



EVALUATION OF GROUNDWATER QUALITY AFFECTED BY LEACHATE AT AJJAGONDANAHALLI SOLID WASTE DUMP SITE IN TUMKURU, KARNATAKA, INDIA

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ABSTRACT

Waste management has become problematic as a result of rapid urbanization, industrialization, and population growth. Ultimately, the garbage is dumped outside of the city or in a landfill. For the residents of the surrounding areas, the smell of landfills and the leachate that mixed with water bodies made life miserable. By assessing the physico-chemical parameters such as pH, electrical conductivity, total dissolved solids, calcium, magnesium, potassium, nitrate, phosphate, and heavy metals (lead, cadmium, mercury, and arsenic) using Standard APHA methods during August (monsoon period), this paper focuses on the groundwater quality which is contaminated by the leachate surrounding this landfill. It has been found that groundwater samples of this area fall under the 'unsuitable for drinking' category. While pH, EC, TDS, Ca, Mg, K⁺ and NO₃ remain within the safe ranges. But the concentration of phosphate and heavy metals such as Lead, Arsenic, Cadmium and mercury was found to be below the detection. However, the elevated WQI and ionic correlations indicate the onset of leachate percolation into the aquifer. Continuous monitoring, coupled with engineered landfill management practices such as leachate collection, liners, and treatment systems, is recommended to safeguard groundwater.

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Keywords: Groundwater contamination, Heavy metals, landfill, leachate, WQI.

INTRODUCTION

In many cities around the world, notably in developing nations like India, managing municipal solid waste (MSW) is a major challenge. Inappropriate disposal, open dumps, and environmental pollution are among the glitches caused by the growing volumes of waste brought on by fast urbanization and industrial expansion (Jithendra *et al.*, 2022; Alexander and Co. 2022; Carmen-Niño *et al.* 2023). Ineffective waste collection methods, societal perceptions, poor infrastructure, and a scarcity of appropriate

management methods make the issue worse and have an influence on ecosystems, economies, and public health (Adabousi, 2022; Kovalenko *et al.*, 2022). Human life, wildlife, and vegetation are at risk when MSW is improperly managed because it releases leachate that encompasses dangerous pollutants like sulphur dioxide, mercury, and black carbon. Municipal solid waste, industrial waste, sanitary waste, and other hazardous waste are all frequently disposed of in landfills worldwide (Siddiqua *et al.*, 2022).

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Landfills continue to play an crucial role in waste management approaches despite criticisms regarding health and environmental risks. They produce leachate and gases like CO₂ and methane, which greatly enhance greenhouse gas emissions (Mishra *et al.*, 2020; Yin *et al.*,2020). For effective MSW management, these issues must be mitigated through better waste collection routes, better operational planning, community involvement, and investments in human and technological resources. At the moment, major Indian cities have fully cut off their aquifers over the past three decades owing to an increased dependence on groundwater for drinking and irrigation due to the country's fast population growth.

On the other hand, leachate that gradually emerges from these solid waste disposal sites and the surrounding area has a higher probability of contaminating groundwater. (Fatta *et.al.*, 1999;A.Gupta *et.al.*,2024; Lee *et.al.*,1993), because it may contain a range of organic and inorganic materials as by-products of its breakdown (Magda M.Abd El-Salam *et.al.*,2015). This has mainly resulted from leachate percolating from unscientific dumping in major cities and nations worldwide, which has led to surface water contamination during the rainy season and underground water contamination(Suna Erses *et.al.*,2005). Municipal, commercial, and industrial solid wastes that encompass hazardous materials may increase the health risks to local users (children are notoriously vulnerable) and the environment²⁰, as well as the safety of society, from leachate and landfill gases (Suna Erses *et.al.*, 2005). In recent years, several studies have become more interested in the influence of leachate on surface and ground water (De Rosa *et.al.*,1996; Abu-Rukah *et.al.*,2001). To develop a feasible and sustainable solution for reducing groundwater pollution attributable to solid waste disposal, a comprehensive evaluation is necessary. Waste disposal techniques, groundwater flow, lithological variation, contaminant transfer, and leachate and groundwater quality characterization are all included.

1. Materials and Methods

2.1 Study Area

The centralised solid waste disposal facility (Ajagondanahalli Landfill Site) is located in Ajagondanahalli village in the Tumkuru Taluk of the Tumkuru district of Karnataka, India. Ajagondanahalli village is located about 12 km from the city headquarters. There are approximately 148 households in Ajagondanahalli village, the total geographical area of which is 343.08 hectares, and the geographical location of Ajagondanahalli village is 13.25'45" N and 77.99'E. according to the 2011 census, the literacy rate of Ajagondanahalli village is 74.25 and the literacy rate of the village is 79.33 and of the women is 68.75. Ajagondanahalli landfill site spread over 42 acres was started in December 2014, leading to a massive protest by villagers.In 2017, a private agency, Sadhana Enviro Engineering Services, took over the operation and maintenance of the plant for a one year contract, after which the plant was shut down for a few months in 2018.

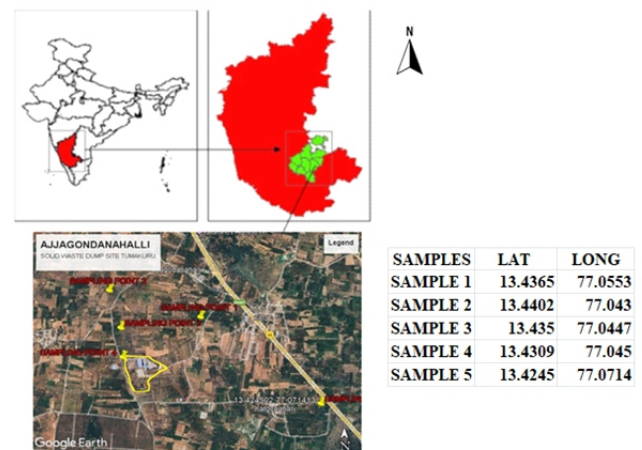


Fig 1: Study area showing Google map of Ajagondanahalli site area with sampling points.

2.2 Methodology

A preliminary field survey was carried out to determine sampling points around the site in order to understand groundwater contamination from leachate. Overall, five groundwater samples were taken randomly during the 2025 monsoons, all five samples were collected using 1L plastic sampling bottles, rinsed with distilled

water, dried and washed with the sample water according to standard APHA methods. Fig.1 shows the sampling points on Google Earth. For the analysis of heavy metals, samples were taken in polyethylene bottles and 2 ml of nitric acid was added to prevent precipitation. The samples were labelled and stored in ice boxes until transport to the laboratory where they were kept at 4 degrees Celsius until analysis. The groundwater quality was assessed by the use of a gravimetric method to analyse certain physico-chemical parameters and heavy metals such as Pb, Cd, As and Hg; pH and electrical conductivity were measured by the use of pH and conductivity meters. For the heavy metal analysis, potassium was determined by flame photometric method, whereas NO₃ and PO₄ were analysed by spectrophotometric method by means of a visible spectrophotometer. and the water quality index has been calculated and statistical analysis like correlation analysis with heat map was performed using SPSS software.

2.3 Water Quality Index (WQI)

Water quality testing involves a wide range of parameters and the simple form of the National Sanitation Foundation Water Quality Index (NSF-WQI) makes it possible to communicate this in a concise manner. The method of calculating the water quality index (WQI) as demonstrated based on the weighted arithmetic index method to understand the suitability of water for human consumption (Yisa and Tijani (2010). The WQI measures the combined impact of a number of characteristics related to water. The quality rating scale for each parameter q_i was calculated by the following equation

$$q_i = (C_i/S_i) \times 100$$

The value of the quality rating scale (q_i) for each parameter was obtained by dividing the concentration of the corresponding standard (C_i) in each water sample by the value of the standard (S_i) multiplied by 100.

For the determination of relative mass (W_i), a value inversely proportional to the proposed standard (S_i) of the associated parameter was used.: $W_i = 1/S_i$

The total water quality index (WQI) was calculated by adding the qualitative value (q_i) and the unit weight (w_i) linearly:

$$WQI = \sum W_i q_i$$

$$i = n$$

$$i = 1$$

In this study, the WQI for drinking water is taken into account and the permitted WQI for drinking water is expressed as 100:

$$\text{Overall WQI} = \sum W_i q_i / \sum W_i$$

1. Result and Discussion

The analytical results of the physicochemical characteristics of groundwater samples around the Ajjagondanahalli landfill are presented in Table 1. The descriptive statistics of groundwater samples around the Ajjagondanahalli landfill show that most physicochemical parameters, including pH (6.82–7.76), EC (856–1265 $\mu\text{S}/\text{cm}$), TDS (484–704 mg/L), calcium (57.6–106.4 mg/L), magnesium (27.7–50.06 mg/L), nitrate (0.15–0.41 mg/L), and potassium (1.51–4.92 mg/L), fall within the BIS permissible limits for drinking water. The mean values of TDS (612.2 mg/L) and EC (1087.8 $\mu\text{S}/\text{cm}$) indicate moderate mineralization and ionic content, which are consistent with findings reported near other landfill sites (Fatta *et al.*, 1999; Gao *et al.*, 2009).

Although parameters remain within permissible levels, the higher values of calcium and magnesium reflect the carbonate lithology of the study area aquifer, which contributes to water hardness. Comparable hydro geochemical patterns have been observed in studies from Jordan (Abu-Rukah & Al-Kofahi, 2001) and Morocco (Smahi *et al.*, 2013), where landfill leachate interacted with carbonate aquifers.

3.1 Heavy Metal Analysis

Heavy metal pollution in water sources is a significant global environmental concern with detrimental effects on aquatic ecosystems and human health. Major sources of contamination include anthropogenic activities such as agricultural practices, mining activities, industrial operations, urbanization, etc (Aziz *et al.*, 2023). Numerous studies revealed that

elevated levels of heavy metals like Iron, Copper, Zinc, Lead, and Cadmium in water, sediment, and fish samples, pose risks to public health and ecosystem integrity(He *et al.*, 2023). Heavy metal pollution not only alters the diversity and composition of microbial communities but also impacts surface water, sediment, and groundwater ecosystems. In this study, the concentration of Heavy metals (Pb, Hg, As, Cd) and phosphate were below the detection limits, suggesting that the landfill is not yet contributing significant heavy metal contamination. Similar observations of non-detectable or low heavy metal levels in young or partially managed landfills were made by Mor *et al.*, (2006) and Abd El-Salam & Abu-Zuid (2015).

3.2 Water Quality Index (WQI)

Groundwater is the major source for agriculture, drinking, and other activities for the people in Ajjagondanahalli, and the surface water bodies are used by cattle for drinking purposes. During rain, there are high chances that the leachate may flow from the waste heap and pollute the surface and groundwater bodies near the landfill. The water Quality index can be implied to rate the overall water quality and suitability for human consumption. The computed values of WQI of groundwater samples are presented in Table 2.and The water quality index classification is presented in Table 3.WQI of groundwater samples in Fig.2.

Table: 1 Physicochemical analysis of Groundwater around Ajjagondanahalli Landfill.

Sl/no	Parameters	units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Min	Ma	Mean	S D	BIS permissible limit for drinking water
1.	pH	---	6.82	7.54	7.5	7.03	7.76	6.82	7.76	7.33	0.389872	6.5-8.5
2.	E C	μS/cm	856	915	1265	1208	1195	856	1265	1087.8	187.7038	3000 μS/cm
3.	T D S	mg/l	507	484	704	688	678	484	704	612.2	107.2436	2000mg/l
4.	Ca	mg/l	57.6	74.4	76.8	106.4	92.8	57.6	106.4	81.6	18.65047	200mg/l
5.	Mg	mg/l	34.02	27.7	41.76	50.06	49.57	27.7	50.06	40.622	9.759637	100mg/l
6.	NO ₃	mg/l	0.27	0.15	0.41	0.32	0.19	0.15	0.41	0.268	0.103537	45mg/l
7.	K ⁺	mg/l	3.45	2.47	2.25	4.92	1.51	1.51	4.92	2.92	1.31533	10mg/l
8.	PO ₄	mg/l	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.3mg/l
9.	Pb	mg/l	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.05mg/l
10.	Hg	mg/l	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.001mg/l
11.	As	mg/l	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.05mg/l
12.	Cd	mg/l	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01mg/l

Table 2: Computed values of WQI of groundwater samples.

Parameters	Relative weight (wi)	Sample 1 w _{iqi}	Sample 2 w _{iqi}	Sample 3 w _{iqi}	Sample 4 w _{iqi}	Sample 5 w _{iqi}
pH	0.117	80.35294	88.82353	88.35294	82.82353	91.41176
Electrical Conductivity μS/cm	0.000333	28.53367	30.50033	42.167	40.267	39.83367
TDS mg/l	0.0005	25.3505	24.2005	35.2005	34.4005	33.9005
Calcium mg/l	0.005	28.805	37.205	38.405	53.205	46.405
Magnesium mg/l	0.01	34.03	27.71	41.77	50.07	49.58
Nitrate mg/l	0.022222	0.622222	0.355556	0.933333	0.733333	0.444444
Potassium mg/l	0.1	34.6	24.8	22.6	49.3	15.2
Σ w _{iqi}	0.255055	232.2943	233.5949	269.4288	310.7994	276.7754
WQI		910.7617	915.861	1056.356	1218.558	1085.16

Table 3: Water Quality index classification using calculated WQI values.

WQI value	Class	Explanation
<50	Excellent	Good for human health
50–100	Good water	Fit for human consumption
100–200	Poor water	Water not in good condition
200–300	Very Poor water	Need attention before use
>300	Unsuitable for drinking	Need too much attention

From the above calculated WQI values (910.7–1218.5) for all samples clearly fall under the category “unsuitable for drinking” (>300). Despite most individual parameters being within safe limits, the cumulative WQI indicates severe deterioration of water quality. This result

highlights the sensitivity of the WQI method in capturing the combined impact of even moderate increases in multiple parameters, in line with the weighted arithmetic index approach (Ramakrishnaiah *et al.*, 2009).

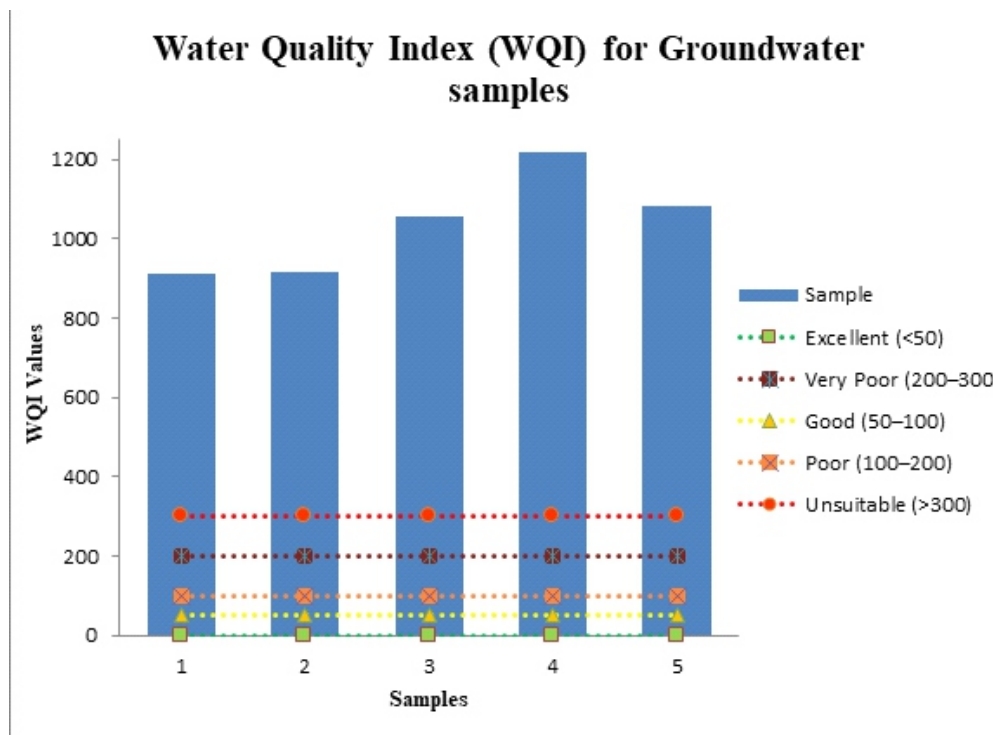


Fig. 2: Water Quality Index of groundwater samples.

The extremely high WQI values are indicative of progressive leachate infiltration into groundwater. Comparable studies in Dhaka (Azims *et al.*, 2011), Egypt (Abd El-Salam & Abu-Zuid, 2015), and Tunisia (Marzougui & Mammou, 2006) have also shown that groundwater down gradient of landfills often rapidly exceeds drinking water suitability thresholds, even when individual contaminants remain below detection limits. This emphasizes the importance of integrated index-based approaches in groundwater quality monitoring.

Therefore, appropriate treatment measures and proper management aspects are required to improve the water quality as it is directly linked to the health of cattle and local people.

3.3 Correlation Analysis

The correlation analysis is done to understand the degree of linear association between the variables. The correlation coefficient ranges from -1 to 1, where -1 indicates a negative linear relationship i.e. if one variable increases the other decreases and vice versa. There is no linear

relationship if the correlation is 0 and +1 indicates a perfect positive linear relationship. Simultaneously, Correlation analysis was also

performed to establish relationships between analysed parameters as variables (Table 4).

Table 4: Correlation analysis of Groundwater samples.

	pH	EC	TDS	Ca	Mg	NO ₃	K ⁺
pH	1						
EC	0.417086	1					
TDS	0.286346	0.980751	1				
Ca	0.250574	0.724014	0.702949	1			
Mg	0.122411	0.826809	0.898043	0.797025	1		
NO ₃	-0.31462	0.552861	0.602545	0.069393	0.362701	1	
K ⁺	-0.82145	-0.07551	-0.00133	0.2807	0.15215	0.31758	1

Blue signifies a negative linear relationship, light blue no relationship, and Red a positive linear relationship.

Correlation analysis reveals strong positive associations between EC and TDS ($r = 0.981$, $p < 0.01$) and between TDS and Mg ($r = 0.898$, $p < 0.05$), reflecting the ionic dominance of magnesium salts in controlling groundwater conductivity. A positive correlation between EC and Ca ($r = 0.724$) also suggests that dissolved calcium salts contribute significantly to total ionic load, as reported in earlier landfill-affected aquifers (Fatta *et al.*, 1999; Looser *et al.*, 1999).

On the other hand, pH showed a strong negative correlation with potassium ($r = -0.821$), implying that acidic conditions may facilitate the mobilization of K⁺ from leachate or soil minerals. Similar inverse relationships between pH and certain cations have been reported in studies from India and Sri Lanka (Esakku *et al.*, 2007) and Sweden (Flyhammar, 1995). Nitrate displayed weak positive correlations with EC and TDS, though values remained far below the BIS permissible limit. This suggests that leachate infiltration during monsoon contributes modestly to nutrient enrichment, a finding consistent with studies in seashore and humid

landfill settings (Tian *et al.*, 2005; Yin *et al.*, 2020). Overall, the correlation patterns indicate that groundwater chemistry in the study area is largely governed by ionic dissolution and early-stage leachate percolation, though the absence of detectable heavy metals suggests limited long-range contamination at present.

1. Conclusion and Recommendations

The evaluation of groundwater quality around the Ajjagondanahalli landfill site indicates that, although most individual physico-chemical parameters such as pH, EC, TDS, Ca, Mg, and NO₃ fall within BIS permissible limits, the Water Quality Index (WQI) values (910–1218) classify all samples as unsuitable for drinking purposes. This demonstrates that the combined effect of multiple parameters has a more significant impact on groundwater quality than individual measurements suggest. Correlation analysis further revealed strong positive relationships among EC, TDS, Ca, and Mg, highlighting the dominance of hardness-producing ions in controlling groundwater chemistry. The negative

association between pH and potassium points to leachate influence, where potassium emerges as a sensitive early tracer of contamination. Heavy metals and phosphate were below detection limits, suggesting limited contamination at present; however, the elevated WQI and ionic correlations indicate the onset of leachate percolation into the aquifer. Continuous monitoring of groundwater, coupled with engineered landfill management practices such as leachate collection, liners, and treatment systems, provide good water from other sources to the community is recommended to safeguard groundwater.

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6. Conflict of Interest

The authors do not have any conflict of interest.

7. Funding Sources

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8. Data Availability Statement

This statement does not apply to this article.

9. Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

10. Clinical Trial Registration

This research does not involve any clinical trials.

11. Authors' Contribution

Kariyanna Harisha: Research Scholar worked for the study in Conceptualization, Sampling, Experiment design, Laboratory experiments, Data analysis and original drafting of paper. Jambhava Samavedamuni. Chandrashekar: Research Guide and reviewed the study.

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