

Original Research Paper

Assessment of Groundwater Quality Due to Leachate Contamination at Municipal Dumpsite, Mandya

Madhusudhan, M. S.[†], Chowdegowda, H. C. and Varshitha, M. S.

Department of Civil Engineering, PES College of Engineering, Mandya, Karnataka, India

[†]Corresponding author: Madhusudhan M. S.; madhusudhanms@pesce.ac.in

0000-0001-8135-3646

Key Words	Heavy metals, Leachate, Water quality index, Leachate pollution index, GIS map
DOI	https://doi.org/10.46488/NEPT.2026.v25i02.B4366 (DOI will be active only after the final publication of the paper)
Citation for the Paper	Madhusudhan, M. S., Chowdegowda, H. C. and Varshitha, M. S., 2026. Assessment of groundwater quality due to leachate contamination at municipal dumpsite, Mandya. <i>Nature Environment and Pollution Technology</i> , 25(2), B4366. https://doi.org/10.46488/NEPT.2026.v25i02.B4366

ABSTRACT

Leachate production from the open disposal of municipal solid waste increases the risk of groundwater pollution. This paper attempts to evaluate the pollution potential of leachate from a solid waste disposal site and its impact on aquifers in the Mandya region of Karnataka, India. Due to the unplanned deposition of municipal solid waste (MSW), leachate accumulated within the waste mass and subsequently flowed into nearby water bodies such as open wells and ponds. The physico-chemical parameters and heavy metal tests were conducted on leachate and groundwater samples to assess their quality against drinking water standards (IS: 10500 – 2012). Based on the test results, the Leachate Pollution Index (LPI) and Water Quality Index (WQI) were calculated. The LPI value indicates that the leachate from the landfill site is moderately contaminated. The WQI showed that groundwater quality in the area ranges from good to poor, very poor, and in some cases, unsuitable for drinking. Hierarchical Cluster Analysis (HCA) was used to categorize groundwater samples into high, moderate, and low groups based on their Total Dissolved Solids (TDS) levels, helping to identify trends in water quality and possible pollution sources. The findings were visualized using Geographic Information System (GIS) software to enhance public understanding and support the implementation of preventive measures against potential environmental risks.

INTRODUCTION

Water is considered the most important non-renewable natural resource on Earth and is necessary for life. It is essential for numerous daily activities, including cooking, cleaning, drinking, and washing. We cannot survive without water, just as we cannot live without air. Along with ice, it can be found in seas, oceans, and

other bodies of water. With a high vulnerability rating and insufficient data, the groundwater system is a hidden natural resource (Nandi et al., 2024). As a result, the difficulties in managing the quality of groundwater resources are unpredictable, making it difficult for stakeholders, decision-makers, and individuals to appropriately connect with the environmental effects on groundwater systems. According to several estimates, the sharp rise in open dumping is to blame for half of the present trends in environmental degradation, including groundwater pollution (Alao et al., 2023; Velis et al., 2023). The relationship between waste management practices, groundwater pollution, and public health often provides valuable insights to support sustainability in MSW management and influence the adoption of sustainable environmental and public health policies (Dalmini et al., 2025).

India produces over 90 million tonnes of municipal solid waste (MSW) annually. Municipalities in metropolitan areas are in charge of gathering this garbage and delivering it to approved disposal locations (Mor et al., 2006). The common way to dispose of MSW in developing nations like India is through landfilling (Rathod et al., 2013; Mishra et al., 2016a). Leachate from these dumps, however, comprises a variety of chemical contaminants that are extremely dangerous for surface and groundwater resources (Christensen et al., 2001). Generally, MSW is disposed of carelessly in low-lying locations. Every element of the ecology is negatively impacted by this open disposal of solid garbage. Leachate is created when solid waste is disposed of in low-lying places because it may come into contact with surface runoff, groundwater, or rainwater (Akinbile et al. 2012). Pollution can stay hidden for years after it enters the subsurface ecosystem, making groundwater unfit for human consumption and other purposes (Nandimandalam, J. R. 2011; Singh et al. 2015b).

Leachate from municipal landfills is a highly concentrated and complex liquid that contains various pollutants, including heavy metals such as cadmium, chromium, copper, lead, nickel, and zinc. It also contains inorganic compounds like ammonium, calcium, magnesium, sodium, potassium, iron, sulphates, and chlorides, as well as organic contaminants such as ammonia, chemical oxygen demand (COD), biochemical oxygen demand (BOD), and additional forms of ammonia (Christensen et al., 2001; Jones et al., 2006; Ogundiran and Afolabi, 2008). The rate and composition of leachate generation are influenced by several factors, including the type and particle size of the solid waste, degree of compaction, site hydrology, landfill age, temperature, moisture content, and oxygen availability (Longe and Balogun, 2010).

The amount of leachate that forms in a landfill is greatly influenced by its age. Leachate produced in landfills during the first five years of garbage deposition has a pH range of 3.7 to 6.5, which indicates the presence of bicarbonate ions and carboxylic acids. Over time, the leachate's pH ranges from 7.0 to 7.6, becoming neutral or slightly alkaline. Long-term landfill exploitation results in alkaline leachate, which has a pH between 8.0 and 8.5 (Słomczyńska and Słomczyński 2004). However, significant leachate leakage can negatively impact aquatic species, plants, soils, groundwater, and human health due to poor landfill management (Mishra et al. 2016b; Talalaj and Biedka 2016). Unchecked landfill leachate has significant and wide-ranging effects on the ecosystem. Leachate can contaminate aquatic habitats, animals, and human health by leaking into surface and groundwater (Essien et al., 2022). In the majority of developing nations, there is increasing concern over the usage of

engineered barrier systems (EBS) in contemporary landfill sites to minimize contamination of soil, groundwater, and surface water.

Assessing groundwater quality requires examining potential pollution via diverse physicochemical analyses. These tests include measuring pH, total alkalinity, total hardness, total dissolved solids, and electrical conductivity. Additionally, testing for heavy metals like iron, calcium, magnesium, fluoride, chloride, nitrate, copper, lead, zinc, nickel, cadmium, chromium, aluminum, manganese, silver, barium, boron, and cobalt is crucial. This study intends to provide a thorough examination of the groundwater's features by comparing these results to set permissible limits. This will help identify any ions that above regulatory limitations, providing a clearer picture of the groundwater's quality.

The Water Quality Index (WQI) and Leachate Pollution Index (LPI) are powerful tools for conveying information about leachate contamination and groundwater quality. They serve as essential indicators for managing and accessing groundwater resources (Shubhra Singh et al. 2015). Efforts have been made to thoroughly examine the parameters in groundwater that help determine its quality and identify any ions that exceed permissible limits. This is done by comparing the findings with established standards using physicochemical parameters, heavy metal tests, WQI, LPI, and HCA.

2. STUDY AREA

The current study's testing of groundwater and leachate quality was restricted to Mandya City, the district's administrative hub, and is also known as "Sugar City" due to the widespread cultivation of sugarcane as the primary crop. The average elevation of Mandaya City is 678 meters (2224 feet) above sea level, and it is located between latitude 12°N and longitude 76°E. Mandya City Municipal Corporation is home to about 1,805,769 people and occupies 17.03 square km. Mandya city is situated in Mandya taluk, which is surrounded by Maddur to the east, Malavalli to the southeast, Srirangapatna to the southwest, and Pandavapura to the west.

Municipal solid waste from Mandya city is disposed of and processed at the Kalenahalli landfill site, located in Mandya district, Karnataka, India, at coordinates 12°29'03.1'' N latitude and 76°49'30.0'' E longitude, approximately 13 km from the city. The waste generated in Mandya City is 60 metric tonnes every day, of which 37% is organic or wet waste, 40% is dry or recyclable waste, and 23% is inert or refuse waste. The majority of the garbage produced, or roughly 59.3% of it, originates from ordinary families. About 29% of the garbage produced comes from small businesses and educational institutions, which are also significant suppliers of waste (HR, M.K. 2024). Hospitals are another source of non-recyclable and toxic trash, accounting for a minor percentage of the total waste produced.

In the present study, the groundwater samples were collected as one leachate sample and seven groundwater samples from the vicinity of the Kalenahalli dump from the existing bore wells. This was done to determine

Fig. 1: Location map of the sample collected

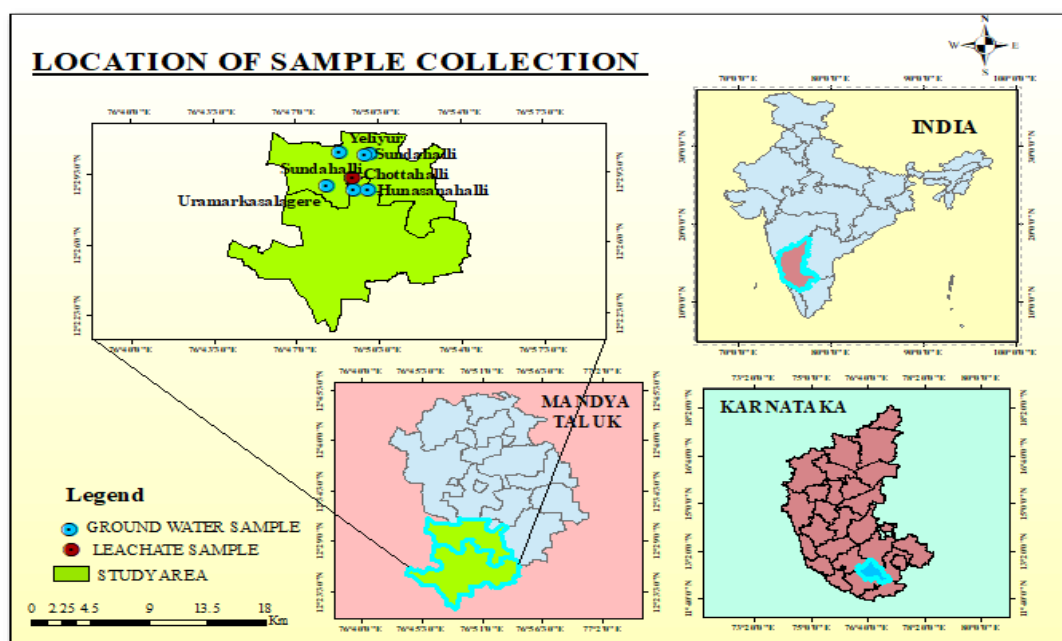


Fig. 1: Location map of the sample collected.

the potential level of groundwater contamination in the locale of the landfill. Figure 1 illustrates the location map of the samples collected.

3. MATERIALS AND SAMPLE COLLECTION DETAILS

The groundwater samples were collected from the study area according to the standards of the American Public Health Association. The physico-chemical analyses of both the water and the leachate samples were carried out using standard analytical methods (APHA, 2012).

From the Kalenahalli municipal dumpsite, seven groundwater samples and one leachate sample were taken using PVC containers. Groundwater samples were collected from bore holes close to the dumpsite in Hunasanahalli, Chottahalli, Uramarkasalagere, Sundahalli, and Yeliyur. Table 1 presents the details of all the collected samples for the present study.

Table 1: Details of sample collection

SL No.	Sample Type	Coordinate		Location	Distance of Sampling locations from dumpsite (km)
		Latitude (N)	Longitude (E)		
1	Leachate	12.487596°	76.824389°	Kalenahalli dumpsite	0
2	Groundwater (GW1)	12.48796°	76.82466°	Kalenahalli dumpsite	0.05
3	Groundwater (GW2)	12.47195°	76.836117°	Hunasanahalli	2.15
4	Groundwater (GW3)	12.475857°	76.825395°	Chottahalli	2.68
5	Groundwater (GW4)	12.476219°	76.815335°	Uramarkasalagere	1.60

6	Groundwater (GW5)	12.490267 ^o	76.828921 ^o	Sundahalli	2.15
7	Groundwater (GW6)	12.50654 ^o	76.833661 ^o	Sundahalli	2.33
8	Groundwater (GW7)	12.503676 ^o	76.827671 ^o	Yeliyur	1.82

To prevent contamination, samples were meticulously gathered in 1-litre PVC containers that had been previously washed with distilled water. For the collection of samples, stagnant water was removed from the borewell by 10 to 15 minutes of pumping. Samples of leachate and groundwater were taken from specific locations between 8 AM and 11 AM and carried in an ice container kept at 4°C. The heavy metals tests were performed in the Mysore Pollution Control Board, while the basic physicochemical tests were done in the Environmental Engineering Laboratory of the Department of Civil Engineering, PES College of Engineering, Mandya.

The current study was conducted based on standard laboratory procedures to analyse seven groundwater samples and one leachate sample for a variety of physicochemical parameters, such as pH, Electrical Conductivity (EC), Turbidity, Total Dissolved Solids (TDS), Alkalinity, Total Hardness, Calcium, Magnesium, Fluoride, Chloride, and Nitrate. Atomic Absorption Spectroscopy (AAS) was used at the Mysore Pollution Control Board to analyse heavy metals for elements like copper, iron, lead, zinc, nickel, cadmium, chromium, aluminium, manganese, silver, barium, boron, and cobalt. Table 2 below provides a summary of the precise techniques used to analyse the physicochemical and heavy metal characteristics in the groundwater and leachate samples.

Table 2: Methods used for analyzing the physicochemical parameters of the sample collected

SL NO	Parameters	Methods
1	pH	pH meter
2	EC	EC meter
3	TDS	TDS meter
4	Alkalinity	Argentometric (titration)
5	Total hardness	EDTA Titration method
6	Calcium hardness	Argentometric (titration)
7	Iron	Spectrophotometer
8	Fluoride	Spectrophotometer
9	Nitrate	Spectrophotometer
10	Heavy metal	Atomic Absorption Spectroscopy

3.1. Leachate Pollution Index

The Leachate Pollution Index (LPI) quantifies the overall contamination potential of a landfill's leachate at a given time by considering multiple pollution parameters, with a theoretical scale ranging from 5 to 100 units. Even if certain pollutants are absent, the LPI cannot drop below 5 units. Poor environmental conditions are indicated by an LPI score of more than 35; higher values imply higher levels of pollution (Kumar and Alappat, 2005). Furthermore, the age of the landfill plays a crucial role in determining the LPI, as it has a substantial impact on the characteristics of the leachate.

3.1.1. Calculating the LPI for a specific landfill site at a given time involves the following three steps:

- **Identification of pollutants in the leachate:** Leachate from a specific landfill was analyzed to measure concentrations of major ions and heavy metals, with the Leachate Pollution Index (LPI) indicating its pollution potential (Table 3). Although 18 chemical parameters are recommended for LPI calculation per Kumar and Alappat (2005), only 9 were examined in this study.
- **Calculating sub-index values:** The "pi" values, or sub-index values (Table 6), are obtained from sub-index curves for each pollutant to compute the LPI (Kumar and Alappat, 2005). These values are determined by locating the concentration of each leachate pollutant on the horizontal axis of its respective sub-index curve, with the intersection point indicating the sub-index score, or "pi" value, for that pollutant.
- **Aggregation of sub-index values:** Based on the significance levels and weight factors outlined by Kumar and Alappat (2005), the "pi" values for the nine parameters are multiplied by their corresponding weights (w_i), as presented in Table 6. The total leachate pollution index is then calculated by summing these weighted values.
- When all 18 leachate pollutant parameters recommended by Kumar and Alappat (2005) are not available for the landfill site under study (i.e., when $m < 18$), the LPI can be calculated using the following equation:

$$LPI = \frac{\sum_{i=1}^M w_i P_i}{\sum_{i=1}^M w_i} \quad \dots(1)$$

Where,

LPI = Leachate Pollution Index value.

W_i = Assigned weight for the i^{th} pollutant variable

P_i = Sub-index value of the i^{th} leachate pollutant variable.

M = The total number of leachate pollutant parameters with available data.

3.2 Water Quality Index

The Water Quality Index (WQI) is a simple yet effective tool for evaluating water quality. It supports more effective management of water-related issues and improves the implementation of protective measures. WQI is a crucial metric for assessing whether water is fit for human consumption (Madhusudhan M. S. et al., 2024). The index is calculated based on the drinking water standards outlined in BIS 10500:2012.

The WQI can be evaluated using a variety of techniques, which are based on a distinct set of water quality parameters. Common methods include the National Sanitation Foundation Water Quality Index (NSF WQI), the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI), and the Weighted Arithmetic Index method (Brown, 1972). The Weighted Arithmetic Index approach was applied in this study. This method calculates the WQI at a specific sampling site in three main steps.

3.2.1. Steps involved in calculation of WQI:

- Step 1: Calculate the unit weight (W_n) factors for each chemical parameter using the following formula.

$$W_n = \frac{K}{S_n} \quad \dots(2)$$

Where,

$$K = \frac{1}{1/S_1 + 1/S_2 + 1/S_3 + \dots + 1/S_n} = \frac{1}{\sum \frac{1}{S_n}} \quad \dots(3)$$

K = proportionality Constant.

S_n = The standard value of the n -th parameter.

The sum of the unit weight factors for all parameters should equal unity (i.e., $W_n = 1$).

- Step 2: Determine the Sub-Index (Q_n) value by applying the formula

$$Q_n = \frac{[(V_n - V_o)]}{[(S_n - S_o)]} \times 100 \quad \dots(4)$$

Where,

V_n = Average concentration of the n -th parameter.

S_n = Standard value of the n th parameter.

V_o = The actual value of a parameter in pure water is typically considered to be $V_o = 0$ for most parameters, with the exception of pH, which is taken as 7, and dissolved oxygen (DO), which is 14.6.

- Step 3: By combining steps 1 and 2, the WQI is calculated using the following equation.

$$WQI = \frac{\sum W_n Q_n}{\sum W_n} \quad \dots(5)$$

4. RESULTS

4.1. Evaluation of Leachate Characteristics

The physicochemical properties of leachate are largely determined by the composition of the waste and its moisture content. The specific characteristics of the leachate samples collected from the Kalenahalli landfill site are presented in Table 3. The Kalenahalli landfill site had a leachate sample pH value of 4.5. The TDS (769 mg/L), Copper (0.665 mg/L), Lead (0.090 mg/L), Iron (65.311 mg/L), Zinc (2.698 mg/L), Nickel (0.276 mg/L), Cadmium (0.017 mg/L), Chromium (0.148 mg/L), Aluminium (43.833 mg/L), Manganese (6.819 mg/L), Silver (0.012 mg/L), Barium (2.169 mg/L), Boron (2.302 mg/L), Cobalt (0.092 mg/L), Magnesium (356 mg/L), Calcium (257 mg/L), Total Hardness (613 mg/L), Chloride (185 mg/L), Nitrate (33.54 mg/L) and Fluoride (0.92 mg/L).

The high Total Dissolved Solids (TDS) concentration of 769 mg/L in the leachate sample from the Kalenahalli landfill site is attributed to the presence of inorganic compounds. When discharged into aquatic environments, such leachate rich in dissolved and suspended solids can degrade water quality, disrupt photosynthesis, harm aquatic organisms, and contribute to sediment buildup, ultimately reducing water depth (Aiyesanmi, A.F. et al., 2011).

A high concentration of total suspended solids in the leachate suggests the presence of dirt, microbes, organic matter, and inorganic debris.

The elevated iron concentration (65.311 mg/L) in the leachate sample suggests substantial disposal of iron and steel scrap at the Kalenahalli landfill site (Chu et al., 1994). Similarly, the presence of zinc (2.698 mg/L) indicates that the landfill likely receives waste materials such as batteries and fluorescent lamps (Mor et al., 2006).

4.2. Evaluation of Groundwater Sample Characteristics

In the research area, groundwater is mostly utilised for household needs and, in many locations, for agriculture. Thus, it is essential to evaluate its suitability for irrigation as well as drinking. The analytical results of the groundwater samples are shown in Tables 4 and 5, which also compare the observed values with the IS 10500:2012 drinking water standards. According to the comparison, several chemical characteristics are higher than what is considered safe for drinking water. While differences in electrical conductivity (EC) indicate larger amounts of dissolved salts, especially in samples taken close to the dump site, the pH readings indicate that the groundwater is mildly alkaline. In wells near the dump, contamination levels are considerably higher.

Seven groundwater samples were chosen at random from the vicinity of the solid waste disposal site to assess the effect of leachate on groundwater resources. The impact of municipal solid waste disposal on groundwater quality was evaluated through a methodical investigation. The findings indicate that leachate from the landfill has seriously contaminated the groundwater in neighboring wells. Samples taken at different distances from the dump were examined to determine the average amounts of main ions and heavy metals. The results

show that the landfill is a point source of contamination, with pollutant levels gradually declining as ground-water moves farther away from the landfill.

Table 3: Physico-chemical properties of the leachate sample from the Kalenahalli landfill site

SL NO	TEST PARAMETERS	VALUES	INDIAN STANDARDS (IS 10500:2012)
1	pH	4.5	6.5-8.5
2	TDS	769 mg/L	500-2000 mg/L
3	Copper	0.665 mg/L	0.05 mg/L
4	Lead	0.090 mg/L	0.01 mg/L
5	Iron	65.311 mg/L	0.3 mg/L
6	Zinc	2.698 mg/L	5 mg/L
7	Nickel	0.276 mg/L	0.02 mg/L
8	Cadmium	0.017 mg/L	0.003 mg/L
9	Chromium	0.148 mg/L	0.05 mg/L
10	Aluminium	43.833 mg/L	0.03 mg/L
11	Manganese	6.819 mg/L	0.1 mg/L
12	Silver	0.012 mg/L	0.1 mg/L
13	Barium	2.169 mg/L	0.7 mg/L
14	Boron	2.302 mg/L	0.5 mg/L
15	Cobalt	0.092 mg/L	0.1 mg/L
16	Magnesium	356 mg/L	30-100 mg/L
17	Calcium	257 mg/L	75-200 mg/L
18	Total Hardness	613 mg/L	200-600 mg/L
19	Chloride	185 mg/L	250-1000 mg/L
20	Nitrate	33.54 mg/L	45 mg/L
21	Fluoride	0.92 mg/L	1-1.5 mg/L

Table 4: Physico-chemical properties of groundwater samples from the Kalenahalli landfill site.

Sl. No.	Test Parameters	Chottahalli	Hunasahalli	Uramarkasalagere	Sundahalli (1)	Sundahalli i (2)	Yaliyur	Kalenahalli
1	pH	7.38	7.09	7.07	7.10	7.08	7.05	6.84
2	EC (S/m)	872	830	756	852	816	745	856
3	Turbidity (NTU)	2.8	1.9	2.1	2.4	2.2	1.7	3.2
4	TDS (mg/L)	548	438	515	523	520	456	568
5	Alkalinity (mg/L)	500	360	480	372	484	356	528
6	Total Hardness (mg/L)	556	344	508	406	498	372	984
7	Calcium (mg/L)	296	144	180	132	282	156	560
8	Magnesium (mg/L)	260	200	328	274	216	216	424

9	Fluoride (mg/L)	0.71	0.83	0.69	0.71	0.65	0.84	2.92
10	Chloride (mg/L)	158	89	100	132	144	126	589
11	Nitrate (mg/L)	13	17	23	11	17	23	72

Table 5: Heavy metal analysis of groundwater samples from the Kalenahalli landfill site.

Sl. No.	Test Parameters	Chottahalli i	Hunasahalli Ili	Uramarkasalage re	Sundahalli i (1)	Sundahalli i (2)	Yaliyur	Kalenahalli
1	Copper (mg/L)	0.003	0.003	0.015	0.001	0.002	0.001	0.004
2	Iron (mg/L)	0.456	0.441	0.314	0.319	0.276	0.326	0.556
3	Lead (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Zinc (mg/L)	0.214	0.247	0.176	0.121	0.127	0.124	0.334
5	Nickel (mg/L)	0.002	0.002	0.001	0.001	0.001	0.001	0.002
6	Cadmium (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Chromium (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Aluminium (mg/L)	1.216	1.176	0.124	0.114	0.056	0.146	1.246
9	Manganese (mg/L)	0.301	0.296	0.156	0.246	0.154	0.171	0.312
10	Silver (mg/L)	0.001	0.001	0.00	0.00	0.00	0.00	0.001
11	Barium (mg/L)	0.065	0.034	0.018	0.025	0.027	0.012	0.085
12	Boron (mg/L)	0.326	0.296	0.304	0.176	0.154	0.146	0.344
13	Cobalt (mg/L)	0.001	0.001	0.00	0.00	0.00	0.00	0.001

4.3. Results of Leachate Pollution Index (LPI)

Concerning the section discussed in 3.1, the final LPI value is obtained by dividing the total overall pollution rating by the sum of the weight factors, resulting in an LPI of 8.598. This value suggests that the leachate from the landfill site is moderately contaminated, primarily due to the low organic matter content. The leachate is also less viscous, as indicated by the relatively low concentrations of chloride (Cl), zinc (Zn), and lead (Pb).

Table 6: Leachate Pollution Index (LPI) of the Kalenahalli landfill site.

Sl. No.	Leachate characteristic	Observed value	Individual Pollution rating (pi)	Significance	Pollutant weight (wi)	Overall pollution rating (pi x wi)
1	pH	4.5	20	3.509	0.055	1.1
2	TDS	769	6	3.196	0.05	0.3
3	Iron	65.311	5	2.83	0.045	0.225
4	Copper	0.665	10	3.17	0.05	0.5
5	Nickel	0.276	5	3.321	0.052	0.26
6	Zinc	2.698	6	3.585	0.056	0.336
7	Lead	0.09	8	4.019	0.063	0.504
8	Chromium	0.148	7	4.057	0.064	0.448
9	Chloride	185	10	3.078	0.048	0.48
	Total				0.483	4.153

4.4. Results of Water Pollution Index (WPI)

The Water Quality Index (WQI), for the current study, is computed as outlined in section 3.2, whose index value varies between 0 and 300, which helps in evaluating the quality of groundwater (Table 7). The study area's groundwater is categorised by this index as excellent, good, poor, very poor, or unfit for human consumption. According to Batabyal and Chakraborty (2015), these classifications provide a clear understanding of the general condition of the groundwater and its suitability for human consumption.

Table 7: Classification of water quality based on WQI value

Water quality	WQI value
Excellent	< 50

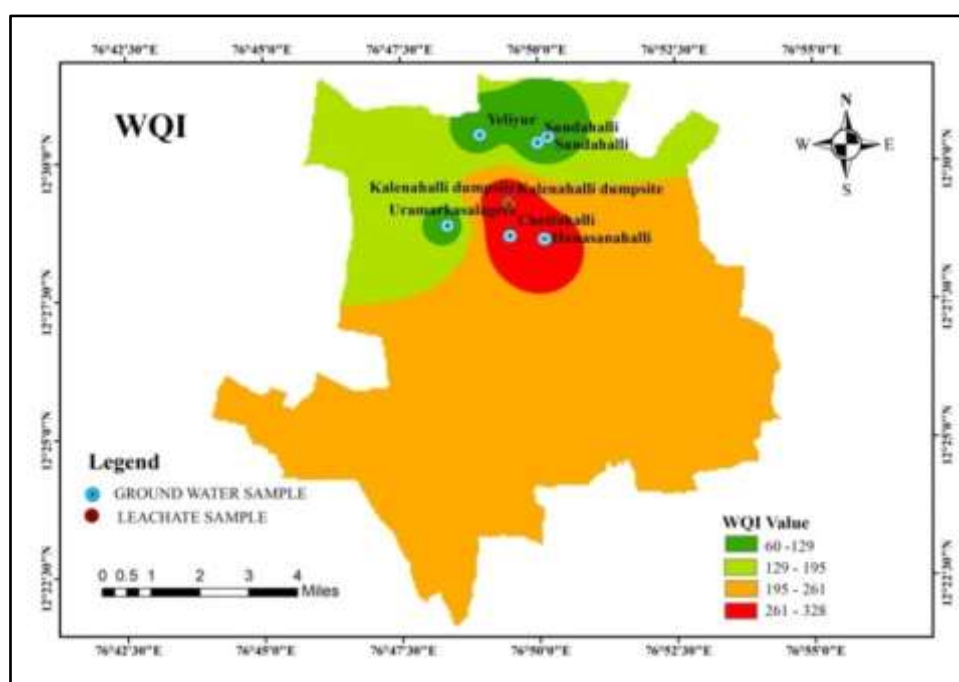


Fig. 2: Spatial distribution map of Water Quality Index (WQI) of the study area

Table 8: Classification of water quality based on WQI value

SL NO	Location	Water Quality Index value	WQI quality
1	Kalenahalli	327.26	Unsuitable for drinking
2	Hunasanahalli	293.60	Very Poor
3	Chottahalli	303.49	Very Poor
4	Uramarkasalage re	82.11	Good
5	Sundahalli	81.68	Good
6	Sundahalli	62.37	Good
7	Yeliyur	87.41	Good

Based on the established Water Quality Index (WQI) values, the above map (Fig. 2) illustrates the distribution of groundwater quality across the study area. It is evident from Table 8 that most of the region is categorised as having poor water quality (200–300), whereas the northeastern section predominantly features good water (50–100). In contrast, certain southern areas exhibit WQI values exceeding 300, signifying that the groundwater is unsuitable for human consumption.

4.5. Hierarchical Cluster Analysis

In environmental studies, one of the most popular multivariate statistical methods is Hierarchical Cluster Analysis (HCA) (Díaz et al., 2002). It is frequently used for hydrogeochemical data classification (Güler et al., 2002). A visual analysis of the dendrogram (Fig. 3) led to the clustering of seven groundwater samples. To determine how cohesive these clusters were, a dendrogram was created, which made it simpler to find relationships between various components (Yongming et al., 2006).

In this study, the distance matrix approach was used to perform hierarchical cluster analysis. Clusters were plotted along two dimensions of the distance matrix, and the Euclidean distance was applied to measure the separation between clusters. The single linkage method was then used to merge the clusters based on the shortest distance between them. Using cluster analysis, sampling points were categorised according to the constituent ion concentration. Total Dissolved Solids (TDS) values, which represent salinity levels and correlate to regions of low, moderate, and high pollution, were used in this study to identify three separate clusters.

Cluster 1, which includes samples 2 and 7, represents a low-pollution region. These samples have low TDS values ranging from 320 to 460 mg/L, indicating minimal groundwater contamination. Cluster 2 comprises samples 4, 5, and 6 and corresponds to a moderately polluted area, with TDS values between 490 and 520 mg/L, suggesting moderate salinity and pollution levels. Cluster 3 contains samples 1 and 3, collected from locations near a landfill site. This cluster is identified as highly polluted, likely due to the influence of domestic and agricultural waste, with TDS values ranging from 530 to 570 mg/L, indicating high salinity and significant groundwater contamination.

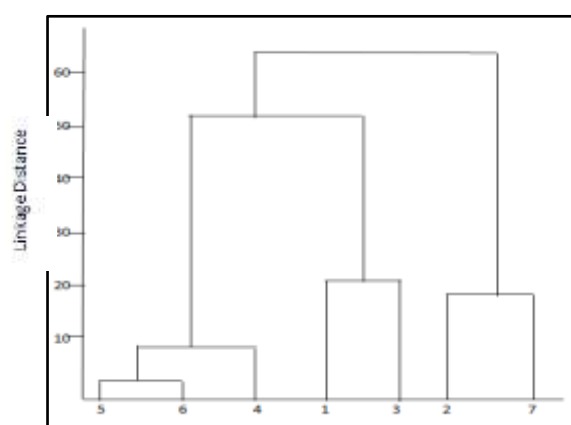


Fig 3: Hierarchical dendrogram for groundwater samples

5. DISCUSSION

The groundwater and leachate samples used in this investigation were collected from in and around the Kalenahalli Mandya municipal dumpsite. To determine the groundwater quality of the dump site, tests including the physiochemical parameter test and the heavy metal test were performed. The percentage of groundwater pollution at the dumpsite is determined by comparing the groundwater quality of this site with neighbouring Kalenahalli neighbourhoods, including Hunasanahalli, Chottahalli, Uramarkasalagere, Sundahalli, and Yeliyur. Appropriate measures are then taken to address the groundwater contamination.

A study conducted by Satish Kumar et al. 2024 on the Mandya, Kalenahalli dumping site yielded similar results to that of our study, revealing an LPI value of 29.32, which exceeds the limits of the Indian standards of disposal. Also, the physicochemical characteristics of the collected leachate samples showed excessive values when compared with the drinking water standards (BIS 10500:2012), which is in line with the results obtained from the current study. Also, a study conducted by Madhusudhan M S et al. 2024 indicates that the WQI of the 35 wards of Mandya district ranges from 28.15 to 193.59, wherein the groundwater sample was collected from each ward. Results of the study indicate the increased levels of iron and fluoride content, and about 60% of the samples fall under poor quality. Even though the results of the paper pertain to the wards of the city, there is a high chance that the water is getting contaminated by the improper disposal of waste or leachate matter entering into the groundwater system, which is similar to the study investigated and presented in the current paper.

Proper waste management systems, as suggested by John Ape et al. 2025 in their study, like improved waste collection and recycling infrastructure, should be considered for the design of landfills, and regular monitoring of the site along with real-time detection technologies should be used for timely identification and remedial steps, along with public awareness programmes to cater to the information regarding civic responsibility in maintaining their health as well as keeping the environmental status intact. Also, the current study can explore the possibility of the implantation of modern eco-friendly methods like bioremediation and phytoremediation at the dumping site.

6. CONCLUSIONS

In developing countries, groundwater serves as a vital source of water supply for both urban and rural communities. Based on our research, the disposal of municipal solid waste at landfill sites has led to the formation of leachate, which has significantly contaminated the groundwater in the area surrounding the landfill. In contrast, locations farther from the landfill site are less affected by groundwater contamination.

The leachate generated in the Kalenahalli landfill site is less polluted, as per the calculated value of LPI (Leachate Pollution Index) 8.598, which is less than 35. The obtained value of LPI indicates that the landfill is contaminated moderately due to low organic matter and low concentrations of contaminants such as Cl, Zn, and Pb present in the leachate sample.

The groundwater quality at the landfill site is divided into five categories by the Water Quality Index (WQI): excellent (< 50), good (50–100), poor (100–200), very poor (200–300), and unfit for human consumption (> 300). To measure groundwater's suitability for human consumption, the WQI is used.

According to the findings, the majority of groundwater samples from the northeast region are categorised as having high quality, whilst those from the southern region are deemed unfit for human consumption. Also, samples collected from Uramarkasalagere, Sundahalli, and Yeliyur in the northeast show superior water quality with lower pollution levels, whereas Hunasanahalli and Chottahalli in the south are found to be more contaminated. It is discovered that Kalenahalli, the dumping site, has extremely contaminated groundwater that is unsafe to drink.

The seven groundwater samples were grouped into three groups using Hierarchical Cluster Analysis (HCA) according to their TDS values, which stand for high, moderate, and low contamination levels. With TDS levels ranging from 320 to 460 mg/L, samples 2 and 7 in Cluster 1 are categorized as low pollution. The three samples (4, 5, and 6) in Cluster 2 exhibit moderate pollution, with TDS levels ranging from 490 to 520 mg/L. With TDS levels ranging from 530 to 570 mg/L, samples 1 and 3 in Cluster 3 have been classified as extremely contaminated. Patterns in water quality and the causes of pollution are revealed by these TDS measurements. Establishing an engineered disposal site is advised for future management in order to lessen the effect of leachate on groundwater in the hydrological region.

Author Contributions: Madhusudhan M S - Conceptualization, methodology, and writing—original draft preparation, review, and editing. Dr. H C Chowdegowda – data validation, supervision, and project administration. Varshitha M S - software, formal analysis, field investigation, and experimental works. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical approval is obtained.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Acknowledgments: The authors would like to express their gratitude to Rudre Gowda Sir (AEE Envi) for granting authorisation to collect the sample in the Kalenahalli dump site. We also acknowledge Vanita Mam for performing the heavy metal test on the samples in the lab and the Kalenahalli staff for helping us with sample collecting. Additionally, the entire staff of PES College of Engineering's Civil Engineering Department in Mandya, Karnataka State, is thanked for their steadfast assistance during the research project.

Conflicts of Interest: There is no conflict of interest.

REFERENCES

1. Aiyesanmi, A.F. & Imoisi, O.B. 2011d. Understanding Leaching Behaviour of Landfill Leachate in Benin-City, Edo State, Nigeria through Dumpsite Monitoring. Zenodo (CERN European Organization for Nuclear Research). URL: <https://doi.org/10.5281/zenodo.8396>.
2. Akinbile, C.O., Yusoff, M.S. and Shian, L.M., 2012. Leachate characterization and phytoremediation using water hyacinth (*Eichhornia crassipes*) in Pulau Burung, Malaysia. *Bioremediation journal*, 16(1), pp.9-18. <https://doi.org/10.1080/10889868.2011.628350>
3. Alao, J. O., Fahad, A., Abdo, H. G., Ayejoto, D. A., Almohamad, H., Ahmad, M. S., Nur, M. S., Danjuma, T. T., Yusuf, M. A., Francis, O. T., & Joy, A. O., 2023. Effects of dumpsite leachate plumes on surface and groundwater and the possible public health risks. *The Science of the Total Environment*, 897, p. 165469. <https://doi.org/10.1016/j.scitotenv.2023.165469>
4. Ape, J., Bathula, S., Samanta, S., & Kotra, K. K. (2025). Assessment of toxic metals in an open dump site near PNG University of Technology, Papua New Guinea. *Nature Environment and Pollution Technology*, 24(2), D1713. <https://doi.org/10.46488/nept.2025.v24i02.d1713>
5. APHA. 2012. Standard methods for the examination of water and wastewater, 22nd edition. Washington: American Public Health Association.
6. Batabyal, A.K. and Chakraborty, S., 2015. Hydrogeochemistry and water quality index in the assessment of groundwater quality for drinking uses. *Water Environment Research*, 87(7), pp.607-617. <https://doi.org/10.2175/106143015x14212658613956>
7. BIS, 2012. Bureau of Indian Standards – BIS: 10500-2012. Drinking water-specification. New Delhi: Second Revision. Government of India.
8. Christensen, T.H., Kjeldsen, P., Bjerg, P.L., Jensen, D.L., Christensen, J.B., Baun, A., Albrechtsen, H.J. and Heron, G., 2001. Biogeochemistry of landfill leachate plumes. *Applied geochemistry*, 16(7-8), pp.659-718. [https://doi.org/10.1016/s0883-2927\(00\)00082-2](https://doi.org/10.1016/s0883-2927(00)00082-2)
9. Chu, L.M., Cheung, K.C. and Wong, M.H., 1994. Variations in the chemical properties of landfill leachate. *Environmental Management*, 18, pp.105-117. <https://doi.org/10.1007/bf02393753>
10. Diaz, R.V. and Aldape, F., 2002. Identification of airborne particulate sources of samples collected in Ticomán, Mexico, using PIXE and multivariate analysis. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 189(1-4), pp.249-253. [https://doi.org/10.1016/s0168-583x\(01\)01073-4](https://doi.org/10.1016/s0168-583x(01)01073-4)
11. Dlamini, N. S., Jha, P. K., Srivastava, A., Elaksher, A. F., and Chakraborty, R., 2025. Assessment of Groundwater Contamination and Human Health Risks from Landfill Leachate: A Case Study of Shivari Landfill, Lucknow, India. *Earth Systems and Environment*. <https://doi.org/10.1007/s41748-025-00677-0>
12. Essien, J. P., Ikpe, D. I., Inam, E. D., Okon, A. O., Ebong, G. A., and Benson, N. U., 2022. Occurrence and spatial distribution of heavy metals in landfill leachates and impacted freshwater ecosystem. *An environmental and human health threat*. 17(2), e0263279. <https://doi.org/10.1371/journal.pone.0263279>
13. Güler, C., Thyne, G.D., McCray, J.E. and Turner, K.A., 2002. Evaluation of graphical and multivariate statistical methods for the classification of water chemistry data. *Hydrogeology journal*, 10, pp.455-474. <https://doi.org/10.1007/s10040-002-0196-6>
14. HR, M.K., 2024. Evaluation Of the Potential Level In The Municipal Solid Waste Of the Dumping Yard Of Mandya By Using the Leachate Pollution Index. *Journal of Advanced Zoology*, 45(2). . <https://doi.org/10.53555/jaz.v45i2.3951>

15. J, S. K., & R, M. K. H. (2024). Evaluation of the potential level of the municipal solid waste of dumping yard of Mandya by using Leachate Pollution Index. *Journal of Advanced Zoology*. <https://doi.org/10.53555/jaz.v45i2.3951>
16. Jones, D.L., Williamson, K.L. and Owen, A.G., 2006. Phytoremediation of landfill leachate. *Waste Management*, 26(8), pp.825-837. <https://doi.org/10.1016/j.wasman.2005.06.014>
17. Kumar, D. and Alappat, B.J., 2005. Evaluating leachate contamination potential of landfill sites using leachate pollution index. *Clean Technologies and Environmental Policy*, 7, pp.190-197. <https://doi.org/10.1007/s10098-004-0269-4>
18. Longe, E.O. and Balogun, M.R., 2010. Groundwater quality assessment near a municipal landfill, Lagos, Nigeria. *Research journal of applied sciences, engineering and technology*, 2(1), pp.39-44. <https://www.cabdirect.org/abstracts/20103322335.html>
19. Madhusudhan, M.S., Rajendra, H.J., Surendra, H.J. and Anusha, M., 2024. Groundwater quality evaluation using Water Quality Index (WQI) under GIS framework for Mandya City, Karnataka. *Sustainable Water Resources Management*, 10(1), p.21. <https://doi.org/10.1007/s40899-023-00998-w>
20. Mishra, H., Karmakar, S., Kumar, R. and Singh, J., 2017. A framework for assessing uncertainty associated with human health risks from MSW landfill leachate contamination. *Risk Analysis*, 37(7), pp.1237-1255. <https://doi.org/10.1111/risa.12713>
21. Mishra, H., Rathod, M., Karmakar, S. and Kumar, R., 2016. A framework for assessment and characterisation of municipal solid waste landfill leachate: an application to the Turbhe landfill, Navi Mumbai, India. *Environmental Monitoring and Assessment*, 188, pp.1-23. <https://doi.org/10.1007/s10661-016-5356-6>
22. Mor, S., Ravindra, K., De Visscher, A., Dahiya, R.P. and Chandra, A., 2006. Municipal solid waste characterization and its assessment for potential methane generation: a case study. *Science of the Total Environment*, 371(1-3), pp.1-10. <https://doi.org/10.1016/j.scitotenv.2006.04.014>
23. Nandi, S., Swain, S., 2024. Role of groundwater systems in fulfilling Sustainable Development Goals: A focus on SDG6 and SDG13. *Current Opinion in Environmental Science & Health*, 42, pp. 100576. <https://doi.org/10.1016/j.coesh.2024.100576>
24. Nandimandalam, J.R., 2012. Evaluation of hydrogeochemical processes in the Pleistocene aquifers of middle Ganga Plain, Uttar Pradesh, India. *Environmental Earth Sciences*, 65, pp.1291-1308. <https://doi.org/10.1007/s12665-011-1377-1>
25. Ogundiran, O.O. and Afolabi, T.A., 2008. Assessment of the physicochemical parameters and heavy metals toxicity of leachates from municipal solid waste open dumpsite. *International Journal of Environmental Science & Technology*, 5, pp.243-250. . <https://doi.org/10.1007/bf03326018>
26. Rathod, M., Mishra, H.. and Karmakar, S., 2013. Leachate characterization and assessment of water pollution near municipal solid waste landfill site. *International Journal of Chemical and Physical Science*, 2, pp.186-189. <http://ijcps.org/sp1/p20.pdf>
27. Singh, S., Raju, N.J. and Ramakrishna, C., 2015. Evaluation of groundwater quality and its suitability for domestic and irrigation use in parts of the Chandauli-Varanasi region, Uttar Pradesh, India. *Journal of Water Resource and Protection*, 7(07), p.572. <https://doi.org/10.4236/jwarp.2015.77046>
28. Singh, S., Raju, N.J., Gossel, W. and Wycisk, P., 2016. Assessment of pollution potential of leachate from the municipal solid waste disposal site and its impact on groundwater quality, Varanasi environs, India. *Arabian Journal of Geosciences*, 9, pp.1-12. <https://doi.org/10.1007/s12517-015-2131-x>

-
29. Słomczyńska, B. and Słomczyński, T., 2004. Physico-chemical and toxicological characteristics of leachates from MSW landfills. *Polish Journal of Environmental Studies*, 13(6), pp.627-637. <http://6csnfn.pjoes.com/pdf/13.6/627-637.pdf>
 30. Talalaj, I.A. and Biedka, P., 2016. Use of the landfill water pollution index (LWPI) for groundwater quality assessment near the landfill sites. *Environmental science and pollution research*, 23, pp.24601-24613. <https://doi.org/10.1007/s11356-016-7622-0>
 31. Velis, C. A., Wilson, D. C., Gavish, Y., Grimes, S. M., and Whiteman, A., 2023. Socio-economic development drives solid waste management performance in cities: A global analysis using machine learning. *The Science of the Total Environment*, 872, p. 161913. <https://doi.org/10.1016/j.scitotenv.2023.161913>
 32. Yongming, H., Peixuan, D., Junji, C. and Posmentier, E.S., 2006. Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. *Science of the total environment*, 355(1-3), pp.176-186.