Ethiopian Journal of Water Science and Technology (EJWST)

DOI: https://doi.org/10.59122/EJWST923

Vol. 9, 2026, Pages: 151~178 ISSN (Print): 2220-7643

Assessment of Water Quality and Associated Health Risks near Addis Ababa Repi Open Dumping Site in Ethiopia

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ABSTRACT

Open dumping remains a common urban waste disposal method in developing nations, including Ethiopia. The Addis Ababa Repi dumping site operates without liner or leachate management, posing risks to surrounding water resources. This study assessed water quality in five groundwater wells (GW1-GW5) and six Jemo River locations (SW1-SW6) during the rainy season (August, 2024). A leachate sample was collected from the site. Parameters used to analyze included pH, turbidity, TDS, nitrate, cyanide, total coliforms, and fecal coliform bacteria. Non-carcinogenic health risks from NO_3^- were assessed using the Hazard Quotient (HQ). Health risks from CN^- and microbial contamination were discussed qualitatively based on drinking water standards. Leachate from Repi showed severe contamination: pH 8.8, turbidity 550 NTU, TDS 15,900 mg/L, NO_3^- 38.7 mg/L, CN^- 0.504 mg/L, TCB 5,100 CFU/100 mL, and FCB 220 CFU/100 mL. Groundwater chemical parameters were within drinking standards. However, GW1 and GW2 (southeast, down gradient) showed fecal contamination (1 CFU/100 mL) exceeding the standard, suggesting possible leachate influence. River water exhibited severe degradation downstream of the dumpsite. Turbidity (48-172 NTU) and TDS (1,401-1,983 mg/L) were used to classify the river water as unacceptable for drinking but useful for irrigation. All river samples showed fecal coliform counts (33-110 CFU/100 mL) far above permissible limits. Downstream site SW6 showed the highest FCB (110 CFU/100 mL) and CN^- (0.143), while upstream sites SW1 and SW2 had elevated CN^- (0.396-0.197 mg/L) from community and industrial wastes, indicating multiple pollution sources. HQ values for NO_3^- were < 1 for all samples, indicating negligible health risk. This study recommends water quality monitoring and remediation near open dumping sites in urban Ethiopia.

Keywords: Dumping Site, Groundwater, Health Risks, Microbial Contamination, River Water

Received: 11 February, 2026; Accepted: 15 May, 2026 Published: 11, June 2026

1. INTRODUCTION

Solid waste refers to discarded materials from residential, commercial, institutional, and industrial activities that are no longer of value to the generator (Mesfin, 2017; Teshome, 2021). A rapidly increasing urban population causes a dramatic increase in the generation and complexity of urban solid waste, with crucial socio-economic, environmental, and public health impacts (Mesfin, 2017; Teshome, 2021). Solid waste management remains one of the most critical environmental challenges in developing nations. Across Africa, Asia, and Latin America, rapid urbanization and changing consumption patterns have led to exponential increases in solid waste generation. The World Bank (WB) estimated that global solid waste generation would increase from 2.01 billion tons in 2016 to 3.40 billion tons by 2050 (Kaza et al., 2018).

Open dumping is the cheapest disposal method for urban solid waste in developing nations, including Addis Ababa, Ethiopia. It poorly manages wastes, posing serious threats to the surrounding environment and public health (Tyagi, 2014). Leachate happens when severely polluted wastewater precipitates and percolates through the waste layer (Gelan, 2021). Leachate consists of organic and inorganic compounds, heavy metals, and disease-causing microorganisms (Arukwe, 2012; Eggen, 2010). Contaminants from dumpsites reach water resources through two primary pathways: (1) vertical percolation of leachate through permeable soils into groundwater aquifers, and (2) surface runoff and direct leachate flow into surface water sources (El-Salam & Abu-Zuid, 2014; Javahershenas et al., 2020).

Studies have shown that even small volumes of leachate from landfills can contaminate large volumes of water resources in urban areas such as Kumasi in Ghana (Amano et al., 2021), Dhaka in Bangladesh (Hredoy et al., 2022), Amazonia in Brazil (Queiroz et al., 2022), and Tychy in Poland (Dabrowska & Witkowski, 2022). Leachate contamination is more severe in developing countries where dumping sites lack bottom liners and leachate management systems (Asifa, 2017). This lack of infrastructure can present major risks to the environment and public health as toxic materials seep into the soil and water sources. As a result of increased exposure to harmful pollutants, public health problems may worsen in communities near these sites (Hredoy et al., 2022).

Open dumping sites contribute to increased soil and water contamination, environmental harm, and disease transmission (Kassahun, 2018; Paweena, 2022). Water resources, soil, and plants near dumping sites are at high risk of contamination, posing serious impacts on local residents and the environment (Anum, 2019; Kofi, 2021; Paweena, 2022; Rysul, 2022).

For humans, the ingestion of contaminated water into soil and consumption of crops grown near dumping sites are the main exposure pathways causing public health problems (Alam, 2013; Anum, 2019). Dumping sites have caused significant harmful effects on resident health, including cholera, diarrhea, typhoid fever, and allergies (Debnath, 2016). Pollutants leaching from these sites pose considerable public health risks through carcinogenicity, mutagenicity, and acute toxicity (Luo, 2020).

Contaminants from dumping sites can persist in the environment for 50 to 100 years, causing long-term risks to human health and the environment if not properly managed (Bashir, 2009; Naminata et al., 2018). Treatment and recovery of contaminated water and soils is difficult and requires huge investment costs (Paweena, 2022). Environmental monitoring and detailed investigations near dumping sites provide early warning of contamination before costly remedial actions are required. Risk assessment identifies hazards, investigates potential risks, quantifies the magnitude and probability of expected harms, and formulates risk-reduction strategies (Ana, 2014; Asifa, 2017).

In Ethiopia, open dumping remains a significant concern (Gelan, 2021). Few studies on open dumping sites are limited to solid waste, leachate and water quality characterization without comprehensive examination of environmental and health risks (Besufekad, 2020; Tamru, 2022; Tigistu, 2012). The Addis Ababa Repi open dumping site is characterized by unmanaged leachate production and poor management (Alemayehu, 2001; Tigistu, 2012).

To our knowledge, previous studies near Repi have not: (1) assessed Jemo River water quality in relation to dumpsite leachate, (2) evaluated non-carcinogenic health risks from nitrate exposure, or (3) indicated cyanide as a contamination indicator. Cyanide was included because it is a highly toxic compound commonly found in leachate from uncontrolled dumpsites owing to disposal of industrial and electronic wastes, yet it has not been previously studied. This study addresses these gaps. Therefore, this study assessed water quality and associated health risks

near the Repi open dumping site to inform future interventions. The specific objectives of this study were to: (1) characterize leachate, groundwater, and river water quality near the Repi dumping site; (2) assess non-carcinogenic health risks from nitrate exposure; and (3) identify potential contamination sources including previously unstudied cyanide.

2. METHODS AND MATERIALS

2.1. Study Area

2.1.1. Location and Climate

The Repi (called Koshe) open dumping site is located in Addis Ababa, Ethiopia, approximately 13 km southwest of the city center coordinates: 8° 580 57″ N, 38°410 78″ E). The site covers 37 hectares at an elevation of approximately 2,276 m above sea level (Figure 1). The area receives an average annual rainfall of approximately 1200 mm, with the rainy season occurring from June to September. Mean annual temperatures range from 10°C to 25°C (Tigistu, 2012).

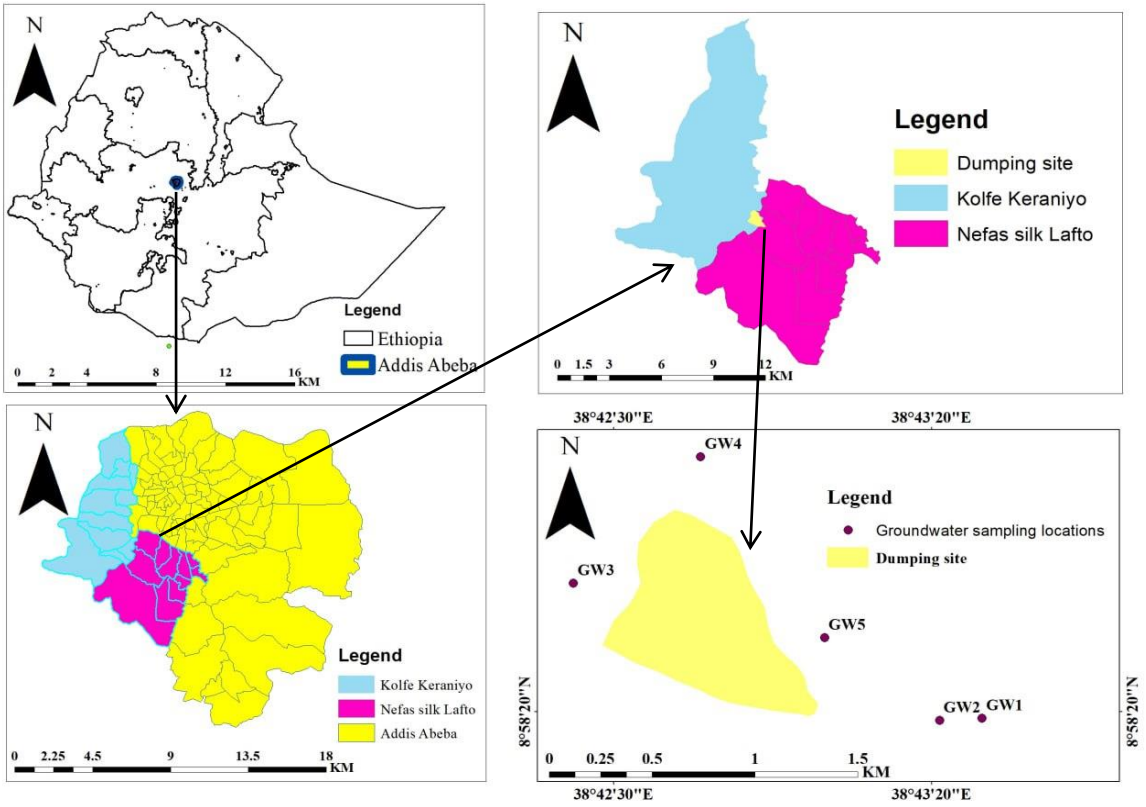

Figure 1: The location of the study area.

2.1.2. Dumpsite Characteristics

The Repi site began operation in 1964 and has been active for 60 years, making it an aged dumpsite. It receives approximately 3000 tons of municipal solid waste daily (Sime, 2012), composed of 40-50% organic matter, 20-30% plastics, 10-15% paper and cardboard, 5-10% metals and glass (Desta, 2022). The waste depth at the site is estimated at 40 meters (Hagos, 2020). The site has no engineered bottom liner, nor leachate collection system. Besides, it has inadequate fencing consistent with the Ethiopian Environmental Protection Authority's classification as open dumping site (Maschal, 2009). A small leachate treatment system exists on the site, but a significant untreated leachate flows east and southwest, eventually reaching the Jemo River approximately 1.9 km downstream (Figure 2).

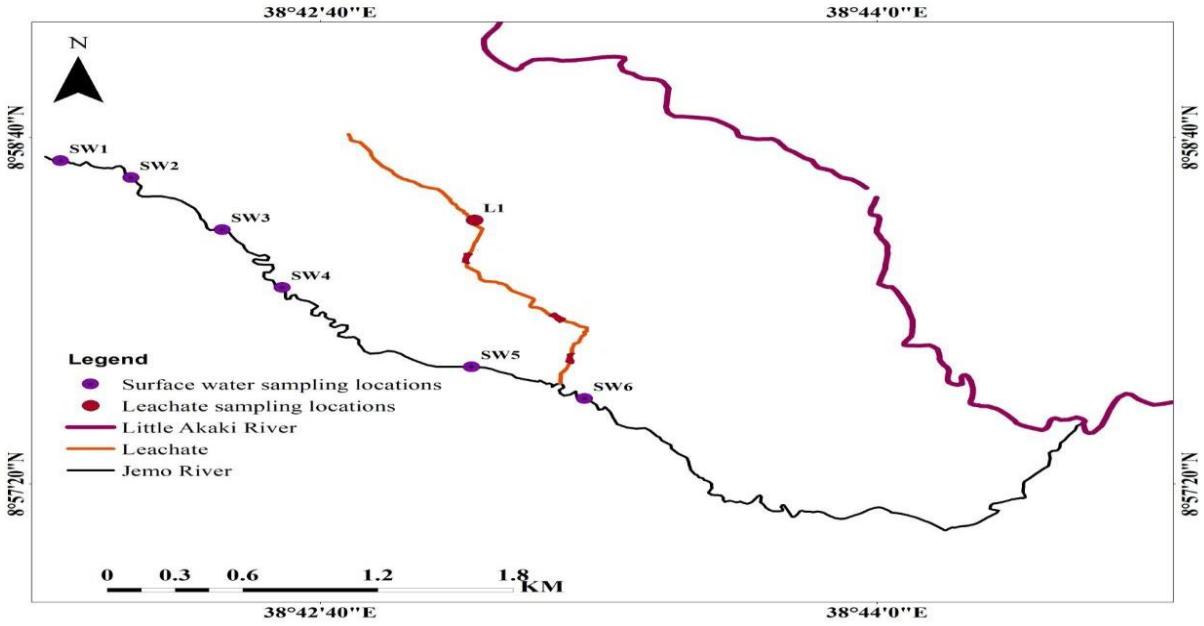

Figure 2: Leachate traveling and joining the studied Jemo River.

2.1.3. Hydrogeology and soils

The dominant soil types in the study area are Eutric Nitisols, and Chromic and Pellic Vertisols. Eutric Nitrisols are deep, weathered soils with porous structure and good permeability, facilitating vertical leachate percolation. Chromic and Pellic Vertisols are clay-rich soils that crack during the dry season, but become nearly impermeable when wet, restricting deep percolations (Figure 3).

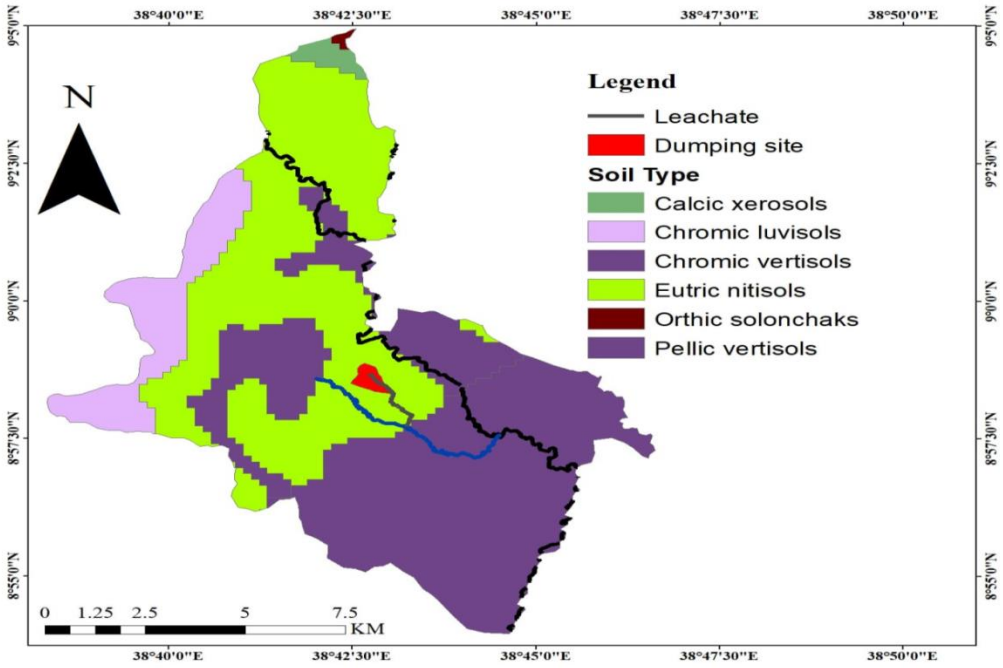

Figure 3: Soil type of the study area (Ethiopian soil map)

Groundwater in the area flows primarily southward, following topographic gradients, as determined by the eight-direction (D8) flow model (Kshetri & Dahal, 2023) (Figure 4). The aquifer is unconsolidated and appears to be unconfined, with static water levels ranging from 0 to 156.8 m (average 74.4 m) in the upstream area and 0 to 111.2 m (average 35.3 m) in the downstream area (Addis Ababa Water and Sewerage Authority, unpublished data). Static water level data for the five sampled wells were not available due to incomplete historical records. Based on data from 37 other wells in the study area, average static water level was 74.4 m in the upstream area (Kolfe Keranio Sub-City) and 35.3 m in the downstream area (Nifas Silk Lafto Sub-City), indicating decreasing groundwater depth in the down-gradient direction.

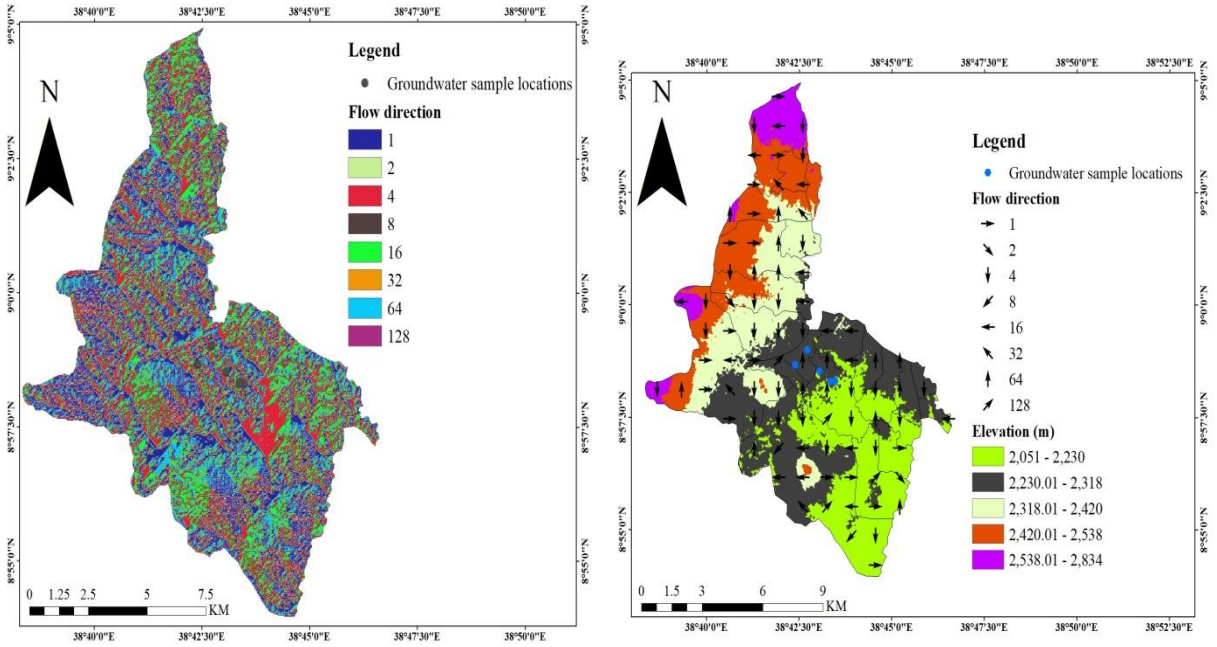

Figure 4: Groundwater flow direction in the study area.

2.1.4. Sampling Location

Five groundwater wells (GW1-GW5) within a 2 km radius of the dumpsite (Figure 1) and six Jemo River locations (SW1-SW6) (Figure 2) were purposively selected for sampling. A leachate sample was also collected from the site (Figure 2). Well locations were chosen based on distance from the dumpsite (0.37-1.73 km) and direction relative to groundwater flow (upstream, adjacent, and downstream). All the groundwater wells were used for domestic purpose such as drinking, food preparation, and hygiene and cleaning. River sampling points included upstream (SW1, SW2), adjacent (SW3, SW4), and downstream (SW5, SW6) locations relative to the dumpsite. Although river water is not typically consumed directly, it is used for showering, gardening, livestock watering, and washing clothes, which can lead to incidental ingestion or dermal contact. During water shortages, some residents collect and treat river water for domestic uses including drinking. Therefore, health risks from river water exposure were assessed. The geographic coordinates, altitudes, and distance from the dumpsite for all samples are presented in Table 1.

Table 1: Groundwater, surface water and leachate sampling points

Samples	Latitude	Longitude	Altitude	Distance and direction from the site
GW1	8° 58' 18.9" N	38° 43' 27.9" E	2264	1.73Km ↘
GW2	8° 58' 18.6" N	38° 43' 21.2" E	2251	1.54Km ↘
GW3	8° 58' 40.5" N	38° 42' 23.6" E	2294	0.37Km ←
GW4	8° 59' 0.7" N	38° 42' 43.6" E	2309	0.68Km ↑
SW1	8° 58' 39.0" N	38° 42' 11.5" E	2290 m	Upstream at 0.66 Km
SW2	8° 58' 36.9" N	38° 42' 14.6" E	2271 m	Upstream at 0.42 Km
SW3	8° 58' 22.8" N	38° 42' 29.2" E	2275 m	Adjacent
SW4	8° 58' 23.3" N	38° 42' 28.3" E	2275 m	Adjacent
SW5	8° 57' 43.8" N	38° 43' 10.7" E	2240 m	1.56 Km
SW6	8° 57' 39.7" N	38° 43' 18.0" E	2231 m	1.92 Km
L1	8° 58' 26.4" N	38° 43' 28.8" E	2276 m	At the site

2.2. Sample Collection and Analysis

2.2.1. Sampling Design

A transverse walk survey was conducted in the study area for one week in July, 2024 to identify leachate emergence and travel points from the dumpsite and to locate nearby water sources. Based on this visual inspection, five groundwater wells (GW1-GW5) within a 2 km radius of the dumpsite and six Jemo River sampling locations (SW1-SW6) were purposively selected. A single leachate sample (L1) was collected directly at the dumpsite. Background groundwater quality reference data were obtained from the school well, located approximately 1.9 km upstream of the dumpsite (Weju & Getaneh, 2024). The geographic coordinates of all samples are presented in Table 1.

2.2.2. Sample Collection

At each sampling location, triplicate samples were collected for each point and composited in the field to obtain representative samples (Hredoy et al., 2022). For groundwater, wells were purged for approximately 5 minutes before sampling. River water samples were collected from mid-stream by hand using pre-cleaned bottles. All samples were collected during rainy season (August, 2024). Seasonal variability in leachate generation, contaminant dilution, and transport are expected. Findings may represent wet season conditions only and should not be generalized to annual averages without further dry season sampling.

Water samples were collected using sterilized and acid-washed 1 L high-density polyethylene (HDPE) sample bottles. Prior to sampling, each bottle was rinsed three times with the water to be sampled. Samples were stored in iceboxes at approximately 4°C during transport to the laboratories and preserved at 4°C until analysis. All sample collection, preservation, and analysis followed standard protocols of the American Public Health Association (APHA, 2005) and World Health Organization (WHO, 2011).

2.2.3. Analytical Methods

The eight studied quality parameters were analyzed in the Water Quality Laboratories at Arba Minch University. The units and determination methods were described in Table 2.

Table 2: Laboratory methods used to determine leachate and water quality

Parameters	Unit	Measuring method
Temperature	°C	Electrometric method (HQ40D *multi-meter)*
pH	pH scale	
Total Dissolved Solids (TDS)	mg/L	
Turbidity	NTU	Nephelometric turbidimeter
Nitrate (No_3^-)	mg/L	Spectrophotometric method
Cyanide (CN-)	mg/L	UV Visible spectrophotometry (SPCORD 50 model, Germany*)* following APHA standard method
Total Coliform bacteria (TCB)	CFU/100 mL	Membrane filtration method. Result reported as colony-forming units per 100 mL (110 CFU/100 mL)
Fecal Coliform bacteria (FCB)	CFU/100 mL	

2.2.4. Quality Control and Assurance

To assure the quality of laboratory results, each parameter was analyzed in triplicate and the mean value was reported. Cyanide analysis followed APHA method, 4500-CN^- for total cyanide. Samples were preserved after collection, stored at 4°C in the dark, and analyzed within 14 days. This was the recommended holding time for cyanide samples. Triplicate analyses were performed to ensure precision. According to the method, the lower limit of determination ranged from 0.005-0.020 mg/L (APHA, 1992). To avoid uncertainty associated with this range, a conservative detection limit of 0.020 mg/L was adopted for this study. Concentrations below this value were reported as < 0.020 mg/L, and were considered semi-quantitative estimates.

2.3. Nitrate Pollution Index (NPI)

The Nitrate Pollution Index (NPI) was used to assess nitrate contamination levels in groundwater samples. NPI categorizes water quality as follows: < 0 (clean water), 0–1 (light pollution), 1–2 (moderate pollution), 2–3 (significant pollution), and > 3 (very significant pollution) (Mountassir et al., 2022; Panneerselvam et al., 2023). NPI was determined using Eq. 1:

$$NPI = \frac{Cs - HAV}{HAV}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

Cs = Measured nitrate concentration in groundwater (mg/L)

HAV = Threshold concentration for anthropogenic nitrate (20 mg/L)

2.4. Health Risk Assessment

Human health risk assessment comprises hazard identification, dose–response assessment, exposure assessment, and risk characterization (Lee J-S, 2005).

2.4.1. Exposure Assessment

Exposure assessment measures the level, frequency, and duration of human exposure to a contaminant (USEPA, 2009). The chronic daily intake (CDI) via ingestion was calculated using Equation (2) (ISPRA, 2013).

$$\mathrm{CDI_{ing}} = \frac{\mathrm{C_{water}} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where:

$\mathrm{CDI_{ing}}$= Chronic daily intake through drinking (mg/kg-day)
$\mathrm{C_{water}}$ = Nitrate concentration in the water (mg/L)
IR = Ingestion rate (L/day): 2 L/day for adults, 1 L/day for children
EF = Exposure frequency (365 days/year)
ED = Duration of exposure (30 year for adult, 6 years for children)
BW = Body mass (70 kg for adults, 30 kg for children)
AT = Average time (days): 10950 days for adults and 2190 for children

These exposure parameters were adopted from similar recent studies done in Ethiopia (Belew et al., 2024) as site-specific data on water consumption patterns were not available. The determination of average time was followed a method from a similar study (Lorestani et al., 2020).

2.4.2. Non-carcinogenic Risk Assessment

Non-carcinogenic human risk from nitrate exposure was assessed using the hazard quotient (HQ) CDI, calculated by Equation (3) (Demissie et al., 2024).

$$\mathrm{HQ}_{ing} \text{ for non} - \text{carcinogenic effect} = \frac{CDI_{ing}}{\mathrm{RfD}_{ing}} \text{.....3}$$

Where RfD is the reference dose for nitrate (1.6 mg/kg-day) (Sailaukhanuly et al., 2024). HQ < 1 indicates negligible non-carcinogenic risk (USEPA, 2009).

Quantitative microbial risk assessment (QMRA) and quantitative cyanide risk assessment were not performed because site specific exposure data were not available. Health risks from CN^- and microbial contamination were therefore discussed qualitatively based on comparisons with drinking water standards.

2.5. Data Analysis

Mean values were determined using SPSS version.23.0. A Spearman correlation analysis was performed to examine the relationship between variables at significance levels of $p < 0.05$ and $p < 0.01$. ArcGIS 10.3 was used to prepare the study area map with clear sampling points. Human health risks from nitrate exposure were assessed using HQ (Equations 3). Measured concentrations were compared with World Health Organization (WHO) and Ethiopian drinking water quality standards. The findings are presented using tables and graphs.

3. RESULTS AND DISCUSSION

3.1. Leachate and Water Quality Characterization

3.1.1. pH Values of Water Resources

pH indicates the acidity or alkalinity of water, controlled by the balance of hydrogen (H^+) and hydroxide (OH^-) ions. The pH values in all studied water samples ranged from 6.97 to 8.37.

Groundwater pH ranged from 6.97 to 7.27, all within WHO and Ethiopian drinking water quality standards (Agency, 2013; WHO, 2011). GW3 (0.37 km west of the dumpsite) indicated the highest pH (7.27), while GW1 and GW5 were neutral (6.97). The slight alkaline pH in GW3 and GW4 (7.23) may reflect leachate influence as mature dumpsite leachate typically exhibits pH (7.5-9.0) owing to ammonia accumulation and methanogenic decomposition of organic waste

(Kjeldsen et al., 2002). The leachate sample from Repi (> 60 years operation) had pH 8.8, consistent with an aged dumpsite (pH > 7.5) (Tchobanoglous et al., 1993; Tejera et al., 2019). For comparison, the upstream reference well (a school well located 1.9 km from the dumpsite) had pH 6.5 (Weju & Getaneh, 2024), which indicated neutral to slightly acidic. The elevated pH in GW3 (7.27) relative to the background (6.5) and proximity to the dumpsite suggested leachate influence on nearby groundwater. Similar studies near Repi reported that groundwater pH values ranged from 7.01 to 7.57 (Haile & Abiye, 2012) to as high as 8.6 (Weju & Getaneh, 2024) to 9.48 (Zewdie, 2007), with variations attributed to seasonal differences and localized contamination sources.

Jemo river water pH ranged from 7.63 to 8.37, all within drinking (WHO, 2011) and aquatic species protection (EPA & UNIDO, 2003) standards. Downstream sites SW5 (8.37) and SW6 (7.97) showed slightly higher pH than upstream sites SW1 (7.97) and SW2 (7.63). This downstream increase aligned with observations on the nearby little Akaki River where pH increased from 7.79 to 8.17 downstream (Haile & Abiye, 2012). The elevated pH at SW5 was due to urban runoff and domestic wastewater discharges while SW6 (collected after leachate enters the river) might receive additional alkaline input from dumpsite leachate. Upstream sites SW1 and SW2 had slightly lower pH but remained alkaline, influenced by community solid waste disposal and poor drainage in upstream residential areas (Table 5).

3.1.2. Turbidity

Turbidity quantifies the degree to which light is scattered by suspended particles in water. In groundwater samples, turbidity ranged from 1.0 to 3.7 NTU, all within WHO and Ethiopian drinking water quality standards of 5 NTU (Table 5). The upstream reference well (a school well located 1.9 km from the dumpsite) had turbidity of 1.12 NTU (Weju & Getaneh, 2024). GW3 (1.0 NTU) and GW4 (1.3 NTU) showed turbidity values similar to the background while GW1 (3.7 NTU), GW2 (1.7 NTU), and GW5 (2.0 NTU) exhibited slightly elevated turbidity, possibly owing to localized influences.

Jemo River water showed severe turbidity ranging from 48.0 to 172.0 NTU, exceeding the drinking water quality by 9 to 34 times (WHO, 2011). The lowest river turbidity (48.0 NTU) was observed at SW3 (adjacent to the site) while the highest (172.0 NTU) was at SW6 (downstream,

after the leachate enters the river). SW5 (153.3 NTU), collected at a downstream location after the river had received apartment wastewater and solid wastes, had the second-highest turbidity. Compared to the five groundwater wells, the background school well (1.12 NTU) and leachate (550 NTU), the extremely high turbidity in river samples had contributions from multiple sources: dumping site leachate, community wastewater discharges, and sediment re-suspension during the rainy season (Table 5).

3.1.3. Total Dissolved Solids (TDS)

TDS concentrations in dumpsite leachate, groundwater, river water, and background reference are presented in Figure 5, with classifications in Table 3 and 4 (Mondal et al., 2005; WHO, 1996). Dumpsite leachate TDS was 15,900 mg/L, a highly elevated value that could pose severe impacts on surrounding water resources.

In groundwater wells, TDS as shown in Table 3 ranged from 528 to 809 mg/L, all within the permissible range of drinking category (500–1000 mg/L) (Mondal et al., 2005). However, all groundwater TDS values exceeded the background well value of 155.1 mg/L (Weju & Getaneh, 2024). Based on taste ranking (WHO, 1996), GW4 (528 mg/L) was good while GW1, GW2, GW3, and GW5 (648–809 mg/L) were fair (Table 4). GW4 (upstream) had the lowest TDS whereas GW1 (southwest, down-gradient) had the highest, suggesting leachate influence through southward groundwater flow. TDS in river water ranged from 1,401 to 1,983 mg/L, exceeding the WHO drinking water quality standard (WHO, 2011), and classified as unacceptable for drinking, but useful for irrigation (≤ 3000 mg/L) (Table 3). The highest TDS was at SW6 (1,983 mg/L) when it was collected after leachate. Upstream sites SW1 (1,594 mg/L) and SW2 (1,410 mg/L) also showed elevated TDS, indicating multiple pollution from community wastes and urban runoffs (Table 5).

Based on TDS concentration for drinking and irrigation suitability (Table 3), the five groundwater samples fell within the ‘permissible range for drinking’ category (500–1000) while all river water samples fell within the ‘useful for irrigation’ category (<3000) (Mondal et al., 2005).

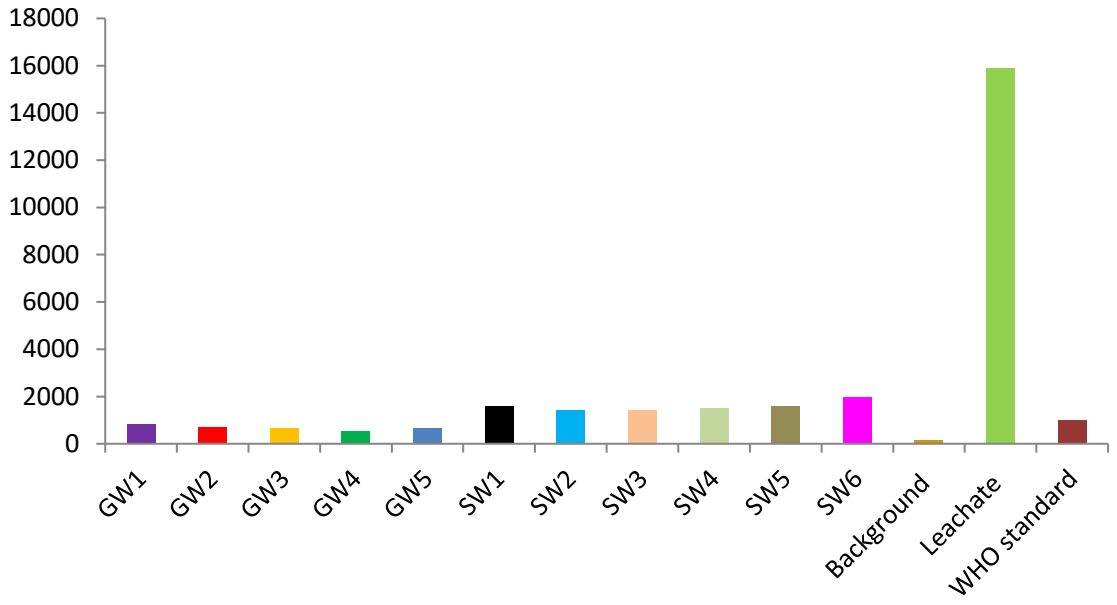

Figure 5: TDS concentrations across all samples

Table 3: Classification of water based on concentration of TDS

TDS	Water type	Samples in the category
Up to 500	Desirable for drinking	No sample, except background reference **(**155.1 mg/L**)**
500–1000	Permissible for drinking	The five groundwater samples
<3000	Useful for irrigation	All the groundwater and surface water samples
>3000	Unfit for drinking and irrigation	Leachate sample

According to the taste ranking classification (Table 4), GW4 was rated 'good' (528 mg/L) while GW1, GW2, GW3, and GW5 were rated as 'fair' (648-809 mg/L) (WHO, 1996). All river water samples were rated as 'unacceptable' (> 1200 mg/L).

Table 4: Classification of drinking water quality based on taste in relation to TDS

TDS	Rating	Samples in the category
< 300	Excellent	No sample, except background reference **(**155.1 mg/L**)**
300 –600	Good	GW4
600 –900	Fair	Four groundwater samples except for GW4
900 –1200	Poor	No sample
> 1200	Unacceptable	All surface water samples including leachate

3.1.4. Nitrate (NO_3^-) Concentrations in Water Resources

Nitrate (NO_3^-) concentration in dumpsite leachate, groundwater, river water, and the background reference are presented in Figure 6 and Table 5. Elevated NO_3^- in drinking water poses health risks including methemoglobinemia (blue baby syndrome) in infants, increased heart rate and abdominal cramp (Gnanachandrasamy, 2021; WHO, 2006). NO_3^- concentration in dumpsite leachate was 38.7 mg/L which was below WHO standard of 50 mg/L, but indicated nitrogen accumulation from decomposing organic waste.

Groundwater NO_3^- ranged from 16.3 to 29.0 mg/L, all within the WHO and Ethiopian drinking water quality standard of 50 mg/L. The background school well (1.9 km upstream) had a NO_3^- concentration of 17.5 mg/L (Weju & Getaneh, 2024). Notably, GW3 (0.37 km) west of the dumpsite (the closest groundwater well to the site) had a NO_3^- concentration of 18.0 mg/L which was nearly identical to the background value (17.5 mg/L). This suggested that the dumpsite was not the dominant source of NO_3^- contamination in the immediate vicinity. In contrast, GW2 (29.0 mg/L) and GW1 (28.0 mg/L), located southeast (down-gradient) at 1.54 km and 1.73 km from the site, showed the highest NO_3^- concentrations. GW4 (north, upstream) had 27.0 mg/L. The spatial pattern of groundwater NO_3^- indicated higher concentrations at downstream wells (GW1, GW2) and upstream wells (GW4). However, the closest well (GW3) showed near-background reference levels. This indicates that NO_3^- originates from multiple sources rather than the dumpsite alone. Potential sources in the study area included community wastewater and open defecation, industrial chemical discharges (reported by Addis Ababa city administration in October, 2025), and agricultural or garden fertilizer use in the surrounding area.

NO_3^- at Jemo River ranged from 2.3 to 31.3 mg/L, all within WHO (WHO, 2011) and aquatic species protection (EPA & UNIDO, 2003) standards. The highest NO_3^- concentration (31.3 mg/L) was observed at SW6, collected downstream after leachate entered the river. SW3 (22.3 mg/L) and SW4 (24.0 mg/L), located adjacent to the dumpsite also showed elevated NO_3^-. Upstream sites SW1 (6.0 mg/L) and SW2 (2.3 mg/L) had the lowest NO_3^- concentrations. This showed that NO_3^- increased with proximity to the dumpsite and downstream transport. However, the river also receives contributions from community waste along its course (Table 5).

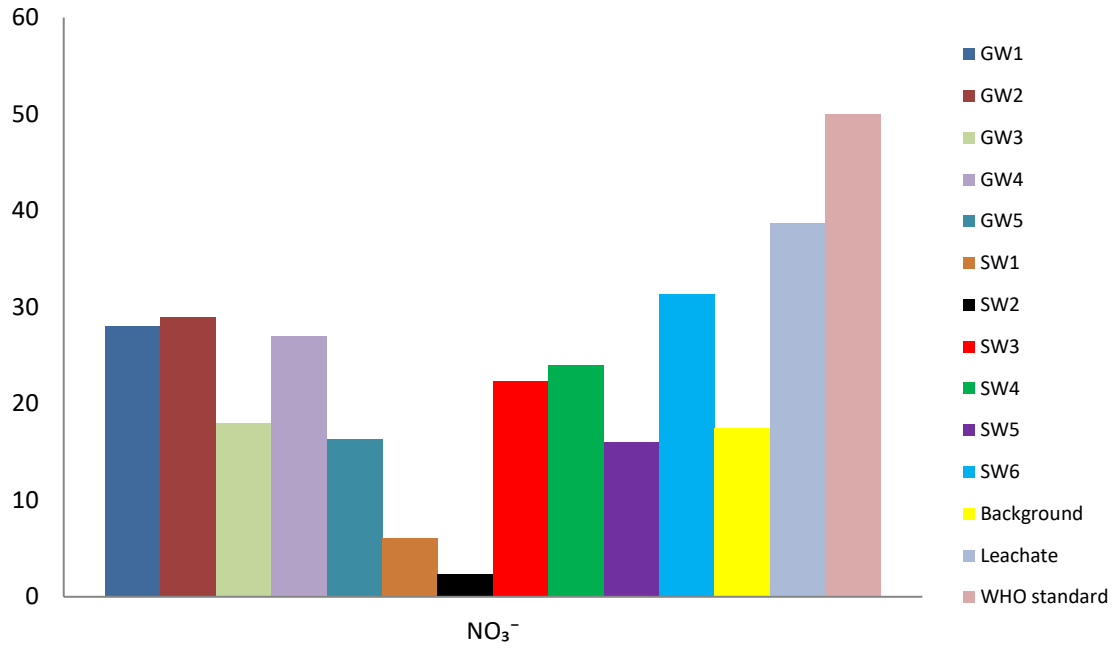

Figure 6: Nitrate (NO_3^-) in leachate, water samples, background reference, and WHO standard

3.1.5. Cyanide (CN^-)

Cyanide (CN^-) is a highly toxic inorganic compound that inhibits cellular respiration by binding to cytochrome c oxidase, leading to histotoxic hypoxia (WHO, 2011). Environmental CN^- originates from industrial effluents, electronic waste, and improper disposal of industrial byproducts. The WHO drinking water guideline for CN^- is 0.07 mg/L while the Ethiopian standard for aquatic species protection is 0.05 mg/L (EPA & UNIDO, 2003). CN^- concentration in Repi dumpsite leachate was 0.504 mg/L, exceeding both the WHO and Ethiopian aquatic species protection guidelines. This indicated that the dumpsite was the source of CN^-.

Groundwater CN^- ranged from < 0.0200 to 0.0414 mg/L, and all below the WHO guideline (WHO, 2011). The highest groundwater concentrations were observed at GW2 (0.0414mg/L) and GW3 (0.0402 mg/), both within safe limits for drinking. CN^- of Jemo River ranged from < 0.0200 to 0.3955 mg/L. Three samples collected after leachate entered the river exceeded the WHO drinking water guideline (WHO, 2011): upstream sites SW1 (0.3955 mg/L, approximately 5 times the guideline) and SW2 (0.1971 mg/L, approximately 3 times the guideline), and downstream site SW6 (0.1434 mg/L).. Four of the six river samples exceeded the Ethiopian

aquatic species protection standard of 0.05 mg/L (EPA & UNIDO, 2003): SW1, SW2, SW4 (0.0681 mg/L), and ,SW6.

Following the adopted detection limit of 0.02 mg/L (APHA, 1992), CN^- concentrations below this threshold (GW4 and SW5) were reported as < 0.02 mg/L in Table 5. All other reported CN^- values were above 0.02 mg/L and considered fully quantitative.

The spatial pattern showed elevation of CN^- at upstream sites (industrial wastes), a decrease through midstream, and a second increase at SW6, indicating additional CN^- input from the Repi dumpsite leachate (Table 5).

3.1.6. Microbial Contamination

Microbial contamination in water poses direct health risks including gastrointestinal diseases, cholera, typhoid fever, and dysentery (WHO, 2011). Total coliform bacteria (TCB) and fecal coliform bacteria (FCB) were analyzed as indicator organisms. FCB (thermo-tolerant coliforms) are considered more reliable indicators of recent fecal contamination than TCB, as TCB can originate from non-fecal environmental sources including soil or vegetation (APHA, 2005). Results for TCB and FCB are presented in Figure 7 and 8, and Table 5.

3.1.6.1. Total Coliform Bacteria (TCB)

Leachate TCB was 5,100 CFU/100 mL. Groundwater TCB counts ranged from 4 to 29 CFU/100 mL, with the highest at GW2 (29 CFU/100 mL) and GW1 (22 CFU/100 mL). River water TCB ranged from 510 to 4,800 CFU/100 mL far exceeding drinking water standards (Table 5). The highest TCB was at SW4 (4,800 CFU/100 mL), located adjacent to the dumpsite, followed by SW5 (4,300 CFU/100 mL) and SW6 (3,100 CFU/100 mL). Upstream sites SW1 (710 CFU/100 mL) and SW2 (612 CFU/100 mL) also showed elevated TCB, indicating contamination sources independent of the dumpsite. However, TCB alone could not confirm fecal contamination, as environmental sources contributed to TCB levels (Table 5). Based on health risk classification for TCB (Alemu et al., 2024), groundwater showed low to moderate health risk, river water showed high to very high risk, and leachate showed very high risk (Figure 7). This indicated that consumption of the groundwater wells could cause health problems and require treatment before consumption.

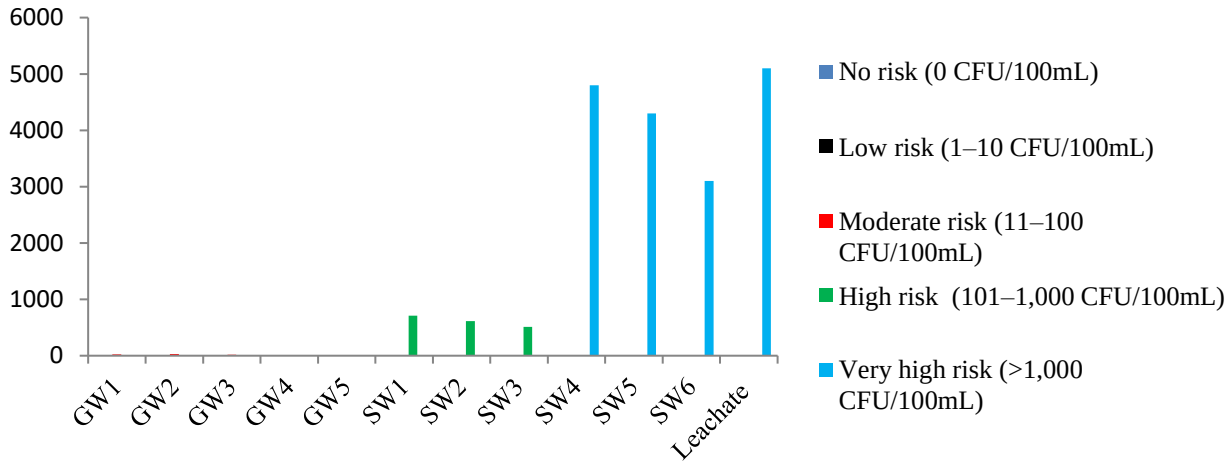

Figure 7: Health risk classification for TCB

3.1.6.2.Fecal Coliform Bacteria (FCB)

Leachate FCB was 220 CFU/100 mL. Groundwater FCB was detected only in GW1 and GW2 (1 CFU/100 mL), exceeding the Ethiopian and WHO drinking water standard of 0 CFU/100 mL (Table 5). GW3, GW4, and GW5 had no detectable FCB. River water FCB ranged from 33 to 110 CFU/100 mL, with all six samples exceeding the standard (WHO, 2011). The highest FCB was at SW6 (110 CFU/100 mL), collected downstream after dumpsite leachate enters the river, followed by SW4 (62 CFU/100 mL) and SW5 (47 CFU/100 mL). Upstream sites SW1 (41 CFU/100 mL) and SW2 (39 CFU/100 mL) showed relatively low but also significant FCB contamination. This spatial pattern indicated multiple sources of fecal contamination in the Jemo River Catchment, including community wastewater discharge, open defecation along riverbanks, solid waste dumping, and urban runoff. The elevated FCB at SW6 indicated additional input from dumpsite leachate, though upstream contamination confirmed that fecal pollution originated from multiple sources beyond the dumpsite. Based on health risk classification for FCB (Alemu et al., 2024), groundwater showed no to low health risk, river water from moderate to high risk, and leachate showed high risk (Figure 8). This indicated that consumption of water from these wells could cause health problems and required treatment before consumption.

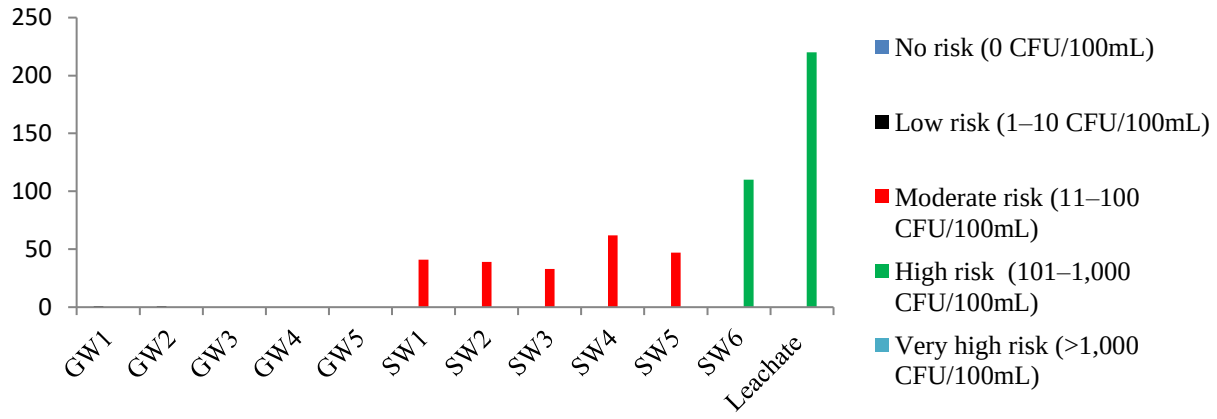

Figure 8: Health risk classification for FCB

Table 5: Laboratory result of the five groundwater and six river water samples and standards

Water samples	Temp.	pH	Turbidity	TDS	NO_3^-	CN^-	TCB	FCB
	°C	pH scale	NTU	mg/L	mg/L	mg/L	CFU/100 mL	
GW1	23.1	6.97	3.7	809.3	28.0	0.0299	22	1.00
GW2	23.3	7.17	1.7	717.0	29.0	0.0414	29	1.00
GW3	23.1	7.27	1.0	648.3	18.0	0.0402	15	0.00
GW4	23.2	7.23	1.3	528.0	27.0	< 0.0200	9	0.00
GW5	22.8	6.97	2.0	653.3	16.3	0.0232	4	0.00
SW1	18.5	7.97	70.0	1594.3	6.0	0.3955	710	41
SW2	18.3	7.63	67.0	1409.7	2.3	0.1971	612	39
SW3	18.5	7.97	48.0	1401.3	22.3	0.0598	510	33
SW4	18.3	7.93	64.0	1488.0	24.0	0.0681	4800	62
SW5	19.2	8.37	153.3	1571.0	16.0	< 0.0200	4300	47
SW6	19.8	7.97	172.0	1982.7	31.3	0.1434	3100	110
Leachate	19.1	8.8	550.0	15900.3	38.7	0.5044	5100	220
WHO standard (WHO, 2011)	------	6.5–8.5	5	1000	50	0.0700	------	0
Ethiopian standards (Agency, 2013)	------	6.5–8.5	5	1000	50	------	------	0
Ethiopian standard, aquatic species protection (EPA & UNIDO, 2003)	------	6–9	------	------	50	0.0500	------	------

Values reported as < 0.020 mg/L for CN^- are below the method detection limit and are semi-quantitative estimates.

3.2. Correlation Analysis

Spearman rank correlation analysis was performed to examine relationships between water quality parameters (pH, turbidity, TDS, NO_3^-, CN^-, TCB, and FCB). Because of the small sample size (n = 11), correlations should be interpreted with caution as they might be influenced by outliers and they might not fully show true population relationships. The Spearman correlation matrix is presented in Table 6. pH showed strong positive correlations with turbidity (r = 0.740),

TCB (r = 0.786), and FCB (r = 0.756), indicating that alkaline pH conditions were associated with increased contamination levels. Turbidity demonstrated very strong positive correlations with TDS (r = 0.964) and FCB (r = 0.910), and a strong positive correlation with TCB (r = 0.818). TDS showed very strong positive correlations with TCB (r = 0.882) and FCB (r = 0.952). The very strong correlation between TCB and FCB (r = 0.961, $p < 0.01$) confirmed FCB as a reliable indicator of fecal contamination in this study (APHA, 2005). These strong associations suggested that turbidity and TDS were reliable indicators of overall water quality degradation, with higher values coinciding with increased microbial contamination. Similar findings were reported near dumpsites, where pH correlated positively with turbidity. This positive correlation may be owing to chemical reactions at different pH values, which cause precipitation of dissolved substances and lead to increased particulate matter (Shah et al., 2025).

CN^- showed a moderate negative correlation with NO_3^- (r = -0.700, $p < 0.05$), indicating inverse relationship or different source pathways. Turbidity showed a moderate positive correlation with TCB TCB (r = 0.547, $p < 0.05$), suggesting that particulate matter influenced microbial transport. When turbidity results from sewage or wastewater, pathogenic organisms may be shielded by suspended particles (Erena, 2015). Notably, NO_3^- showed no significant correlation with pH, turbidity, TDS, TCB, or FCB ($p > 0.05$ for all), indicating that NO_3^- originated from different sources or followed different transport mechanisms when compared to turbidity, CN^-, and microbial contamination. CN^- showed no statistically significant correlation with pH (r = 0.474), turbidity (r = 0.327), TDS (r = 0.382), TCB (r=0.455), or FCB (r=0.313) at $p < 0.05$ (Table 6).

Table 6: Spearman correlation matrix between parameters of water quality

	pH	Turbidity	TDS	NO_3^-	CN^-	TCB	FCB
pH	1.000						
Turbidity	.740**	1.000					
TDS	.754**	.964**	1.000				
NO_3^-	-.280	-.200	-.127	1.000			
CN^-	.474	.327	.382	-.700*	1.000		
TCB	.786**	.818**	.882**	-.091	.455	1.000	
FCB	.756**	.910**	.952**	.005	.313	.961**	1.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3.3. Nitrate Pollution Index (NPI)

The NPI was used to assess NO_3^- contamination level in groundwater samples. The five groundwater wells revealed that two of the wells were classified as clean or unpolluted (GW3 (NPI: -0.1) and GW5 (NPI: -0.18)), while the remaining three showed light pollution level (GW1 NPI: 0.4), GW2 (NPI: 0.45) and GW4 (NPI: 0.35). The findings of this study suggested that anthropogenic activities caused a minor but detectable impact on the NO_3^- levels in groundwater wells nearby the dumping site.

3.4. Health Risk Assessment of Nitrate (NO_3^-) Exposure

Chronic Daily Intake (CDI) and Hazard Quotient (HQ) for NO_3^- exposure through water ingestion were calculated for both adult and children population groups consuming directly/indirectly groundwater and surface water in the study area. The HQ values < 1 show negligible non-carcinogenic human health risks for NO_3^- exposure while HQ values above 1 indicate potential adverse health effects (USEPA, 2009). For adults, CDI values in the studied groundwater wells ranged from 0.47-0.83mg/kg-day, with corresponding HQ values ranging from 0.29-0.52. Children showed higher CDI values of 0.54-0.97 mg/kg-day with HQ values between 0.34-0.60. This might be due to lower body mass and high water consumption per unit body weight. Average HQ for groundwater wells was 0.422 and 0.492 for adult and children, respectively, showing no significant human health risk from NO_3^- exposure. GW2 located at 1.54 km southeast of Repi dumping site had the highest HQ value of 0.52 for adults and 0.60 for children among groundwater wells, consistent with its high NO_3^- concentration of 29.0 mg/L (Table 2). GW1 situated at 1.73km southeast of Repi dumping site closely followed GW2 with HQ values of 0.50 for adult and 0.58 for child. The spatial pattern of HQ values indicated that groundwater found in southeast of the site beyond 1km might be much vulnerable to NO_3^- contamination that could potentially be due to groundwater flow direction and local land use practices (Table 7).

River water samples had variable CDI and HQ values when compared to groundwater wells. CDI for adult ranged from 0.07-0.89mg/kg-day with HQ values from 0.04-0.56. Children indicated CDI values of 0.08-1.04mg/kg-day with HQ of 0.05-0.65. Average HQ for river water was 0.31 and 0.36 for adults and children, respectively. This was slightly lower than groundwater

wells average, despite the high NO_3^- contamination levels due to the low NO_3^- concentrations in most river water samples. Although SW6 showed highest HQ (0.65 for children), all HQ values remained below the threshold of 1, indicating negligible non-carcinogenic health risks from NO_3^- exposure. The HQ values in river water samples were sequenced as follow: SW6 > SW4 > SW3 > SW5 > SW1 > SW2. Groundwater wells showed high average HQ values of 0.42 and 0.49 for adult and children in comparison to river water with average HQ of 0.31 for adult and 0.31 for children despite river water showing severe contamination. This apparent paradox revealed the higher NO_3^- concentrations in groundwater with mean of 23.7mg/L when compared to river water with mean of 18.8mg/L. However, the maximum child HQ value of 0.65 for river water at SW6 exceeded the maximum groundwater child HQ value of 0.60 at GW2, showing that specific river water point posed greater NO_3^- risk than the studied groundwater sources (Table 7).

Table 7: Non-carcinogenic health risk assessment associated with NO_3^- exposure

	Adult		Child	
Samples	CDI	HQ	CDI	HQ
GW1	0.80	0.50	0.93	0.58
GW2	0.83	0.52	0.97	0.60
GW3	0.51	0.32	0.6	0.38
GW4	0.77	0.48	0.9	0.56
GW5	0.47	0.29	0.54	0.34
Minimum	*0.47*	*0.29*	*0.54*	*0.34*
Maximum	*0.83*	*0.52*	*0.97*	*0.60*
Mean	*0.676*	*0.422*	*0.788*	*0.492*
SW1	0.17	0.11	0.20	0.13
SW 2	0.07	0.04	0.08	0.05
SW3	0.64	0.40	0.74	0.47
SW4	0.69	0.43	0.8	0.50
SW5	0.46	0.29	0.53	0.33
SW6	0.89	0.56	1.04	0.65
Minimum	*0.07*	*0.04*	*0.08*	*0.05*
Maximum	*0.89*	*0.56*	*1.04*	*0.65*
Mean	*0.49*	*0.31*	*0.57*	*0.36*

4. CONCLUSION

In conclusion, leachate from the Repi dumping site was severely contaminated because of TDS level which was unfit for drinking and irrigation. CN^- value exceeded WHO and aquatic standards, and FCB showed extreme fecal contamination. Groundwater TDS was permissible for

drinking but exceeded the background value, indicating anthropogenic influences. GW1 and GW2 showed fecal contamination of 1 CFU/100 mL, suggesting leachate influence through groundwater flow. River water TDS was classified as unacceptable for human drinking but useful for irrigation. All the six river samples exceeded FCB standards, with the highest FCB at SW6, after leachate entered the river. CN^- levels in upstream river water exceeded WHO guidelines by five times, indicating a potential health concern. Critically, upstream CN^- contamination and elevated FCB indicated multiple pollution sources independent of the dumping site, including industrial waste, waste dumping, community wastewater, open defecation, and urban runoff. Non-carcinogenic health risk assessment for NO_3^- showed all HQ values < 1, indicating negligible nitrate-related health risk. Apart from fecal contamination at GW1 and GW2, all groundwater chemical parameters met WHO drinking standards.

This study had some limitations. Samples were collected and analyzed only during rainy seasons (August 2024). This might not capture seasonal differences during dry periods when dilution was reduced. The small sample size used for correlation limited statistical power, and thus correlations had to be interpreted with caution. Because microbial contamination source tracking and pathogen-specific analysis were not conducted, definitive source attribution remains speculative. Despite these limitations, this study demonstrated important strengths. It provided the first Jemo River water quality assessment in connection to the Repi dumping site. These included previously unstudied parameters such as CN^-. The use of multiple analysis and indices (NPI, HQ, and Spearman correlation) and comparison with a school well as a background reference data (1.9 km upstream) strengthened reliability of the findings and discussions. The spatial sampling design for both surface and groundwater (upstream, adjacent, and downstream) allowed identification of multiple pollution sources independent of the dumping site.

Microbial contamination posing health threats required water treatment and community awareness. Upstream pollution sources revealed that dumpsite management alone was not sufficient, but required integrated intervention strategies that would combine community sanitation, waste collection, and urban drainage systems. Policy reforms should establish water quality monitoring programs and enforce buffer zones between dumping sites and water resources. This study recommended further research on seasonal variations and broader geographic coverage to understand spatiotemporal contamination dynamics.

ABBREVIATIONS

APHA: American Public Health Association; CDI: Chronic Daily Intake; CFU: Colony Forming Unit; CN-: Cyanide; EEPA: Ethiopian Environmental Protection Authority; FCB: Fecal Coliform Bacteria; GW: Groundwater; HQ: Hazard Quotient; No_3^-: Nitrate; SW: Surface Water; TCB: Total Coliform Bacteria; USEPA: United States Environmental Protection Authority; WB: World Bank; WHO: World Health Organization

AUTHORS' CONTRIBUTIONS

Demamu Haligamo, Tamru Aragaw, and Esayas Alemayehu led the conceptualization of the study and research proposal development. Demamu Haligamo conducted and led the sample collection, lab investigation, and performed data analysis. Demamu Haligamo, Tamru Aragaw, and Esayas Alemayehu wrote the original manuscript. Tamru Aragaw monitored the research work as supervisor, developed methodology, conducted lab results validation, provided essential resources, and reviewed and edited the manuscript. Esayas Alemayehu oversaw the research work as a supervisor, contributed to visualization, and provided critical feedback during the entire research work.

ACKNOWLEDGMENT

The authors acknowledge Arba Minch University, Water Resource Research Center (WRRC) for funding the research work under project code: GOV/AMU/PT/TH04/AWTI/WRRC/04/2016.

FUNDING

Arba Minch University, Water Resource Research Center (WRRC) funded this research under award number "GOV/AMU/PT/TH04/AWTI/WRRC/04/2016".

Availability of data and materials

Data will be available upon request.

Competing interests

Authors declare that there is no competing interest.

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