



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

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ABSTRACT

Open disposal of municipal solid waste elevates the risk of groundwater contamination. This study evaluated the pollution potential of leachate from a solid waste disposal site and its impact on aquifers in the Mandya region of Karnataka, India. Unplanned disposal of municipal solid waste (MSW) led to leachate accumulation within the waste mass, subsequently flowing into nearby water bodies, such as open wells and ponds. 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). The Leachate Pollution Index (LPI) and Water Quality Index (WQI) were calculated based on the test results. The LPI value indicated that the leachate from the landfill site was moderately contaminated. The WQI revealed that groundwater quality in the area ranged from good to poor and unsuitable for drinking in certain cases. Hierarchical cluster analysis (HCA) categorized groundwater samples into high, moderate, and low groups based on their total dissolved solids (TDS) levels, helping to identify trends in water quality and potential 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. In addition to ice, it is found in seas, oceans, and other bodies of water. Owing to its high vulnerability rating and insufficient data, the groundwater system is a hidden natural resource (Nandi & Swain 2024). Consequently, 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 increase in open dumping is responsible 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 metric tons of municipal solid waste (MSW) annually. Municipalities in metropolitan areas are responsible for collecting this garbage and delivering it to approved disposal locations (Mor et al. 2006). In developing nations like India, MSW is commonly disposed of via landfilling (Rathod et al. 2013, Mishra et al. 2016). Leachate from these dumps comprises a variety of chemical contaminants that are extremely dangerous for surface and

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groundwater resources (Christensen et al. 2001). Generally, MSW is disposed of carelessly in low-lying locations. All ecological elements are negatively impacted by the open disposal of solid waste. Leachate is generated 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 2012, Singh et al. 2016).

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, such as ammonium, calcium, magnesium, sodium, potassium, iron, sulfates, 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 & 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 & 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 after 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 pH of leachate 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 & 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. 2017, Talalaj & 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 use 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, such as 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 features of groundwater by comparing these results to set permissible limits. This will help identify any ions that exceed regulatory limitations, providing a clearer picture of groundwater 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 assessing groundwater resources (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 hierarchical cluster analysis (HCA).

STUDY AREA

The quality of groundwater and leachate was tested only in Mandya City, the district's administrative hub, also known as the "Sugar City" due to the widespread cultivation of sugarcane as the primary crop. The average elevation of Mandya 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 tons per 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 (approximately 59.3%) originates from ordinary families. Approximately 29% of the garbage produced comes from small businesses and educational institutions, which are also significant suppliers of waste (Meena Kumari 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, groundwater samples were collected as one leachate sample and seven groundwater samples from the vicinity of the Kalenahalli dump from existing bore wells. This was done to determine the potential level of groundwater

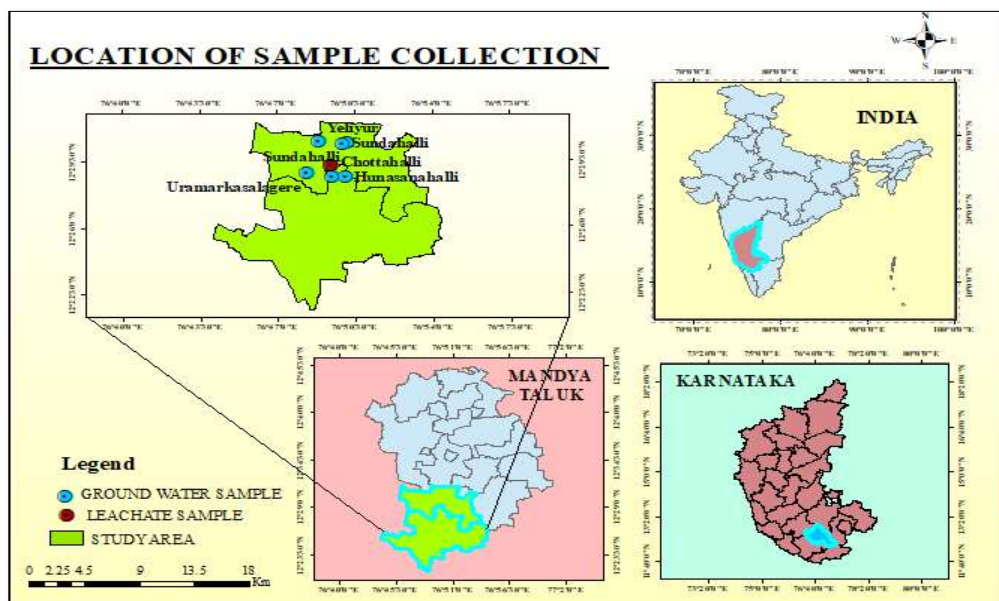


Fig. 1: Location map of the samples collected.

Table 1: Details of sample collection.

Sl. No.	Sample Type	Coordinate		Location	Distance of Sampling locations from the 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°	76.828921°	Sundahalli	2.15
7.	Groundwater (GW6)	12.50654°	76.833661°	Sundahalli	2.33
8.	Groundwater (GW7)	12.503676°	76.827671°	Yeliyur	1.82

contamination near the landfill. Fig. 1 illustrates a map showing the locations where the samples were collected.

MATERIALS AND METHODS

Groundwater samples were collected from the study area according to the standards of the American Public Health Association. Physico-chemical analyses were performed on both water and leachate samples using standard analytical methods (APHA 2012).

From the Kalenahalli municipal dumpsite, seven groundwater samples and one leachate sample were collected using polyvinyl chloride (PVC) containers. Groundwater samples were collected from boreholes close to the dumpsite in Hunasanahalli, Chottahalli, Uramarkasalagere, Sundahalli, and Yeliyur. Table 1 presents the details of all samples collected for this study.

To prevent contamination, samples were meticulously collected in 1-L polyvinyl chloride (PVC) containers that had been previously washed with distilled water. Stagnant water was removed from the borewell by pumping for 10–15 min to collect samples. Leachate and groundwater samples were collected from specific locations between 8 a.m. and 11 a.m. and transported in an ice container maintained at 4°C. Heavy metal tests were performed by the Mysore Pollution Control Board, and basic physicochemical tests were performed 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 analyze seven groundwater and one leachate samples 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 by the Mysore Pollution Control Board to analyze heavy metals, including copper, iron, lead, zinc, nickel, cadmium, chromium, aluminum, manganese, silver, barium, boron, and cobalt. Table 2 summarizes the specific techniques used to analyze the physicochemical and heavy metal characteristics of the groundwater and leachate samples.

Leachate Pollution Index

The 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. A score of > 35 indicates poor environmental conditions, implying higher levels of pollution (Kumar & Alappat 2005). Furthermore, the age of the landfill plays a crucial role in determining the LPI, as it has a substantial impact on leachate characteristics.

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 the 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 nine were examined in this study.
- **Calculating sub-index values:** The “pi” values, or sub-index values (Table 6), are obtained from the sub-index curves for each pollutant to compute the LPI (Kumar & 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

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

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 any of the 18 leachate pollutant parameters recommended by Kumar and Alappat (2005) are unavailable 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

where P_i is the sub-index value of the i^{th} leachate pollutant variable.

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

Water Quality Index

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

The WQI can be evaluated using a variety of techniques 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 method was applied in this study. This method calculates the WQI at a specific sampling site in three main steps.

Steps Involved in the 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 is the proportionality constant.

S_n = Standard value of the n-th parameter.

The sum of the unit weight factors for all the parameters should be equal to 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.

where S_n is the standard value of the n th parameter.

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.

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

RESULTS AND DISCUSSION

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 leachate collected from the Kalenahalli landfill site exhibited an acidic pH of 4.5. The analysis revealed elevated concentrations of several physicochemical parameters and heavy metals. The total dissolved solids (TDS) measured 769 mg L⁻¹, while the major cations included magnesium (356 mg L⁻¹) and calcium (257 mg L⁻¹), contributing to a total hardness of 613 mg L⁻¹. Chloride and nitrate levels were 185 mg L⁻¹ and 33.54 mg L⁻¹, respectively, with fluoride recorded at 0.92 mg L⁻¹.

Among trace metals, copper (0.665 mg L⁻¹), lead (0.090 mg L⁻¹), iron (65.311 mg L⁻¹), zinc (2.698 mg L⁻¹), nickel (0.276 mg L⁻¹), cadmium (0.017 mg L⁻¹), chromium (0.148 mg L⁻¹), aluminium (43.833 mg L⁻¹), manganese (6.819 mg L⁻¹), silver (0.012 mg L⁻¹), barium (2.169 mg L⁻¹), boron (2.302 mg L⁻¹), and cobalt (0.092 mg L⁻¹) were detected.

The high total dissolved solids (TDS) concentration (769 mg.L⁻¹) of 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⁻¹) 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 Zn (2.698 mg.L⁻¹) indicates that the landfill likely receives waste materials, such as batteries and fluorescent lamps (Mor et al. 2006).

Evaluation of Groundwater Sample Characteristics

In the research area, groundwater is mostly utilized for household needs and, in many locations, for agriculture. Thus, it is essential to evaluate its suitability for irrigation and drinking. The analytical results of the groundwater samples are shown in Tables 4 and 5, which also compare the observed values with the standards set by IS 10500:2012

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 ⁻¹	500-2000 mg.L ⁻¹
3.	Copper	0.665 mg.L ⁻¹	0.05 mg.L ⁻¹
4.	Lead	0.090 mg.L ⁻¹	0.01 mg.L ⁻¹
5.	Iron	65.311 mg.L ⁻¹	0.3 mg.L ⁻¹
6.	Zinc	2.698 mg.L ⁻¹	5 mg.L ⁻¹
7.	Nickel	0.276 mg.L ⁻¹	0.02 mg.L ⁻¹
8.	Cadmium	0.017 mg.L ⁻¹	0.003 mg.L ⁻¹
9.	Chromium	0.148 mg.L ⁻¹	0.05 mg.L ⁻¹
10.	Aluminium	43.833 mg.L ⁻¹	0.03 mg.L ⁻¹
11.	Manganese	6.819 mg.L ⁻¹	0.1 mg.L ⁻¹
12.	Silver	0.012 mg.L ⁻¹	0.1 mg.L ⁻¹
13.	Barium	2.169 mg.L ⁻¹	0.7 mg.L ⁻¹
14.	Boron	2.302 mg.L ⁻¹	0.5 mg.L ⁻¹
15.	Cobalt	0.092 mg.L ⁻¹	0.1 mg.L ⁻¹
16.	Magnesium	356 mg.L ⁻¹	30-100 mg.L ⁻¹
17.	Calcium	257 mg.L ⁻¹	75-200 mg.L ⁻¹
18.	Total Hardness	613 mg.L ⁻¹	200-600 mg.L ⁻¹
19.	Chloride	185 mg.L ⁻¹	250-1000 mg.L ⁻¹
20.	Nitrate	33.54 mg.L ⁻¹	45 mg.L ⁻¹
21.	Fluoride	0.92 mg.L ⁻¹	1-1.5 mg.L ⁻¹

for drinking water. According to the comparison, several chemical characteristics were higher than those 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. Contamination levels were considerably higher in wells near the dump.

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 seriously contaminated the groundwater in neighboring wells. Samples were collected at different distances from the dump to

determine the average amounts of the main ions and heavy metals. The results show that the landfill is a point source of contamination, with pollutant levels gradually declining as groundwater moves farther away from the landfill.

Results of Leachate Pollution Index (LPI)

The final LPI value was 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 because of the low organic matter content. The leachate was also less viscous, as indicated by the relatively low concentrations of chloride (Cl), zinc (Zn), and lead (Pb).

Results of Water Pollution Index (WPI)

The WQI, for the current study, was computed as outlined

Table 4: Physicochemical properties of groundwater samples from the Kalenahalli landfill site.

Sl. No.	Test Parameters	Chottahalli	Hunasahalli	Uramarkasalagere	Sundahalli (1)	Sundahalli (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 ⁻¹)	548	438	515	523	520	456	568
5.	Alkalinity (mg.L ⁻¹)	500	360	480	372	484	356	528
6.	Total Hardness (mg.L ⁻¹)	556	344	508	406	498	372	984
7.	Calcium (mg.L ⁻¹)	296	144	180	132	282	156	560
8.	Magnesium (mg.L ⁻¹)	260	200	328	274	216	216	424
9.	Fluoride (mg.L ⁻¹)	0.71	0.83	0.69	0.71	0.65	0.84	2.92
10.	Chloride (mg.L ⁻¹)	158	89	100	132	144	126	589
11.	Nitrate (mg.L ⁻¹)	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	Hunasahalli	Uramarkasalagere	Sundahalli (1)	Sundahalli (2)	Yaliyur	Kalenahalli
1.	Copper (mg.L ⁻¹)	0.003	0.003	0.015	0.001	0.002	0.001	0.004
2.	Iron (mg.L ⁻¹)	0.456	0.441	0.314	0.319	0.276	0.326	0.556
3.	Lead (mg.L ⁻¹)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.	Zinc (mg.L ⁻¹)	0.214	0.247	0.176	0.121	0.127	0.124	0.334
5.	Nickel (mg.L ⁻¹)	0.002	0.002	0.001	0.001	0.001	0.001	0.002
6.	Cadmium (mg.L ⁻¹)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.	Chromium (mg.L ⁻¹)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.	Aluminium (mg.L ⁻¹)	1.216	1.176	0.124	0.114	0.056	0.146	1.246
9.	Manganese (mg.L ⁻¹)	0.301	0.296	0.156	0.246	0.154	0.171	0.312
10.	Silver (mg.L ⁻¹)	0.001	0.001	0.00	0.00	0.00	0.00	0.001
11.	Barium (mg.L ⁻¹)	0.065	0.034	0.018	0.025	0.027	0.012	0.085
12.	Boron (mg.L ⁻¹)	0.326	0.296	0.304	0.176	0.154	0.146	0.344
13.	Cobalt (mg.L ⁻¹)	0.001	0.001	0.00	0.00	0.00	0.00	0.001

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

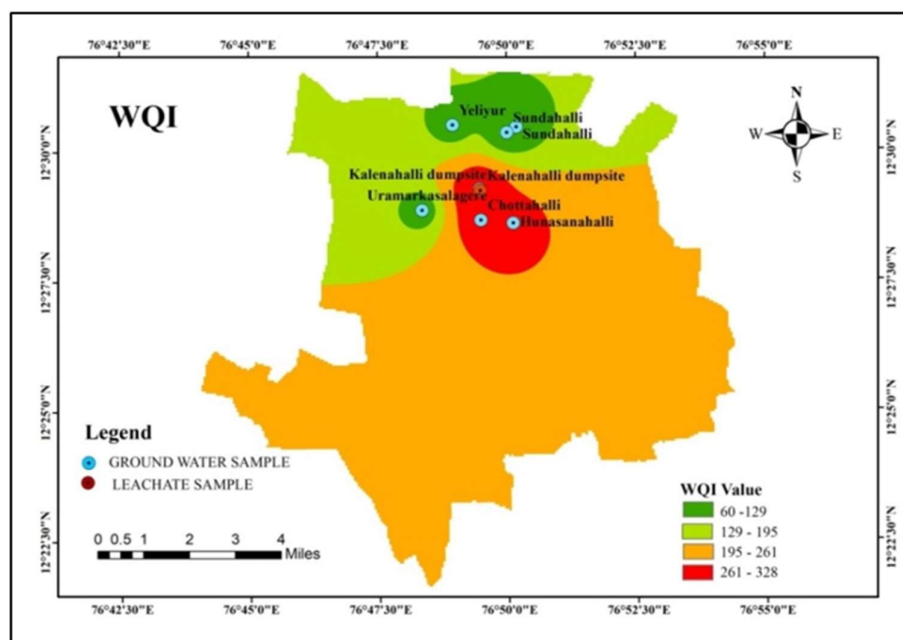


Fig. 2: Spatial distribution map of Water Quality Index (WQI) of the study area.

in Section 3.2, and its index value varies between 0 and 300, which helps in evaluating the quality of groundwater (Table 7). The study area's groundwater was categorized as excellent, good, poor, very poor, or unfit for human consumption using this index. According to Batabyal and Chakraborty (2015), these classifications provide a clear

Table 7: Classification of water quality based on WQI value

Water quality	WQI value
Excellent	< 50
Good	50-100
Poor	100-200
Very Poor	200-300
Unsuitable for drinking	>300

understanding of the general condition of groundwater and its suitability for human consumption.

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.	Uramarkasalagere	82.11	Good
5.	Sundahalli	81.68	Good
6.	Sundahalli	62.37	Good
7.	Yeliyur	87.41	Good

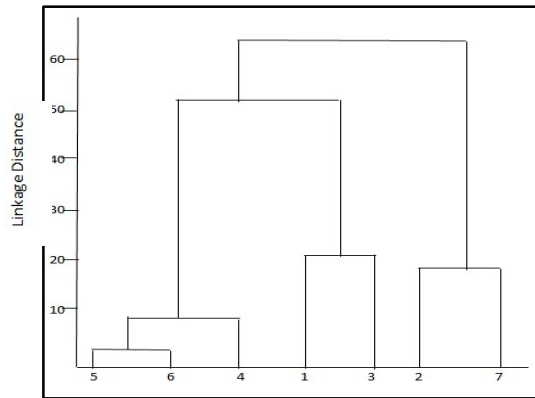


Fig. 3: Hierarchical dendrogram for groundwater samples.

Based on the established water quality index (WQI) values, the map shown in Fig. 2 illustrates the distribution of groundwater quality across the study area. As shown in Table 8, most of the region is categorized 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.

Hierarchical Cluster Analysis

In environmental studies, one of the most popular multivariate statistical methods is Hierarchical Cluster Analysis (HCA) (Díaz & Aldape 2002). It is frequently used for hydrogeochemical data classification (Güler et al. 2002). 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 determine the relationships between various components (Yongming et al. 2006).

In this study, the distance matrix approach was used to perform hierarchical cluster analysis. The clusters were plotted along the two dimensions of the distance matrix, and Euclidean distance was used 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 categorized according to the constituent ion concentration. Total dissolved solids (TDS) values, which represent salinity levels and are correlated 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 had low TDS values ranging from 320 to 460 mg.L⁻¹, indicating minimal groundwater contamination. Cluster 2 comprised samples

4, 5, and 6 and corresponded to a moderately polluted area, with TDS values between 490 and 520 mg.L⁻¹, suggesting moderate salinity and pollution levels. Cluster 3 contained samples 1 and 3 collected from locations near a landfill site. This cluster was identified as highly polluted, likely due to the influence of domestic and agricultural waste, with TDS values ranging from 530 to 570 mg.L⁻¹, indicating high salinity and significant groundwater contamination.

DISCUSSION

Groundwater and leachate samples were collected from and around the Kalenahalli Mandya municipal dumpsite for this study. Physicochemical parameters and heavy metal tests were performed to evaluate groundwater quality at the dumpsite. The percentage of groundwater contamination at the dumpsite was determined by comparing the groundwater quality of this site with that of neighboring Kalenahalli neighborhoods, including Hunasanahalli, Chottahalli, Uramarkasalagere, Sundahalli, and Yeliyur. Appropriate measures were then undertaken to address groundwater contamination.

A study conducted by Satish & Meena Kumari (2024) on the Mandya Kalenahalli dumping site yielded results similar to those of our study, revealing an LPI value of 29.32, which exceeds the limits of Indian standards of disposal. In addition, the physicochemical characteristics of the collected leachate samples showed excessive values when compared with drinking water standards (BIS 2012), which is in line with the results obtained in the current study. Moreover, Madhusudhan et al. (2024) indicated that the water quality index (WQI) of the 35 wards of Mandya district ranges from 28.15 to 193.59, wherein groundwater samples were collected from each ward. The results of the study indicate increased levels of iron and fluoride content, and approximately 60% of the samples fall under poor quality. Although the results of the paper pertain to the wards

of the city, there is a high chance that the water is being contaminated by the improper disposal of waste or leachate matter entering the groundwater system, which is similar to the study investigated and presented in the current paper.

Proper waste management systems, as suggested by Ape et al. (2025) in their study, such as 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 actions, along with public awareness programs to provide information regarding civic responsibility in maintaining health as well as maintaining environmental status. In addition, the current study can explore the possibility of implementing modern eco-friendly methods, such as bioremediation and phytoremediation, at the dumping site.

CONCLUSIONS

In developing countries, groundwater serves as a vital source of water 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 groundwater in the area surrounding the landfill. In contrast, locations farther from the landfill site are less affected by groundwater contamination.

The leachate generated at the Kalenahalli landfill site is less polluted, as indicated by an LPI value of 8.598, which is less than 35. The LPI value indicates that the landfill is moderately contaminated because of low organic matter and low concentrations of contaminants, such as Cl, Zn, and Pb, in the leachate sample.

Groundwater quality at the landfill site was categorized into five classes based on the water quality index (WQI): excellent (< 50), good (50–100), poor (100–200), very poor (200–300), and unfit for human consumption (>300). The WQI was used to measure groundwater suitability for human consumption.

Based on these findings, most groundwater samples from the northeast region are categorized as having high quality, whereas those from the southern region are deemed unfit for human consumption. In addition, 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. Kalenahalli, the dumping site, has extremely contaminated groundwater that is unsafe for drinking.

The seven groundwater samples were grouped into three groups based on their total dissolved solids (TDS) values,

which indicated high, moderate, and low contamination levels. With TDS levels ranging from 320 to 460 mg.L⁻¹, samples 2 and 7 in Cluster 1 were categorized as being from low-polluted sources. The three samples (4, 5, and 6) in Cluster 2 exhibited moderate pollution, with TDS levels ranging from 490 to 520 mg.L⁻¹. Samples 1 and 3 in Cluster 3 had TDS levels ranging from 530 to 570 mg.L⁻¹ and were classified as being from extremely contaminated sources. Patterns in water quality and the causes of pollution were revealed by these TDS measurements. Establishing an engineered disposal site is advised for future management to lessen the effects of leachate on groundwater in the hydrological region.

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