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ANALYSIS OF FLUCTUATIONS IN LEACHATE POLLUTANTS DUE TO PRECIPITATION: A CASE STUDY IN BARISAL

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ABSTRACT

Landfill leachate, known for its high pollutant levels, undergoes seasonal changes influenced by rainfall. This study examines how precipitation affects leachate composition from a methanogenic landfill in Bangladesh in 2023. Data of nine leachate parameters were gathered during the dry and monsoon seasons. Parameters such as pH, BOD_5, COD, NH_4^+, PO_4^{3-}, TDS, Chloride (Cl^-), Iron (Fe), and Arsenic (As) were analyzed for seasonal variations. The results showed that rainfall significantly increased BOD_5, COD, NH_4^+, and TDS, indicating higher leaching and microbial activity during the monsoon. BOD_5 levels increased from 290 mg/L in February to 500 mg/L in August, while NH_4^+rose from 13 mg/L to 35 mg/L. In the rainy season, there was a slight pH neutralization and higher iron and arsenic concentrations, suggesting dilution and mobilization of metals. This emphasizes the need for leachate treatment strategies to reduce environmental risks in areas prone to heavy rainfall.

***Keywords**: Methanogenic landfill, Pollutant variability, Seasonal rainfall impact, Leachate pollutant analysis*

INTRODUCTION

Leachate is a liquid waste produced from the decomposition of organic materials. It presents considerable environmental issues due to its elevated levels of organic pollutants, nutrients, heavy metals, and dissolved salts. Landfills that facilitate anaerobic decomposition are particularly prone to generating complex leachate. Furthermore, rainfall can alter the characteristics of leachate, impacting pollutant concentrations and heightening the risk of environmental contamination (Kjeldsen et al., 2002). In landfills where methanogenic processes dominate, the leachate composition is notably complex and can be further affected by external factors such as precipitation. If not treated adequately, leachate can infiltrate surrounding areas, posing significant threats to nearby ecosystems and communities (Kulikowska & Klimiuk, 2007).

This study examines the Barisal landfill in Bangladesh, a facility that produces methane and has been in operation for ten years, located near heavily populated areas. The landfill lacks any systems for treating leachate, which increases the environmental hazards associated with its operation. Without treated leachate, there is a direct threat to the surrounding region, as it can pollute crucial surface water supplies for the local population (Marzougui & Mammou, 2006). Such contamination could lead to a decline in water quality, disrupt aquatic ecosystems, and create health risks for residents who rely on these water sources. Methanogenic landfills are characterized by advanced waste decomposition, where anaerobic microbial processes are the primary drivers. The anaerobic breakdown of organic matter in landfills primarily produces methane (CH_4) and carbon dioxide (CO_2). While landfills stabilize waste effectively, they also generate leachate, a liquid byproduct that can contain harmful environmental contaminants (Al-Yaqout & Hamoda, 2020). Leachate from methanogenic landfills contains high levels of dissolved organic carbon, ammonia, nutrients like phosphate, and various heavy metals. The characteristics of landfill leachate are influenced by factors such as waste composition, landfill age, and environmental conditions.

Table 1. Pollutant Profiles of Methanogenic Landfills

Leachate Parameters	Pollutant Profiles of Methanogenic Landfills
Biochemical Oxygen Demand (BOD_5)	BOD5 measures biodegradable organic matter, showing high levels in the early stages of a landfill and lower levels during the methanogenic phases, indicating a decline in readily degradable organic matter.
Chemical Oxygen Demand (COD)	Methanogenic leachate consistently has high COD due to non-biodegradable organic compounds, which remain elevated because of soluble organic compounds that resist degradation.
Ammonium (NH_4^+)	Ammonia is a significant pollutant in methanogenic leachate, resulting from the anaerobic degradation of nitrogen-containing organic matter. Its toxicity and persistence raise major environmental concerns, as it is often found in substantial amounts.
Heavy Metals	Elements such as iron (Fe), arsenic (As), lead (Pb), and mercury (Hg) are mobilized from waste materials, which can bioaccumulate and pose significant ecological risks.
Total Dissolved Solids (TDS) and Chlorides	Indicators of salinity and ionic strength are often elevated due to the decomposition of waste and interactions with precipitation.
Dissolved Organic Carbon (DOC)	Methanogenic leachate contains high levels of organic matter, including persistent volatile fatty acids (VFAs) and high-molecular-weight humic substances, which are products of anaerobic degradation.
Persistent Organic Pollutants (POPs)	Leachate contains harmful organic compounds such as pesticides, BTEXs, and phenolic compounds, which contribute significantly to its toxicological profile.

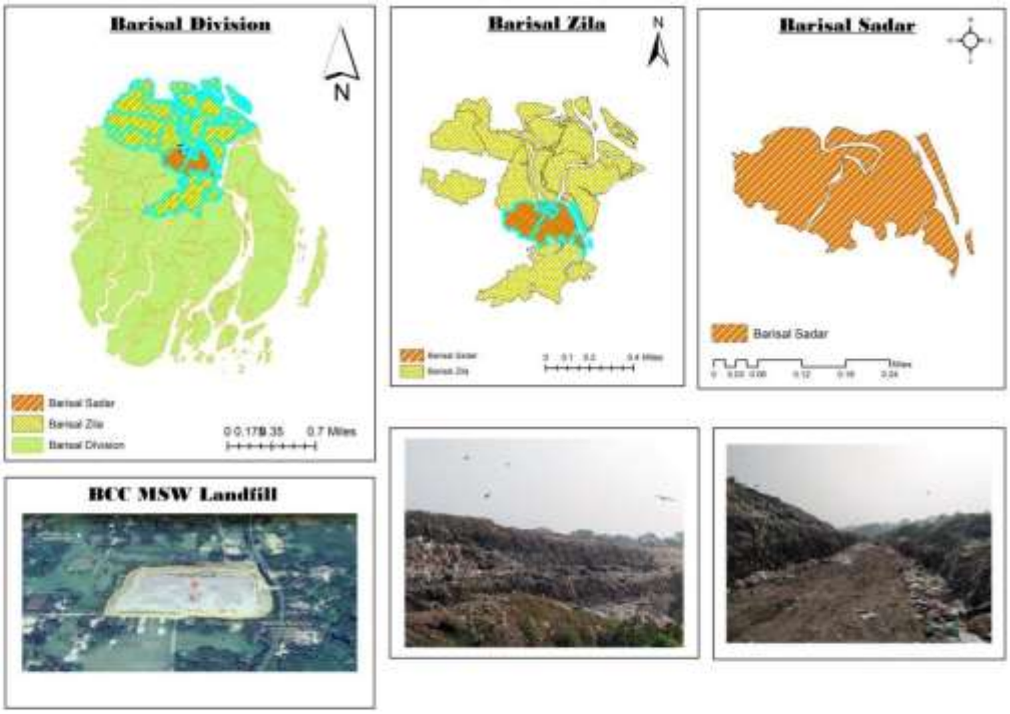
Precipitation increases landfill leachate quantity and composition by raising the hydraulic load and enhancing the leaching of soluble pollutants. Seasonal rainfall, especially during monsoon seasons, leads to higher leachate production and pollutant mobilization. While rainwater may dilute some pollutants, it generally contributes to a higher overall pollutant load. Intense rainfall can elevate hydraulic pressure, risking leachate movement into nearby environments and increasing the potential for contamination of surface and groundwater. Additionally, wet seasons result in higher levels of ammonia, chemical oxygen demand (COD), and nutrients in leachate. Surface water contamination disrupts aquatic life by lowering oxygen levels and introducing toxins such as ammonia and heavy metals (Mor et al., 2006). Groundwater pollution from leachate affects drinking water, leading to long-term health issues like metal poisoning and waterborne diseases. Uncontrolled leachate runoff during heavy rain can cause localized flooding, spreading contaminants widely.

The main goal of this research is to examine how precipitation affects the variability of leachate pollutants, particularly regarding the environmental consequences of these variations. The study spans from January to August 2023, encompassing both the dry and monsoon seasons to assess changes across seasons. Nine key parameters were tracked to measure fluctuations in pollutants: pH, Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), ammonium (NH_4^+), phosphate (PO_4^{3-}), total dissolved solids (TDS), chloride (Cl^-), iron (Fe), and arsenic (As). The studies show that monsoon rainfall notably elevates pollutant concentrations. For example, the Chemical Oxygen Demand (COD) increased from 980 mg/L in February to 1,250 mg/L in August, while ammonium levels rose from 13 mg/L to 35 mg/L in the same timeframe. These findings highlight the increased risk of leachate contaminating surface water during the rainy season, which may worsen environmental and public health challenges in the surrounding areas.

METHODOLOGY

Study Area

The study examines the Barisal City Corporation landfill in Barisal Sadar Upazila, Bangladesh, specifically in Kaunia at coordinates 22°42'N and 90°21'E. This untreated, open landfill has been operating for over ten years and is currently in its methanogenic phase. It poses environmental risks due to leachate contamination of surface and groundwater, exacerbated by local precipitation. The landfill's location on rural outskirts near agricultural fields and water bodies increases its environmental sensitivity to leachate seepage.



Figrue 1. Study Area BCC MSW Landfill

Sampling Period

The sampling took place from January to August 2023 to assess the impact of dry and wet seasons on leachate pollutant concentrations, with significant months being January and February (dry season) and July and August (wet season).

Sampling Method:

The collected leachate samples were analyzed for the following physicochemical parameters:

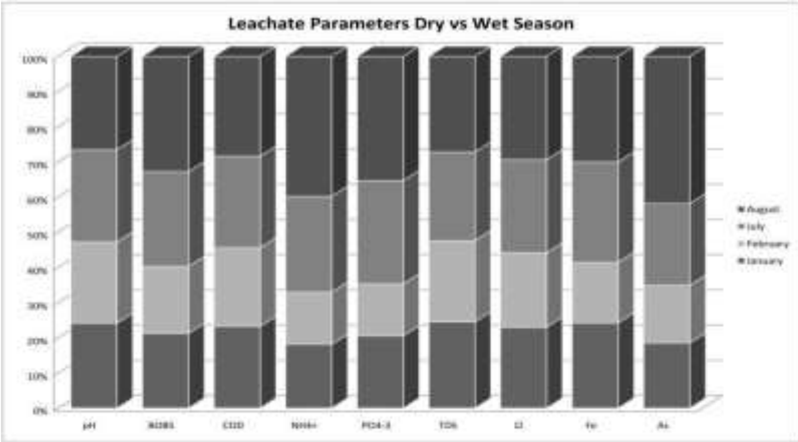
- **pH**: Measured using a calibrated digital pH meter.
- **Biochemical Oxygen Demand (BOD_5)**: Determined via the 5-day BOD test using standard Winkler methods.
- **Chemical Oxygen Demand (COD)**: Assessed using the open reflux method.
- **Ammonium (NH_4^+)**: Analyzed using the spectrophotometric salicylate method.
- **Phosphate (PO_4^{3-})**: Measured via the molybdenum blue method.
- **Total Dissolved Solids (TDS)**: Determined using a TDS meter.
- **Chloride (Cl^-)**: Quantified using the argentometric method.
- **Iron (Fe)**: Measured using an atomic absorption spectrophotometer (AAS).
- **Arsenic (As)**: Quantified using AAS after digestion of samples.

The procedures followed standard methods established by the American Public Health Association (B. Baird et al., n.d.). Equipment calibration and quality control protocols were implemented before analyses, and analytical-grade reagents were used throughout the study to ensure reliable results.

RESULTS

Table 2. Leachate Sample Values in Dry and Wet Season

Parameters	pH	BOB5	COD	NH_{4+}	PO_4^{3}	TDS	Cl	Fe	As
January	6.1	324	1025	16	7	2390	235	0.17	0.008
February	5.8	290	980	13	5	2245	215	0.12	0.007
July	6.6	410	1145	24	10	2450	270	0.2	0.01
August	6.7	500	1250	35	12	2650	300	0.21	0.018



Figrue 2. Variation of Parameters in Dry and Wet Season

The chart illustrates seasonal changes in leachate parameters, comparing dry months (January, February) to wet months (July, August). pH levels remain consistent across seasons, indicating minimal variations in acidity. However, there are significant increases in organic and inorganic pollutants during the wet months. Elevated BOD_5 and COD suggest increased breakdown of organic matter. Additionally, levels of Ammonium (NH_4^+), Phosphate (PO_4^{3-}), TDS, Chloride (Cl), Iron (Fe), and Arsenic (As) rise, reflecting enhanced leaching and mobilization of nutrients and metals. These results highlight the impact of seasonal rainfall on landfill leachate composition and pollution potential.

DISCUSSION

The analysis of landfill leachate parameters reveals seasonal variations in environmental impact. Higher concentrations of pollutants are observed during the wet months of July and August, while lower levels occur in the dry months of January and February. This difference is attributed to increased precipitation and runoff during the wet season, which enhances the leaching of pollutants from landfill waste. The subsequent discussion will further explore these findings with supporting literature.

pH Stability

The pH levels showed a slight increase from the dry (5.8–6.1) to the wet season (6.6–6.7). It remain relatively constant throughout different seasons, typically staying neutral to slightly alkaline. This stability is attributed to the landfill system's buffering capacity, which is influenced by the breakdown of organic materials and the dissolution of carbonates (El-Fadel et al., 1997). Maintaining stable pH levels in leachate is crucial, as they affect the solubility and movement of heavy metals and pollutants.

Elevated BOD_5 and COD in Wet Season

The levels of Biological Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD) are elevated during the rainy season. Both parameters were higher during the wet season (BOD_5: 410–500 mg/L, COD: 1145–1250 mg/L) compared to the dry season (BOD_5: 290–324 mg/L, COD: 980–1025 mg/L). This suggests heightened microbial activity and an increase in the breakdown of organic matter. The infiltration of rainwater probably enhances the movement of biodegradable organic materials into the leachate, as observed in the research conducted by (Christensen et al., 2001). The increased BOD_5 and COD levels indicate a higher potential for pollution in the leachate, which raises concerns regarding its treatment and management.

Nutrient Enrichment (NH_4^+ and PO_4^{3-})

Ammonium (NH_4^+) and phosphate (PO_4^{3-}) levels exhibited a sharp rise during the wet season, with NH_4^+ increasing from 13–16 mg/L in the dry months to 24–35 mg/L in the wet months. The heightened concentrations of ammonium (NH_4^+) and phosphate (PO_4^{3-}) in the wet season suggest an increase in nutrient leaching resulting from organic decomposition and surface runoff. Ammonium is generated through the anaerobic breakdown of nitrogen-rich organic materials, whereas phosphate leaching is generally associated with the dissolution of minerals. Research, such as that by (Kjeldsen et al., 2002), highlights the significance of seasonal infiltration in mobilizing these nutrients, which raises concerns about the potential for eutrophication in the affected water bodies.

Increased TDS, Chloride, and Metals (Fe, As) in Wet Season

TDS and Cl^- levels were substantially higher during the wet season, indicating increased dissolution of salts and minerals. TDS rose from 2245–2390 mg/L in the dry season to 2450–2650 mg/L in the wet season, while Cl^- levels rose from 215–235 mg/L to 270–300 mg/L. The levels of Total Dissolved Solids (TDS), Chloride (Cl), Iron (Fe), and Arsenic (As) are notably elevated during the rainy season. This rise is attributed to the solubilization and movement of dissolved ions and heavy metals, which occurs due to the heightened water flow through the waste material. These results align with the findings of which suggest that intense rainfall increases leachate production and the release of hazardous metals, subsequently raising the pollution burden of the landfill.

The research highlights the significant impact of seasonal rainfall on landfill leachate composition and quality. It emphasizes the challenges in managing leachate, especially during the rainy season when pollutant levels are notably higher.

CONCLUSION

This research emphasizes the notable influence of seasonal rainfall on the makeup of landfill leachate, with a specific focus on the Barisal landfill in Bangladesh. Important findings reveal that monsoon precipitation significantly raises the levels of pollutants, such as BOD_5, COD, ammonium, phosphate, and heavy metals like iron and arsenic. These increased concentrations amplify the environmental threats posed by untreated leachate, particularly in terms of contaminating both surface and groundwater sources. Although the pH levels remained consistent due to the landfill's buffering properties, the increase in pollutant concentrations during the rainy season underscores an urgent need for effective leachate management approaches. Without corrective measures, the heightened levels of pollutants could lead to persistent ecological and public health challenges, including eutrophication, waterborne illnesses, and disruptions to ecosystems. Future waste management plans should take into account the effects of seasonal rainfall when designing leachate treatment systems. Preventive actions, such as containment technologies and advanced treatment methods, are essential for alleviating the detrimental impacts of leachate pollution. This will aid in ensuring sustainable landfill practices and safeguarding environmental and public health in areas subject to heavy rainfall.

REFERENCES

Kjeldsen, P., Barlaz, M. A., Rooker, A. P., Baun, A., Ledin, A., & Christensen, T. H. (2002). Present and Long-Term Composition of MSW Landfill Leachate: A review. *Critical Reviews in Environmental Science and Technology*, *32*(4), 297–336. https://doi.org/10.1080/10643380290813462

Kulikowska, D., & Klimiuk, E. (2007). The effect of landfill age on municipal leachate composition. *Bioresource Technology*, *99*(13), 5981–5985. https://doi.org/10.1016/j.biortech.2007.10.015

Marzougui, A., & Mammou, A. B. (2006). Impacts of the dumping site on the environment: Case of the Henchir El Yahoudia Site, Tunis, Tunisia. *Comptes Rendus Géoscience*, *338*(16), 1176–1183. https://doi.org/10.1016/j.crte.2006.09.020

Al-Yaqout, A., & Hamoda, M. F. (2020). Long-term Temporal Variations in Characteristics of Leachates from a Closed Landfill in an Arid Region. *Water Air & Soil Pollution*, *231*(6). https://doi.org/10.1007/s11270-020-04688-7

Mor, S., Ravindra, K., Dahiya, R. P., & Chandra, A. (2006). Leachate Characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environmental Monitoring and Assessment*, *118*(1–3), 435–456. https://doi.org/10.1007/s10661-006-1505-7

B. Baird, R., W. Rice, E., Posavec, S., American Public Health Association, & American Water Works Association. (n.d.). *Standard methods for the examination of water and wastewater*. https://yabesh.ir/wp-content/uploads/2018/02/Standard-Methods-23rd-Perv.pdf

El-Fadel, M., Findikakis, A. N., & Leckie, J. O. (1997). Environmental impacts of solid waste landfilling. *Journal of Environmental Management*, *50*(1), 1–25. https://doi.org/10.1006/jema.1995.0131

Christensen, T. H., Kjeldsen, P., Bjerg, P. L., Jensen, D. L., Christensen, J. B., Baun, A., Albrechtsen, H., & Heron, G. (2001). Biogeochemistry of landfill leachate plumes. *Applied Geochemistry*, *16*(7–8), 659–718. https://doi.org/10.1016/s0883-2927(00)00082-2