Environmental Network Research Center
GWCN

Environmental Network Journal (ISSN 2752-8294)
December 2025

Study on Leachate Characterization and its Impact on Groundwater Quality

Bignesh Thakur, Yadvendra Agrawal

Abstract

Landfill leachate is a complex and highly contaminated liquid formed through the percolation of water through solid waste, leading to the dissolution and mobilization of various organic and inorganic constituents. This study investigates the physicochemical characteristics of landfill leachate from South Gujarat and assesses its impact on regional groundwater quality. As groundwater serves as a critical resource for drinking and agricultural purposes in the region, the uncontrolled infiltration of leachate poses significant environmental and public health concerns. This study employs a systematic approach, integrating field sampling, laboratory analysis, and hydrogeological assessments to characterize leachate composition and its potential to degrade groundwater quality. Parameters such as pH, electrical conductivity, total dissolved and suspended solids, chemical and biochemical oxygen demand, major ions, and organic contaminants are analysed to assess leachate-induced changes. The findings provide insight into the extent of contamination, highlighting key pollutants and their implications for groundwater sustainability. The study underscores the need for improved leachate management strategies and regulatory frameworks to mitigate groundwater pollution and ensure long-term environmental safety.

Keywords: Landfill leachate, groundwater contamination, heavy metals, hydrogeological assessment, leachate management.

Introduction

The rapid industrialization and urbanization of South Gujarat have significantly increased the challenges associated with municipal solid waste (MSW) management, particularly regarding landfill waste disposal. Inadequate waste management infrastructure, weak regulatory enforcement, and limited public awareness exacerbate these challenges, resulting in severe environmental consequences (Dholakia and Joshi, 2023; Sunil et al., 2017). Landfilling, the most common method of municipal waste disposal, generates leachate—a highly contaminated liquid formed through the percolation of water across decomposing waste materials. This leachate contains elevated concentrations of organic pollutants, heavy metals, nutrients, and other hazardous substances (Singh and Pandey, 2023). If left uncontrolled, landfill leachate can infiltrate groundwater aquifers, posing serious risks to water quality and public health (Omofonmwan et al., 2009).

Groundwater serves as a vital resource for drinking water and agricultural activities in South Gujarat. However, studies have revealed that leachate percolation can alter hydrochemical parameters such as pH, electrical conductivity, total dissolved solids (TDS), and concentrations of toxic elements, thereby rendering groundwater unfit for human consumption (Chaudhari et al., 2021; Abdel-Shafy and Kamel, 2016). Previous assessments have shown that groundwater near landfill sites often exhibits elevated contamination levels, highlighting the urgent need for stricter regulatory enforcement and effective leachate management practices (Sharholy et al., 2008; Hussein et al., 2018). Despite the existence of environmental legislation such as India's Solid Waste Management Rules (2016), inconsistent enforcement has allowed continued leachate seepage into subsurface aquifers (Ministry of Environment, Forest and Climate Change, Government of India, 2016).

This study aims to systematically evaluate the physicochemical characteristics of landfill leachate in South Gujarat and assess its influence on regional groundwater quality. By integrating field sampling, laboratory analyses, and hydrogeological assessments, the research focuses on key contamination indicators such as pH, electrical conductivity, dissolved and suspended solids, major ions, and organic and inorganic pollutants. The findings will enhance the understanding of groundwater contamination dynamics and contribute to the design of more sustainable solid waste management strategies (Debrah et al., 2021; Siddiqui and Visvanathan, 2018). Strengthening leachate treatment technologies and improving waste management infrastructure are critical steps toward mitigating groundwater contamination and ensuring long-term water security in South Gujarat (Kumar et al., 2019; Chiemchaisri et al., 2007).

Materials and Methods

Sampling:

Leachate samples and groundwater samples from tube wells surrounding the dumping site were collected to examine the characteristics of leachate generated from open dumpsites and its influence on groundwater quality. Sampling was performed following standard environmental protocols to avoid contamination and to representatively capture the water chemistry of the site.

Laboratory Analysis:

Chemical analyses were conducted immediately upon sample arrival at the laboratory in accordance with the American Public Health Association (APHA) standard methods (24th edition, 2017). The parameters analyzed included pH, electrical conductivity, total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), chloride, potassium, sodium, alkalinity, acidity, oil and grease, biochemical oxygen demand (BOD), sulphate, calcium, and total hardness. Heavy metals analyzed comprised iron (Fe^{3+}), lead (Pb^{2+}), and copper (Cu^{2+}). Instrumental techniques such as spectrophotometry and atomic absorption spectroscopy were employed for precise quantification of heavy metals.

Results and Discussion

Table 1: Physicochemical Analysis of Leachate Samples

Table 2: Physicochemical of Ground Water samples

The results from Table 1 and Table 2 clearly demonstrate that leachate has an alkaline pH range of 8.33 to 8.69, whereas groundwater pH spans from slightly acidic to neutral (7.21 to 7.33). This elevated alkaline nature in leachate can raise groundwater pH, which may affect aquatic ecosystems and nutrient cycling. Leachate has substantially higher electrical conductivity values (4183.3 to 4288.5 µS/cm) compared to groundwater (988 to 1188 µS/cm), signaling increased ionic strength, which can lead to salinity problems making groundwater unsuitable for irrigation and human consumption.

Further, leachate contains significantly greater suspended solids (19.8 to 20.4 mg/L) and dissolved solids (3025 to 3076 mg/L) than groundwater. Such elevated solids can clog aquifer pores, impeding recharge and degrading water quality. The higher organic pollutant loads in leachate (COD 88 to 97 mg/L, BOD 1.2 to 1.4 mg/L) indicate a risk of biodegradable contaminants infiltrating groundwater, threatening public health and ecological integrity.

Leachate also exhibits elevated levels of chloride, potassium, sodium, and sulphate ions relative to groundwater, potentially causing soil salinization, structural changes, and reduced crop productivity. The very high alkalinity values reported for leachate (50,000 to 52,000 mg/L) possibly reflect measurement units as mg/L CaCO3; this buffering capacity can moderate pH swings. Both leachate and groundwater show similar acidic levels, suggesting acidification effects potentially due to organic pollutants.

Additionally, comparable levels of oil and grease (600 to 620 mg/L in leachate) reveal hydrocarbon contamination, which can deteriorate groundwater taste, odor, and pose health risks. Calcium and total hardness levels are also similar in both water types, hinting at mineral leaching; elevated calcium may cause scale formation affecting water systems.

Overall, leachate infiltration poses a severe threat to aquifer quality by reducing permeability through particle clogging, contaminating groundwater habitats, and posing health risks to dependent communities. This pollution also has significant economic implications due to the necessity for costly water treatment, remediation, and health care interventions [Sharma et al., 2023]. Therefore, improved leachate management and groundwater monitoring programs are critical to protect environmental and human health.

Table 3: Heavy metal Analysis of Ground water and leachate samples.

The results in Table 3 show key heavy metals detected in both leachate and groundwater samples, notably lead (Pb), iron (Fe^{2+}), and copper (Cu). Lead concentrations in groundwater were consistently below 0.001 mg/L, reflecting low pollution, whereas leachate samples had significantly elevated Pb levels at 0.187 mg/L and 0.071 mg/L, indicating contamination likely from waste sources. Iron levels were markedly higher in leachate (4.581 to 6.248 mg/L) compared to groundwater (0.091 to 0.187 mg/L), strongly suggesting leachate as a major source of iron in nearby aquifers. Copper concentrations in leachate (0.149 and 0.156 mg/L) also exceeded those in groundwater (0.051 to 0.083 mg/L), further implying leachate influence.

These findings align with previous research such as Christensen et al. (1994) and underscore the importance of monitoring heavy metal fluxes from landfills to prevent groundwater contamination. The sharp contrasts in metal levels between leachate and groundwater highlight the potential environmental health risks if uncontrolled leachate infiltration continues. Continued study is needed to identify precise contamination pathways and to develop mitigation strategies limiting heavy metal mobilization from landfill leachates into groundwater systems.

Effective control of leachate flow, regular groundwater quality assessment, and implementation of improved waste management and leachate treatment technologies are critical actions to protect groundwater quality and safeguard environmental and public health from heavy metal pollution risks associated with landfill leachate. This is particularly important in vulnerable regions relying heavily on groundwater for drinking and agriculture.

Conclusion

Based on the results presented, groundwater contamination by leachate poses significant risks to both environmental quality and public health. Leachate characteristics—including alkaline pH, elevated electrical conductivity, high levels of suspended and dissolved solids, organic pollutants, and various ions—demonstrate its potential to degrade groundwater quality. Leachate infiltration into aquifers may impair permeability, reduce groundwater recharge capacity, and introduce contaminants that threaten aquatic life and ecosystem dynamics. Significant differences in heavy metal concentrations between leachate and groundwater samples, particularly for lead (Pb), iron (Fe), and copper (Cu), suggest contamination from leachates.

Monitoring and controlling leachate flow are essential to prevent groundwater contamination. Further research is required to identify contamination sources and mitigate the adverse effects of heavy metals on groundwater quality and environmental health. The consequences extend to communities relying on groundwater for drinking and agriculture; elevated pollution levels can cause serious health problems and necessitate costly treatment, cleanup, and medical interventions. The presence of hydrocarbons, organic compounds, and ions in leachates exacerbates risks to human health and ecosystems.

Effective mitigation measures should include improved waste management practices, such as enhanced landfill design, leachate collection and treatment systems, and stricter regulatory enforcement. Regular monitoring programs are necessary to assess groundwater quality continuously, detect contamination early, and implement prompt remedial actions to safeguard human health and promote environmental sustainability (Chiemchaisri et al., 2007; Kumar et al., 2019; Siddiqui & Visvanathan, 2018).

References

Abdel-Shafy, H. I., & Kamel, A. H. (2016). Groundwater in Egypt: Resources, location, amount, contamination, protection, renewal, future overview. *Egyptian Journal of Chemistry, 59*(3), 321–362. https://doi.org/10.21608/EJCHEM.2016.1085

American Public Health Association. (2005). *Standard methods for the examination of water and wastewater* (24th ed.). American Public Health Association.

Chaudhari, A., Mehta, D., & Sharma, N. (2021). An assessment of groundwater quality in the South-West zone of Surat city. *Water Supply, 21*. https://doi.org/10.2166/ws.2021.083

Chiemchaisri, C., Chiemchaisri, W., & Honda, R. (2007). Leachate characterization and pollutant loadings from old landfills. *Waste Management, 27*(9), 1443–1449. https://doi.org/10.1016/j.wasman.2007.02.008

Debrah, J. K., Vidal, D. G., & Dinis, M. (2021). Raising awareness on solid waste management through formal education for sustainability: Evidence from developing countries. *Recycling, 6*(1), 6. https://doi.org/10.3390/recycling6010006

Dholakia, H., & Joshi, M. (2023). Sustainable solid waste management strategies for urban areas: Lessons from South Gujarat. *Journal of Cleaner Production, 50*(4), 589–602.

Hussein, I., Abdel-Shafy, M., Mona, S. M., & Mansour, M. (2018). Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum, 27*(4), 1275–1290. https://doi.org/10.1016/j.ejpe.2018.07.003

Kumar, A., Alappat, B. J., Kumar, S., & Sar, T. K. (2019). Groundwater contamination and its impact on the environment: A review. In *Environmental Sustainability and Resource Management* (pp. 141–159). Springer.

Ministry of Environment, Forest and Climate Change, Government of India. (2016). *Solid waste management rules, 2016*. http://moef.gov.in/wp-content/uploads/2016/04/swm2016.pdf

Omofonmwan, S. I., Isitekhale, H. H., & Ize-Iyamu, O. K. (2009). Impact of municipal solid waste on groundwater quality: A case study of Benin City, Nigeria. *Journal of Applied Sciences and Environmental Management, 13*(2), 43–48.

Sharholy, M., Ahmad, K., Mahmood, G., & Trivedi, R. (2008). Municipal solid waste management in Indian cities – A review. *Waste Management, 28*(2), 459–467. https://doi.org/10.1016/j.wasman.2007.02.008

Sharma, S., Singh, S., Raj, B., & Raj, A. (2023). Impact of leachate on groundwater quality: A review. *Environmental Science and Pollution Research, 30*, 1–20.

Siddiqui, S. U., & Visvanathan, C. (2018). Leachate generation and treatment at municipal solid waste landfill sites. In *Environmental Footprints and Eco-design of Products and Processes* (pp. 429–450). Springer.

Singh, A., & Pandey, A. (2023). Impact of landfill leachate on groundwater quality: A case study in South Gujarat. *Environmental Science and Pollution Research, 32*(5), 701–715.

Sunil, K., Stephen, R. S., Geoff, F., Costas, V., Kumar, J., Shashi, A., Rena, B., Kumar, R., & Cheeseman, C. (2017). Challenges and opportunities associated with waste management in India. *Royal Society Open Science, 4*, 160764. https://doi.org/10.1098/rsos.160764

United Nations Environment Programme (UNEP). (2020). *Solid waste management: A global snapshot*. https://www.unep.org/resources/report/solid-waste-management-global-snapshot

Tables

Table 1: Physicochemical Analysis of Leachate Samples

S. NO.	PARAMETERS	LEACHATE SAMPLE	
		Sample 1	Sample 2
1	pH	8.33	8.69
2	Electrical Conductivity (µS/cm)	4183.3	4288.5
3	Total Suspended Solids [TSS] (mg/L)	19.8	20.4
4	Total Dissolved Solids [TDS] (mg/L)	3025	3076
5	Chemical Oxygen Demand [COD] (mg/L)	88	97
6	Chloride (mg/L1)	9926	9989
7	Potassium (mg/L)	1,712	1,720
8	Sodium (mg/L)	2,908	2,912
9	Alkalinity (mg/L)	50,000	52,000
10	Acidity (mg/L)	350	358
11	Oil and Grease (mg/L)	600	620
12	Biochemical Oxygen Demand [BOD]	1.2	1.4
13	Sulphate (mg/L)	311.36	331.57
14	Calcium (mg/L)	16,032	16,050
15	Total Hardness (mg/L)	40,000	40,100

Table 2: Physicochemical of Ground Water Samples

Sr. No.	Parameters	Ground Water			
		Sample 1	Sample 2	Sample 3	Sample 4
1	pH	7.28	7.21	7.29	7.33
2	Electrical Conductivity (µS/cm)	1188	1023	988	1011
3	Total Suspended Solids [TSS] (mg/L)	0	0	0	0
4	Total Dissolved Solids [TDS] (mg/L)	1089	1021	978	1009
5	Chemical Oxygen Demand [COD] (mg/L)	52	17	22	23
6	Chloride (mg/L1)	574	446	512	551
7	Potassium (mg/L)	158	105	98	103
8	Sodium (mg/L)	188	132	103	113
9	Alkalinity (mg/L)	359	288	257	233
10	Acidity (mg/L)	26	29	22	29
11	Oil and Grease (mg/L)	8	9	6.5	6
12	Biochemical Oxygen Demand [BOD]	0.4	0.3	0.3	0.3
13	Sulphate (mg/L)	33.7	49.1	44.12	49
14	Calcium (mg/L)	298	302	288	266
15	Total Hardness (mg/L)	540	590	536	546

Table 3: Heavy Metal Analysis of Ground Water and Leachate Samples

Heavy Metal	GW 1 SAMPLE				LEACHATE SAMPLE	
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2
Pb (mg/L)	>0.001	>0.001	>0.001	>0.001	0.187	0.071
Fe (mg/L)	0.187	0.182	0.098	0.091	4.581	6.248
Cu (mg/L)	0.071	0.083	0.051	0.063	0.149	0.156