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Assessing the Influence of Bandhwari Landfills on Groundwater Quality using Pollution index of groundwater (PIG) and Leachate pollution index (LPI) in Gurugram, India

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Abstract: -
This study focuses on characterizing landfill leachate and assessing its impact on surrounding groundwater at the Bandhwari landfill site. Leachate samples collected from landfills show high levels of organics, nutrients, salts, and heavy metals, indicating a methanogenic phase at the landfill site. We collected fourteen groundwater samples and five leachate samples from different parts of the study area in June 2023. The physicochemical parameters of these samples showed big differences, with mercury, copper, lead, cadmium, chromium, iron, and zinc being the most common contaminants. The significant changes in groundwater quality indicate the influence of leachate. Comparison with World Health Organization (WHO) and Bureau of Indian Standards (BIS 10500:2012) guidelines highlights the inadequacy of most groundwater samples for potable use. These findings underscore the need for targeted policies and treatment programs to mitigate landfill leachate impacts and control groundwater pollution in the area.

Keywords: Groundwater quality, Landfill, Heavy metals, Leachate, Municipal solid waste

Introduction:

Landfill sites play a pivotal role in waste management, serving as repositories for the ever-increasing volumes of domestic and industrial waste generated by urban areas (Maalouf et al., 2023). However, their operation raises concerns about potential environmental hazards, particularly regarding groundwater pollution (Kumar et al., 2023). As waste decomposes within landfills, leachate, a complex mixture of organic and inorganic compounds, can seep into the surrounding environment, posing significant risks to soil, surface water, and groundwater quality (Ma et al., 2022). The composition of leachate varies widely, depending on the types of waste deposited and the biochemical processes occurring within the landfill. Industrial wastes, in particular, present a challenge due to their resistance to degradation, potentially persisting for extended periods and introducing harmful substances into the environment (Parvin et al., 2021). Consequently, understanding the chemical makeup of leachate and its impact on groundwater has become a subject of extensive research. Various studies have explored the constituents and behavior of landfill leachate, as well as its effects on adjacent surface and groundwater systems. Scholars have investigated various aspects, from analyzing leachate quality in different geographical contexts to assessing its intrusion into groundwater reservoirs (Gupta et al., 2023). These studies have highlighted the importance of considering leachate characteristics in landfill design and management practices.

In this manuscript, we focus on assessing the impact of the Bandhari landfill in Gurugram on groundwater quality. Utilizing a modified water quality index known as the Pollution Index of Groundwater (PIG) and Leachate Pollution Index (LPI), we evaluate the extent of leachate contamination and its variability in groundwater samples collected from surrounding areas. By integrating heavy metal analysis into the LPI and PIG calculations, we aim to comprehensively understand the landfill's influence on groundwater quality and contribute to effective environmental management strategies. This study aims to shed light on the complex dynamics between landfill operations and groundwater pollution, offering insights that can inform sustainable waste management practices and mitigate environmental risks associated with landfill activities.

Study Area

The study area focuses exclusively on the Bandhwari landfill site, situated in Bandhwari village along the Gurugram-Faridabad National Highway-48 in Northern India. Bandhwari village, with a population of approximately 3,624 residents residing in around 557 households, hosts this significant landfill. Established in 2009, the Bandhwari landfill serves as a primary dumping ground for municipal waste generated from the urban areas of Gurugram and Faridabad. Occupying a sprawling area of nearly 30 acres, the landfill stands at an imposing height of 37.2 meters. The site's geographical location is of particular concern, as it was built upon an old mining pit with a depth of 250 feet, placing it near groundwater aquifers. Moreover, the landfill site is perilously close to the last remaining area of the Aravalli forest, an ecologically sensitive region and a sacred grove for indigenous communities. Recent reports submitted to the National Green Tribunal (NGT) by the Municipal Corporation of Gurugram (MCG) indicate that the Bandhwari landfill receives an alarming quantity of approximately 1,800 tonnes of fresh municipal waste daily. Consequently, the quantity of untreated waste at the landfill has surged, reaching an estimated 40 lakh tonnes. The environmental ramifications of the Bandhwari landfill are multifaceted, with concerns ranging from groundwater contamination to biodiversity loss and the disruption of the fragile Aravalli range ecosystem. Given these pressing issues, a comprehensive understanding of the landfill's impact on the surrounding environment is imperative for effective environmental management and sustainable waste disposal practices.

Figure 1. Sample location point of the study area

Sampling and Analysis:

In June 2023, a total of fourteen groundwater samples were systematically collected from bore wells (hand pumps) within a 3 km^2 radius encompassing the Bandhwari municipal solid waste disposal site in Gurugram. Additionally, five leachate samples were collected directly from the Bandhwari landfill site. Groundwater samples were collected from selected bore wells and hand pumps situated near the surrounding area of the landfill site (figure 1). Before collection, the hand pumps were flushed for 5-10 minutes to ensure representative sampling (Alam et al., 2023). These samples, crucially used for drinking and domestic purposes, were preserved at 4°C to prevent significant chemical alterations until analysis (Alam et al., 2023). The examination of groundwater samples followed the standard methodology specified by the American Public Health Association (APHA 2017). The quantification of heavy metals in both leachate and groundwater samples required the treatment of 50 ml samples with 10 ml concentrated HNO_3 at 80°C until the solution became transparent. Afterward, the solution underwent filtration using a 0.45µm Millipore filter paper and was then diluted to a volume of 50 ml using double distilled water.

To analyse the main cations and anions, vacuum filtering equipment was used using 0.45µm Millipore filter paper to exclude any suspended sediments from the samples (Alam et al., 2023). The pH and EC values were measured on-site using a digital pH metre and EC metre, respectively (Alam et al., 2022). Concentrations of Ca^{2+}, $Mg^{2+,}$ and hardness were determined via the EDTA titrimetric method, while Na^+ and K^+ content were measured using a flame photometer. Cl^- was estimated through $AgNO_3$ titration, while HCO_3-, was assessed via the electrometric titration method. Further, SO_4^2, and NO_3-, were determined using a UV-visible spectrophotometer (Alam et al., 2024). These comprehensive sampling and analytical procedures were employed to evaluate the quality of groundwater and leachate, providing insights into potential environmental impacts associated with the Bandhwari landfill site in Gurugram. The measurement of several heavy metals in water was performed using the atomic absorption spectrophotometer technique (Marcovecchio et al.,2007) (specifically, the Thermo Scientific AAS). To guarantee the quality of the results, we constantly used double distilled water during the study. Additionally, we included measures such as blank and duplicate samples. The reproducibility of analytical data was maintained within a 5% margin of error, with analytical precision estimated to be less than 10%.

Pollution index of groundwater (PIG)

The pollution index of groundwater is a numerical scale that measures the degree of contamination. The total water quality of the aquifer is influenced by a combination of distinct water quality indicators. The proposal was first made by (Subba Rao, 2012), and since then it has been extensively utilized to evaluate the fluctuation in groundwater quality resulting from different geochemical causes (Rao et al., 2018; Subba Rao, 2012). The computation of the PIG involves five phases. The initial stage involves assigning the relative weight (R_w) to each chemical characteristic. Typically, the R_w value ranges from 1 to 5, based on its proportionate influence on human health. The heavy metals, Cl^-, and SO_4^{2-}, were awarded the highest weight of 5, while K^+ and HCO_3^-. were given the lowest weight of 1. During the second stage, the weight parameter (W_p) is computed for each chemical parameter to assess its proportionate contribution to the total groundwater quality. The value of W_p is calculated using the following equation:

$$W_p = \frac{R_w}{\sum R_w}$$

In the third step, the concentration status (SC) is determined using the equation:

$$SC = \frac{C_i^n}{DWQS_i^n}$$

The symbol (C) denotes the concentration of the chemical parameter (n), whereas (DWQS) indicates the drinking water quality standard for the nth parameter.

In the fourth stage, the computation of the overall groundwater quality (OW) involves multiplying the weight parameter (W_p) by SC, as shown in Equation.

$$OW = W_p * SC$$

Finally, the Pollution Index of Groundwater (PIG) is calculated by summing up the OW values for all parameters, as shown in Eq.:

$$PIG = \sum_i^n OW$$

Leachate pollution index (LPI)

The Leachate Pollution Index (LPI) has several functions, such as evaluating the ranking of landfills, directing the allocation of resources for waste rehabilitation, analysing patterns, enforcing rules, performing scientific research, and providing information to the public (Mukherjee e al., 2015). The landfill's leachate pollution potential is measured by giving a numerical grade between 5 and 100, which is based on several leachate pollution factors at a certain moment (Singh et al., 2016). The trend analysis obtained from the LPI can assist in determining the duration of post-closure monitoring periods for the landfill. The Rand Corporation Delphi Technique is employed to determine the Leachate Polluting Index, which quantifies the total polluting potential of landfill leachate (Kumar and Alappat, 2005). Changes in leachate pollution within a landfill over time are tracked, with higher LPI numbers indicating poorer environmental conditions. This index can signal whether immediate remedial actions are necessary for a landfill, facilitating timely interventions.

Calculate the Leachate Pollution Index (LPI) according to the procedure outlined by Kumar and Alappat (2005a). Therefore, we've used a modified equation with the addition of eight heavy metals to calculate the LPI,

The modified equation for calculating the LPI is:

$$LPI = \frac{\sum_{i=1}^{m} w_i p_i}{\sum_{i=1}^{m} w_i}$$

Where:

LPI = Leachate Pollution Index

w_i = represents the weight assigned to the ith pollutant variable.

p_i = represents the sub-index score of the ith leachate pollutant.

m = represents the total number of leachate pollutant variables that are utilised in the calculation of the Leachate Pollution Index (LPI).

This equation essentially calculates a weighted average of the sub-index scores for each pollutant variable, with the weights being determined by the importance or significance of each pollutant in contributing to the overall leachate pollution.

Table 1. Standards limits of measured parameters as per standard agencies.

		Standards Drinking water quality standards	
Parameters	Leachate discharge MoEFCC standard	BIS standards (BIS 10200: 2012)	WHO standards
pH	5.5 – 9	6.5 – 8.5	6.5 – 8.5
TDS	2100	500	500
Ca^{2+}	-	75	75
Mg^{2+}	-	30	50
Cl^{-}	1000	250	250
HCO_3^-	-	250	-
SO_4^{2-}	-	200	200
Fe	-	0.3	-
Pb	0.1	0.01	0.01
Zn	5	5	-
NI	3	0.02	0.07
cu	3	0.05	2
Cr	2	0.05	0.05
Cd	2	0.003	0.003
Hg	0.01	0.001	0.006

All parameters are in mg/l except pH, EC (µS/cm) at 25◦C

Results and discussion

Physicochemical and Heavy metal analysis of Groundwater samples

The pH values of the groundwater samples varied from 6.7 to 7.6, showing a minor level of acidity to alkalinity. All of these values were within the acceptable range established by the Bureau of Indian Standards (BIS 2012), which is 6.5–8.5. Nevertheless, the electrical conductivity (EC) of these samples varied between 1.15 and 5.25 mS/cm, above the BIS threshold of 2.5 mS/cm. The sample site S1, located near the Bandhwari dump site, had the highest EC (Electrical Conductivity) value. It was closely followed by sampling site S9 and S10. The elevated EC levels at both sites can be attributed to the percolation of leachate. Similarly, the Total Dissolved Solids (TDS) in the samples varied from 229 to 1640 mg/L. Approximately 67% of the samples exceeded the BIS limit of 500 mg/L, making the water unsuitable for drinking owing to the risk of gastrointestinal discomfort. The reported Total Alkalinity (TA) levels ranged from 208 to 576 mg/L, all of which above the BIS limit of 200 mg/L. The Total Hardness (TH) readings varied between 186 and 1,220 mg/L, exceeding the BIS threshold of 200 mg/L, suggesting the presence of water with a high level of hardness. The calcium (Ca^{2+}) levels varied between 49.64 and 179.41 mg/L, with more than 70% of the samples over the BIS threshold of 75 mg/L. This poses health hazards, including the formation of kidney stones. The concentration of magnesium ions (Mg^{2+}) varied between 10.65 and 84.6 mg/L in the samples. Out of the 14 samples, 12 had levels of magnesium surpassing the BIS limit of 30 mg/L. This high quantity of magnesium has the potential to cause diarrhoea. The sodium (Na) and potassium (K) levels were within the permissible range. The quantities of chloride ions (Cl-) varied from 33 to 202.00 mg/L, with the majority of samples falling below the BIS limit of 250 mg/L, save for a single sample located next to the landfill. The amounts of sulphate (SO_4^{2-}) were predominantly below the BIS limit of 200 mg/L, except two samples. The samples in closest proximity to the landfill exhibited the most significant impact from leachate, but other impacted samples might be influenced by a range of human activities. Table 1 contains precise measurements and comparisons based on the criteria outlined in BIS (2012) and WHO (2017).

Table 1 also provides an overview of the fluctuations in the levels of eight different heavy metals found in groundwater samples. The concentrations of various metals in groundwater samples show changes. The concentration of iron (Fe) ranges from 0.25 to 0.87, lead (Pb) ranges from 0.26 to 0.64, zinc (Zn) ranges from 0 to 4.42, nickel (Ni) ranges from 0.23 to 0.49, copper (Cu) ranges from 0.21 to 0.37, chromium (Cr) ranges from 0 to 0.64, cadmium (Cd) ranges from 0.52 to 1.20, and mercury (Hg) ranges from 0.01 to 0.34. The current study demonstrates reduced metal contents in comparison to previous studies conducted by (Srivastava and Ramanathan 2008). The difference in results may be due to a change in the pH level of the leachate, shifting from being close to neutral to being strongly alkaline. This change causes metals to become immobilised by sorption and precipitation processes, as suggested by (Kjeldsen et al. 2002). There is a lack of documented natural sources of heavy metals in the research region. Metals like iron, chromium, zinc, copper, nickel, cobalt, lead, and cadmium are commonly found in the leachate. These metals are likely coming from various sources such as plastics, batteries, leather, paint products, metallic items, fluorescent lamps, wood preservatives, metal scrap, and steel industrial waste in the nearby area (Singh et al., 2016). Typically, these wastes are directly disposed of at the solid waste disposal site without any treatment or separation of elements beforehand.

Table 1. Descriptive statics of Groundwater samples

	Mean	Standard Deviation	Skewness	Minimum	Maximum
pH	7.20	0.27	-0.22	6.70	7.60
EC	2.65	1.17	0.98	1.15	5.25
TDS	979.15	517.08	-0.24	229.00	1640.00
TH	563.54	375.44	0.63	186.00	1220.00
TA	389.00	117.22	0.22	208.00	576.00
Ca^{2+}	94.78	46.04	0.65	49.64	179.41
Mg^{2+}	44.09	23.65	0.24	10.65	84.60
Na	59.46	33.35	1.20	19.00	141.00
K	3.51	2.14	1.43	1.50	8.40
SO_4^{2-}	52.71	68.47	3.21	15.30	273.00
Cl^-	71.39	45.17	2.26	33.00	202.00
Fe	0.45	0.20	1.48	0.25	0.87
Pb	0.33	0.78	2.67	0.26	0.64
Zn	0.69	1.11	2.98	0.00	4.42
NI	0.33	0.54	2.67	0.23	0.49
Cu	0.28	0.78	3.26	0.21	0.37
Cr	0.04	0.09	2.25	0.00	0.64
Cd	1.04	0.21	-0.59	0.52	1.20
Hg	0.09	0.08	1.67	0.01	0.34

All parameters are in mg/l except pH, EC (mS/cm) at 25◦C

Physicochemical and Heavy metal analysis of Leachate samples

The properties of leachate samples obtained from the Bandhwari dump site are determined by the nature of municipal solid waste (MSW) and the amount of moisture it contains. The data analysis displayed in Table 2. The samples demonstrate heightened amounts of many chemical markers. The pH values of the leachate samples vary between 7.80 and 8.50. Landfills generally have alkaline pH values around ten years following trash dumping. The presence of dissolved inorganic elements is indicated by a high electrical conductivity range of 17567-22500 μ mho/cm. Additionally, the concentrations of total dissolved solids (TDS) vary from 12465-14500mg/l. The levels of inorganic pollutants often decrease as leachate ages and becomes more stable, which is consistent with the pattern reported in leachates from recently formed acidogenic landfills. The presence of Calcium and Magnesium is linked to the dumping of building waste alongside Municipal Solid Waste (MSW), with concentrations ranging from 55 to 460 mg/l and 165 to 685 mg/l, respectively. The amounts of calcium and magnesium drop over time as a result of biological activity, a rise in pH, and subsequent precipitation. The concentrations of chloride exhibit significant variations, and human activities probably contribute to these variations, particularly through the disposal of kitchen waste from residences, restaurants, and hotels. The range of values is between 3033 and 5675 mg/L. The bicarbonate levels vary from 5139 to 7765 mg/L, indicating a high level of organic strength, with the bulk of it being biodegradable. The presence of iron (0.95-1.62 mg/L) indicates that steel scrap has been disposed of in the landfill. The dark brown hue of leachate is caused by the oxidation of ferrous compounds and the production of colloidal ferric hydroxide. The solubilization of trace metals such as Cd, Cu, Fe, Ni, Pb, and Zn is increased in leachate due to the lower pH resulting from the generation of organic acids. As the age of a landfill increases, the pH level increases, which results in a decrease in the solubility of metals. The presence of zinc (1.59-4.18 mg/L) suggests the input of waste from batteries and fluorescent bulbs, whereas lead concentrations (0.54-3.55 mg/L) imply sources such as batteries, photographic chemicals, outdated lead-based paints, and lead pipes, which pose hazards of poisoning. Refuse in acidic leachate conditions promotes the release of lead. Cadmium and copper are both found in the sample. The presence of high amounts of cadmium (ranging from 0.01 to 1.45 mg/L) and copper (ranging from 0.17 to 3.22 mg/L) indicates a significant reduction in the environment. The prevalence of Fe, Pb, Zn, Ni, Cu, Cr, Cd, and Hg in the leachate at the Bandhwari dump site is likely due to the various types of garbage there. When comparing the levels of leachate concentrations for various criteria with established standards, it is evident that the concentrations of all parameters exceeded the allowable limits.

Table 2. Descriptive statics of leachate samples

	Mean	Standard Deviation	Skewness	Minimum	Maximum
pH	8.18	0.26	-0.50	7.80	8.50
EC	19472.00	1892.31	1.17	17567.00	22500.00
TDS	13320.20	752.14	0.95	12465.00	14500.00
Ca^{2+}	271.00	161.37	-0.20	55.00	460.00
Mg^{2+}	404.20	186.62	0.53	165.00	685.00
Na	775.52	512.58	1.53	282.60	1632.00
K	421.84	199.12	0.93	186.73	735.45
Cl	4314.20	981.24	0.21	3033.00	5675.00
HCO_3^-	6290.00	967.78	0.73	5139.00	7765.00
SO_4^{2-}	371.93	35.74	-0.55	323.40	410.00
Fe	1.35	0.27	-0.80	0.95	1.62
Pb	0.59	0.04	0.04	0.54	3.55
Zn	2.76	1.09	0.85	1.59	4.18
Ni	0.33	0.11	0.84	0.20	2.41
Cu	0.27	0.08	-0.19	0.17	3.22
Cr	0.38	0.19	-0.12	0.10	0.25
Cd	0.43	0.53	0.96	0.01	1.45
Hg	0.50	0.37	0.93	0.15	1.06

All parameters are in mg/l except pH, EC (µS/cm) at 25◦C

Pollution Index of Groundwater (PIG)

PIG has proven to be a valuable tool for assessing groundwater quality, and it has been widely adopted by researchers (Subba Rao, 2012; Subba Rao and Chaudhary, 2019). When the concentrations of water quality measures in a particular groundwater sample match those of potable water, the Pollution Index of Groundwater (PIG) is computed as 1.0. Thus, a PIG value less than 1.0 indicates insignificant pollution, while a value exceeding 1.0 suggests additional concentrations of water quality measures resulting from the introduction of foreign matter into an aquifer, indicating pollution. Here are the classifications based on PIG values: PIG < 1.0 signifies insignificant pollution; 1.0 < PIG < 1.5 indicates low pollution; 1.5 < PIG < 2.0 suggests moderate pollution; 2.0 < PIG < 2.5 implies high pollution, and PIG > 2.5 denotes very high pollution. This system enables the categorization of water quality based on pollution intensity, providing a framework for assessing environmental conditions. So, the classification of PIG results for 14 groundwater samples from the study area ranges from 1.15 to 4.32.

According to the PIG classification, 0% of the collected groundwater samples are categorized as having insignificant pollution levels, while 36%, 21%, 28%, and 15% fall into the low, moderate, high, and very high pollution zones, respectively.

Leachate Pollution Index (LPI)

The Leachate Pollution Index (LPI) has several functions, such as evaluating the ranking of landfills, directing the allocation of resources for waste rehabilitation, analysing trends, enforcing standards, enabling scientific study, and giving public information. The landfill's leachate pollution potential is assessed by awarding a numerical grade between 5 and 100, which is determined by evaluating several leachate pollution factors at a certain moment. An examination of the patterns in data collected from a landfill can assist in determining the necessary duration for monitoring activities after the dump has been closed. The Rand Corporation Delphi Technique is utilised to quantify the comprehensive contamination potential of landfill leachate, as outlined by Kumar and Alappat in 2005. The conducted research found that the LPI measures above 30. It is worth mentioning that according to Kumar and Alappat (2005a), an LPI surpassing 35 indicates a below-average environmental condition. Recorded levels of LPI were elevated, with measurements of 33.7 in landfill site sample L1, 33.2 in leachate sample L2, 31.45 in leachate sample L3, 30.85 in sample L4, and 32.38 in sample L5. Furthermore, the LPI value of the Varanasi landfill leachate (23.56) was found to be lower compared to the LPI value of the current investigation conducted by Singh et al. in 2016. Due to the elevated LPI readings, urgent action is necessary at the Bandhwari dump sites to minimise or avert substantial contamination risks. The LPI value is influenced by variations in individual quality factors, which makes it a dependable instrument for reporting variances in landfill leachate quality that are particular to seasons and sites.

Conclusion

The evaluation of groundwater quality in the Bandhwari dump site region indicated that the groundwater in the study area had certain physicochemical properties at levels that beyond the thresholds established by the World Health Organisation. All integrated waste management systems universally acknowledge the indiscriminate disposal and unrefined dumping of municipal solid waste (MSW) as hazardous practices. Initial evaluations of solid waste composition indicate that samples obtained from the open dump site mostly consist of leachate samples that demonstrate notably increased concentrations of chemical parameters. The analysis of heavy metal concentrations in the collected leachate samples reveals a greater extent of metal dissolution in comparison to the groundwater samples. The elements are arranged in the following order based on their average values: Zn > Pb > Cu > Ni > Cd > Hg > Cr. Although several metrics of groundwater samples fall within the permitted ranges defined by the Bureau of Indian Standards (BIS), the physicochemical analysis of a few groundwater samples is still causing concerns. The pH levels, electrical conductivity (EC), total dissolved solids (TDS), hardness, chloride, and sulphate concentrations in all sample locations exceed the allowed limits, surpassing the values of other parameters. High concentrations of heavy metals (Pb, Cu, Cd, Ni, Hg, and Zn) in groundwater samples indicate substantial pollution from the movement of leachate from the open dumping site. Based on their average concentrations, the heavy metal components in groundwater samples rank in the following order: Zinc (Zn) > Cadmium (Cd) > Chromium (Cr) > Lead (Pb) > Nickel (Ni) > Copper (Cu) > Mercury (Hg). The findings suggest that the groundwater is not suitable for drinking because it exceeds acceptable thresholds for both physicochemical properties and heavy metal levels. The Bandhwari dump site poses a significant and grave danger to local aquifers. The results of the study, which include the composition of solid waste, the characteristics of leachate, and the analysis of groundwater samples, will be used to create a contaminant transport model. This model will be developed using Visual MODFLOW and MT3DMS software to evaluate the movement of leachate from the open dumping site into the underground system. This work offers significant insights for future research that focuses on the analysis of metal concentrations and groundwater characteristics near the Bandhwari dump site.

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