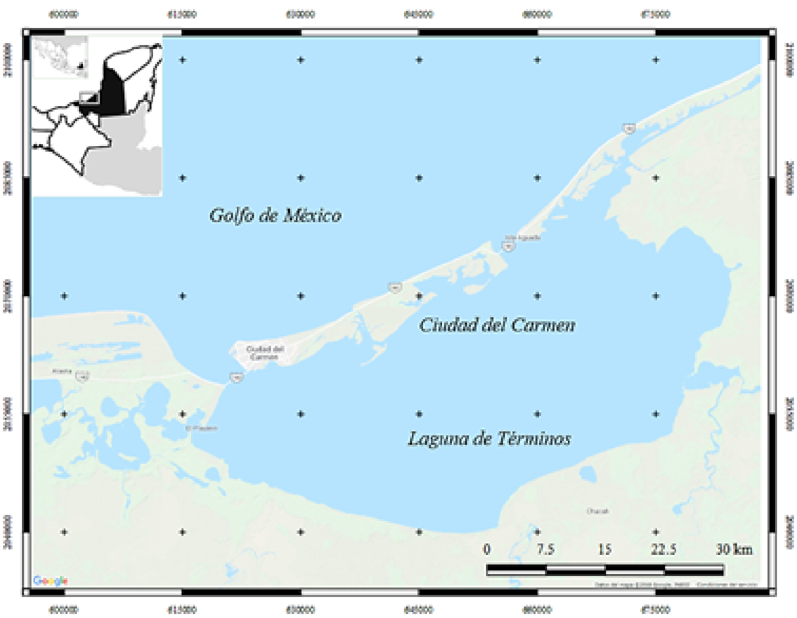

Figure 1. . Location of Ciudad del Carmen, Campeche (Modified by INEGI (2010)).

The island has great ecological importance because it is dominated by a mangrove-like ecosystem (mangrove "Isla del Carmen"; 43.92 Km^2) that extends over 43.92 Km^2 (4392 ha) (CONABIO, 2012) and is part of the RAMSAR area called "Area de Protection de Flora y Fauna Laguna de Términos", which has an area of 705 016 ha that includes the island, the Laguna de Protección and some portions surrounding them (CONANP, 2018).

Wetlands represent one of the most important types of ecosystems in the world, and are also one of the most threatened (Hu et al., 2017). Such ecosystems are ecologically important because they serve as habitat for various fish and wildlife communities, as well as various commercially valuable species, and are buffers of the coastline, provide fresh water, reduce sedimentation in navigable waters, and potentially aid in the storage of floodwaters. In addition to this, its soils contain some of the largest carbon reserves in the biosphere (Maynard et al., 2014; Ghosh et al., 2016; Nahlik and Fennessy, 2016; Rains et al., 2016).

1.1 Lithology

The study area is located 8 km (approx.) from Ciudad del Carmen, in the vicinity of the municipal landfill (Figure 1), former delta Cocoyotes-el Cayo (Palacio-Prieto et al., 1999). This landfill is surrounded by a series of channels that flow into Laguna de Términos (current direction N-S), all these channels were part of the old internal delta.

Isla del Carmen (of Quaternary age) is formed by a coastal plain to the north, made up of high and low beach cords on sandy sediments, and a low floodplain lagoon to the south dominated by a fluvial-marine over slimy clay sediments (Ramos-Reyes et al., 2016). Lithologically, the island consists of a sequence of coastal sediments to the north, and a sequence of palustre sediments to the south; in the Laguna de Términos are reported silts rich in organic matter, as well as sands rich in aluminosilicates and carbonates derived from the alluvial supply of the sea and isla del Carmen (Darnell, 2015; Jones, 2015; Magallanes-Ordóñez et al., 2015).

Palustres deposits are characterized by a low energy level. In these environments the dynamics of sediments and all processes are linked to tides and currents, which play an essential role in this type of environment, and the silts are predominant. Meanwhile, coastal deposits are characterized by a high level of energy, which allows the deposit of sands (Martínez et al., 2015).

The spatial distribution of sediments is as follows: 1) sands on the island's inland coast, 2) slimy sands at the entrance of the island (west) and at the mouths of the Palizada, Chumpán and Candelaria rivers, and 3) the sands are present on the island coast (Magallanes-Ordóñez et al., 2015).

1.2 Regulations

The general rules applicable for the final disposal of waste correspond to NOM-083-SEMARNAT-2003 (SEMARNAT, 2003), en el apartado de "Specifications for the Site Selection " and "Restrictions for the Site Location" in which is stated:

- Final disposition sites should not be located within protected natural areas. In any case, the order in the corresponding "Declaration of Creation and the subzonification and administrative rules contained in the Management Program" must be observed. According to CONANP (2018), the municipal landfill is located within the Area of Protection of Flora and Fauna Laguna de Términos.
- "It should not be located in areas of: marshes, mangroves, swamps, wetlands, estuaries, alluvial plains, river, aquifer recharge; nor on caverns, fractures or active geological faults". According to CONABIO (2012), the island is dominated by a mangrove-like ecosystem.
- On the other hand, according to the Guidelines of technical specifications for the construction of landfills for MSW and RME (SEMARNAT, 2009), a landfill must have the following technical specifications: (i) cells, (ii) waterproofing system, (iii) biogas extraction, uptake and control system, and (iv) leach extraction, capture and control system. The municipal landfill fails to comply with the engineering established by this guideline, so its operation is affects the environmental protection of the area.

The objective of this article is to evaluate the environmental impact generated by the landfill of the Carmen municipality, Camp, in the subsoil of the central northern region of "Área de Protección de Flora y Fauna Laguna de Términos (APFFLT)" through a sedimentological analysis, to determine the infiltration capacity of leachates in the sustainable development. In order to differentiate sediment samples from water samples, the VP key (vertical profile) for sediments and WS (water sample) were used for water, respectively.

2 Materials and methods

Sustainability indicators (SI) allow environmental and social information to be related to information on pollution, deterioration of productive development or well-being achieved by the population (Ibáñez-Forés et al., 2013). According to the information of the National Census of Municipal Governments of the National Institute of Statistics and Geography (INEGI, 2017), 792 190 kg of solid urban waste (RSU) is collected daily in Campeche, of which 289 140 kg per day are collected in Ciudad del Carmen, representing a total of 36.5% of the total waste collected in Campeche; MSWs are not subjected to any treatment or selection and are transported to the landfill selected in this research.

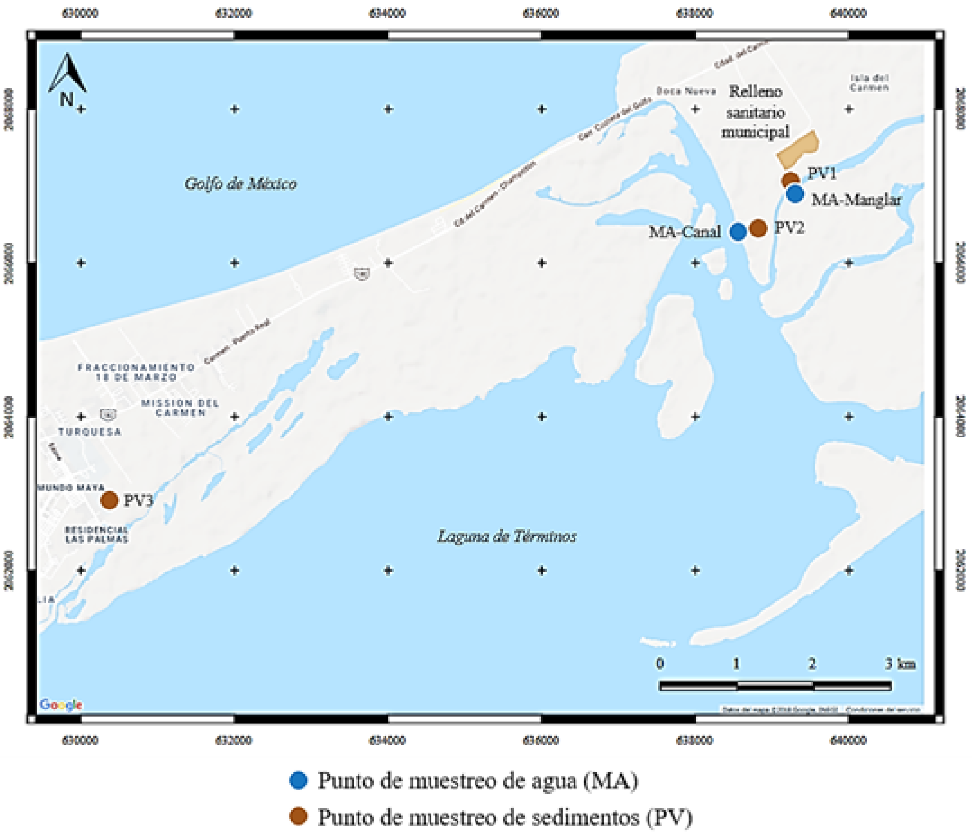

Figure 2. Location of sampling areas.

The ampling was carried out during the time of wattage, considering that during this period leachates are more mobile due to increased rainfall runoff, which is considered feasible for the sampling of water quality. Sediment samples were collected at 3 stations on the periphery of the municipal landfill and within the mangrove of the study area, as shown in Figure 2, following NOM-021-SEMARNAT-2000 which "establishes fertility, salinity and soil classification specifications, studies, sampling and analysis" (SEMARNAT, 2000). The collection points were selected according to the proximity to the landfill of the municipality of Carmen and randomly around it, considering the uniformity of the sedimentary facies throughout the island. Pv1 is located at ± 407.25 m from the landfill (18°41′25.332″ N, 91°40′46.307″ W). Pv2 is located at ± 1184.21 m from the landfill (18°41′5.46″ N, 91°41′4.199″ W). And finally the PV3 is located at ± 10104.23 m from the landfill (18°39′12″ N, 91°45′51″ W). The sedimentological analysis was carried out according to the methodology proposed by Álvarez Arellano (2003) and Honarpour (2018). As a first step, the samples were subjected to the sieving method for granulometric analysis, using 14 sieves of openings -2 to 4 φ (4 a 0.063 mm), every 0.5 φ. This procedure was performed in the Geophysics Laboratory of Universidad Autónoma del Carmen (UNACAR). Subsequently, the samples were transferred to the Biotechn o-environmental Research Laboratory of Universidad Popular Autónoma del Puebla (UPAEP), where sedimentary components were determined and the determination of mass properties (porosity) was carried out. Particle size measurements and porosity determination were done in triplicate to obtain a valid data. The corresponding tables and graphs were created by applying descriptive statistics (Rendón-Macías et al., 2016). Within the analysis of the survey conditions of the study area, a trigonometry calculation (by differentiation of elevations) was implemented to obtain the inclination angle of the area to determine the runoff slope of the leachates to the main channels.

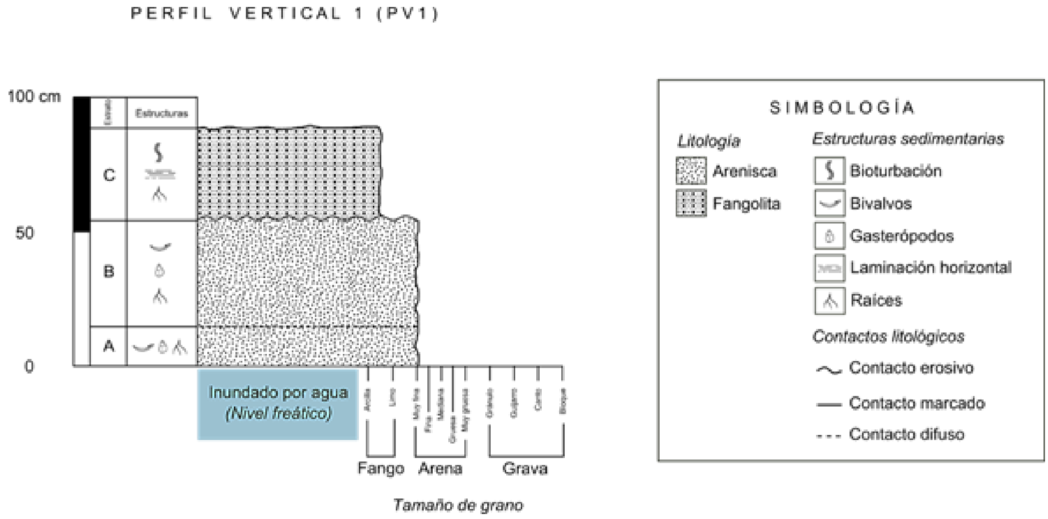

Figure 3. Lithological column of the VP1.

Water samples were collected at two stations (Figure 2), according to NMX-AA-003-1980 ("Wastewater – Sampling") (SCFI, 1980a) and NMX-AA-014-1980 ("Receiver Bodies – Sampling") (SCFI, 1980b), and were preserved according to NMX-AA-028-SCFI-2001 ("Water Analysis - Determination of Biochemical Oxygen Demand in Natural Water, Waste (DBO_5) and treated residuals - Test Method") (SCFI, 2001a) for DBO_5, NMX-AA-030/2-SCFI-2011 ("Water Analysis - Determination of Chemical Demand for Oxygen in Natural, Waste and Treated WasteWater - Test Method - Part 2 -Determination of the Chemical Oxygen Demand Index – Small-Scale Sealed Tube Method") (SCFI, 2011b) for COD, NMX-AA-029-SCFI-2001 ("Water Analysis - Determination of Total Phosphorus in Natural Water, Waste and Treated Waste - Test Method") (SCFI, 2001b) for Total Phosphorus Total Phosphorus , NMX-AA-026-SCFI-2010 ("Water Analysis - Total Kjeldahl Nitrogen Measurement in Natural Water, Waste and Treated Wastewater - Test Method") (SCFI, 2011a) for Total Kjeldahl Nitrogen, and NMX-AA-051-SCFI-2016 ("Water Analysis - Measurement of metals by atomic absorption in natural, drinking, waste and treated wastewater- Test method") (SCFI, 2016) for metals.

The collection points were selected, the first is close to the landfill of the municipality of Carmen ($\pm$481.65 m from landfill; coordinates $18^{\circ}41'22.452''$ N, $91^{\circ}40'45.732''$ W), and the second considering the transport of the effluent through the main channel (at $\pm$1270.46 m from the landfill; coordinates $18^{\circ}41'4.416''$ N, $91^{\circ}41'7.62''$ W).

It should be noted that the relationship between the distance of the points with the municipal landfill and the topography of the area (pending in favor of the runoff towards the mangrove) allowed to evaluate the environmental impact. For the determination of DBO_5, DQO, Total Phosphorus and Total Kjeldahl Nitrogen, the samples were analyzed by Litoral Laboratorios Industriales (Cd. del Carmen, Camp.; with the accreditation EMA: AG-0135-015/11), under the compliance of NOM-001-SEMARNAT-1996 which "sets the maximum permissible limits of pollutants in discharges of wastewater in domestic water and goods. Ministry of Environment and Natural Resources" (SEMARNAT, 1996).

For the determination of heavy metals, the samples were transferred for analysis at the UPAEP Bioengineering Laboratory, where the quantitative analysis carried out from the atomic absorption spectrophotometry methodology was carried out, according to NMX-AA-051-SCFI-2001 (SCFI, 2016). Descriptive statistics were also applied for the analysis of the above data (Rendón-Macías et al., 2016).

3 Results

3.1 Sedimentological analysis

3.1.1 VP1 (Vertical Profile 1)

A lithological column with a thickness of 0.90 m.s.n.m. was identified, consisting of 3 strata. Granulometrically, sands of 0.125 to 0.062 mm composed of calcareous bigens and organic matter dominate the area. A porosity with a range of 20.2 to 30,2 % was determined (Figure 3).

Stratum A (VP1-A): Dominated by particles of very fine sand size (3.5 φ to 0.125 mm) (Figure 4). It belongs to the textural group Gravelly Sand, classified with the name of the sediment Fine Gravelly Fine Sand. Compositionally dominated by calcareous bigens and organic matter and with a porosity percentage of 20.2 %.

Stratum B (VP1-B): It is dominated by particles of fine-sized sands (2.5 φ to 0.25 mm) (Figure 5). It belongs to the Gravelly Sand textural group, classified as very Fine Gravelly Fine Sand sediment. Compositionally dominated by organic matter and quartz. It has a porosity percentage of 30.2 %.

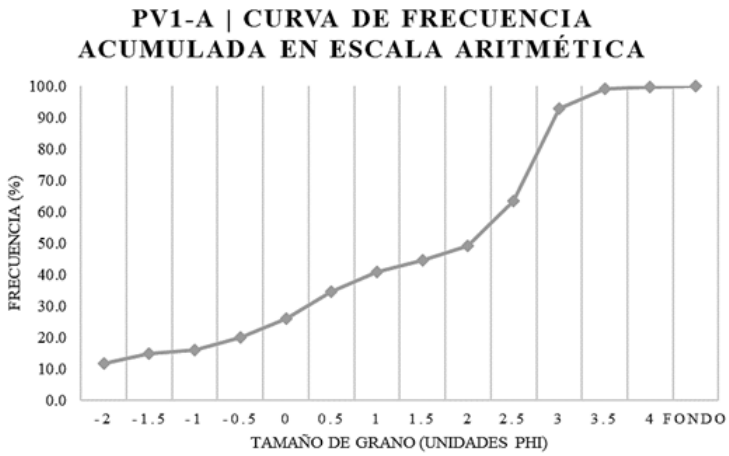

Figure 4. Curve of accumulated frequency in artithmetic scale of VP1-A

Figure 5. Curve of accumulated frequency in arithmetic scale of VP1-B

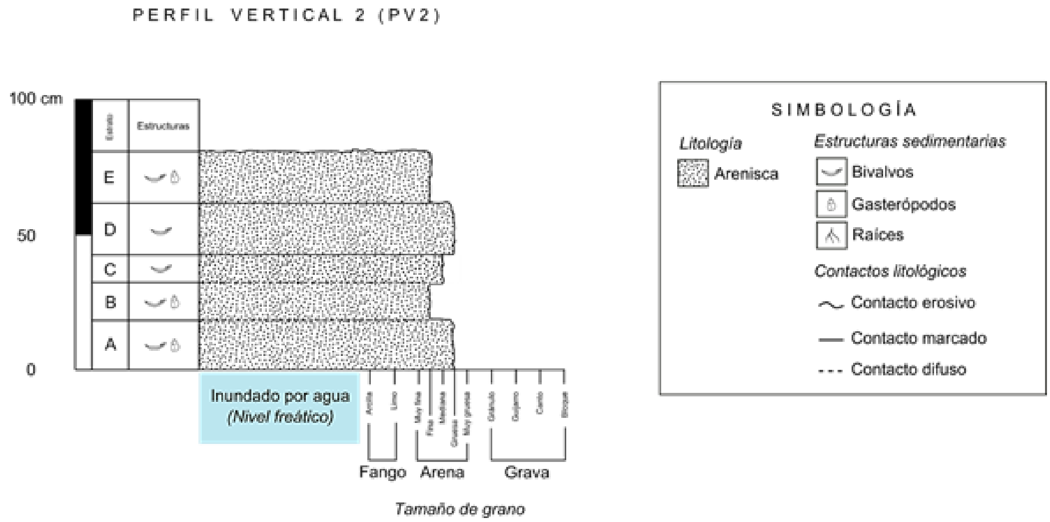

Figure 6. Lithological colum of VP2

3.1.2 VP2 (Vertical Profile 2)

It was identified as a lithological column with a thickness of 0.83 m.a.s.l, consisting of 5 strata. Granulometrically, sands of 1 to 0.125 mm composed of calcareous biogens and dethyritic material dominate the area. A porosity with a range of 20.3 to 36.5 % was determined (Figure 6).

Stratum A (VP2-A): It is dominated by particles thick-size sands (0.5 φ to 1 mm) (Figure 7). It belongs to the textural group Gravelly Sand, classified with the name of the sediment Fine Gravelly Coarse Sand. Compositionally, it is dominated by calcareous bigens and quartz. It has a porosity percentage of 20.3 %.

Stratum B (VP2-B): It is dominated by particles of very fine size to fine sands (3.5 φ to 0.25 mm) (Figure 8). It belongs to the textural group Gravelly Sand, classified with the name of the sediment Fine Gravelly Fine Sand. Compositionally, it is dominated by calcareous bigens and rock fragments. It has a porosity percentage of 36.5 %.

Stratum D (VP2-D): It is dominated by particles of very fine to very thick size sands (3.5 φ to 2 mm) (Figure 9). It belongs to the textural group Gravelly Sand, classified with the name of the sediment Fine Gravelly Fine Sand. Compositionally, it is dominated by calcareous bigens and rock fragments. It has a porosity percentage of 36.5 %.

Stratum E (VP2-E): It is dominated by particles of very fine to fine size sands (3.5 φ to 0.25 mm) (Figure 10). It belongs to the textural group Gravelly Sand, classified with the name of the sediment Fine Gravelly Fine Sand. Compositionally, it is dominated by calcareous and calcite bigens. It has a porosity percentage of 29.7 %.

3.1.3 VP3 (Vertical Profile 3)

A lithological column with a thickness of 0.88 m.a.s.l was identified consisting of 5 strata. Granulometrically, gravel and sands from 4 mm to 0.25 mm dominate, composed of calcareous biogens and dethyritic material. A porosity with a range of 26.1 to 40.1 % was determined (Figure 11).

Stratum A (VP3-A): It is dominated by granule-sized particles (2.8 to 4 mm) (Figure 12). It belongs to the sandy gravel textural group, classified with the sediment name Sandy Fine Gravel. Compositionally, it is dominated by calcareous bigens and rock fragments. It has a porosity percentage of 36.8 %.

Stratum B (VP3-B): It is dominated by particles of fine to medium size sands (2.5 φ to 0.5 mm) (Figure 13). It belongs to the gravelly Sand textural group, classified with the name fine Gravelly Medium Sand. Compositionally, it is dominated by

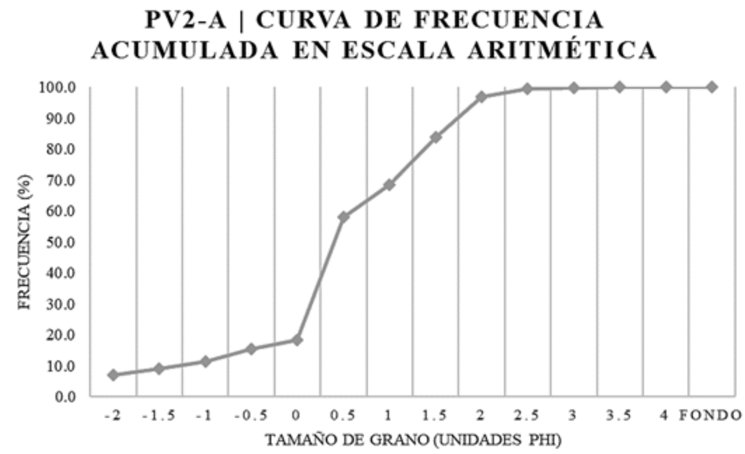

Figure 7. Curve of accumulated frequency in arithmetic scale of VP2-A

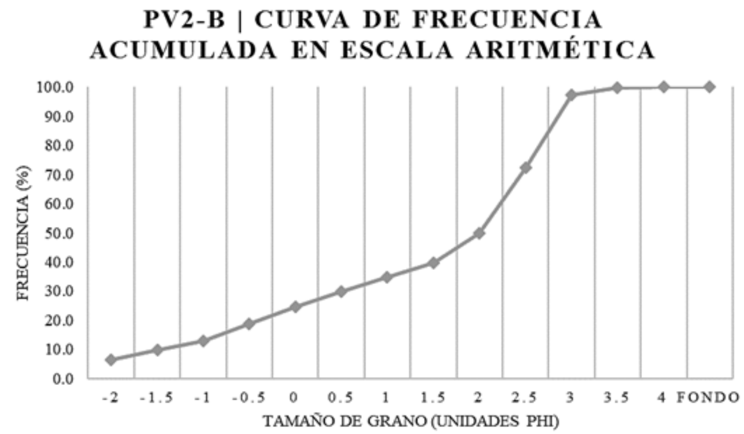

Figure 8. Curve of accumulated frequency in arithmetic scale of VP2-B

calcareous bigens and rock fragments. It has a porosity percentage of 26.1%.

Stratum C (VP3-C): It is dominated by particles of very thick size sands to granules (1.4 to 4 mm) (Figure 14). It belongs to the sandy gravel textural group, classified with the sediment name Sandy Very Fine Gravel. Compositionally, it is dominated by calcareous bigens and rock fragments. It has a porosity percentage of 33.2%.

Stratum D (VP3-D): It is dominated by particles of fine to thick size sands (2.5 phi to 1 mm) (Figure 15). It belongs to the textural group Slightly Gravelly Sand, classified with the name of the very Slightly Fine Gravelly Medium Sand sediment. Compositionally, it is dominated by calcareous bigens and rock fragments. It has a porosity percentage of 36.6%.

Stratum E (VP3-E): It is dominated by particles of medium to thick size sands (1.5 φ to 1 mm) (Figure 16). It belongs to the textural group Gravelly Sand, classified with the name of the very Fine Gravelly Coarse Sand sediment. Compositionally, it is dominated by calcareous bigens and organic matter. It has a porosity percentage of 40.1%.

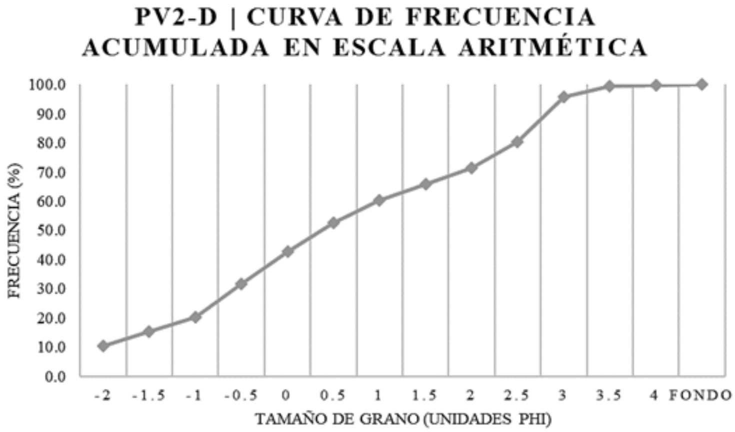

Figure 9. Curve of accumulated frequency in arithmetic scale of VP2-D

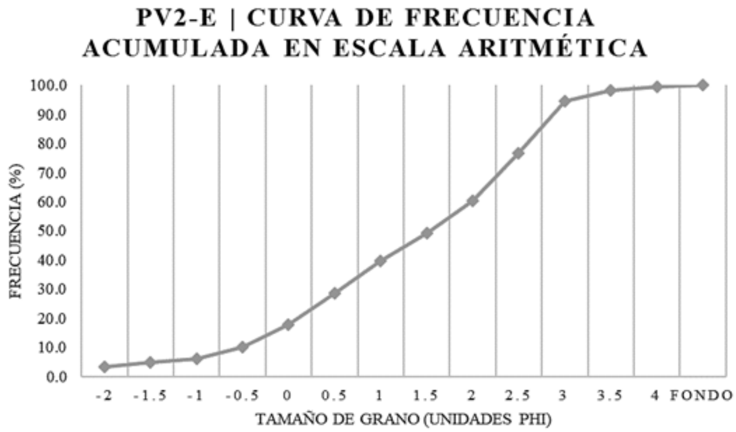

Figure 10. Curve of accumulated frequency in arithmetic scale of VP2-E

3.2 Water quality

The first sampling point is located at ±481.65 m from the landfill (18°41′22.452″ N, 91°40′45.732″ W), in one of the aqueous bodies of the mangrove area, which allowed this point to be classified as a dilution zone for leachate from the landfill. The water quality analysis for this sampling point is described in Table 1.

For its part, the second sampling point is located at ±1270.46 m from the landfill (18°41′4.416″ N, 91°41′7.62″ W), within the main channel (laminar flow with an N-S current direction) that crosses the study area. The concentrations of the different water quality parameters for this sampling point are described in Table 1.

For heavy metals, and considering sampling points as a dilution zone (MA-Mangrove and MA-Channel), trace concentrations of the metals Cd, Cu, Ni and Zn (Table 2) were detected.

4 Discussion

4.1 Sedimentological analysis

A similarity was found between VP2 and VP3 from the granulometric analysis and sedimentary components of the three vertical profiles (VP), since both have the same size range (2.5 φ to 2 mm) and components (calcareous biogens and rock fragments), thus a lateral continuity of the strata was determined. Meanwhile, the first stratum (VP2-A) of VP2 with the last stratum (VP1-B) of VP1, bears a similarity in granulometry (2.5 φ), sedimentary components (calcareous biogens, organic matter and quartz) and correspondence in topographical elevation, which allowed them to be stratigraphically correlated (Figure 17).

Therefore, points VP1 and VP2 make up the lithological column of the study area, with VP2 and VP3 being the stratigraphic continuation of VP1, and forming the same sandy and silty sedimentary facies (Darnell, 2015; Jones, 2015; Magallanes-Ordóñez et al., 2015; Ramos-Reyes et al., 2016).

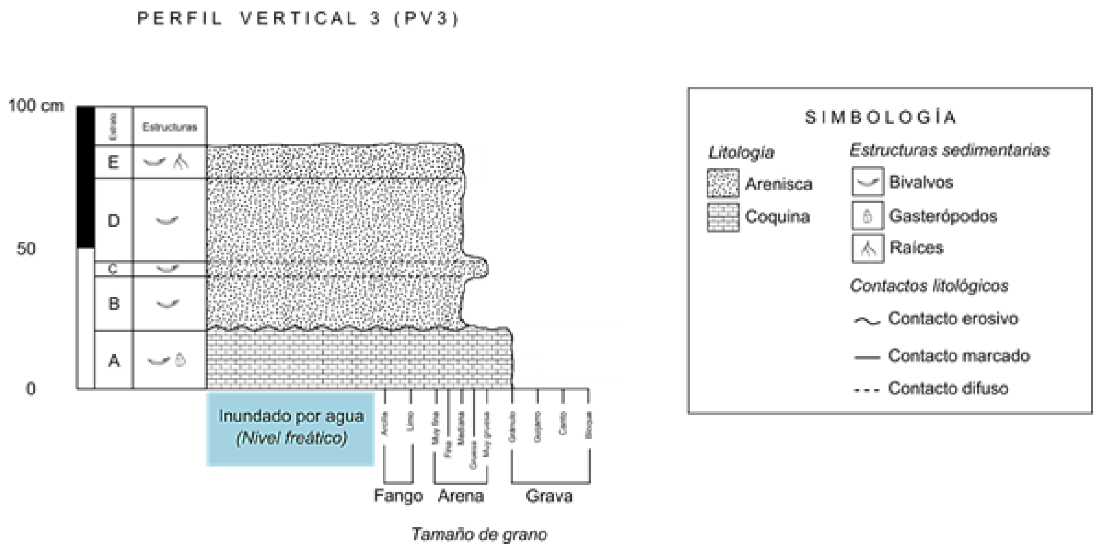

Figure 11. Lithological column of VP3

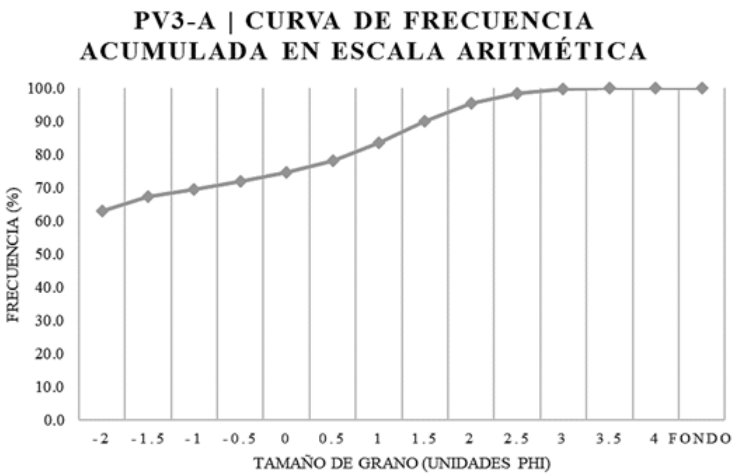

Figure 12. Curve of accumulated frequency in arithmetic scale of VP3-A

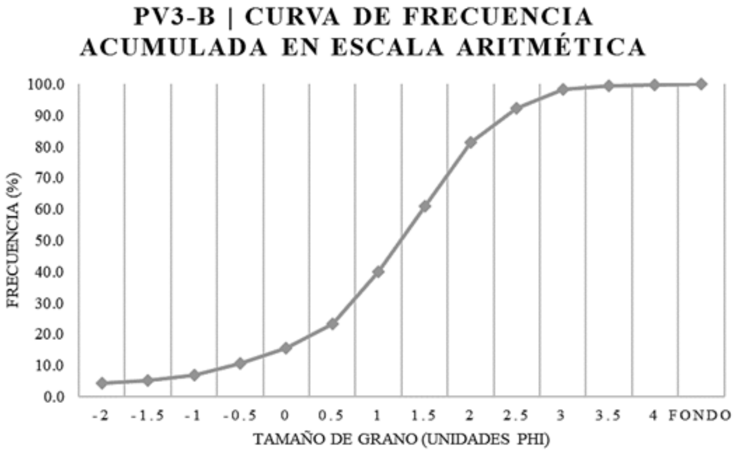

Figure 13. Curve of accumulated frequency in arithmetic scale of VP3-B

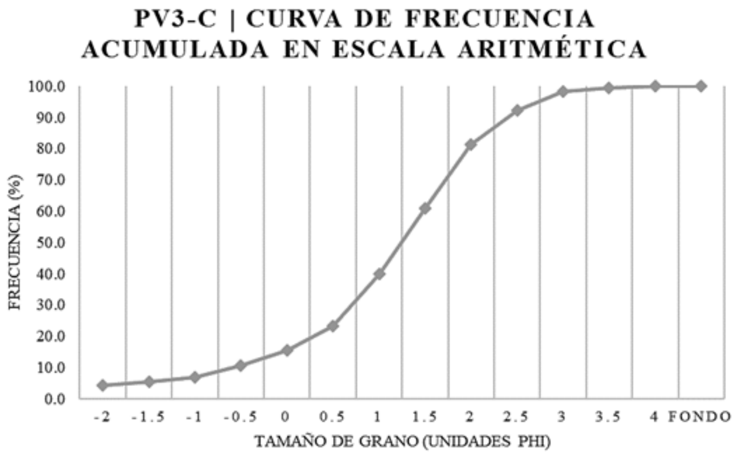

Figure 14. Curve of accumulated frequency in arithmetic scale of VP3-C

Thus, it was determined that the study area is formed by a lithological column consisting of six main strata, granulometrically dominated by sands of sizes 0.062 to 4 mm, composed of calcareous bigens and earthic material (Figure 18). According to Magallanes-Ordóñez et al. (2015), the sands could come from the sea; and the clays are from the adjacent continent.

The grains in a sand are usually in tangential contact, forming an open network, i.e. three-dimensional. As a result, the sands have a great porosity (they have a pore system full of fluid) (Pettijohn et al., 2014). From the analysis of the mass properties, a porosity range of 20.2 – 40.1 % was determined, and depending on the particle size it was possible to determine a permeability range of ±10-2 -10-4 m/s. These values allowed to define that the sediments have a good porosity and a very fast permeability capacity indicative of good aquifers, i.e., the fluids are transported quickly through the porous medium (Álvarez Arellano, 2003; Anovitz et al., 2018).

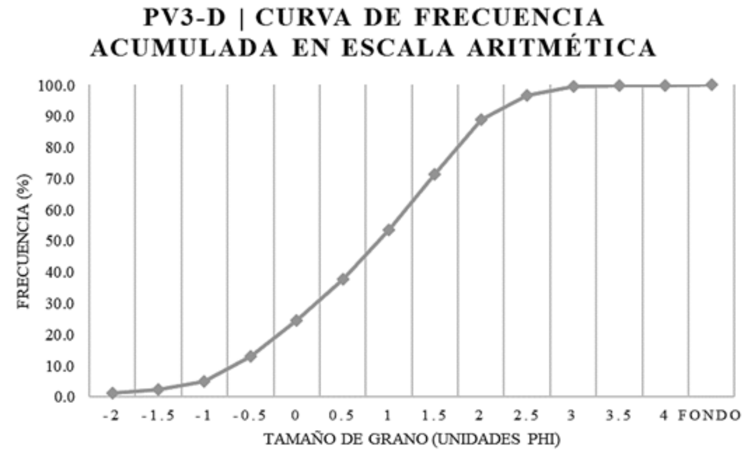

Figure 15. Curve of accumulated frequency in arithmetic scale of VP3-D

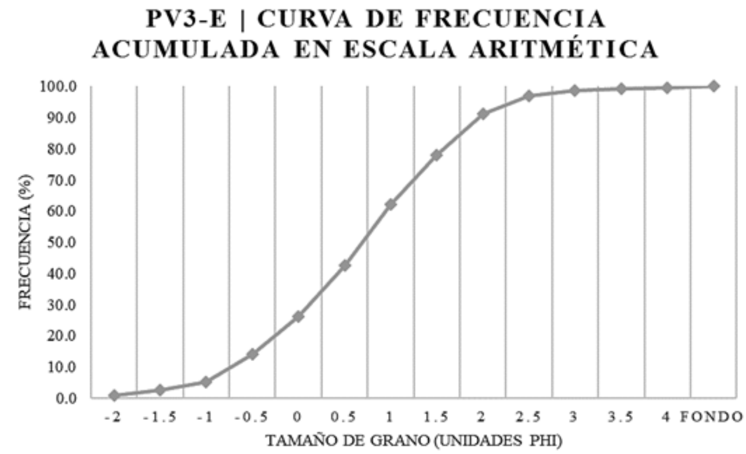

Figure 16. Curve of accumulated frequency in arithmetic scale of VP3-E

Table 1. Concentrations of determined parameters in the water quality in the MA-Mangrove and MA-Channel points

Sample	Parameter	Concentration (mg/L)	Maximum permissible limits (according to CONAGUA (2016))
MA-Mangrove	DBO_5	63.06	30
	DQO	1338.13	40
	Total phosphorous	1.17	N/A
	Total Kjeldahl nitrogen	5.49	N/A
MA-Channel	DBO_5	<20	30
	DQO	71.94	40
	Total phosphorous	1.17	N/A
	Total Kjeldahl nitrogen	5.49	N/A

The dominance of calcareous biogens, as well as the evidence of dissolution in some grains allowed to consider a secondary porosity in the sediments. According to Braga et al. (2015), dissolution processes significantly increase porosity. These processes include 1) stormwater discharge, 2) quartz alkaline

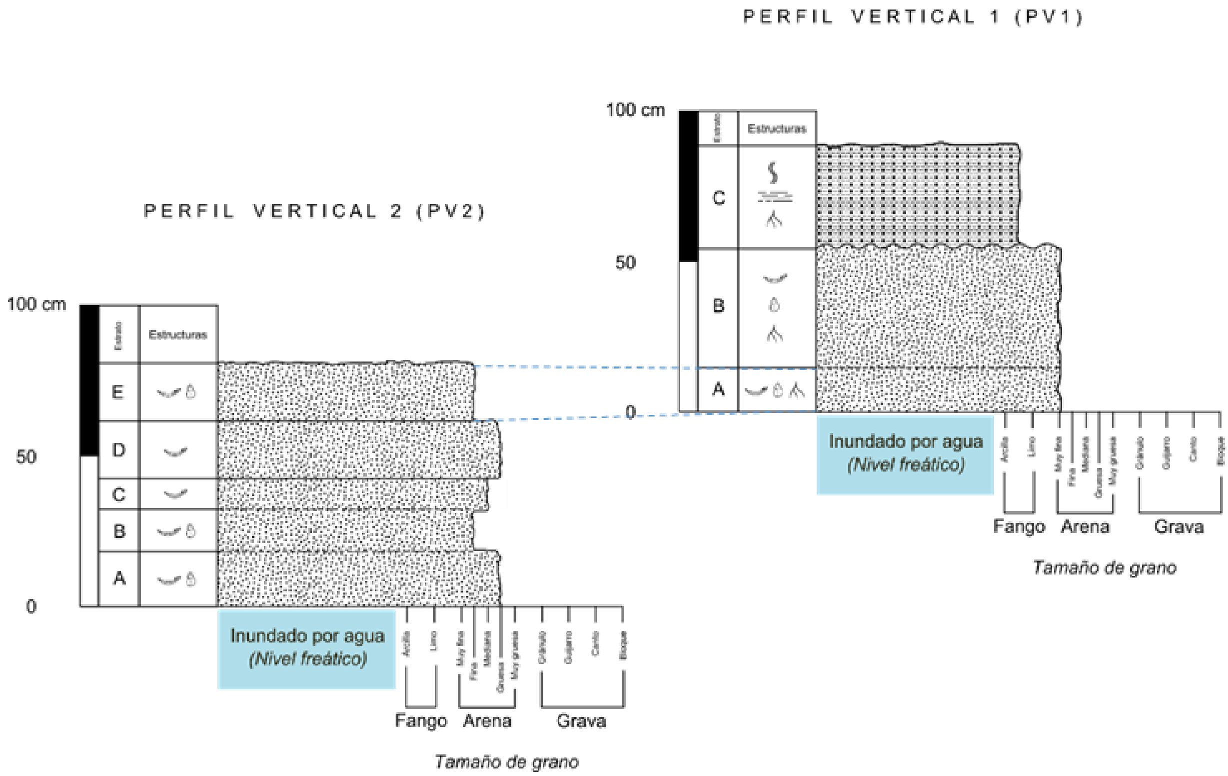

Figure 17. Stratigraphic correlation of VP1-a with VP2-E

solution, 3) leaching of unstable minerals (e.g. feldspars, carbonate cements and rock fragments) with respect to acidic fluids generated by the thermal maturation of organic matter or clay, when mineral reactions occur in adjacent lutites (Zheng et al., 2015).

Table 2. Heavy metal concentrations determined in the water quality of the MA-Mangrove and MA-Channel points.

Sample	Parameter	Concentration (mg/L)	Maximum permissible limits (according to NOM-001-SEMARNAT-1996)
MA-Mangrove	Cadmium	0.038	0.2
	Copper	0.168	6
	Nickel	0.41	4
	Zinc	3.037	20
MA-Channel	Cadmium	0.008	0.2
	Copper	0.013	6
	Nickel	0.16	4

Groundwater flows play an important role as means of transportation for leachates, both vertically and horizontally; for this reason, they are important to perceive the risks associated with this flow (Lobo-García de Cortázar et al., 2017; Niño-Carvajal et al., 2016). Therefore, the sedimentological characteristics of the subsoil of the municipal landfill allow the generated leachates (and accumulated in the hydrological environment over the years), to infiltrate and move, heading at a maxi-

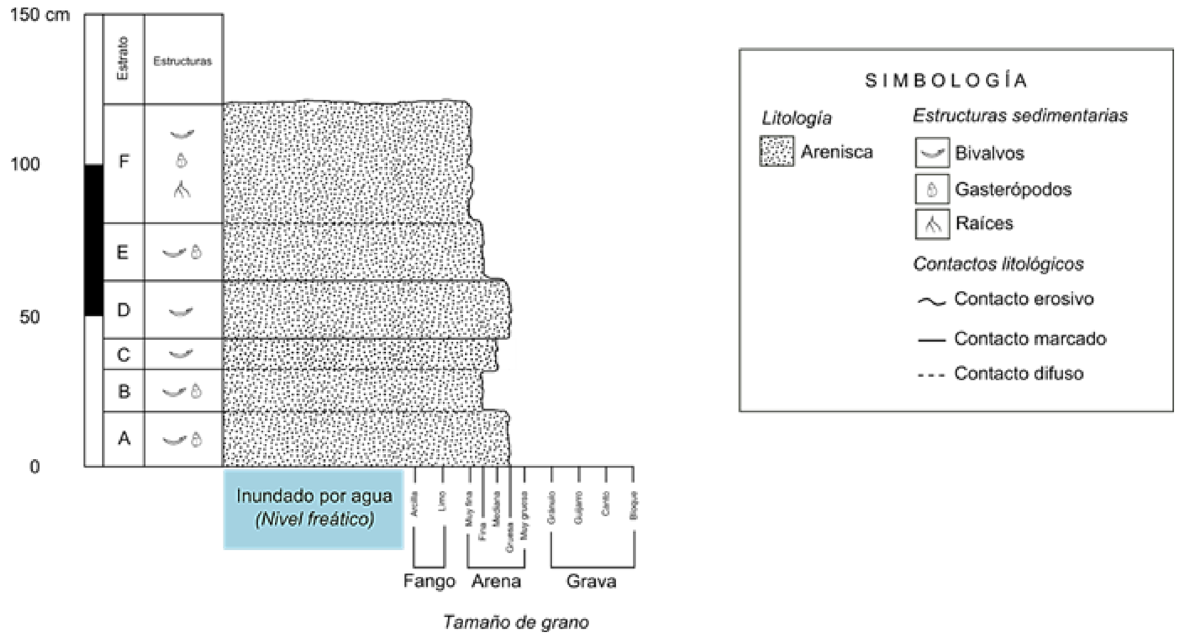

Figure 18. Lithological column of the study area

mum angle of ±1,7° (naturally and from the topographical elevation to the midpoint of the landfill) towards the areas of runoff, i.e., towards the aqueous bodies that make up the mangrove area.

It should be noted that one of the elements that influence this transport is the water table, which was found at ±0.87 m (i.e. classifying it as a flood zone). Thus, during the vertical and horizontal transportation of the leachates, they are mixed in the water table. A case study very similar to this is reported by Niño-Carvajal et al. (2016) at the final solid waste disposal site of El Carrasco, located in the municipality of Bucaramanga, Colombia, where the same problem was reported and subsoil areas were found completely saturated by leachates that were not properly managed at the disposal site.

4.2 Water quality

Considering the maximum permissible limits according to NOM-001-SEMARNAT-1996 (SEMARNAT, 1996), and the surface water classification of CONAGUA (2016), the concentrations found corresponding to the DBO_5 and DQO parameters indicate contaminated and heavily contaminated bodies, respectively.

Therefore, it was determined that the main source of contamination in the aqueous bodies comes from inorganic materials, with the first sampling point (MA-Mangrove) being the most representative due to the ratio of 4.7% organic, and 95.3% inorganic. For its part, the total phosphorus and total Kjeldahl nitrogen values at both sampling points are within the maximum permissible limits according to NOM-001-SEMARNAT-1996. The concentration of these parameters is associated with the biological activity of mangroves that dominate the study area, since both phosphorus and nitrogen are essential macronutrients in the photosynthesis process of the biota that makes up the mangrove (Bravo-Chaves et al., 2012).

In the case of heavy metals, trace concentrations of Cd, Cu, Ni and Zn were detected below the maximum permissible limits by NOM-001-SEMARNAT-1996 (SEMARNAT, 1996). However, it should be noted that when they enter the aquatic system directly via atmospheric or with runoff waters, they can cause serious impacts at high concentrations due to their high toxicity (Bravo-Chaves et al., 2012). The obvious decrease in the concentration of heavy metals from point 2 (MA-Channel) to point 1 (MA-

Mangrove) is due to the fact that point 1 is located in one the aqueous bodies of the mangrove, i.e., without any influence by internal marine currents. While point 2 is located in one of the main channels of the area, where internal marine currents significantly influence the dissolution of pollutants.

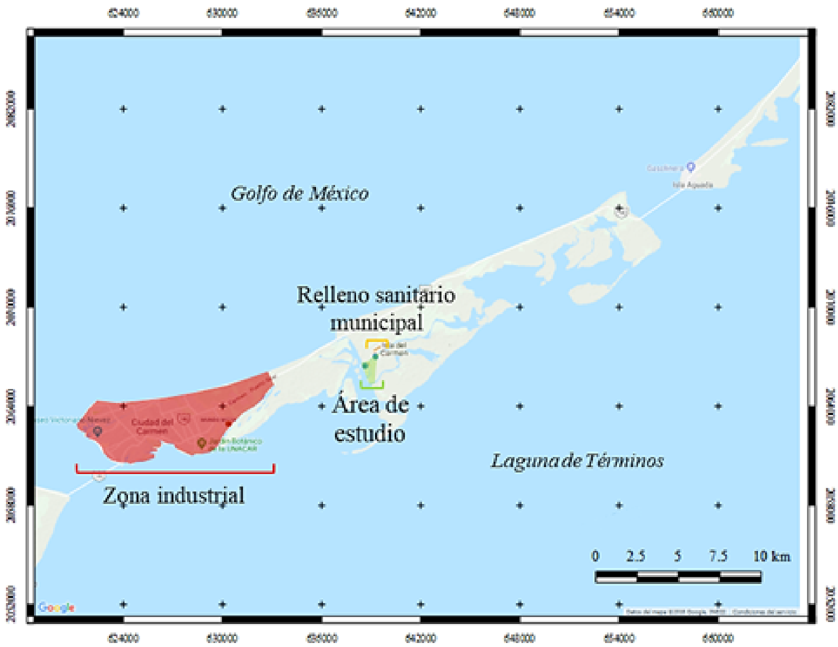

Figure 19. Geographical relationship between the industrial area, the municipal landfill and the study area. (Modified from INEGI (2017)).

The origin of this type of contamination can be natural (wear of igneous and metamorphic rocks, oceanic aerosols and decomposition of detritus) or anthropogenic (industrial and domestic water discharges) (Bravo-Chaves et al., 2012). In this case, the presence of landfill, and the absence of industries on the periphery of the study area ($\pm 127\ Km^2$) (INEGI, 2017) (Figure 19), suggests that the origin of these concentrations may be associated with leachates from the landfill, which infiltrate the subsoil (highly porous and permeable) and are deposited in the aqueous bodies of the area. Heavy metals are one of the most important contaminants in aquatic ecosystems due to their potential toxicity, persistence and bioaccumulation. It is well known that heavy metals have a significant risk in the human health when the exposure dose exceeds safe consumption levels (Mussali-Galante et al., 2013; Zhong et al., 2018). Several authors have detected accumulation of toxic metals in fish tissues and molluscs for the human consumption (Covarrubias and Peña-Cabriales, 2017).

From the comparison of the values of DBO_5 and DQO identified in the point MA-Mangrove (aqueous body inside the mangrove) with the leachate effluents of two municipal landfills and a drinking water well (case study: Landfill "Tultitlán", Tultitlán, Mexico state and Landfill "El Milagro", Ixtapaluca, Mexico state, M. E. Tavera, personal communication , December 06, 2017) (Table 3), both BOD_5 and DQO of the MA-Mangrove were found to be below the values presented in the leachates of a typical municipal landfill. On the other hand, for the case of the drinking water well near a municipal landfill, the values of the MA-Mangrove are above it, which confirms the previous determination by classifying it as a contaminated body according to CONAGUA (2016).

It is important to consider that the proliferation of algae and macrophytes depending on the burden of nutrients (nitrogen (N) and phosphorus (P)) is one of the main manifestations of the eutrophication process in aqueous bodies. Wastewater discharges from anthropic activities are mainly responsible for this phenomenon (Ramos, 2018). Eutrophication has the adverse effect of an increase in algae biomass, oxygen loss and mortality of some aquatic species (Espósito et al., 2016).

Table 3. Comparison of leachate and drinking water well values of two typical landfills with the MA-Mangrove sample (Modified by Tavera Cortés M. E., personal communication, December 06, 2017).

Sampling area	Medium	DBO_5 (mg/L)	DQO (mg/L)
RS "Tultitlán" (Tultitlán, Mexico state)	Leachate 1	958.562	19166.667
	Leachate 2	3717.461	20833.333
RS "El Milagro" (Ixtapaluca, Mexico state)	Leachate	1337.134	45833.333
Drinking water well (near the RS "El Milagro")	Water	Lower than 4,757	2.882
Mangrove (MA-Mangrove) (Ciudad del Carmen, Camp.)	Water	63,06	1338.13

5 Conclusions

Litologically, the study area consists of a sandy and silty sedimentary facies, composed of a succession of six strata of sands with sizes from 0.062 to 4 mm, compositionally formed by calcareous bigens and terrigenous material. A porosity range of 20.2-40.1 %, and a permeability range of ±10-2-10-4 m/s were determined.

This relationship, along with the dissolution of carbonated particles (dominant in the sediments analyzed), made it possible to determine that the sedimentological characteristics of the subsoil of the municipal landfill allow the generated leachates to infiltrate and move through it, heading (naturally and from the topographical elevation of the area by a maximum angle of ±1.7°) towards the aqueous bodies that make up the mangrove area. It should be noted that one of the elements that influence this transport is the water table level, located at ±0.87 m. Thus, during the vertical transportation of the leachates, these mix in the water table, representing a negative impact on the environment.

Evidence of the above can be reflected in water quality, where from the analysis of the values of DBO_5 and DQO, it was possible to classify the aqueous bodies (according to CONAGUA (2016) and their comparison with the monitoring of the aqueous bodies of the country) in a range of "contaminated to heavily contaminated", which is attributed to the high concentration of inorganic constituents (DQO), within which are considered trace concentrations of heavy metals such as cadmium, copper, nickel and zinc, the origin of which is related to the presence of municipal landfill in the study area.

As a point above, there is a negative environmental impact on the study area and a comprehensive management plan that mitigates and restores the ecosystem is required. Considering the works of Bravo-Chaves et al. (2012) it is proposed that the most viable option would be the closure of the municipal landfill, and the opening of a new one that complies with the guidelines established in the corresponding regulations. However, Ciudad del Carmen does not have an area that meets the requirements for its selection as a landfill, due to the granulometric characteristics of the sub-soil and the slight presence of the water table level (±0.87 m).

6 Recommendations

1. Characterize the waste associated with a control of the types available in the landfill, limiting them only to urban solid waste.

2. Close the landfill in stages, proposing a re-

engineering in it to implement new areas that have the corresponding systems of waterproofing and the capture and extraction of leachates, considering the work of Lobo-García de Cortázar et al. (2017) and Niño-Carvajal et al. (2016).

3. Carry out (in parallel to the previous point) the treatment and/ or recovery of the residues present in it. It is important to note that the comprehensive management of MSW, in accordance with environmental standards, will reduce negative impacts on the environment and, therefore, on the sustainable development.

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