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Puerto Rico Municipal Landfill Leachate Quality Characterization

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Puerto Rico Municipal Landfill Leachate Quality Characterization

By

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Foreword

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The Center for Environmental Solutions and Emergency Response (CESER) within the Office of Research and Development (ORD) conducts applied, stakeholder-driven research and provides responsive technical support to help solve the Nation's environmental challenges. The Center's research focuses on innovative approaches to address environmental challenges associated with the built environment. The Center develops technologies and decision-support tools to help safeguard public water systems and groundwater, guide sustainable materials management, remediate sites from traditional contamination sources and emerging environmental stressors, and address potential threats from terrorism and natural disasters. Through collaboration with both public and private sector partners, we foster technologies that improve the effectiveness and reduce the cost of compliance, while anticipating emerging problems. The Center also provides technical support to EPA regions and programs, states, tribal nations, and federal partners, and serves as the interagency liaison for EPA in homeland security research and technology. The Center is a leader in providing scientific solutions to protect human health and the environment.

This report presents leachate quality data for several municipal solid waste landfills in Puerto Rico. Leachate is generated when moisture (e.g., rain, humidity) comes into contact with the waste or liquids entrained, infiltrates through the degrading waste, and draws out chemicals and other constituents. Leachate might contain organic and inorganic contaminants, toxic chemicals, heavy metals, microbial pathogens, and metabolites. Its composition is highly variable and site-specific, varying with waste type, age and degree of decomposition, moisture content, water balance, waste-filling procedure, and climatic conditions.

In this project, the physical and chemical properties of leachate from six landfills within different ecozones in Puerto Rico were analyzed during seven sampling events. Samples were obtained from leachate collection systems when available and from leachate storage ponds, seepage areas, runoff, and boreholes/test pits within the waste. Physicochemical parameters such as temperature, pH, turbidity, dissolved oxygen, and conductivity were measured onsite.

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Notice/Disclaimer Statement

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, funded and managed the research described herein under contract 68HERD20A0010 to PTS. This document has been reviewed in accordance with the U.S. Environmental Protection Agency policy and approved for publication. Any mention of trade names, manufacturers or products does not imply an endorsement by the United States Government or the U.S. Environmental Protection Agency. The EPA and its employees do not endorse any commercial products, services, or enterprises. The contractor's role did not include establishing Agency policy.

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Acronyms and Abbreviations

BDL	below detection limit
BOD	biochemical oxygen demand
COD	chemical oxygen demand
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
NTU	nephelometric turbidity unit
ORD	Office of Research and Development
PR	Puerto Rico
TOC	total organic carbon
TSS	total suspended solids

1 Introduction

The Resource Conservation and Recovery Act, Subtitle D, regulates the disposal of all non-hazardous solid waste, including aspects such as location, liner requirements, leachate collection and removal systems, groundwater monitoring requirements, closure and post-closure, and other operational practices and corrective actions. The waste decomposition and the level of unmitigated exposure to weather factors (e.g., rain, humidity) affects the dissolution or decay of the material and the production of leachate and gases in landfill facilities (Armstrong and Rowe, 1999).

Landfill leachate is generated when moisture (e.g., rain, humidity) comes into contact with and infiltrates through the degrading waste or liquids entrained. This liquid will often draw out chemicals and other constituents during the process. Leachate might contain organic and inorganic contaminants, toxic chemicals, heavy metals, and microbial pathogens (e.g., enteric bacteria, fungi, viruses, and parasites) and their metabolites (Jayawardhana et al., 2016). Leachate composition is highly variable and site-specific; it varies with waste nature, age and degree of decomposition, moisture content, water balance, waste-filling procedure, and climatic conditions (Armstrong and Rowe, 1999). For these reasons, databases for landfill leachates should be geographically specific (Reinhart and Grosh, 1998). Additional background information can be found in Appendix A.

The goal of this project was to characterize the physical and chemical properties of leachate from six landfills in Puerto Rico (PR) representing different ecozones. Leachate was analyzed from seven sampling events (Table 1.1). Samples were collected from leachate collection systems when available and from leachate accumulation ponds, seepage sites, runoff, and boreholes/test pits within the waste. Global Positioning System (GPS) coordinates of the sampling sites were recorded (See Table 1.1). Field conditions (e.g., sunny, raining) were also recorded, and photos were taken to document relevant site information. When available, samples were collected from leachate collection points. The type of sampling point was noted in the sample collection sheets. Sampling time, sampling volume, and preservative used (if any) were recorded in the sampling sheets. For every sampling event, one site per landfill was selected for duplicate sampling to detect any variability. Physicochemical parameters such as temperature, pH, turbidity, dissolved oxygen, and conductivity were measured at the time of sample collection following standard methods (Table 1.2). A 125-mL sample was collected for pH and turbidity determination in the laboratory. Samples for total organic carbon (TOC), total suspended solids (TSS), and chemical oxygen demand (COD) were collected in chemically cleaned 500 mL amber glass containers and preserved with sulfuric acid. Samples for nutrient analyses were collected into 500-mL polypropylene copolymer bottles. Samples for biological oxygen demand (BOD) were collected in chemically cleaned amber glass bottles. Following collection, all samples were placed in coolers and maintained on ice during transport to the laboratory for analysis. Additional details on methodology and quality assurance can be found in Table 1.3.

Table 1.1. Landfills Studied in this Project

Landfill	Municipality	Latitude	Longitude	Ecological Zone	Year Opened
Fajardo Municipal Landfill	Fajardo, PR	18.2913	−65.6793	Humacao	1970
Cabo Rojo Landfill/ Cabo Rojo Eco-park	Cabo Rojo, PR	17.9763	−67.1527	San Germán	1994
Hormigueros Landfill	Hormigueros, PR	18.1508	−67.0978	San Germán	1984
Moca Landfill	Moca, PR	18.4146	−67.1161	Mayaguez	1967
Cayey Landfill	Cayey, PR	18.1458	−66.1029	Ponce	1972
La Vega Landfill	Vega Baja, PR	18.4783	−66.3598	Arecibo	1970

Table 1.2. Field Measurements Recorded at Each Site for Each Sampling Event

Measurement	Description	Units/Format
Date and Time	Date and time of day	Mm/dd/yy; hh:mm
Weather Conditions	Recorded on the day and time of sample collection	Sunny, overcast, raining, windy
Leachate Temperature	Measured using a field thermometer (Fluke-51 [Fluke Corporation, WA, USA] or equivalent)	°C
Turbidity	Measured for each sample by nephelometer after microbiological analysis processing, per standard methods or equivalent (HACH 46500-00 [HACH Company, Loveland, CO, USA] or equivalent)	Nephelometric turbidity units (NTUs)
pH	Measured in each sample after microbiological analysis processing, per standard methods or equivalent (OAKTON 300 series [OAKTON Instruments, Vernon Hills, IL, USA] or equivalent)	pH units
Dissolved Oxygen (DO) and Conductivity	Measured using a YSI Pro 2030 (YSI Inc., Yellow Springs, OH, USA) or equivalent	mg/L and µS

Table 1.3. Methods and Storage Requirements for Target Physicochemical Properties

Analyte	Method	Preservation Method	Storage and Holding Time
COD	Standard Method 5220, Thermo Scientific Orion AQUAfast AC4007	Preserve samples to pH <2 with concentrated H_2SO_4	Preserved samples can be stored at 4ºC for up to 28 days
BOD	Standard Method 5210B	4ºC	Ideally 6–24 hours Maximum holding time 48 hours
TSS	Standard Method 2540D	4ºC	Ideally less than 24 hours Max holding time 7 days
TOC	Standard Method 5310	Preserve in H_2SO_4	Preserved samples can be stored at 4ºC Max holding time 28 days
Nutrients			
Nitrate	Standard Method 4500-NO_3^-E; Thermo Scientific Orion AQUAfast AC4007	4ºC if analyzed within 24 hours, freeze samples	24 hours or months if frozen
Nitrite	Standard Method 4500-NO_2^-E; Thermo Scientific Orion AQUAfast AC4007	4ºC if analyzed within 24 hours, freeze samples	24 hours or months if frozen
Ammonia	Standard Method 4500-NH_3; Thermo Scientific Orion AQUAfast AC4007	4ºC if analyzed within 24 hours, freeze samples	24 hours or months if frozen
Phosphate	Standard Method 4500-P-D; Thermo Scientific Orion AQUAfast AC4007	4ºC if analyzed within 24 hours, freeze samples	24 hours or months if frozen

1.1 Quality Assurance Project Plan (QAPP)

Sample collection and data analysis for this study were performed in accordance with the quality assurance project plan (QAPP), which was developed in accordance with EPA's Center for Environmental Solutions and Emergency Response quality assurance requirements for secondary data projects. The primary focus of the QAPP was to characterize the physical and chemical composition of landfill leachate in six different landfills in PR located in different ecozones. As part of the QAPP, sampling methods were developed, and analysis procedures were identified. Research activities were documented according to the requirements of Office Research and Development (ORD) Policies and Procedures Manual (PPM) Sections 13.2, 13.6, and 13.4 entitled "Scientific Recordkeeping: Paper; Scientific Recordkeeping: Electronic; and Quality Assurance/Quality Control Practices for ORD Laboratory and Field-Based Research," respectively, as well as requirements defined in this QAPP. The

ORD PPM requires the use of research notebooks and the management of research records, both paper and electronic, such that the project research data generation may continue even if a researcher or analyst participating in the project leaves the project staff.

Electronic records were maintained in a manner that maximizes the confidentiality, accessibility, and integrity of the data. Data from the field data sheets will be transcribed into a dedicated Excel worksheet. The electronic record is kept in a dedicated computer in the library of Center for Environmental Education, Conservation and Research (CECIA). Records that were generated under this research effort are retained in accordance with EPA Records Schedule 1035, and as required by Section 5.1 of the ORD Quality Management Plan (QMP) for QA Category B Projects.

1.2 Quality Metrics

As part of each sampling event, an interview with the landfill operators was performed to acquire information regarding the site's operation, conditions, age, size, and management of the leachate, including seepage issues, leachate generation rate, age, and capture of leachate in lagoons or storage in tanks.

All field instruments such as pH, turbidity, dissolved oxygen (DO), and conductivity meters were calibrated in the lab just prior to travel for sample collection using procedures specified in the standard methods. In addition, post-calibration checks were performed for these instruments upon return to the lab, and recorded in appropriate instrument log sheets.

All samples from each sampling site were analyzed for COD, BOD, TSS, TOC, nitrate, nitrite, ammonia, and phosphate within sample holding times specified in the standard methods. In addition, at each sampling site, a duplicate sample was collected from one of the sampling locations. For all analytes, relative percent differences (RPDs) for the duplicate sample were calculated, and were found to be within acceptable limits (< 15%). For nitrate, nitrite, COD, and ammonia, fast zero auto test kits from the instrument manufacturer were used to test the instruments prior to use each day, and the value was found to be 0 ppm as recommended by the manufacturer. In addition, blanks were measured and found to be below the minimum detection limit (MDL). Freshly prepared calibration standards were analyzed and were found to be within 15% of the nominal value. Continuing calibration checks were analyzed once every nine samples. For TOC, a 4-point calibration curve was analyzed on the day the instrument was used followed by lab blanks and continuing check standards every nine samples. The continuing check standards for all analytes were within 10% of the nominal value.

2 Fajardo Municipal Landfill

Fajardo municipal landfill, located in the municipality of Fajardo, PR (Figure 2.1), was opened in 1970. Since 2007, it has been managed by ConWaste. The most recent cell was constructed in 2011 with a bottom liner that meets federal Subtitle D criteria. The site receives about 600 tons of waste per day from the municipalities of Fajardo, Luquillo, Canovanas, Rio Grande, Naguabo, and Loiza, as well as the private sector. This landfill is located in the Humacao Eco-zone, a zone of tropical marine climate and abundant rainfall. Rainfall is at a minimum during February and March.

Figure 2.1. Fajardo landfill. The yellow square indicates the area where the leachate collection tank is located. The red circle denotes the area where the trench sampling was done.

Leachate management infrastructure: The landfill has a 10-foot deep trench with a pump installed at the old cell (Figure 2.2). The landfill also has one 150,000-gallon leachate storage tank (Figure 2.3B). The site pumps approximately 6,000 gallons of leachate into the tank daily. The landfill also has a pilot-scale reverse osmosis leachate treatment system, which treats about 5,000 gallons of leachate per day, and a phytoremediation system (Figure 2.3C).

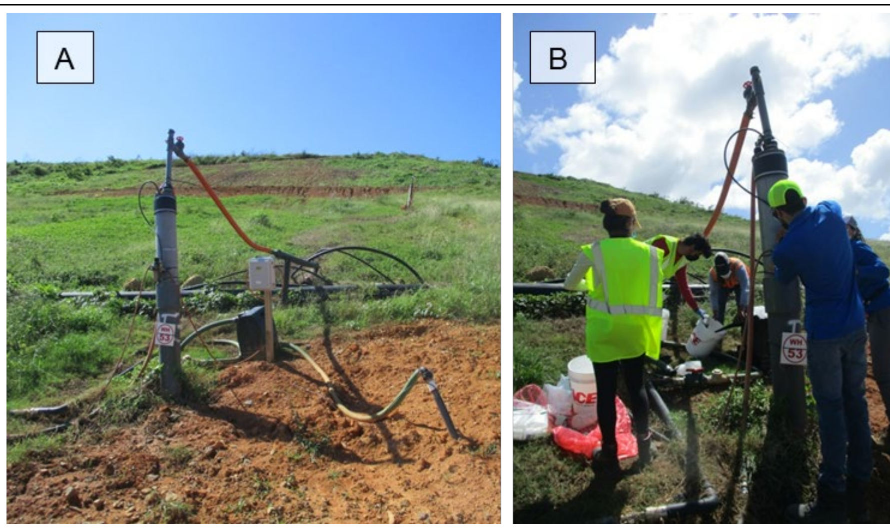

Figure 2.2. Old cell trench at Fajardo landfill (A) and trench sampling using an on-site pump (B).

Other infrastructure: Gas sampling points on the perimeter of the landfill are used for quarterly gas and groundwater sampling. The site also has a gas-to-energy plant (Figure 2.3A).

Figure 2.3. Gas-to-energy generation plant (A); 150,000-gallon leachate storage tank (B); Phytoremediation system (C); Intake to the tank and to the phytoremediation system (sample XXX2) (D).

Sample collection: The research team performed two sampling events at this landfill. The first was on November 20, 2020 and was used to test sampling methods and analyses. The old cell trench area could not be reached because it rained heavily during the night, making the area inaccessible. The second visit was March 2, 2020. Sampling started with the trench, but leachate could not be pumped out. The operators explained that a 50-gallon collection tank accumulates the leachate from the trench and that the pump has a sensor level; if there was not enough leachate accumulated, then leachate could not be pumped out. After sampling all other points, the collection team returned to the trench and obtained samples for most parameters. The reverse osmosis system was not operational during this second visit because the pump that brings leachate into the system was broken. Table 2.1 summarizes the sampling points, types, and dates at the landfill.

Results: Tables 2.2 and 2.3 summarize the physicochemical properties of the samples collected from the Fajardo landfill.

Table 2.1. Fajardo Sample Descriptions

Sample ID	Sampling Points and Description	Type of Sampling	Sampling Dates
XXX1	**Recirculation line** – Leachate and Condensate	Valve	20-Nov-2020; 2-Mar-2021
XXX2	**Riser** – Leachate intake of the collection tank	Valve	20-Nov-2020; 2-Mar-2021
MS06	Outlet of the collection tank	Valve	20-Nov-2020; 2-Mar-2021
Trench	Old cell trench – Leachate seepage	Pump sample out	2-Mar-2021
GC04	Condensate from the knockout at the flare system before the 150,000-gallon storage tank	Valve	20-Nov-2020; 2-Mar-2021
IN01	Intake of reverse osmosis	Valve	20-Nov-2020
OUT01 Perm	Outlet of reverse osmosis	Valve	20-Nov-2020
Out02	Downstream of the phytoremediation system	Grab sample	20-Nov-2020; 2-Mar-2021

Table 2.2. Physicochemical Parameters of Fajardo Leachate Samples

Sampling Date	Sample ID	Temp (°C)	DO (mg/L)	Cond (µS)	Salinity (ppt)	pH		Turbidity (NTU)	
						Field	Lab	Field	Lab
20-Nov-20	XXX1	32.6	0.58	1.1	0	7.580	7.764	19.3	17.3
20-Nov-20	XXX2	30.5	0.35	0.6	0	7.390	7.482	47.1	48.4
20-Nov-20	MS06	31.1	2.08	0.3	0	7.980	8.217	15.2	8.01
20-Nov-20	GC04	37.6	1.01	5.94	2.5	7.730	7.954	13.7	35.6
20-Nov-20	OUT02	34.2	0.94	1.7	0	8.100	8.316	30.5	26.8
20-Nov-20	IN01	29.3	1.3	0.4	0	7.940	8.202	47.1	42.1
20-Nov-20	OUT01 PERM	30.5	2.99	0.8	0	7.810	8.055	24.9	22.1
2-Mar-21	XXX1	29.4	3.47	114.1	0	7.67	8.135	54.2	53.8
2-Mar-21	XXX2	30.6	1.26	17.1	4.0	7.67	8.123	35.0	29.4
2-Mar-21	MS06	25.7	3.14	24.1	3.4	8.30	8.382	16.4	13.2
2-Mar-21	GC04	27.5	1.81	32.5	1.6	8.07	8.399	28.0	15.5
2-Mar-21	OUT02	27.6	0.75	8.0	0	8.31	8.792	9.90	10.4
2-Mar-21	TRENCH	35.2	0.51	9.66	4.4	7.41	7.817	62.2	52.4

Table 2.3. Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), Total Suspended Solids (TSS), Phosphate (PO_4), Ammonia (NH_3), Nitrite (NO_2), and Nitrate (NO_3) of Fajardo Leachate Samples

Sampling Date	Sample ID	mg/L							
		COD	BOD	TOC	TSS	PO_4	NH_3	NO_2	NO_3
20-Nov-20	XXX1	3,168.4	ND	1,024.8	25.3	28.205	840	0.544	24.31
20-Nov-20	XXX2	2,415.9	ND	643.2	48.8	15.99	672.50	0.34	7.06
20-Nov-20	MS06	1,867.0	ND	536	36.0	14.03	7.04	0.29	7.87
20-Nov-20	GC04	1,385.4	ND	299.08	7.8	7.24	577.50	0.19	6.25
20-Nov-20	OUT02	1,886.2	ND	503.2	38.0	11.89	9.11	6.45	0.20
20-Nov-20	IN01	2,678.4	ND	266.36	7.5	6.32	476.20	0.17	2.82
20-Nov-20	OUT01 PERM	694.6	ND	166.44	24.0	2.97	316.80	0.19	147.34
2-Mar-21	XXX1	4,562.4	1,452.0	1,238.8	98.6	33.265	575.2	0.608	22.67
2-Mar-21	XXX2	2,210.8	1,188.0	565.6	37.8	12.714	712.5	0.404	7.497
2-Mar-21	MS06	1,837.2	1,152.0	515.6	7.0	0.56	664.50	0.78	5.06
2-Mar-21	GC04	459.9	1,176.0	88.16	15.6	1.40	641.00	0.12	6.07
2-Mar-21	OUT2	1,755.2	1,014.0	470	13.2	8.68	309.40	0.27	BDL
2-Mar-21	TRENCH	3,354.0	1,200.0	969.6	71.1	22.39	583.10	0.46	12.62

ND – not determined. The sample used for the analyses was too concentrated, resulting in final DO measurements below the instrument's detection limit <1 mg/L, so BOD could not be calculated.

BDL – Below detection limit.

3 Cabo Rojo Landfill

Cabo Rojo landfill (Figure 3.1) has been in operation since 1994. It has been owned by the Municipality of Cabo Rojo and operated by Cabo Rojo Eco-Park LLC since June 2015. This landfill contains an old, unlined cell and a newer lined cell. This landfill is located in the San Germán Eco-zone, a zone with abundant rainfall that falls to a minimum during February and March. Soils consist of mainly clayey material weathered from basic volcanic rocks.

Figure 3.1. Cabo Rojo landfill. Red dot indicates sampling point.

It is estimated that this landfill manages 150 daily tons of municipal solid waste; however, currently, only vegetative waste is deposited there. For other types of waste, the site serves as a transfer zone ("*trasbordo*") to other landfills.

Leachate management infrastructure:

A retention lagoon (Figure 3.2A) can be seen at this landfill. The lagoon receives a mixture of rainwater and leachate that seeps into it. The landfill operators indicated that they do not see leachate seeping from the old unlined cell but observed occasional seeps from the toe of the slope. The landfill operator indicates that observed seeps are covered with soil. At the time of sampling, leachate was actively seeping into the lagoon (Figure 3.2B).

The site also has four leachate collection tanks: two 6,000-gallon capacity tanks and two 5,000-gallon capacity tanks (Figure 3.3). According to the site operator, the leachate collection system pump was damaged in 2018 and fixed in March 2020. At the time of the sampling, only two tanks were functioning and have been full since March 2020. When the system was fixed, the two 5,000-gallon tanks filled in four hours.

Other infrastructure: Gas sampling points are at the perimeter of the landfill. The gas and groundwater sampling are conducted quarterly.

Sample collection: The first sampling at this site took place on January 13, 2021. The second sampling event took place on February 2, 2021. Not all parameters were sampled during the second sampling event. Samples were collected from the intake to the tank (MS08), from the outlet (XX1) (Figure 3.3B), and from two areas within the lagoon: one near the leachate seepage (MS11) and one away (MS12). Tables 3.1 and 3.2 include the sample IDs.

Figure 3.2. Retention lagoon (A); leachate seeping into the lagoon (B).

Figure 3.3. 5,000-gallon leachate tanks: intake (A); outlet (B).

Results: This section presents the results from the two sampling events at the site. Tables 3.1 and 3.2 summarize the physicochemical properties of the samples collected from the landfill.

Table 3.1. Physicochemical Parameters of Cabo Rojo Leachate Samples

Sampling Date	Sample ID	Temp (ºC)	DO (mg/L)	Cond (µS)	Salinity (ppt)	pH		Turbidity (NTU)	
						Field	Lab	Field	Lab
13-Jan-21	XXX1	39.2	0.06	1.7	0	8.410	8.786	38.3	33.4
13-Jan-21	XXX1 DUP	30.2	1.08	71.8	0	8.8	8.800	37.6	29.5
13-Jan-21	MS08	38.1	0.17	9.94	5.5	7.740	8.643	38.1	36.4
13-Jan-21	MS12	30.5	6.56	0	0	8.460	8.288	20.2	13.21
13-Jan-21	MS11	32.8	3.53	49.2	0	8.280	8.130	32.3	25.6
2-Feb-21	XXX1	30.4	0.45	10.53	5.3	8.52	8.708	38.9	29.8
2-Feb-21	MS08	38.1	5.4*	8.6	0	7.59	7.802	39.2	34.1
2-Feb-21	MS08-DUP	38.1	3.4*	8.6	0	7.63	7.889	40.3	35.8
2-Feb-21	MS12	32.5	9.61	3.7	1.7	8.53	8.619	65.9	43.8
2-Feb-21	MS11	27.3	8.9	2.3	0	8.44	8.511	64.2	35.6

* DO in these samples was recorded as %, not as mg/L.

Table 3.2. Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), Total Suspended Solids (TSS), Phosphate (PO_4), Ammonia (NH_3), Nitrite (NO_2), and Nitrate (NO_3) of Cabo Rojo Leachate Samples

Sampling Date	Sample ID	mg/L							
		COD	BOD	TOC	TSS	PO_4	NH_3	NO_2	NO_3
13-Jan-21	XX1	5,894.9	ND	1,431.6	282.5	8.87	230.40	0.52	18.99
13-Jan-21	XX1 DUP	6,210.9	ND	1,393.6	162.5	11.06	259.40	0.69	41.54
13-Jan-21	MS08	5,846.9	ND	1,591.2	225.0	10.40	246.20	0.43	35.22
13-Jan-21	MS12	391.2	ND	100.1	32.0	0.38	6.43	0.04	6.86
13-Jan-21	MS11	416.8	ND	99.35	54.0	0.13	7.62	0.14	14.27
2-Feb-21	MS12	407.5	63.6	NS	NS	NS	NS	NS	NS
2-Feb-21	MS11	458.6	65.3	NS	NS	NS	NS	NS	NS
2-Feb-21	XXX1	7,336.7	ND	NS	NS	NS	NS	NS	NS
2-Feb-21	MS08	9,006.7	ND	NS	NS	NS	NS	NS	NS
2-Feb-21	MS08-DUP	8,270.7	ND	NS	NS	NS	NS	NS	NS

ND – not determined. The sample used for the analyses was too concentrated, resulting in final DO measurements below the detection limit of the instrument <1 mg/L, and hence BOD could not be calculated.

NS – no sample was collected. This second sampling event was to collect physicochemical parameters and to repeat the sample for the BOD.

4 Hormigueros Landfill

The Hormigueros landfill was constructed in 1983-1984. The site consists of about 25 acres of land owned by the Municipality of Hormigueros. The landfill receives waste only from Hormigueros. The landfill has an unlined cell and a lined cell. The operators indicated observing leachate seeps from the old cell during rain events. A newer cell has been operating since 2018. This landfill is located in the San Germán Eco-zone, which has abundant rainfall that falls to a minimum during February and March. Soils are formed mainly of clayey material weathered from basic volcanic rocks.

Leachate management infrastructure: The site has six leachate collection tanks of 6,000 gallons each. Three tanks are used at a time. The tanks fill up in 4–5 hours during the rainy season. This landfill has a system to discharge leachate directly to the Puerto Rico Aqueduct and Sewer Authority (PRASA) Wastewater Treatment Plant; however, at the time of sampling, the system was not working because of a failure of the pH meter. PRASA regulations require pH to be monitored for the leachate, and direct discharge is allowed only when the pH is within an acceptable range. When working, approximately 2,000–3,000 gallons per day of leachate are discharged to PRASA. When not discharging directly to PRASA, leachate is trucked offsite approximately three trips a week, with 10,000 gallons of leachate hauled per trip.

Other infrastructure: This landfill has gas and groundwater monitoring wells that a private company routinely samples. Figure 4.1 shows the layout of the Hormigueros landfill.

Figure 4.1. Hormigueros landfill.

Results: This section presents the results from the two sampling events in the Hormigueros Landfill. Tables 4.1 and 4.2 summarize the physicochemical properties of the samples collected.

Table 4.1. Physicochemical Parameters of Hormigueros Leachate Samples

Sampling Date	Sample ID	Temp (ºC)	DO (mg/L)	Cond (µS)	Salinity (ppt)	pH		Turbidity (NTU)	
						Field	Lab	Field	Lab
21-Jan-21	VH-OUT	25.3	5.94	0.6	0	7.56	7.790	0.560	0.48
21-Jan-21	VH-IN	34.5	1.74	1.1	0	6.45	6.766	7.960	11.40
21-Jan-21	VH-IN DUP	33.1	1.51	2215	2.1	6.39	6.620	1.040	11.74
19-Feb-21	VH-OUT	26.6	1.98	0	0	7.33	7.434	0.88	0.85
19-Feb-21	VH-OUT DUP	27.9	1.7	8.0	0	7.70	7.815	1.160	1.14
19-Feb-21	VH-IN	33.5	1.5	1.3	0	6.78	6.871	8.220	27.6

Table 4.2. Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), Total Suspended Solids (TSS), Phosphate (PO_4), Ammonia (NH_3), Nitrite (NO_2), and Nitrate (NO_3) of Hormigueros Leachate Samples

Sampling Date	Sample ID	mg/L							
		COD	BOD	TOC	TSS	PO_4	NH_3	NO_2	NO_3
21-Jan-21	VH-OUT	259.0	ND	40.64	0.9	under	4.77	under	957.80
21-Jan-21	VH-IN	331.4	ND	53.34	14.0	0.47	106.80	under	17.82
21-Jan-21	VH-IN DUP	332.6	ND	70.2	21.1	0.64	134.63	under	22.59
19-Feb-21	VH-OUT	120.1	723.0	39.16	1.9	0.00	18.83	0.05	987.00
19-Feb-21	VH-OUT DUP	123.0	1047.0	37.28	1.9	0.05	24.68	0.52	842.20
19-Feb-21	VH-IN	197.6	561.0	55.04	18	0.26	71.28	0.12	3.64

ND – not determined. The sample used for the analyses was too concentrated, resulting in final DO measurements below the detection limit of the instrument <1 mg/L, hence BOD could not be calculated.

5 Moca Landfill

Moca Landfill is in the northwest area of Puerto Rico, in the karst region (Figure 5.1). The site consists of approximately 85 acres of land and has received waste since the 1970s. It currently receives waste from the municipalities of Moca, Aguada, San Sebastian, and Camuy, as well as private companies. The landfill is owned by the Municipality of Moca and has been operated by ECO-Park Corporation since 2011. This landfill is located in the Mayaguez Eco-zone, a very rainy zone.

Figure 5.1. Moca landfill.

Leachate management infrastructure: This landfill does not have a lined cell; therefore the site does not have the infrastructure to collect and store leachate. Several seeps were observed on the side slopes and along the toe of the landfill. Leachate is constantly flowing through and accumulates into two stormwater ponds.

Other infrastructure: This landfill has gas and groundwater monitoring wells that a private company routinely samples.

Sample collection: Sampling at this site occurred on January 28, 2021. Leachate samples were collected from an area of active seepage (Sample VM-L1), from one of the leachate accumulation ponds (VM-L2), and from one of the leachate streams (VM-L3) that ended in the second accumulation pond (Figure 5.2). The second accumulation pond was not accessible during the sampling because of dense vegetation.

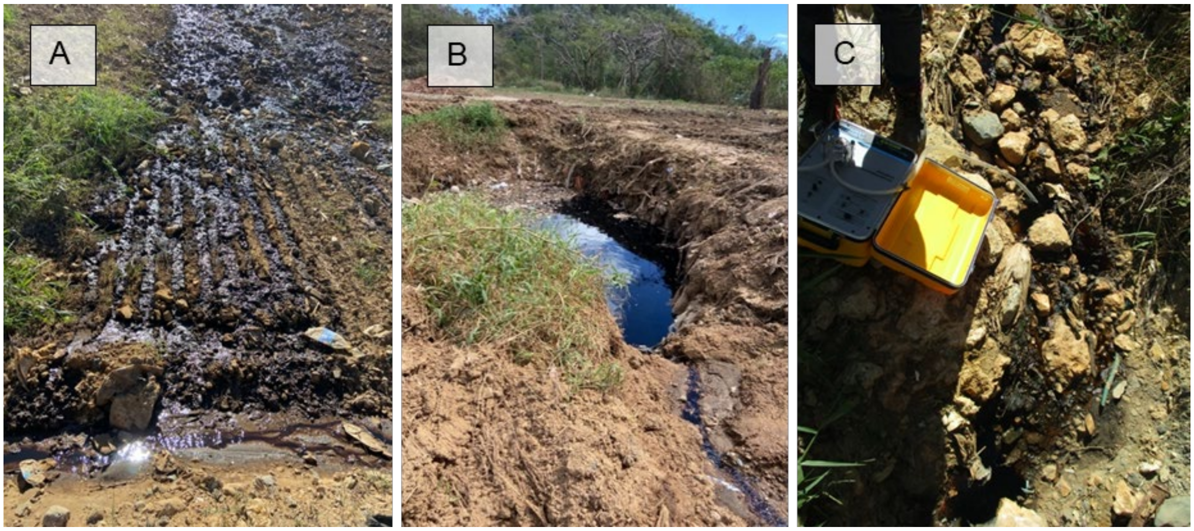

Figure 5.2. Site of active leachate seepage where sample VM-L1 was collected (A); leachate accumulation pond where sample VM-L2 was collected (B); leachate stream where sample VM-L3 was collected (C).

Results: This section presents the results from the two sampling events at the Moca Landfill. Tables 5.1 and 5.2 summarize the physicochemical properties of the samples collected.

Table 5.1. Physicochemical Parameters of Moca Leachate Samples

Sample ID	Temp (ºC)	DO (mg/L)	Cond (µS)	Salinity (ppt)	pH		Turbidity (NTU)	
					Field	Lab	Field	Lab
VML1	31.8	1.72	0	0	7.96	7.978	190.0	145.6
VML1 DUP	NS	NS	NS	NS	7.93	8.014	186.0	148.4
VML2	28.4	0.37	4.6	0	8.21	8.236	77.0	71.2
VML3	33	24.8*	7.95**	0	8.17	8.341	41.0	41.1

*This value was reported as %, not as mg/L.

**This value was reported as mS, not as µS.

NS –no sample was collected for physicochemical parameters from the duplicate.

Table 5.2. Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), Total Suspended Solids (TSS), Phosphate (PO_4), Ammonia (NH_3), Nitrite (NO_2), and Nitrate (NO_3) of Moca Leachate Samples

Sample ID	mg/L							
	COD	BOD	TOC	TSS	PO_4	NH_3	NO_2	NO_3
VML1	8,310.7	ND	1,098.4	500.0	9.75	495.60	0.21	34.81
VML1 DUP	8,918.7	ND	NS	196.0	7.39	686.00	0.19	BDL
VML2	5,676.7	ND	793.2	200.0	11.68	194.75	0.18	15.90
VML3	8,432.7	ND	1,140.8	156.0	23.87	182.80	0.33	28.54

ND – not determined. The sample used for the analyses was too concentrated, resulting in final DO measurements below the detection limit of the instrument <1mg/L; hence, BOD could not be calculated.

NS – no sample. No sample for TOC was collected from the duplicate.

BDL – below detection limit.

6 Cayey Landfill

The Cayey landfill was built in the 1970s. It is located in the Ponce Eco-zone, which has abundant rainfall that falls to a minimum during February and March. No operator was present during site visits, but during a phone conversation, the operator mentioned that they do not see leachate seepage unless there are very heavy rains.

Leachate management infrastructure: This site does not have a leachate collection tank. Leachate accumulates in two ponds, which were empty at the time of sampling. The sampling team collected from a small puddle inside one of the retention ponds (Figure 6.1) and a creek that runs through the landfill (Figure 6.2).

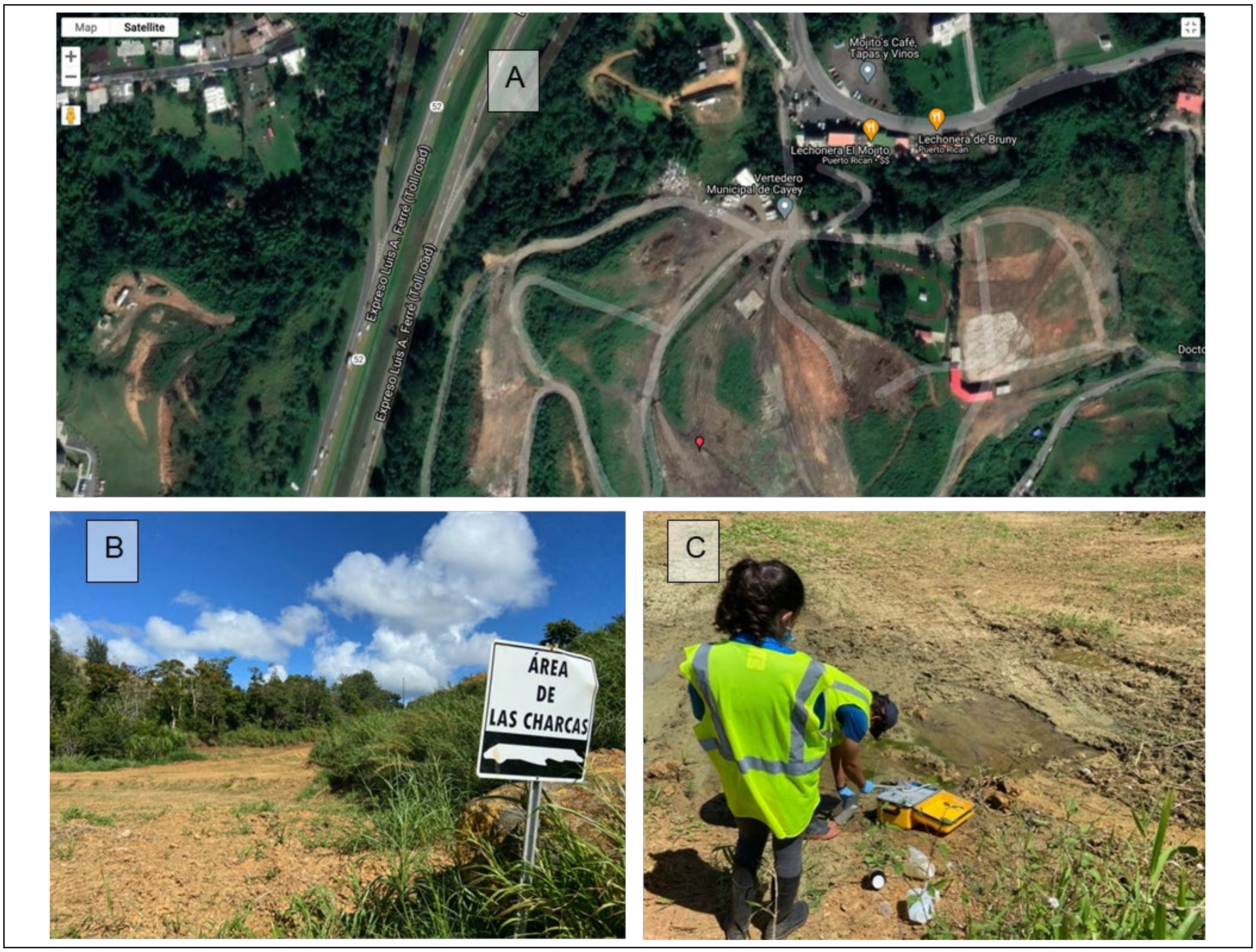

Figure 6.1. Cayey Landfill location (A); area where the accumulation ponds are located (B); small puddle inside one of the accumulation pond used for sample VC-1 (C).

Figure 6.2. VC-Rio sample site.

Results: This section presents the results from the two sampling events at the Cayey Landfill. Tables 6.1 and 6.2 summarize the physicochemical properties of the samples collected.

Table 6.1. Physicochemical Parameters of Cayey Leachate Samples

Sample ID	Temp (ºC)	DO (mg/L)	Cond (µS)	Salinity (ppt)	pH		Turbidity (NTU)	
					Field	Lab	Field	Lab
VC-1	29.4	9.35	2.3	0	8.19	8.355	11.2	7.79
VC-Rio	28.1	6.93	0	0	7.69	7.594	1.70	1.38

Table 6.2. Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), Total Suspended Solids (TSS), Phosphate (PO_4), Ammonia (NH_3), Nitrite (NO_2), and Nitrate (NO_3) of Cayey Leachate Samples

Sample ID	mg/L							
	COD	BOD	TOC	TSS	PO_4	NH_3	NO_2	NO_3
VC-1	250.6	1,101.0	1305.6	21.83	BDL	1.67	0.03	3.23
VC-Rio	14.9	1,485.0	1262.8	19.98	BDL	0.05	BDL	25.12

BDL – below the detection limit. Detection limit for PO_4 is 0.3 mg/L and for NO_2^- is 0.08.

7 La Vega Landfill

Vega Baja Landfill started operating in 1970 in the municipality of Vega Baja in the northern part of Puerto Rico (Figure 7.1). Since 2007, La Vega Landfill and Resources, Inc. has operated the landfill. It is estimated to manage over 600 daily tons of municipal solid waste from ten municipalities and the private sector. This landfill is located in the Arecibo Eco-zone, with abundant rainfall except during February and March. From June to November, occasional tropical depressions cause heavy rainfall and severe flooding in the area.

Figure 7.1. La Vega Landfill.

Leachate management infrastructure:
La Vega landfill has a 115,000-gallon leachate collection tank from its newer cell (Figure 7.2). A leachate accumulation canal also surrounds the cell, and leachate can be seen seeping from different areas of the landfill into the canal (Figure 7.3).

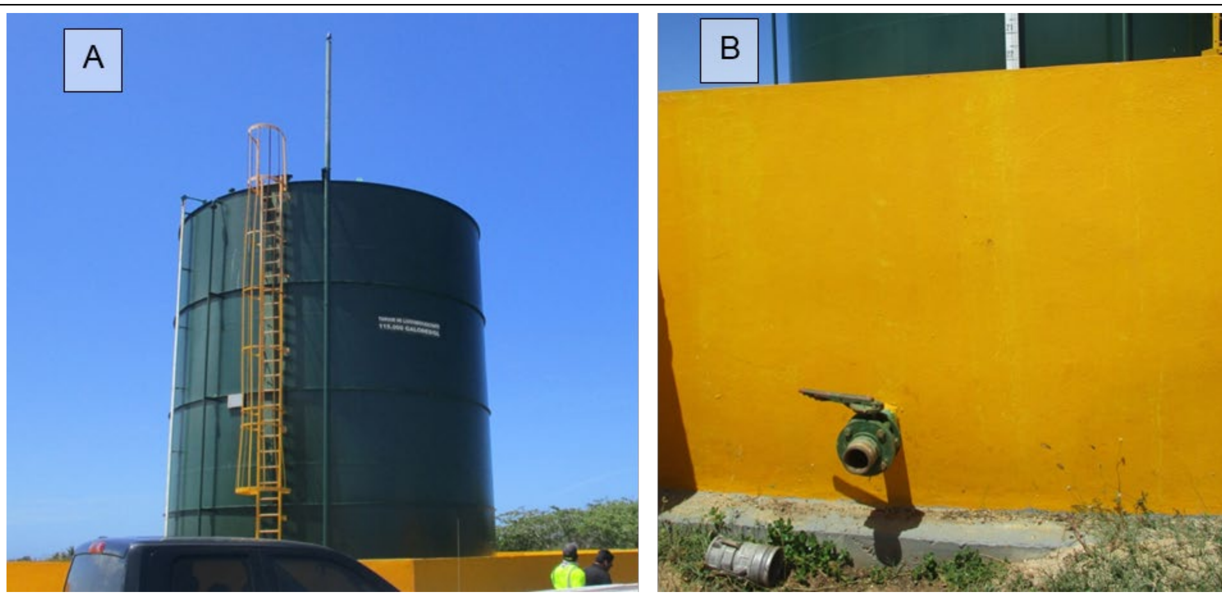

Figure 7.2. Leachate collection tank (A); its sampling port (B).

Figure 7.3. Leachate accumulation canal.

Sample collection: The site operators installed a leachate sampler (Figure 7.4A) for this project, but no samples could be obtained from it. Therefore, a new trench was dug during the collection visit for sampling (Figures 7.4B and 7.4C).

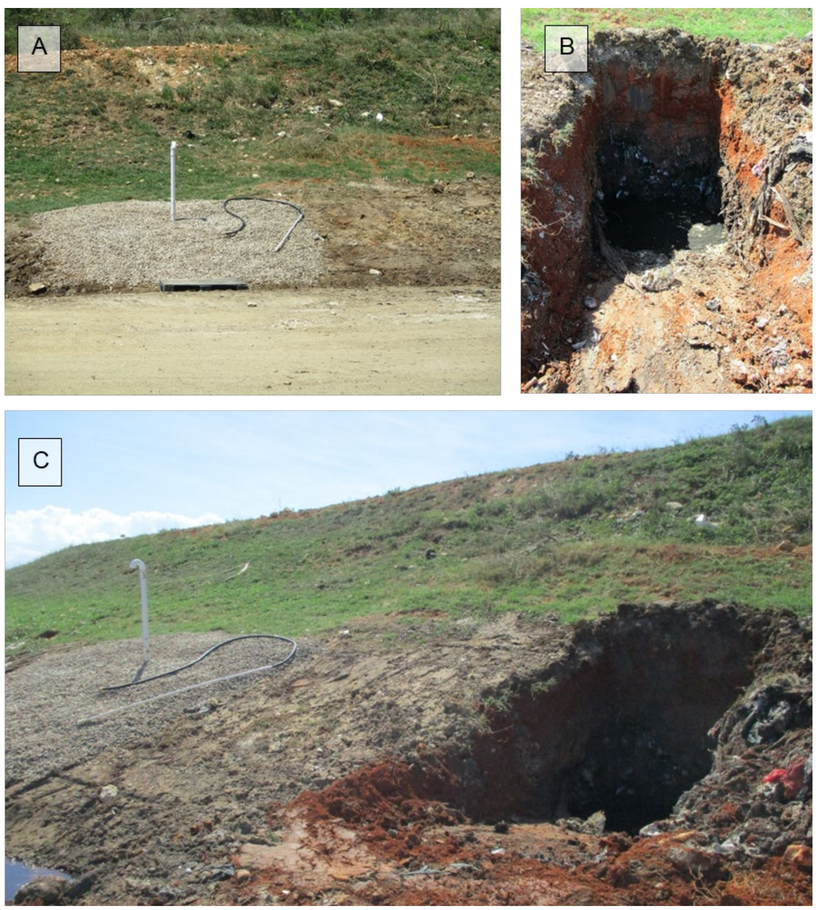

Figure 7.4. Trench dug with sampler installed before sampling visit (A). A new trench dug for sampling point MS08 (B). (C) Location of the new trench in respect to the original dig.

Sampling took place on March 11, 2021, and the samples were named as shown in Table 7.1.

Table 7.1. Sampling Locations in La Vega Landfill

Sample ID	Description
MS13	Outlet to the storage tank
MS14	Leachate accumulation pond/canal
MS14 DUP	Duplicate sample from MS14
ST08	Trench

Results: This section presents the results from the two sampling events at the La Vega Landfill. Tables 7.1 and 7.2 summarize the physicochemical properties of the samples.

Table 7.2. Physicochemical Parameters of La Vega Leachate Samples

Sample ID	Temp (ºC)	DO (mg/L)	Cond* (mS)	Salinity (ppt)	pH		Turbidity (NTU)	
					Field	Lab	Field	Lab
MS14	36.1	0.27	21.66	10.4	8.04	8.436	41.7	26.7
MS14 DUP	NS	NS	NS	NS	8.03	8.461	43.1	26.6
MS13	31.6	0.89	0	0	0.36	8.620	9.88	8.3
ST08	35.0	0.24	19.66	0.1	7.22	7.947	193	129.3

*The conductivity values were recorded as mS, not µS, as in other sites.

NS – no sample, physicochemical parameters were not measured from the duplicate sample.

Table 7.3. Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), Total Suspended Solids (TSS), Phosphate (PO_4), Ammonia (NH_3), Nitrite (NO_2), and Nitrate (NO_3) of La Vega Leachate Samples

Sample ID	mg/L							
	COD	BOD	TOC	TSS	PO_4	NH_3	NO_2	NO_3
MS14	10,548.7	1,104.0	1,305.6	21.83	7.54	246.95	0.32	40.13
MS14 DUP	8,596.7	1,536.0	1,262.8	19.98	8.69	318.75	0.43	33.52
MS13	10,570.7	828.0	3,044.4	7.00	BDL	1185.00	0.77	41.16
ST08	3,383.9	1,146.0	854.8	165.8	25.26	721.40	0.43	29.88

BDL – below the detection limit. For phosphate, the detection limit was 0.3 mg/L.

8 Results and Discussion

This section summarizes the results obtained from the analyses of leachate sampling sites for comparison.

8.1 pH

The pH measurements from all samples varied from 6.4 to 8.8. The highest pH was collected from Cabo Rojo at the outlet of the leachate collection tank, whereas the samples with the lowest pH were those collected from the intake to the leachate collection tanks at Hormigueros during the January 21 sampling event. This pH range corresponds to intermediate aged leachate (pH between 5–10; Bhalla et al., 2013).

8.2 Turbidity

In general, turbidity ranged from 0.5 to 193 NTU. The samples with the lowest turbidity were collected from the Hormigueros landfill, whereas the samples with the highest turbidity were collected at the active leachate seepage site at Moca and the trench site at Vega Baja.

8.3 Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD)

Most sites had low initial DO. In most cases, it was less than 1 mg/L, which is the detection limit of the test. The final DO was also below the detection limit when testing BOD following Standard Method 5210B with undiluted samples. Dilution results were best with 1-mL dilution.[1]

The samples had elevated BOD but were not measurable until dilution was employed.

8.4 Chemical Oxygen Demand (COD)

COD was measured using Standard Method 5220 and a Thermo Scientific Orion AQUAfast AC4007. Samples with lower COD were collected from the lagoon in Cabo Rojo (MS11 and MS12), Hormigueros, and Cayey. Samples collected from the intake and outlet of the tank in Cabo Rojo, Moca, and Vega Baja had elevated COD concentrations.

8.5 BOD/COD Ratio

For samples for which both BOD and COD data were available, the BOD/COD ratio was calculated. According to Bhalla et al. (2013), a BOD/COD ratio of 0.1–0.3 is characteristic of intermediate leachate.

8.6 Total Organic Carbon (TOC)

The sample with the highest TOC level was collected in Vega Baja from the outlet of the collection tank. This sample had a TOC level of 3,044 mg/L. In general, samples from Hormigueros, both the tank intake and outlet, had low TOC levels (37–55 mg/L). The lowest TOC value measured was from VC-Rio, which was a sample collected from a small creek that passes by the Cayey landfill.

8.7 Nutrients

The levels of phosphate (PO_4), ammonia (NH_3), nitrite (NO_2), and nitrate (NO_3) were measured using a

[1] 1 mL of the sample was used for analysis in a 300-mL BOD bottle.

Thermo Scientific Orion AQUAfast AC4007. The limits of detection for the different methods are presented in Table 8.1.

Table 8.1. Limits of Detection for Various Analytes of Interest

	mg/L			
	PO_4	**NH_3**	**NO_2**	**NO_3**
Low limit	0.3	1.5	0.08	5
High limit	8.0	14	1.0	50

Most of the samples had elevated ammonia and low nitrite and nitrate.

The OUT02 sample from Fajardo landfill, collected on November 20, 2020, had elevated nitrite compared to the other samples (6.45 mg/L). That same sample had a dip in the ammonium concentration (9.109 mg/L). This sample was collected at the outlet of the phytoremediation system.

9 References

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Appendix A. Literature Review for Landfill Leachate Quality of Samples from Puerto Rico

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Background

A municipal solid waste landfill is an area of land that receives household waste such as food and garden waste, metal, glass, wood, and rubber, among others. In some cases, municipal solid waste landfills can also receive other types of waste, such as commercial solid waste, sludge, and industrial solid waste, as long as these are non-hazardous. Subtitle D of the Resource Conservation and Recovery Act regulates all non-hazardous solid waste, including location, liner requirements, leachate collection and removal systems, groundwater monitoring requirements, closure and post-closure requirements, operational practices, and corrective actions.

The decomposition of the waste and the level of exposure to weather factors (e.g., rain, humidity) affect the dissolution or decay of the material and the production of leachate and gases (Armstrong and Rowe, 1999). Microbial decomposition of the organic fraction of the municipal solid waste (MSW), under anaerobic conditions, produces landfill gas, which is mostly methane (CH4: 55%–60% v/v) and carbon dioxide (CO_2: 40%–45% v/v) (Scheutz et al., 2009). Other trace products of bacterial decomposition include hydrogen sulfide, ammonia, and volatile organic compounds. Carbon dioxide and methane are greenhouse gases. Landfills have been cited as the largest anthropogenic sources of atmospheric methane globally, comprising about 11% of the total anthropogenic global methane contribution (Spokas et al., 2003). A global estimate of methane emission from landfills approximately 24 Tg/year and ranges from 30 to 70 Tg/year (icp.giss.nasa.gov/).

Leachate is generated when moisture (e.g., rain, humidity) comes into contact with the waste or liquids entrained, infiltrates through the degrading waste, and draws out chemicals and other constituents during the process. Leachate might contain organic and inorganic contaminants, toxic chemicals, heavy metals, and microbial pathogens (e.g., enteric bacteria, fungi, viruses, and parasites) and their metabolites (Jayawardhana et al., 2016). Leachate composition is highly variable and site-specific, varying with waste nature, age and degree of decomposition, moisture content, water balance, waste-filling procedure, and climatic conditions (Armstrong and Rowe, 1999). For these reasons, databases for landfill leachates should be geographically specific (Reinhart and Grosh, 1998).

If not disposed of properly, leachate can negatively affect the environment and human health. To control leachate release from landfills, engineering requisites include surface water run-on controls, impermeable liners, and leachate collection systems. If the landfill does not have a liner, there is a risk that the leachate will infiltrate the groundwater or surface water near the site, affecting water quality. Inorganic pollutants in leachate can increase water turbidity and hardness and cause iron and mineral deposits in pipes. Other environmental effects from the improper disposition of leachate include emission of volatile organic compounds, landscape alteration, and airborne particulate matter. The U.S. Environmental Protection Agency (EPA) estimates that 75% of the landfills in the United States (U.S.) have contaminated aquifers because of the infiltration of leachate. Characterization of composition and concentration of pollutants in leachate is needed to assess the impact of its infiltration into groundwater and to assess treatment methods. A set of environmental parameters utilized in leachate characterization include ammonia, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total dissolved solids, and heavy metal concentration. COD and TOC concentrations and volatile fatty acids are measurements of how much dissolved organic matter is in leachate. Inorganic compounds in leachate might include Ca, Mg, Na, K, NH4, Fe, Mn, and Cl, among others, and heavy metals include Cd, Cr, Cu, Pb, Hg, and Zn (Slack et al., 2005; Christensen et al., 2001).

Even though microorganisms play a key role in landfill environments, from the decomposition of organic matter (e.g., via degradation of cellulose), to the production and oxidation of methane, the composition and abundance of indigenous microbial communities are not understood well, partly because of the varying conditions between landfills.

The Situation in Puerto Rico

In Puerto Rico, a small tropical island with an area of only 9,104 km^2 (compared with the U.S. area of 9.8 million km^2), there is a discharge of over 62,000 metric tons of waste per week. In 2018, the Autoridad de Desperdicios Sólidos de Puerto Rico reported that in Puerto Rico, the average amount of solid waste discarded per person is 5.6 pounds/day, which is one of the highest numbers per capita for a country. According to EPA (2014), almost 6% of the total greenhouse gas emissions on the island come from the waste sector (ghgdata.epa.gov). The waste sector emissions are likely even higher than reported values. The report accounts for only 13 of the 28 MSW landfills that were open in 2014 and omits the island's unauthorized and clandestine landfills. Leachate contamination has also been recognized as a problem. For example, leachate from the Arecibo MSW landfill is likely to be listed as a hazardous waste, F039, based on the age of the landfill, past practices, and contamination issues at other contemporary landfills on the island (40 CFR§ 261.3). EPA estimates that the leachate flow rate for this landfill is about 1,000 gal/day/acre (Tchobanoglous et al., 1993).

Most landfills in Puerto Rico do not have an operational impermeable liner or an operational leachate interception and collection system. Liners, which are required for "new municipal solid waste landfill units" and "lateral expansions," as those terms are defined in 40 C.F.R § 258.2, minimize the possibility that liquids—including leachate—can percolate and seep through a landfill to infiltrate the subsurface and contaminate soil and groundwater. Interception and collection systems are required in Puerto Rico for sanitary landfill systems under Environmental Quality Board regulations to manage non-hazardous solid waste (Rule 548C). Owners and operators of sanitary landfill systems are required to design, construct, and maintain a leachate control system to prevent and control the pollution of surface and underground water.

Leachate Characteristics from Literature

Leachate characteristics depend on several factors, including waste composition, age, degree of decomposition, waste-filling procedure, moisture content of the waste, rate of water movement, and climatic conditions (Armstrong and Rowe, 1999). Young leachate, or leachate in Phases I and II (acidic phase), occurs within the first weeks of formation until about two years. "Mature" Phases III and IV can last for 15 years. According to Bhalla et al. (2013), young, intermediate, and old leachate can be recognized by the characteristics listed in Table A-1. Table A-2 shows more detailed parameters/ranges compared to the age of the sample. Table A-3 shows other parameters characteristics of leachate according to a review by Kjeldsen et al. (2002). The range of values presented tends to be very large because the leachate composition is highly variable.

Table A-1: Some Parameters to Distinguish Young, Intermediate, and Old Leachate (Bhalla et al., 2013)

	Young	Intermediate	Old
Age	<5	5–10	>10
pH	6.5	6.5–7.5	>7.5
COD	>10,000	4,000–10,000	<4000
BOD/COD	>0.3	0.1–0.3	<0.1

Table A-2: Geochemical Characteristics of Young and Mature Leachate.

Constituent	Units	Young Leachate (Phases I and II)	Mature Leachate (Phases III and IV)
Ammonia-nitrogen	mg/L as NH_3-N	10–800	20–40
BOD	mg/L as O_2	2,000–30,000 (10,000–25,000)	100–200 (500–1,000)
COD	mg/L as O_2	3,000–60,000 (20,000–30,000)	100–500 (1,500–2,000)
pH	pH units	4.5–7.5 (5–6.5)	6.6–7.5 (7.5–9)
Alkalinity	mg/L as $CaCO_3$	1,000–10,000	200–1,000
TSS	mg/L	200–2000	100–400
Iron	mg/L	50–1,200 (5–20)	20–200 (<5)
Zinc*	mg/L	1–5	0.03–1
Cadmium*	mg/L	< 30	6
Ammonia*	mg/L	900–1,500	900–1,500
Chloride*	mg/L	1,200–3,000	1,000–3,000

Values in parentheses or denoted by an asterisks (*) are from Johannessen (1999), Guidance Note on Leachate Management for Municipal Solid Waste Landfills.

Table A-3. Comparison of Landfill Leachate

Parameter	Range (mg/L)
pH	4.5–9.0
Spec. Cond. (uS/cm)	2,500–35,000
Total Solids	2,000–60,000
Organic Matter	
Total Organic Carbon (TOC)	30–29,000
Biological Oxygen Demand (BOD)	20–57,000
Chemical Oxygen Demand (COD)	140–152,000
BOD/COD (ratio)	0.02–0.80
Organic Nitrogen	14–2500
Inorganic Macro Components	
Total Phosphorous	0.1–23
Chloride	150–4500
Sulfate	610–7320
HydrogPostassiumenbicarbonate	70–7750
Sodium	50–3700
Ammonium–N	10–7200
Magnesium	30–15,000
Iron	3–5,500
Manganese	0.03–1400
Silica	4–70

Parameter	Range (mg/L)
Heavy Metals	
Arsenic	0.01–1
Cadmium	0.0001–0.4
Chromium	0.02–1.5
Cobalt	0.005–1.5
Copper	0.005–10
Lead	0.001–5
Mercury	0.00005–0.16
Nickel	0.015–3
Zinc	0.03–1000

From Kjeldsen et al. (2002).

Within the first couple of years of establishing a new landfill site, leachate can be composed mostly of low molecular weight organic acids, reaching up to 95% of its TOC. After the first couple of years, a drop in COD can be observed due to increased metabolic activity in the site. The COD/BOD ratio increases, and organic pollutants' composition switches to heavier, long-chain carbohydrates, which are more difficult to degrade biologically (Qasim and Chiang, 1994).

According to Chian and DeWalle (1976), a 1-year-old landfill leachate can have from 7,500 to 28,000 mg/L BOD and from 10,000 to 40,000 mg/L COD, whereas in a 5-year-old landfill leachate, the BOD decreases to 4,000 and COD to 8,000 mg/L. In older leachate (16 years old), these concentrations were 80 and 400 mg/L.

Reinhart and Grosh (1998) did a study to characterize MSW landfill leachate from Florida, and found the following:

- BOD and COD concentrations appeared to remain low (less than 1,500 mg/L) throughout the life of the landfill, most likely because of dilution and stimulation of methanogenesis. The stimulation of methanogenesis was supported by elevated pH in the acidogenic phase, higher Browning-Ferris Industries (BFI) to Florida ratio for BOD relative to the other parameters, low BOD concentrations, and significant gas production during the early years of landfill operation.
- No clearly determined chronological pattern in BOD and COD concentrations was observed.
- Leachate from the shredded waste fill had significantly higher concentrations of organic pollutants than leachate from the unshredded waste landfills, as evidenced in the high COD and BOD levels from the South Dade Shredded Landfill.
- A wide variety of toxic and organic compounds could be found in Florida landfill leachate. However, the concentration of these constituents was generally on the order of micrograms per liter.
- Codisposal of ash with MSW did not appear to impact leachate quality adversely. Concentrations of heavy metals, BOD, COD, and ammonia in leachate from co-disposal sites were not statistically higher than values reported for MSW sites. Chloride values were elevated in the ash leachate in the methanogenic phase because of the high chloride content of ash.
- Florida leachates seemed dilute compared with national landfill data obtained from Browning-Ferris Industries landfill data.

Leachate Effects in the Environments and Treatment

Groundwater usually has few mg/L dissolved organic matter, but this can increase to a few hundreds of mg/L near the landfill. Inorganic pollutants in leachate can increase water turbidity and hardness and cause iron and mineral deposits in pipes.

Leachate generated from open dumpsites is usually directed to surface water bodies with no treatment (Jayawardhana et al., 2016). A significant impact of this is the eutrophication of aquatic systems and toxic effects on fauna.

The leachate treatment options include (1) aerobic or anaerobic biological processing; (2) chemical and physical treatments, such as flotation, coagulation/flocculation, chemical precipitation, adsorption, ammonium striping, chemical oxidation, ion exchange, and electrochemical treatment; and (3) membrane filtration—microfiltration, ultrafiltration, nano-filtration, or reverse osmosis.

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