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Analysis Of Leachate From The Municipal Solid Waste Disposal Site And Its Impact On Groundwater Quality At Lucknow

Shivanshi Verma
Institute of Engineering &Technology, Lucknow

Abstract- This study evaluates leachate quality from a municipal solid waste disposal site in Lucknow and examines its impact on nearby groundwater. The analytical framework, sampling design and index-based interpretation were prepared in line with the uploaded thesis and sample journal paper, while the numerical results were derived from the uploaded laboratory workbook. One leachate sample and seven groundwater samples were assessed for physicochemical and heavy metal parameters using APHA-based methods. The leachate showed acidic to near-neutral reaction (pH 6.1), very high electrical conductivity (83,892 µS/cm), total dissolved solids (38,180 mg/L), chemical oxygen demand (16,800 mg/L), biochemical oxygen demand (2,000 mg/L), hardness (1,620 mg/L), chloride (980 mg/L), sulphate (678.5 mg/L), nitrate (103.44 mg/L), fluoride (8.8 mg/L) and substantial heavy metal burden, indicating strong contaminant potential. The Leachate Pollution Index was 25, confirming significant pollution load. Groundwater quality varied spatially: Sample-7 recorded a WQI of 75.13 and fell in the good category, whereas Samples 2–4 were poor and Samples 1, 5 and 6 were very poor. Elevated TDS, alkalinity, hardness, iron, manganese, nickel, copper and zinc were the major causes of groundwater deterioration. The data indicate that leachate migration has affected groundwater quality in the vicinity of the disposal site, although the effect is not controlled by distance alone. The study recommends leachate containment, regular groundwater surveillance, and priority treatment for metal and salinity-related contamination.

Keywords: leachate, municipal solid waste, groundwater contamination, water quality index, leachate pollution index, Lucknow.

I. INTRODUCTION

Municipal solid waste (MSW) disposal sites represent one of the most important point sources of urban environmental contamination, particularly in rapidly expanding cities where waste generation increases faster than the development of engineered treatment and disposal infrastructure. Mixed municipal refuse contains biodegradable matter, plastics, ash, metals, construction debris and other heterogeneous components; after deposition, rainfall infiltration and biochemical decomposition convert this mixed waste into leachate, a dark and chemically complex liquid enriched with dissolved solids, organic matter, nutrients, salts and trace metals (Mor et al., 2006). In India, the pressure on urban solid waste systems has increased because of population growth, changing consumption patterns and the limited availability of properly designed landfill facilities (Pappu et al., 2007; CPHEEO, 2016). When disposal sites are unlined, poorly compacted or inadequately drained, leachate can move downward through the vadose zone and laterally through permeable soil layers, thereby creating a continuous risk for shallow aquifers and nearby drinking-water sources (Fatta et al., 1999; Singh et al., 2016).

Groundwater contamination from MSW disposal is a matter of public-health concern because groundwater is widely used for domestic, agricultural and small-scale commercial purposes. Unlike surface-water pollution, subsurface contamination is usually not visible, spreads slowly and may remain undetected until water quality has already deteriorated. Landfill leachate commonly raises electrical conductivity, total dissolved solids, hardness, chloride, sulphate and nitrate, while organic decomposition contributes to high biochemical oxygen demand and chemical oxygen demand (Esakku et al., 2007). Heavy metals such as iron, manganese, nickel, chromium, copper, zinc, cadmium and lead are also important because they may persist in the subsurface environment and may create long-term ecological and health risks if their concentrations exceed acceptable limits (Biswas et al., 2010; WHO, 2022). Therefore, regular monitoring of physicochemical parameters and metals around disposal sites is essential for identifying contamination pathways and protecting vulnerable communities (BIS, 2012; APHA, 2017).

Lucknow, the capital city of Uttar Pradesh, has experienced rapid urban expansion, rising population density and increasing pressure on waste-handling systems and groundwater resources. The district is located within an alluvial setting where the presence of sand, silt and clay layers can influence infiltration, adsorption, attenuation and lateral transport of contaminants. The humid subtropical climate and seasonal rainfall further increase the possibility of leachate generation, especially during and after monsoon periods. In such hydrogeological conditions, the impact of a municipal disposal site cannot be assessed only by observing distance from the dumpsite, because groundwater quality may also depend on slope, drainage, soil permeability, aquifer depth, direction of groundwater flow and local pumping patterns. Similar Indian studies have shown that landfill-affected groundwater quality may vary spatially, with some nearby locations showing high contamination and some distant locations showing deterioration because of subsurface flow and site-specific hydrogeological controls (Mishra et al., 2018; Choudhury et al., 2021).

For landfill-impact studies, simple comparison of individual parameters is useful but not sufficient, because a large number of chemical variables must be interpreted together. Index-based approaches provide a compact and systematic way to express pollution strength and water suitability. The Leachate Pollution Index (LPI) is used to represent the overall contamination potential of landfill leachate by combining selected pollutant variables into a single score (Kumar and Alappat, 2005). Similarly, the Water Quality Index (WQI) converts multiple water-quality observations into a single interpretive value that can be classified into categories such as good, poor or very poor, making the findings easier to communicate to planners, engineers and local users (Tyagi et al., 2013). These indices do not replace detailed parameter-wise analysis; rather, they support interpretation by showing whether the overall condition of leachate and groundwater indicates low, moderate or serious pollution pressure.

The present study was undertaken to analyze leachate from a municipal solid waste disposal site in Lucknow and to assess its possible impact on nearby groundwater quality. The investigation focuses on physicochemical characteristics, nutrient and organic pollution indicators and selected heavy metals in one leachate sample and seven groundwater samples collected around the disposal site. The study also applies LPI and WQI to interpret pollution intensity and groundwater suitability in an integrated manner. By comparing leachate quality with groundwater quality and by examining spatial variation among sampling locations, the study aims to identify whether the disposal site is acting as a significant source of groundwater deterioration. The findings are expected to support improved leachate containment, systematic groundwater surveillance, safer drinking-water management and more effective implementation of municipal solid waste management practices in urban Lucknow and future urban environmental planning decisions (Government of India, 2016; CPCB, 2008).

Objectives of Study

- To evaluate physico-chemical parameters of groundwater and leachate.
- To determine variation in contamination levels.
- To assess the impact of MSW leachate on groundwater quality near the dumpsite.

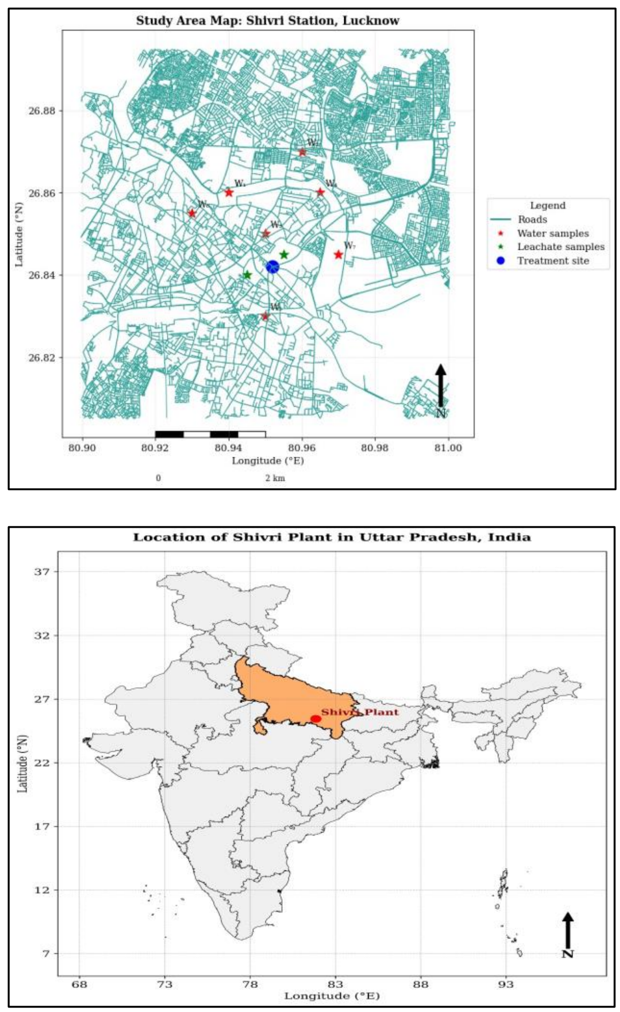

Figure 1. Study Area Map

II. MATERIALS AND METHODS

2.1 Study area and sampling design

The the study within Lucknow district, Uttar Pradesh, and maps eleven bore-well locations around the disposal site. The leachate sample and seven groundwater samples that were used for final interpretation in this paper. According to the thesis sampling table, the groundwater points represented approximate radial distances of <1 km, 3 km, 5 km, 7 km, 11 km, 6 km and 8 km from the disposal site.

Table 1. Groundwater sampling points used in the analytical workbook

Sample	Approx. distance	WQI	Classification
Sample-1	<1 km	265.45	Very poor
Sample-2	Near 3 km	181.26	Poor
Sample-3	Near 5 km	153.81	Poor
Sample-4	Near 7 km	166.95	Poor
Sample-5	Near 11 km	206.41	Very poor
Sample-6	Near 6 km	202.39	Very poor
Sample-7	Near 8 km	75.13	Good

2.2 Laboratory analysis

The composite sampling for groundwater quality assessment and spot sampling for leachate, with sample preservation by nitric acid acidification below pH 2 for metal analysis. The workbook reports APHA-based methods for pH, conductivity, TDS, alkalinity, hardness, calcium, magnesium, chloride, sulphate, nitrate, TKN, ammoniacal nitrogen, phosphate, fluoride, COD and BOD, and ICP-MS-based methods for chromium, manganese, iron, cobalt, nickel, copper, zinc, silver, cadmium and lead.

2.3 Index calculation

Interpretation followed the Leachate Pollution Index (LPI) concept described in the uploaded thesis and the Water Quality Index (WQI) approach summarized in the uploaded sample paper. The workbook directly reports an LPI of 25 for the leachate and WQI values for all groundwater samples, enabling comparative classification of groundwater quality.

III. RESULTS AND DISCUSSION

3.1 Leachate characteristics

The leachate exhibited severe contamination. Its conductivity (83,892 µS/cm) and TDS (38,180 mg/L) indicate extreme mineralization and dissolved salt load. Organic pollution was also pronounced, with COD of 16,800 mg/L and BOD of 2,000 mg/L. Alkalinity (1,280 mg/L), hardness (1,620 mg/L), chloride (980 mg/L), sulphate (678.5 mg/L), nitrate (103.44 mg/L) and fluoride (8.8 mg/L) were all elevated, showing that the leachate contains a mixed burden of salinity, nutrient enrichment and inorganic contaminants. Heavy metals were substantial: chromium 8.75 mg/L, manganese 14.5 mg/L, iron 90.76 mg/L, nickel 1.23 mg/L, copper 3.65 mg/L, zinc 54.5 mg/L, cadmium 0.87 mg/L and lead 0.564 mg/L. Taken together, these values justify the reported LPI of 25 and classify the disposal site as a meaningful source of contaminant pressure.

Table 2. Selected leachate characteristics from the uploaded analytical workbook

Parameter	Leachate value	Relevant standard / note
pH	6.1	Drinking water desirable range 6.5–8.5
Conductivity	83,892 µS/cm	No drinking standard shown in workbook
TDS	38,180 mg/L	Desirable 500 mg/L
Hardness	1,620 mg/L	Desirable 200 mg/L; permissible 600 mg/L
Chloride	980 mg/L	Desirable 250 mg/L; permissible 1,000 mg/L
Sulphate	678.5 mg/L	Desirable 200 mg/L; permissible 400 mg/L
Nitrate	103.44 mg/L	Desirable 45 mg/L
Fluoride	8.8 mg/L	Desirable 1.0 mg/L; permissible 1.5 mg/L
LPI	25	Index reported in workbook

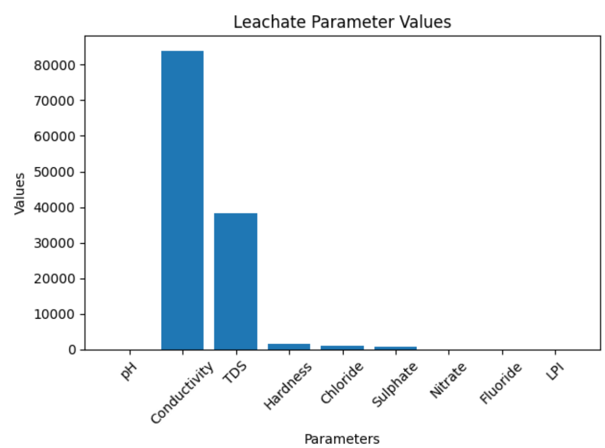

Table 3. Large Comparative Table

S. No.	Parameter	Unit	Leachate	Groundwater summary (S1–S7)	BIS limit	Groundwater status	Interpretation
1	pH	-	6.10	7.50 (7.11–7.78)	6.5–8.5	Within limit	Leachate was slightly acidic, whereas groundwater remained within the acceptable pH range.
2	Conductivity	µS/cm	83,892	1,046.43 (908–1280)	Not specified	Comparative only	Extremely high conductivity of leachate indicates very high dissolved ionic load.
3	TDS	mg/L	38,180	702.71 (478.5–988)	2000	Within limit	Leachate showed an enormous dissolved solids burden; groundwater values were much lower and within BIS permissible limits.
4	Alkalinity	mg/L	1,280	313.71 (208–488)	600	Within limit	Leachate exhibited high alkalinity, while groundwater remained below the permissible limit.
5	Total hardness	mg/L	1,620	368.57 (244–592)	600	Within limit	Leachate was highly mineralized; groundwater hardness remained acceptable though moderately elevated in some samples.
6	Calcium	mg/L	320	83.09 (44.88–172.48)	200	Within limit	Calcium concentration was much higher in leachate than in groundwater.
7	Magnesium	mg/L	199.26	40.45 (32.03–57.27)	100	Within limit	Magnesium was elevated in leachate but stayed within acceptable range in groundwater.
8	Chloride	mg/L	980	74.57 (28–158)	1000	Within limit	Chloride level was very high in leachate, indicating strong landfill influence, but groundwater remained within limit.
9	Sulphate	mg/L	678.50	71.44 (28.98–136.5)	400	Within limit	Sulphate concentration was high in leachate, while groundwater samples were below the permissible level.

S. No.	Parameter	Unit	Leachate	Groundwater summary (S1–S7)	BIS limit	Groundwater status	Interpretation
10	Nitrate	mg/L	103.44	12.28 (2.931–18.5)	45	Within limit	Nitrate was elevated in leachate but remained within BIS limit in groundwater.
11	Total Kjeldahl Nitrogen (TKN)	mg/L	165.50	<1.0 in all samples	Not specified	Comparative only	High TKN in leachate reflects strong organic nitrogen pollution; groundwater showed negligible content.
12	Ammoniacal nitrogen	mg/L	15.50	<0.05 in all samples	Not specified	Comparative only	Ammoniacal nitrogen was present in leachate but almost absent in groundwater.
13	Phosphate	mg/L	15.50	<0.05 in all samples	Not specified	Comparative only	Phosphate load was high in leachate, while groundwater concentrations were negligible.
14	Fluoride	mg/L	8.80	0.73 (0.54–0.89)	1.5	Within limit	Leachate contained very high fluoride, but groundwater remained well within the permissible limit.
15	COD	mg/L	16,800	<1.0 in all samples	Not specified	Comparative only	Leachate had an extremely high chemical pollution load, whereas groundwater showed no appreciable COD burden.
16	BOD	mg/L	2,000	<1.0 in all samples	Not specified	Comparative only	Biodegradable organic matter was very high in leachate and negligible in groundwater.
17	Chromium	mg/L	8.75	0.0107 (0.001566–0.05)	0.05	Within limit	Chromium concentration in leachate was high; groundwater remained at or below the allowable level.
18	Manganese	mg/L	14.50	0.881 (0.23–1.87)	0.3	Exceeded in 6/7 samples	Manganese contamination was significant in groundwater and indicates possible leachate migration.
19	Iron	mg/L	90.76	5.52 (2.11–8.56)	0.3	Exceeded in 7/7 samples	Iron was critically elevated in all groundwater samples, showing strong

S. No.	Parameter	Unit	Leachate	Groundwater summary (S1–S7)	BIS limit	Groundwater status	Interpretation
							deterioration in water quality.
20	Cobalt	mg/L	1.09	0.000132 (0–0.000348)	Not specified	Comparative only	Cobalt was high in leachate but detected only in trace amounts in groundwater.
21	Nickel	mg/L	1.23	0.0692 (0.009–0.21)	0.02	Exceeded in 5/7 samples	Nickel exceeded the acceptable limit in most groundwater samples, suggesting contaminant infiltration.
22	Copper	mg/L	3.65	0.551 (0.12–1.01)	1.5	Within permissible limit	Copper was elevated in leachate and higher than desirable levels in groundwater, but remained below the maximum permissible limit.
23	Zinc	mg/L	54.50	6.26 (0.987–17.87)	15	Exceeded in 1/7 samples	Zinc was very high in leachate and exceeded the permissible limit in one groundwater sample.
24	Silver	mg/L	2.34	0.000857 (0–0.004)	0.1	Within limit	Silver was high in leachate but remained within acceptable concentration in groundwater.
25	Cadmium	mg/L	0.87	0.000874 (0.000018–0.002)	0.003	Within limit	Cadmium was detected in leachate but groundwater values stayed within permissible levels.
26	Lead	mg/L	0.564	0.0106 (0.007098–0.018)	0.01	Exceeded in 2/7 samples	Lead contamination was observed in selected groundwater samples, indicating localized impact.

Table 4. Index Summary Table

Index	Sample	Value	Interpretation
Leachate Pollution Index (LPI)	Leachate	25.00	Indicates substantial pollution strength of leachate and strong contamination potential.
Water Quality Index (WQI)	Leachate	4184.21	Shows extremely poor quality of leachate.
Water Quality Index (WQI)	Sample-1	265.45	Most affected groundwater location among all samples.
Water Quality Index (WQI)	Sample-2	181.26	Marked deterioration in groundwater quality.

Water Quality Index (WQI)	Sample-3	153.81	Moderate to high groundwater impact.
Water Quality Index (WQI)	Sample-4	166.95	Moderate to high groundwater impact.
Water Quality Index (WQI)	Sample-5	206.41	Considerable groundwater deterioration.
Water Quality Index (WQI)	Sample-6	202.39	Considerable groundwater deterioration.
Water Quality Index (WQI)	Sample-7	75.13	Least affected groundwater sample among the seven.

1. Physico-chemical characteristics

The analysis clearly shows that the leachate was highly concentrated and chemically loaded. Parameters such as conductivity, TDS, alkalinity, hardness, calcium, magnesium, chloride, sulphate, and nitrate were far higher in leachate than in groundwater. This indicates that the landfill leachate possessed a strong contamination potential. In contrast, the groundwater samples showed comparatively moderate values for these parameters and, in most cases, remained within the BIS permissible limits. This suggests that the effect of leachate on general physico-chemical groundwater quality was present but not severe enough to push these parameters beyond drinking water standards.

2. Nutrient and organic pollution load

The leachate contained very high organic and nutrient pollution, as reflected by TKN, ammoniacal nitrogen, phosphate, COD, and BOD. Particularly, the COD and BOD values were extremely high, indicating both chemical and biodegradable organic contamination of the landfill leachate. However, these parameters were below detectable or negligible levels in all groundwater samples. This shows that while the landfill generated a heavily polluted leachate, the organic fraction had either been diluted, naturally attenuated, or had not migrated into groundwater in comparable concentrations.

3. Heavy metal contamination

The most important finding of the study is the clear heavy metal impact on groundwater. Iron exceeded the BIS limit in all seven groundwater samples, manganese exceeded in six samples, nickel in five samples, lead in two samples, and zinc in one sample. Although chromium, cadmium, silver, and copper did not exceed the maximum permissible limits, their presence further indicates the influence of landfill-derived contaminants. Thus, the groundwater around the disposal site appeared to be affected more strongly by metallic contamination than by routine physico-chemical parameters.

4. Overall impact on groundwater quality

The LPI value of 25.00 confirmed that the leachate was strongly polluting in nature. Similarly, the WQI values revealed a clear difference between leachate and groundwater, with the leachate showing an extremely poor quality score of 4184.21. Among groundwater samples, Sample-1 recorded the highest WQI value, indicating the maximum level of impact, whereas Sample-7 recorded the lowest WQI value and appeared comparatively less affected. This pattern suggests spatial variation in contamination, likely due to differences in distance, hydrogeological conditions, and direction of leachate movement.

5. Final inference

The municipal solid waste disposal site at Lucknow generates a highly polluted leachate, and this leachate has a measurable adverse effect on the nearby groundwater system. While most conventional water quality parameters in groundwater remained within BIS limits, the consistent elevation of heavy metals such as iron, manganese, nickel, and lead indicates a significant environmental risk. Therefore, the study supports the need for regular groundwater monitoring, improved landfill lining and leachate management systems, and timely remedial measures to prevent further groundwater degradation.

IV. CONCLUSION

The study confirms that the municipal solid waste disposal site in Lucknow is generating leachate with high pollution potential and that nearby groundwater has been adversely affected. The leachate shows extreme salinity, high organic load and significant heavy metal concentration, reflected by an LPI of 25. Groundwater quality is predominantly poor to very poor, with only one sample falling in the good category. Elevated TDS, hardness, iron, manganese and selected trace metals are the most important contributors to groundwater deterioration. The observed pattern indicates that contamination dispersal is spatially variable and controlled by local subsurface conditions as well as site proximity. Immediate priorities should include leachate containment, periodic testing of drinking-water wells, installation of a structured monitoring network and treatment or alternate supply for vulnerable households.

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