IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
onal Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 7, May 2026
Impact Factor: 8.2

Health Risk Assessment of Contaminated Groundwater Influenced by Leachate Using Water Quality Index and Heavy-Metal Exposure Modelling

Shivanshi Verma
Institute of Engineering & Technology, Lucknow

Abstract: *Groundwater contamination near leachate-affected sites presents a significant public-health concern because dissolved salts, nutrients and toxic metals can migrate from waste deposits into shallow aquifers used for drinking and domestic purposes. This paper presents the assessment of groundwater health risk by integrating water quality index (WQI), leachate pollution index (LPI), standard comparison and human health-risk modelling. The leachate sample and seven groundwater samples analyzed for physicochemical parameters, nutrients and heavy metals including chromium, manganese, iron, cobalt, nickel, copper, zinc, silver, cadmium and lead. The results show that leachate has very high conductivity (83,892 µS/cm), total dissolved solids (38,180 mg/L), COD (16,800 mg/L), BOD (2,000 mg/L), nitrate (103.44 mg/L), fluoride (8.8 mg/L), chromium (8.75 mg/L), cadmium (0.87 mg/L) and lead (0.564 mg/L), indicating a concentrated pollution source. The LPI value of 20.86 places the leachate in the moderate pollution class, while the WQI of leachate is 20,626, showing that it is not suitable for direct use and can severely degrade groundwater if migration occurs. Groundwater WQI values range from 88.50 to 233.36, with Sample-1 classified as very poor, Samples 2 to 5 as poor and Samples 6 and 7 as good. Heavy-metal screening indicates widespread exceedance of iron, manganese, nickel, copper and selected lead/zinc limits. Adult non-carcinogenic hazard index values exceed unity in Samples 1 to 5, whereas child hazard index values exceed unity in all groundwater samples. Carcinogenic screening risk for Cr, Cd, Ni and Pb remains above the commonly used risk-management benchmark of 10^-4 in all samples, with the highest value in Sample-1. The study concludes that leachate control, source protection, periodic groundwater monitoring and treatment of contaminated water are necessary to reduce chronic health risk*

Keywords: groundwater contamination; leachate; heavy metals; water quality index; hazard index; carcinogenic risk; human health-risk assessment

I. INTRODUCTION

Groundwater is one of the most important freshwater resources for drinking, domestic use, irrigation and small-scale industrial activity. In many peri-urban and rural settings, groundwater is preferred because it is available throughout the year and requires less conveyance infrastructure than surface water. However, once contaminants enter an aquifer, their detection and removal become difficult because pollutants move through soil and aquifer materials slowly and may remain in the subsurface for long periods (Freeze & Cherry, 1979; Hem, 1985; Fetter, 2001; Todd & Mays, 2005).

Leachate generated from municipal solid waste, dumpsites or landfill cells is a complex liquid formed by the percolation of rainwater and moisture through decomposing waste. It normally contains high dissolved solids, organic matter, nitrogenous compounds, chloride, sulphate, fluoride and trace metals. If leachate is not collected and treated properly, it can infiltrate the soil and reach groundwater. The resulting contamination may not be immediately visible

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 7, May 2026 Impact Factor: 8.2

but can create chronic exposure through drinking water consumption (Christensen et al., 2001; Kjeldsen et al., 2002; Mor et al., 2006; Tchobanoglous et al., 1993).

Health risk from contaminated groundwater is influenced by the concentration of pollutants, duration and route of exposure, toxicity of contaminants and vulnerability of receptors. Non-carcinogenic risk is usually assessed using hazard quotient (HQ) and hazard index (HI), while carcinogenic risk is estimated using lifetime average daily dose and cancer slope factors. Heavy metals are particularly important because several metals can accumulate in the body and may affect the nervous system, kidneys, liver, gastrointestinal system and blood-forming tissues (ATSDR, 2005; U.S. EPA, 1989, 2004, 2011; WHO, 2017).

Water quality index (WQI) provides a single numerical expression of the overall suitability of groundwater by combining multiple water quality parameters. Similarly, leachate pollution index (LPI) is useful for summarizing the pollution potential of leachate. However, index values alone cannot fully describe human health risk. A sample may show moderate WQI but still contain specific toxic elements that produce unacceptable health risk. Therefore, the present paper combines index-based assessment with parameter-wise standard comparison and human health-risk calculations (Brown et al., 1970; Horton, 1965; Kumar & Alappat, 2005; Mohan et al., 1996; Prasad & Bose, 2001).

The major objectives of this study are:

- To assess health risks from contaminated groundwater.
- To evaluate carcinogenic and non-carcinogenic risks.
- To determine the impact of leachate on human health.
- To analyze heavy metal exposure risks through groundwater.

II. STUDY FRAMEWORK

The study is based on the results for one leachate sample and seven groundwater samples. The dataset includes general water quality parameters, nutrients, organic pollution indicators and trace/heavy metals. The available results include pH, electrical conductivity, total dissolved solids, alkalinity, hardness, calcium, magnesium, chloride, sulphate, nitrate, total Kjeldahl nitrogen, ammoniacal nitrogen, phosphate, fluoride, COD, BOD and metals analyzed by ICP-MS (American Public Health Association, 2017; Bureau of Indian Standards, 2012; Final 07.04.2026.xlsx, 2026; WHO, 2017).

The groundwater samples are treated as potential receptor points affected by contaminated leachate. The leachate sample is treated as the source-strength indicator. Drinking-water suitability was compared with IS 10500:2012 acceptable and permissible limits wherever limits were available in the Excel sheet.

Attribute	Description
Sample types	One leachate sample and seven groundwater samples
Main categories	Physicochemical parameters, nutrients, organic pollution indicators and heavy metals
Primary standards used	Indian Standards as per IS 10500:2012 (Reaffirmed 2018)
Indices used	Water Quality Index (WQI) and Leachate Pollution Index (LPI)
Risk metrics used	Chronic daily intake (CDI), hazard quotient (HQ), hazard index (HI) and carcinogenic risk (CR)

Table 1 : Groundwater and leachate

III. REVIEW OF LITERATURE

Groundwater quality studies commonly use WQI of water quality. WQI is effective for screening because it enables comparison between sites and helps managers prioritize areas requiring treatment or detailed monitoring. Nevertheless, WQI can mask the influence of individual toxic pollutants because the index is a composite measure (Backman et al., 1998; Brown et al., 1970; Horton, 1965).

Leachate-related studies emphasize that landfill leachate can contain high concentrations of dissolved salts, organic matter, ammonia, chloride, sulphate and heavy metals. Leachate pollution index provides a useful means of

ISSN: 2581-9429
Volume 6, Issue 7, May 2026
Impact Factor: 8.2

summarizing leachate strength and identifying whether treatment or containment is required. However, leachate impact on human health depends on the extent of migration, dilution and exposure through wells or boreholes (Christensen et al., 2001; Kjeldsen et al., 2002; Mor et al., 2006).

Human health-risk assessment frameworks separate non-carcinogenic and carcinogenic endpoints. For non-carcinogenic effects, the estimated dose is divided by a reference dose to obtain a hazard quotient. A hazard quotient above unity suggests that the exposure level may exceed the safe reference level. For carcinogenic effects, lifetime dose is multiplied by a cancer slope factor to estimate excess lifetime cancer risk (ATSDR, 2005; U.S. EPA, 1989, 2011).

Heavy metals are among the most important groundwater contaminants because they may persist in aquifers and produce long-term health concerns. Chromium, cadmium, nickel and lead are frequently treated as carcinogenic or potentially carcinogenic screening metals. Manganese, iron, copper and zinc are also important because high concentrations can affect taste, staining, neurological health, gastrointestinal response and overall acceptability of drinking water (Alloway, 2013; Hakanson, 1980; Mohan et al., 1996).

IV. MATERIALS AND METHODS

4.1 Parameter selection and standard comparison

All available Excel parameters were reviewed. For general quality interpretation, the study emphasized pH, conductivity, TDS, alkalinity, hardness, calcium, magnesium, chloride, sulphate, nitrate and fluoride. For health-risk modelling, the focus was placed on heavy metals: chromium, manganese, iron, cobalt, nickel, copper, zinc, silver, cadmium and lead. Each measured value was compared against the desirable and permissible values provided in the workbook (Bureau of Indian Standards, 2012; WHO, 2017).

When no relaxation was given in the Excel standard column, the desirable limit was treated as the maximum acceptable limit. When a permissible limit was listed, exceedance of the permissible limit was interpreted as a stronger indication of unsuitability in the absence of treatment or alternate source.

Parameter	Unit	Leachate	Groundwater range	Desirable limit	Permissible limit
pH	-	8.100	7.110-7.780	6.5-8.5	No Relax
Conductivity	us/cm	83,892	908.000-1,280	-	-
TDS	mg/L	38,180	478.500-988.000	500	2000
Alkalinity	mg/L	1,280	208.000-488.000	200	600
Hardness	mg/L	1,620	244.000-592.000	200	600
Chloride	mg/L	980.000	28.000-158.000	250	1000
Sulphate	mg/L	678.500	28.980-136.500	200	400
Nitrate	mg/L	103.440	2.931-18.500	45	No Relax
Fluoride	mg/L	8.800	0.540-0.890	1	1.5
Chromium	mg/L	8.750	0.002-0.050	0.05	No Relax
Manganese	mg/L	14.500	0.230-1.870	0.1	0.3
Iron	mg/L	90.760	2.110-8.560	0.3	No Relax
Nickel	mg/L	1.230	0.009-0.210	0.02	No Relax
Cadmium	mg/L	0.870	1.80E-05-0.002	0.003	No Relax
Lead	mg/L	0.564	0.007-0.018	0.01	No Relax

Table 2 : Selected leachate and groundwater values used for health-risk interpretation.

4.2 Water Quality Index and Leachate Pollution Index

WQI values were taken from the workbook calculations, where quality ratings and parameter weights were used to combine multiple parameters into a single index. The WQI classes used in the paper are: excellent (<50), good (50-100), poor (100-200), very poor (200-300) and unsuitable (>300).

DOI: 10.48175/IJARSCT-35442

The LPI calculation used the general expression LPI = Σ(wi × pi) / Σwi, where wi is pollutant weight and pi is the single pollution rating. The Excel sheet classified LPI values as low (<7), moderate (7-25) and high (>25) (Kumar & Alappat, 2005).

4.3 Human health-risk assessment

The oral ingestion pathway was considered for health-risk screening because groundwater is generally consumed as drinking water. The chronic daily intake for non-carcinogenic risk was calculated using the following expression: (U.S. EPA, 1989, 2011)

$$CDI = (C \times IR \times EF \times ED) / (BW \times AT)$$

where C is concentration in mg/L, IR is ingestion rate, EF is exposure frequency, ED is exposure duration, BW is body weight and AT is averaging time. For non-carcinogenic assessment, AT = ED × 365 days; therefore, CDI simplifies to C × IR / BW when daily exposure is assumed.

Non-carcinogenic risk was calculated as HQ = CDI / RfD and HI = ΣHQ. An HI value greater than 1 indicates potential non-carcinogenic concern. Cancer risk was calculated as CR = LADD × CSF, where LADD is the lifetime average daily dose and CSF is the oral cancer slope factor. A total carcinogenic risk between 10^-6 and 10^-4 is commonly treated as an acceptable to tolerable range, while values above 10^-4 require management attention (U.S. EPA, 1989, 2004).

Variable	Adult	Child	Use in calculation
Ingestion rate (IR)	2 L/day	1 L/day	Oral drinking-water exposure
Body weight (BW)	70 kg	15 kg	Dose normalization
Exposure frequency (EF)	365 days/year	365 days/year	Daily exposure assumption
Exposure duration (ED)	30 years	6 years	Adult and child screening periods
Averaging time for non-cancer	ED × 365	ED × 365	Non-carcinogenic HQ and HI
Averaging time for cancer	70 × 365 days	70 × 365 days	Lifetime cancer-risk estimate

Table 3 : Exposure assumptions used for screening-level health-risk assessment.

Metal	RfD (mg/kg-day)	Cancer slope factor	Comment
Chromium	0.003	0.5	Used for carcinogenic screening
Manganese	0.14	-	Used for non-carcinogenic screening
Iron	0.7	-	Used for non-carcinogenic screening
Cobalt	0.0003	-	Used for non-carcinogenic screening
Nickel	0.02	0.84	Used for carcinogenic screening
Copper	0.04	-	Used for non-carcinogenic screening
Zinc	0.3	-	Used for non-carcinogenic screening
Silver	0.005	-	Used for non-carcinogenic

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 7, May 2026
Impact Factor: 8.2

			screening
Cadmium	0.0005	0.38	Used for carcinogenic screening
Lead	0.0035	0.0085	Used for carcinogenic screening

Table 4 : Toxicity factors applied for screening calculations.

V. RESULTS AND DISCUSSION

5.1 Overall leachate and groundwater quality

The leachate sample contains a much higher pollution load than groundwater. Conductivity is 83,892 µS/cm in leachate compared with a groundwater range of 908-1,280 µS/cm. TDS is 38,180 mg/L in leachate compared with 478.5-988 mg/L in groundwater. The leachate also contains COD of 16,800 mg/L and BOD of 2,000 mg/L, indicating strong organic pollution. The groundwater samples do not show measurable COD or BOD above the reported detection values, but their chemical profile indicates the influence of dissolved solids, hardness and heavy metals (Appelo & Postma, 2005; Domenico & Schwartz, 1998; Hem, 1985).

The leachate-to-groundwater mean ratio is especially high for chromium, cadmium, conductivity, TDS and lead. This indicates that uncontrolled leachate migration could significantly increase health risk even after dilution. Chromium in leachate is approximately 821 times the mean groundwater chromium level, cadmium is nearly 995 times the mean groundwater cadmium level, and lead is about 53 times the mean groundwater lead level. These ratios identify leachate as a major potential source of toxic metal loading.

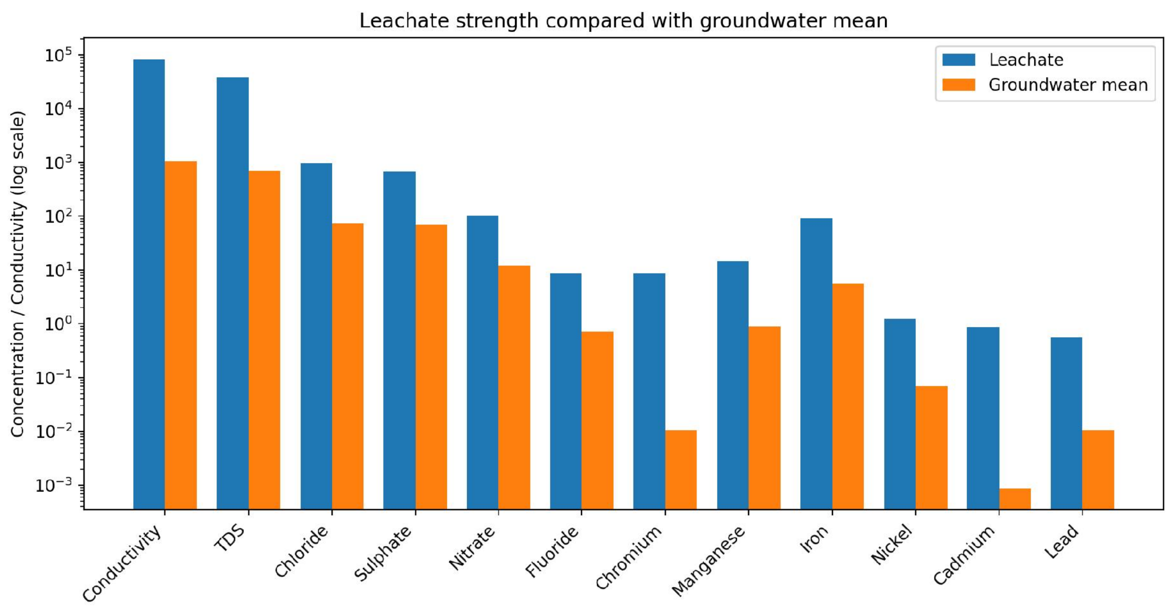

Figure 2 : Leachate strength compared with groundwater mean for selected parameters.

5.2 Water Quality Index interpretation

The calculated WQI values demonstrate that overall water quality varies substantially among the seven groundwater samples. Sample-1 shows a WQI of 233.36 and falls in the very poor category. Samples 2, 3, 4 and 5 fall in the poor category, while Samples 6 and 7 fall in the good category. The leachate WQI of 20,626 is extremely high, confirming that leachate is unsuitable and cannot be considered a safe water source.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 7, May 2026
Impact Factor: 8.2

Sample	WQI	Quality class
Leachate	20626.00	Unsuitable
Sample-1	233.36	Very poor
Sample-2	156.13	Poor
Sample-3	115.78	Poor
Sample-4	121.12	Poor
Sample-5	153.54	Poor
Sample-6	91.24	Good
Sample-7	88.50	Good

Table 5 : Water Quality Index results and interpretation.

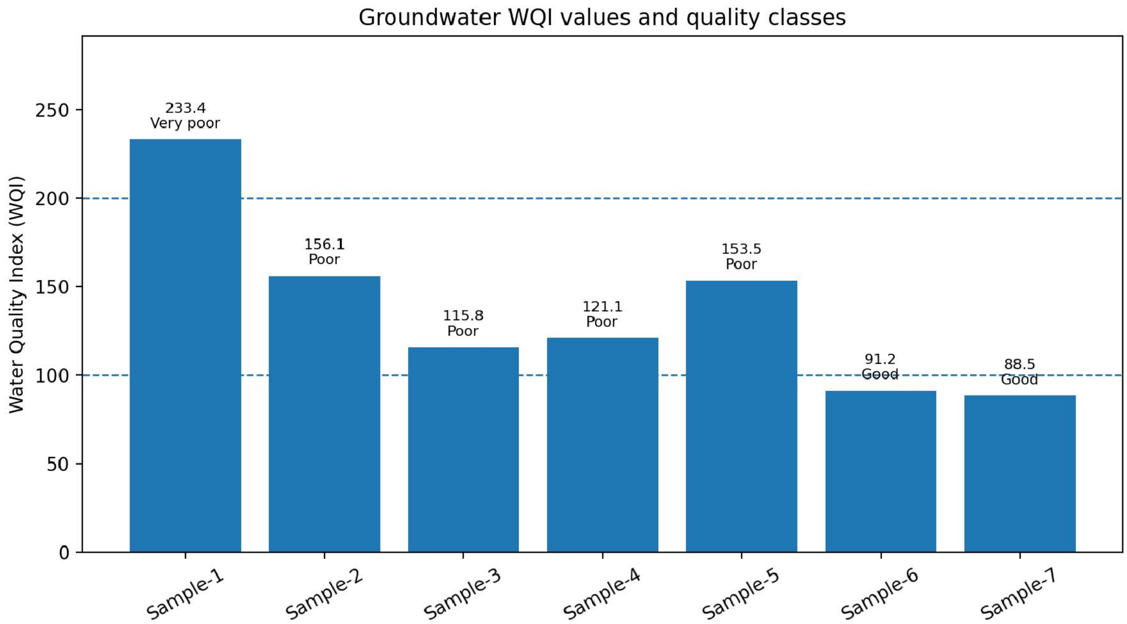

Figure 3 : Groundwater WQI values and quality classes.

5.3 Leachate Pollution Index and human-health implication

The Leachate Pollution Index is 20.86, which falls in the moderate leachate pollution class according to the Excel classification. Although the LPI class is moderate, several single parameters show critical levels. Conductivity, TDS, COD, BOD, chromium and cadmium were assigned high or critical pollution ratings in the leachate sheet. This means the leachate has enough contaminant strength to affect groundwater if containment is weak (Kjeldsen et al., 2002; Kumar & Alappat, 2005; Mor et al., 2006).

Leachate parameter	Observed value	LPI significance	Health relevance
Conductivity	83,892 µS/cm	Critical	High dissolved ion load and salinity
TDS	38,180 mg/L	Critical	Unacceptable dissolved solids and taste/acceptability concern
COD	16,800 mg/L	Critical	Strong organic pollution load
BOD	2,000 mg/L	Critical	High biodegradable organic load
Chromium	8.75 mg/L	Critical	Toxic metal with carcinogenic screening relevance

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 7, May 2026 Impact Factor: 8.2

Cadmium	0.87 mg/L	Critical	Toxic metal with kidney and cancer-risk concern
Lead	0.564 mg/L	High	Neurological and developmental risk concern

Table 6 : Key leachate pollutants and human-health relevance.

5.4 Standard exceedance in groundwater

The groundwater samples show several exceedances of the standards listed in the Excel workbook. TDS exceeds the desirable limit in six of the seven groundwater samples, although none exceed the permissible limit of 2,000 mg/L. Alkalinity, hardness and magnesium exceed desirable limits in all samples. The most important health-related exceedances occur in heavy metals, especially iron, manganese, nickel, copper, zinc and lead.

Metal	Groundwater range (mg/L)	Desirable	Permissible	Samples above desirable	Samples above permissible/no-relax
Chromium	0.002-0.050	0.05	No Relax	0	0
Manganese	0.230-1.870	0.1	0.3	7	6
Iron	2.110-8.560	0.3	No Relax	7	7
Nickel	0.009-0.210	0.02	No Relax	5	5
Copper	0.120-1.010	0.05	1.5	7	0
Zinc	0.987-17.870	5	15	4	1
Cadmium	1.80E-05-0.002	0.003	No Relax	0	0
Lead	0.007-0.018	0.01	No Relax	2	2

Table 7 : Heavy-metal exceedance pattern in groundwater.

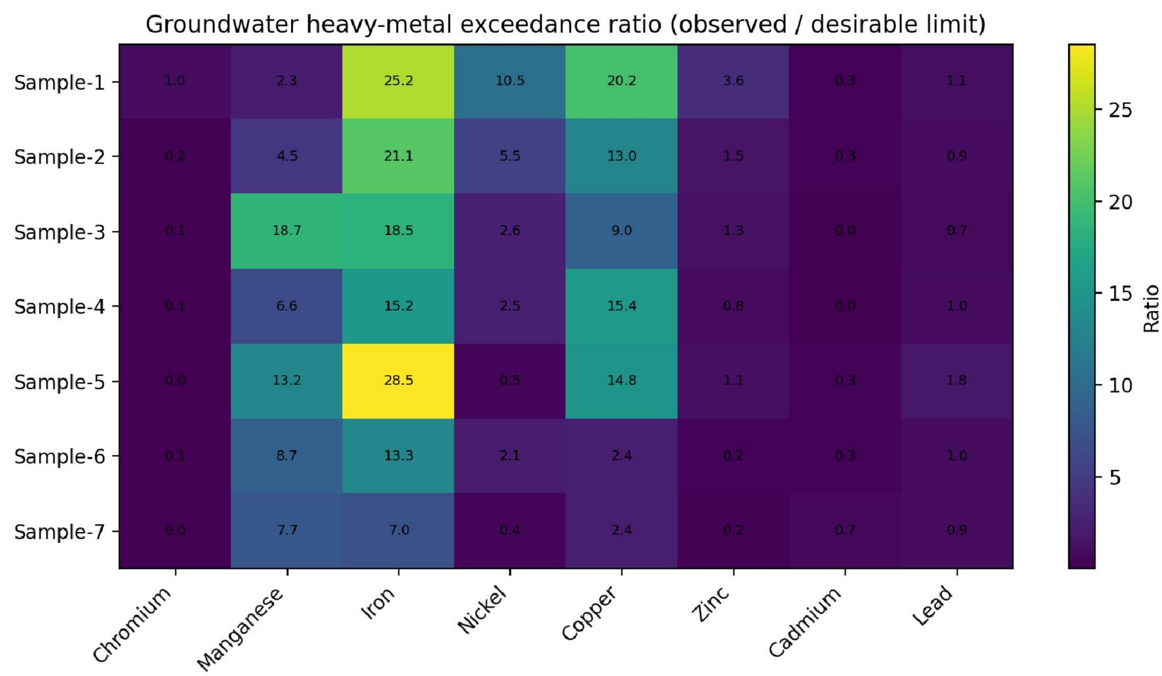

Figure 4 : Groundwater heavy-metal exceedance ratio against desirable limits.

5.5 Non-carcinogenic health risk

The non-carcinogenic risk assessment indicates that adult HI values exceed 1 in Samples 1 to 5. Sample-1 has the highest adult HI at 3.73, followed by Samples 5 and 2. Samples 6 and 7 have adult HI values below unity, suggesting lower adult non-carcinogenic concern under the selected assumptions. In contrast, child HI values exceed 1 in all samples, with Sample-1 again showing the highest value. This is expected because children have lower body weight and therefore receive a higher dose per kilogram of body weight for the same concentration (ATSDR, 2005; U.S. EPA, 1989).

For adult exposure, the dominant contributors vary by sample. Sample-1 is influenced mainly by zinc, copper and chromium; Sample-2 by zinc, copper and iron; Sample-3 by zinc, manganese and copper; Sample-4 by copper, zinc and iron; Sample-5 by zinc, copper and iron; and Samples 6 and 7 by manganese, iron and zinc/cadmium. This indicates that health management should not rely on one metal only; multi-metal exposure drives the final risk.

Sample	Adult HI	Child HI	Adult risk class	Dominant adult HQ contributors
Sample-1	3.73	8.70	Potential concern	Zinc (1.70), Copper (0.72), Chromium (0.48)
Sample-2	1.92	4.47	Potential concern	Zinc (0.72), Copper (0.46), Iron (0.26)
Sample-3	1.76	4.10	Potential concern	Zinc (0.61), Manganese (0.38), Copper (0.32)
Sample-4	1.47	3.43	Potential concern	Copper (0.55), Zinc (0.38), Iron (0.19)
Sample-5	1.94	4.53	Potential concern	Zinc (0.54), Copper (0.53), Iron (0.35)
Sample-6	0.78	1.82	Lower concern	Manganese (0.18), Iron (0.16), Zinc (0.12)
Sample-7	0.64	1.50	Lower concern	Manganese (0.16), Cadmium (0.11), Zinc (0.09)

Table 8 : Non-carcinogenic health-risk summary from heavy-metal ingestion.

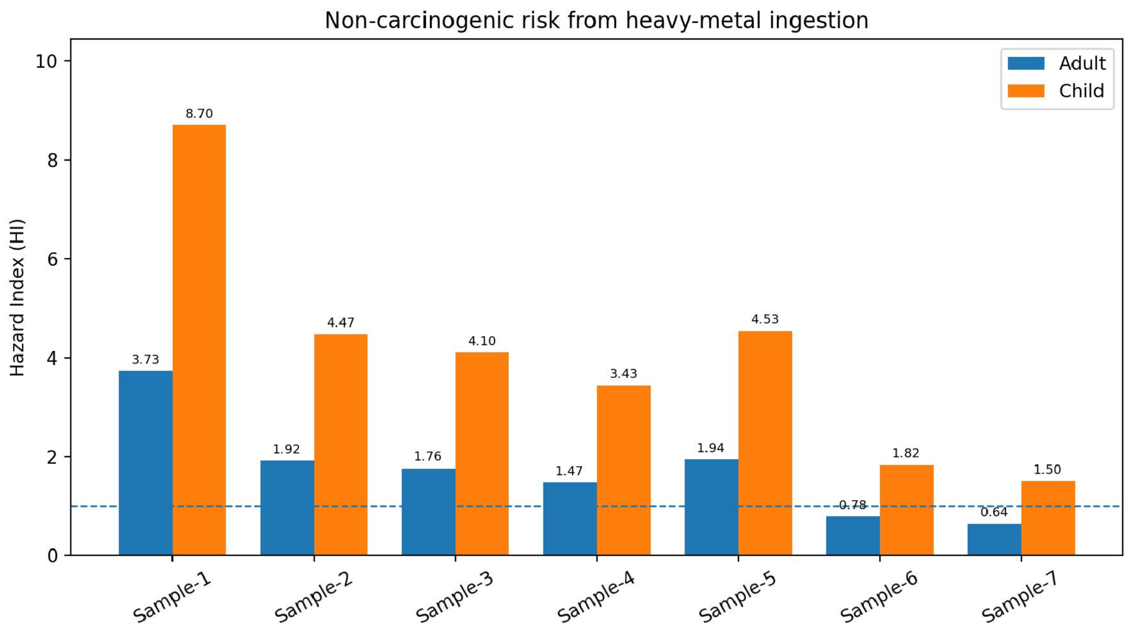

Figure 5 : Adult and child hazard index values for heavy-metal ingestion.

5.6 Carcinogenic health risk

Carcinogenic risk was calculated for chromium, cadmium, nickel and lead using selected oral cancer slope factors. Because chromium speciation was not available, chromium was assessed conservatively for screening. The total adult carcinogenic risk values range from 1.15E-04 to 2.47E-03. All samples exceed 1.0E-04, indicating that detailed site-specific evaluation and risk reduction should be prioritized (U.S. EPA, 1989, 2004; WHO, 2017).

Sample-1 presents the highest total carcinogenic risk due to elevated chromium and nickel. Samples 2, 3, 4 and 6 are also influenced by nickel and chromium. The cancer-risk values should be interpreted as screening estimates because metal speciation, well-use frequency and actual individual exposure behavior were not measured. Nevertheless, the results clearly show that heavy-metal exposure through groundwater cannot be ignored.

Sample	Cr risk	Cd risk	Ni risk	Pb risk	Total adult CR
Sample-1	3.06E-04	4.65E-06	2.16E-03	1.14E-06	2.47E-03
Sample-2	4.90E-05	4.65E-06	1.13E-03	9.37E-07	1.19E-03
Sample-3	3.06E-05	8.38E-08	5.35E-04	7.39E-07	5.66E-04
Sample-4	3.06E-05	4.65E-07	5.14E-04	1.04E-06	5.46E-04
Sample-5	9.59E-06	4.65E-06	1.05E-04	1.87E-06	1.21E-04
Sample-6	1.84E-05	4.65E-06	4.42E-04	1.04E-06	4.66E-04
Sample-7	1.22E-05	9.31E-06	9.26E-05	9.37E-07	1.15E-04

Table 9 : Adult carcinogenic risk estimates for selected heavy metals.

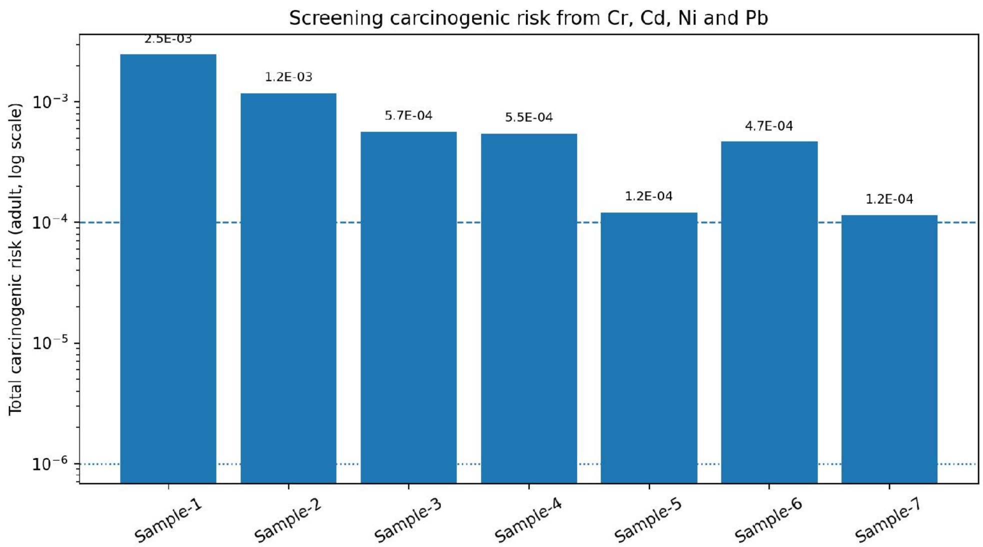

Figure 6 : Screening carcinogenic risk from chromium, cadmium, nickel and lead.

VI. MANAGEMENT IMPLICATIONS

The results indicate the need for source control, receptor protection and regular monitoring. The leachate sample has a pollution strength that can severely degrade aquifers if leachate collection systems, liners, drains or waste-containment measures fail. Therefore, leachate should be collected, treated and prevented from contacting soil and shallow groundwater (Christensen et al., 2001; Kjeldsen et al., 2002; Tchobanoglous et al., 1993).

Groundwater samples with poor and very poor WQI should not be used for drinking without appropriate treatment. For heavy metals, simple boiling is not sufficient because boiling can concentrate dissolved metals. Treatment options may include activated alumina or ion exchange for specific metals, reverse osmosis, adsorption media, coagulation-filtration and blending only where scientifically justified (Bureau of Indian Standards, 2012; WHO, 2017).

Monitoring programs should include seasonal sampling because monsoon recharge may dilute or mobilize pollutants depending on site conditions. Monitoring should include pH, EC, TDS, hardness, chloride, nitrate, sulphate, fluoride and heavy metals. Wells near waste-disposal boundaries should be sampled more frequently than background wells (American Public Health Association, 2017; Jensen, 2015).

Risk communication is also important. Communities using groundwater should be informed about the specific contaminants present, possible health effects and treatment requirements. Vulnerable groups such as children, pregnant women and elderly persons should be given priority in exposure reduction because they may be more sensitive to chronic water contamination.

VII. CONCLUSION

The leachate is a concentrated pollution source with very high EC, TDS, COD, BOD, fluoride, chromium, cadmium and lead.

The leachate LPI is 20.86, indicating moderate pollution, but the leachate WQI is 20,626, confirming severe unsuitability and high potential impact on groundwater.

Groundwater WQI ranges from 88.50 to 233.36. Sample-1 is very poor, Samples 2 to 5 are poor, and Samples 6 and 7 are good.

TDS, alkalinity, hardness, magnesium, iron, manganese, nickel, copper and selected zinc/lead values exceed listed drinking-water criteria, showing that groundwater suitability is compromised.

Adult non-carcinogenic HI exceeds 1 in Samples 1 to 5, while child HI exceeds 1 in all seven samples. Therefore, children represent the more vulnerable receptor group.

Screening carcinogenic risk for Cr, Cd, Ni and Pb exceeds 10^-4 in all groundwater samples, with the highest risk in Sample-1.

Leachate containment, groundwater treatment, wellhead protection and periodic health-risk monitoring are necessary to reduce long-term human health risk.

VIII. RECOMMENDATIONS AND FUTURE SCOPE

Install and maintain proper leachate collection, drainage and treatment systems at the waste site.

Avoid using Sample-1 type groundwater for drinking without treatment and confirm treatment efficiency through post-treatment testing.

Conduct seasonal groundwater monitoring upstream and downstream of the leachate source.

Include microbial parameters, arsenic, mercury and other emerging contaminants in future analysis.

Use geospatial mapping to identify the direction of pollutant migration and high-risk receptor wells.

Perform metal speciation, especially for chromium, to refine carcinogenic risk estimates.

Carry out community-level exposure surveys to validate actual water ingestion rate, well-use history and sensitive receptor groups.

REFERENCES

[1]. Agency for Toxic Substances and Disease Registry. (2005). Public health assessment guidance manual. U.S. Department of Health and Human Services.

[2]. Alloway, B. J. (Ed.). (2013). Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability (3rd ed.). Springer.

[3]. American Public Health Association. (2017). Standard methods for the examination of water and wastewater (23rd ed.). American Public Health Association.

[4]. Appelo, C. A. J., & Postma, D. (2005). Geochemistry, groundwater and pollution (2nd ed.). A.A. Balkema.

[5]. Backman, B., Bodis, D., Lahermo, P., Rapant, S., & Tarvainen, T. (1998). Application of a groundwater contamination index in Finland and Slovakia. Environmental Geology, 36, 55-64.

[6]. Brown, R. M., McClelland, N. I., Deininger, R. A., & Tozer, R. G. (1970). A water quality index-do we dare? Water & Sewage Works, 117(10), 339-343.

[7]. Bureau of Indian Standards. (2012). Indian standard drinking water specification (IS 10500:2012). Bureau of Indian Standards.

[8]. Christensen, T. H., Kjeldsen, P., Bjerg, P. L., Jensen, D. L., Christensen, J. B., Baun, A., Albrechtsen, H.-J., & Heron, G. (2001). Biogeochemistry of landfill leachate plumes. Applied Geochemistry, 16(7-8), 659-718.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 7, May 2026
Impact Factor: 8.2

[9]. Domenico, P. A., & Schwartz, F. W. (1998). Physical and chemical hydrogeology (2nd ed.). Wiley.
[10]. Fetter, C. W. (2001). Applied hydrogeology (4th ed.). Prentice Hall.
[11]. Freeze, R. A., & Cherry, J. A. (1979). Groundwater. Prentice-Hall.
[12]. Hakanson, L. (1980). An ecological risk index for aquatic pollution control: A sedimentological approach. Water Research, 14(8), 975-1001.
[13]. Hem, J. D. (1985). Study and interpretation of the chemical characteristics of natural water (3rd ed., U.S. Geological Survey Water-Supply Paper 2254). U.S. Geological Survey.
[14]. Horton, R. K. (1965). An index number system for rating water quality. Journal of the Water Pollution Control Federation, 37(3), 300-306.
[15]. Jensen, J. R. (2015). Introductory digital image processing: A remote sensing perspective (4th ed.). Pearson.
[16]. Kjeldsen, P., Barlaz, M. A., Rooker, A. P., Baun, A., Ledin, A., & Christensen, T. H. (2002). Present and long-term composition of MSW landfill leachate: A review. Critical Reviews in Environmental Science and Technology, 32(4), 297-336.
[17]. Kumar, D., & Alappat, B. J. (2005). Evaluating leachate contamination potential of landfill sites using leachate pollution index. Clean Technologies and Environmental Policy, 7(3), 190-197.
[18]. Mohan, S. V., Nithila, P., & Reddy, S. J. (1996). Estimation of heavy metal in drinking water and development of heavy metal pollution index. Journal of Environmental Science & Health, Part A, 31(2), 283-289.
[19]. Mor, S., Ravindra, K., Dahiya, R. P., & Chandra, A. (2006). Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. Environmental Monitoring and Assessment, 118, 435-456.
[20]. Prasad, B., & Bose, J. M. (2001). Evaluation of the heavy metal pollution index for surface and spring water near a limestone mining area. Environmental Geology, 41, 183-188.
[21]. Tchobanoglous, G., Theisen, H., & Vigil, S. A. (1993). Integrated solid waste management: Engineering principles and management issues. McGraw-Hill.
[22]. Todd, D. K., & Mays, L. W. (2005). Groundwater hydrology (3rd ed.). Wiley.
[23]. U.S. Environmental Protection Agency. (1989). Risk assessment guidance for Superfund: Volume I, Human health evaluation manual (Part A) (EPA/540/1-89/002). Office of Emergency and Remedial Response.
[24]. U.S. Environmental Protection Agency. (2004). Risk assessment guidance for Superfund: Volume I, Human health evaluation manual (Part E, Supplemental guidance for dermal risk assessment) (EPA/540/R/99/005). Office of Superfund Remediation and Technology Innovation.
[25]. U.S. Environmental Protection Agency. (2011). Exposure factors handbook: 2011 edition (EPA/600/R-09/052F). National Center for Environmental Assessment.
[26]. World Health Organization. (2017). Guidelines for drinking-water quality (4th ed., incorporating the 1st addendum). World Health Organization