INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

Investigation and Indexing of Eco-Toxic Metals in the Groundwater Around the Kodungaiyur Dumpsite

R Aishwarya[1]*, **A Hemamathi**[2], **Sukumar Binu**[3], **V Suvetha**[4]

1 Assistant Professor, Department of Civil Engineering, R.M.K. Engineering College, India
2 Associate Professor, Department of Civil Engineering, R.M.K. Engineering College, India
3 Professor, Department of Civil Engineering, R.M.K. Engineering College, India
4 Quality Control Engineer, Airport Authority of India, India

OPEN ACCESS

Received: 05-07-2022
Accepted: 25-02-2023
Published: 01-04-2023

Citation: Aishwarya R, Hemamathi A, Binu S, Suvetha V (2023) Investigation and Indexing of Eco-Toxic Metals in the Groundwater Around the Kodungaiyur Dumpsite. Indian Journal of Science and Technology 16(13): 998-1006. https://doi.org/10.17485/IJST/v16i13.1405

* **Corresponding author**.

raa.civil@rmkec.ac.in;
aishurrajan@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Objectives: To determine the eco-toxic metal pollution in the groundwaters of the residential area around the Kodungaiyur dumping ground in Chennai, India, using the indexing approach. **Methods:** The concentration of five heavy metals such as Lead, Copper, Cadmium, Iron and Nickel, were analyzed for 12 sites within a buffer of 2km range from the dumpsite during the post-monsoon season using Inductively Coupled Plasma Optical Emission Spectroscopy. These results are analysed to determine the Heavy metal Pollution Index (HPI) and Metal Index (MI). **Findings:** The average ion concentration of heavy metals in the dumpsite follows the order: Fe>Pb>Cu Cd>Ni in the range of 0.058±0.102, 0.02±0.00, 0.017±0.003, 0.015±0.00 and 0.011±0.001 mg/L respectively. An upper value of 100 is crucial for HPI, and two borewells out of the 12 sites have an index above 100. The index ranging from 51-75 is categorized as poor, 66.67% of bore wells borne poor quality of drinking vulnerable to the residents for heavy metal exposure. On the other facet of analysis using the metal index, the average concentration of metal index was 2.99, and all groundwater samples fall under the moderately affected category (metal index values 2-4). The results show that 2 household units are consuming unsuitable water having high metal exposure, 8 households are exposed to very poor-quality water and 2 sites possess a good quality of water based on HPI values while all the 12 household units are exposed to groundwater moderately affected by heavy metals by MI indexing. **Novelty:** The present study reveals the vulnerability of the public to heavy metal exposure; It brings out two pollution indices HPI and MI which have not been reported in the study area.

Keywords: Kodungaiyur; dump yard; heavy metal; heavy metal pollution index; metal index

1 Introduction

Kodungaiyur dumpsite in Tamil Nādu is one of the two dumping grounds of Greater Chennai Corporation serving for waste dumping for nine out of the 15 zones of the corporation limits. Around 3000 tonnes of garbage reach the dumping ground every day, out of which only 200 tonnes are segregated waste[1]. The bio-mining of the biodegradable waste, incineration of plastic waste and processing of construction and demolition waste (C&D) are proposed in the yard. But the unhealthy effects of waste prevail to cause detrimental effects on human health. Landfill leachate is a virulent liquid that discharges into the groundwater through percolation into the soil mass[2]. The ill effects of leachate percolation on groundwater quality are discussed to understand the impact of the landfill in the Kodungaiyur dump yard. The spatial distribution of the Physico-chemical parameters and heavy metals is represented in maps confirming the presence of heavy metals in the Kodungaiyur dump yard. These maps help represent the variation of water quality parameters but, the potable and domestic characteristics of the groundwater cannot be derived from these maps[3]. Potential ecological risk (PERI), pollution load index (PLI) and Geo-Accumulation Index (Igeo) characterize the soil pollution by heavy metal around the solid waste dumpsites[4]. Similarly, the weighted arithmetic WQI index explicitly gives water quality information by analysing the water quality parameters concerning the Bureau of Indian Standards of Drinking water. Heavy metals are named so due to their high atomic weight and density. These metalloids and chemical elements which are present in the soil, water and air due to rapid industrialization and our careless attitude to live in harmony with nature have increased the presence of eco-toxic metals in our day-to-day life. The heavy metal ingestion into our body through various sources go through a variety of toxicological process that leads to cell damage, neuro damage and lipid profile alteration. The[5] pharmacokinetics that happens due to the bioaccumulation of these heavy metals is dangerous that activates DNA damage gene activation which is the main cause of carcinogenesis.[6] The potential risk of heavy metal-contaminated drinking water is a threat to the environment due to these metal ions' persistence and non-biogenic nature. This will lead to the bioaccumulation of these metals by plants and animals, which can lead to crucial health problems along the food chain. As humans are the last in the food chain, the effect is more due to more accumulation along the food chain. The sewage again contains traces of heavy metals, and when discharged into the water bodies affects fish, large mammals, and human beings again in the chain. This gives us a clear idea of the effect of environmental pollution due to the presence of toxic metals.

The previous study represents the presence and variation of the physicochemical parameters of the groundwater around the Kodungaiyur dumpsite[7] and the water quality index of groundwater explained fails to address the effects of eco-toxic metals in the study area. The leachate liquid discharged from the landfill consists of many pollutants including heavy metals. While water quality indices qualify the groundwater based on the permissible limits of the physicochemical parameters in comparison with BIS, a method is proposed to assess the heavy metal pollution in groundwater using the Heavy Metal Pollution Index (HPI) and Metal Index (MI).

2 Methodology

2.1 Study area

According to the newsletter by[8] Afroz Khan (2020) Kodungaiyur dumping ground situated in North Chennai was 400 acres of appealing alluvial plain land with a vast and flourishing grass cover. But our 'use and throw' lifestyles began producing huge waste. It was a sporadic flood susceptible alluvial meadowland of the Kosasthalaiyar river in Kodungaiyur. Many species of flora and fauna peacefully co-existed alongside the small residential conglomeration of Kaviarasu Kannadasan Nagar, Krishnamurthy Nagar and MKB Nagar. Till the 1980s, Kodungaiyur and its surroundings were a retirement retreat, a rightful recline, as well as a sanctuary for nature enthusiasts. There was no water catastrophe, air pollution or any other environmental crisis. But the imprudent invasion of garbage and sewage plants into the alluvial plain has made it an ordeal for the people of Kodungaiyur. The latitude and longitude of Kodungaiyur are 13°8'02" N and 80°16'09" E as shown in Figure 1. It comes under Perambur taluk of Chennai city surrounded by educational institutions and industrial sectors such as Madras fertilizer limited, Indian oil corporation and Madras refinery limited etc.

2.2 Testing Protocol

To study the groundwater contamination, water samples were collected around the Kodungaiyur dump yard from 12 locations in the post-monsoon season each of quantity of one litre. The sample was numbered, and all locations' latitude and longitude are noted. It is to be noted that the colour of the water is straw yellow. A more advanced technique used for the determination of heavy metal study is ICP-OES (Inductively Coupled Plasma-Optical Emission Spectroscopy). As groundwater samples are tested, no dilution of samples was done in the sample preparation stage. This technique uses plasma which is the fourth state of matter the result arrives at the more accurate Nano range. In this method, the plasma produces the excited atoms that emit electromagnetic radiation at the wavelengths of a particular element. The intensity of this emission is indicative of the concentration of the element within the sample. The test results obtained are presented in Table 1 .

Fig 1. Study area

Table 1. Heavy metal concentration in water samples

Location	Nickel(mg/L)	Copper(mg/L)	Cadmium(mg/L)	Lead(mg/L)	Iron(mg/L)
1	0.01	0.014	0.015	0.02	0.02
2	0.011	0.015	0.015	0.02	0.02
3	0.012	0.017	0.015	0.02	0.02
4	0.011	0.015	0.015	0.02	0.37
5	0.011	0.022	0.015	0.02	0.02
6	0.01	0.016	0.015	0.02	0.02
7	0.012	0.017	0.015	0.02	0.03
8	0.011	0.015	0.015	0.02	0.02
9	0.011	0.015	0.015	0.02	0.02
10	0.013	0.022	0.015	0.02	0.02
11	0.011	0.014	0.015	0.02	0.11
12	0.011	0.022	0.015	0.02	0.02
MEAN	**0.011**	**0.017**	**0.015**	**0.020**	**0.058**
MEDIAN	**0.011**	**0.016**	**0.015**	**0.020**	**0.020**
STANDARD DEVIATION	**0.001**	**0.003**	**0.000**	**0.000**	**0.102**
BIS	**0.02**	**0.05**	**0.01**	**0.05**	**0.3**

2.3 Heavy Metal Pollution Indexing[9,10]

HPI is a powerful technique for the assessment of water quality that depicts the composite influence of individual heavy metals on the overall quality of water[11]. The HPI is arrived at by assigning a weightage (Wi) for each eco-toxic metal. The rating system is an arbitrary value between zero and one, reflecting the relative importance of individual quality considerations, and thus, Wi can be defined as inversely proportional to the recommended standard (Si) for each parameter. The highest tolerant value (Si) refers to the maximum allowable concentration in drinking water. The desirable value (Ii) indicates the ideal limits for the same parameter in drinking water. HPI has been developed and formulated by Mohan et al. 1996 as:

$$\text{HPI} = \frac{\sum_{i=1}^{n} Qiw_i}{\sum_{i=1}^{n} w_i}$$

Qi and Wi represent the sub-index and unit weightage of the ith parameter respectively and n represents the total number of parameters that have been considered for the study. The sub-index (Qi) is calculated by :

$$\text{Qi}= 100 \text{ x } \frac{\sum_{i=1}^{n} (V-Vi]}{\sum_{i=1}^{n} (Vsn-Vi]]}$$

Where V and Vi denote the monitored value and the ideal value of the ith parameter, while Si represents a standard value of the ith parameter. Among the six parameters studied BIS has placed the upper limit (maximum permissible limit) only for Cu. Since it is not desirable to have these metals or ions in drinking water, the ideal value is 0. The critical pollution index of HPI for drinking water is 100[12]. Wi, the unit weightage is stated to be inversely proportional to MAC, i.e., the maximum concentration of the corresponding parameter as proposed. The calculation for HPI in the study area is presented in Table 2. The HPI model appears to be promising and proved to be a useful tool in evaluating the overall pollution level of groundwater in terms of heavy metals in the water samples.

Table 2. Heavy metal Pollution Index calculation

Parameters	Nickel	Copper	Cadmium	Lead	Iron	HPI
BIS Standards (Sn)	0.02	0.05	0.01	0.05	0.3	
w= 1/Sn	50	20	100	20	3.333333	
Ideal value	0	1.5	0	0	0	
Concentration of heavy metals in Site 1 (13.1368^{o} N, 80.2485^{o}E)	0.01	0.014	0.015	0.02	0.02	
Q=(V-Vi)/(VSn-Vi)	0.5	1.024828	1.5	0.4	0.066667	
Q*100	50	102.4828	150	40	6.666667	
W*Q	2500	2049.655	15000	800	22.22222	105.3718
Concentration of heavy metals in Site 2 (13.1339 ^{o} N, 80.2616^{o}E)	0.011	0.015	0.015	0.02	0.02	
Q=(V-Vi)/(VSn-Vi)	0.55	1.024138	1.5	0.4	0.066667	
Q*100	55	102.4138	150	40	6.666667	
W*Q	2750	10495.65	22500	1600	44.44444	107.0891
Concentration of heavy metals in Site3 (13.1209 ^{o} N, 80.2593^{o}E)	0.012	0.017	0.015	0.02	0.02	
Q=(V-Vi)/(VSn-Vi)	0.6	1.022759	1.5	0.4	0.066667	
Q*100	60	102.2759	150	40	6.666667	
W*Q	3000	2045.517	15000	800	22.22222	58.93502
Concentration of heavy metals in Site 4 (13.1291 ^{o} N, 80.2659^{o}E)	0.011	0.015	0.015	0.02	0.37	
Q=(V-Vi)/(VSn-Vi)	0.55	1.024138	1.5	0.4	1.233333	
Q*100	55	102.4138	150	40	123.3333	
W*Q	2750	2048.276	15000	800	411.1111	58.53134
Concentration of heavy metals in Site 5 (13.1280 ^{o} N, 80.271^{o}E)	0.011	0.022	0.015	0.02	0.02	
Q=(V-Vi)/(VSn-Vi)	0.55	1.01931	1.5	0.4	0.066667	
Q*100	55	101.931	150	40	6.666667	
W*Q	2750	2038.621	15000	800	22.22222	43.78326
Concentration of heavy metals in Site 6 (13.1314 ^{o} N, 80.2793^{o}E)	0.01	0.016	0.015	0.02	0.02	
Q=(V-Vi)/(VSn-Vi)	0.5	0.32	1.5	0.4	0.666667	
Q*100	50	32	150	40	66.66667	
W*Q	2500	640	15000	800	222.22	54.19215
Concentration of heavy metals in Site 7 (13.139 ^{o} N, 80.256^{o}E)	0.012	0.017	0.015	0.02	0.03	
Q=(V-Vi)/(VSn-Vi)	0.6	0.34	1.5	0.4	1	
Q*100	60	34	150	40	100	
W*Q	3000	680	15000	800	333.33	58.50393
Concentration of heavy metals in Site 8 (13.1428 ^{o} N, 80.2568^{o}E)	0.011	0.015	0.015	0.02	0.02	
Q=(V-Vi)/(VSn-Vi)	0.55	0.3	1.5	0.4	0.666667	
Q*100	55	30	150	40	66.66667	
W*Q	2750	600	15000	800	222.22	50.44849
Concentration of heavy metals in Site 9 (13.1442 ^{o} N, 80.2544^{o}E)	0.011	0.015	0.015	0.02	0.02	
Q=(V-Vi)/(VSn-Vi)	0.55	0.3	1.5	0.4	0.666667	
Q*100	55	30	150	40	66.66667	
W*Q	2750	600	15000	800	222.22	56.69918
Concentration of heavy metals in Site 10 (13.1446 ^{o} N, 80.2577^{o}E)	0.013	0.022	0.015	0.02	0.02	
Q=(V-Vi)/(VSn-Vi)	0.65	0.44	1.5	0.4	0.666667	
Q*100	65	44	150	40	66.66667	
W*Q	3250	880	15000	800	222.22	58.98211
Concentration of heavy metals in Site 11 (13.1282 ^{o} N, 80.2515^{o}E)	0.011	0.014	0.015	0.02	0.11	
Q=(V-Vi)/(VSn-Vi)	0.55	0.28	1.5	0.4	3.666667	
Q*100	55	28	150	40	366.6667	
W*Q	2750	560	15000	800	1222.21	55.60313
Concentration of heavy metals in Site 12 (13.1338 ^{o} N, 80.2552^{o}E)	0.011	0.022	0.015	0.02	0.02	
Q=(V-Vi)/(VSn-Vi)	0.55	0.44	1.5	0.4	0.666667	
Q*100	55	44	150	40	66.66667	
W*Q	2750	880	15000	800	222.22	30.7226

Based on the critical index presented in Table 3 below, the HPI as calculated in table 2, 61.67 % of samples have HPI ranging from 51-75 and classified as Poor in water quality. Two out of 12 sites have an HPI of more than 100 and these two sites are unsuitable for drinking. Also, only two out of twelve sites have good-quality water for drinking.

Table 3. Groundwater categorization based on HPI

HPI	Category
<25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Totally unsuitable

2.4 Metal Index

[13] The metal index (MI) can be expressed by the following equation:

$$MI = \frac{\sum_{i=1}^{n}(Ci]}{MAC}$$

where MI is the metal index, C is the concentration of each element in solution, MAC is the maximum allowable concentration for each element, and the subscript i is the ith sample. The calculation for calculating MI for groundwater samples is presented in Table 4.

Table 4. Calculation of MI

	Nickel(mg/L)	Copper(mg/L)	Cadmium(mg/L)	Lead(mg/L)	Iron(mg/L)	Metal Index
Site 1	0.01	0.014	0.015	0.02	0.02	2.746667
Site 2	0.011	0.015	0.015	0.02	0.02	2.816667
Site 3	0.012	0.017	0.015	0.02	0.02	2.906667
Site 4	0.011	0.015	0.015	0.02	0.37	3.983333
Site 5	0.011	0.022	0.015	0.02	0.02	2.956667
Site 6	0.01	0.016	0.015	0.02	0.02	2.786667
Site 7	0.012	0.017	0.015	0.02	0.03	2.94
Site 8	0.011	0.015	0.015	0.02	0.02	2.816667
Site 9	0.011	0.015	0.015	0.02	0.02	2.816667
Site 10	0.013	0.022	0.015	0.02	0.02	3.056667
Site 11	0.011	0.014	0.015	0.02	0.11	3.096667
Site 12	0.011	0.022	0.015	0.02	0.02	2.956667

Further individual sampling sites were classified according to the literature [14] as shown in Table 5 and 61.5% of the samples were found to fall under the moderately affected class (MI values above 2-4). Site 4 has an MI value close to 4 and therefore can be considered as strongly affected.

Table 5. Groundwater categorization based on MI

MI	Category
<0.3	Very pure
0.3-1	Pure
1-2	Slightly affected
2-4	Moderately affected
4-6	Strongly affected
>6	Seriously affected

3 Results and Discussion

3.1 Comparison of HPI and MI

The following graph (Figures 3 and 4 and Table 6) represents the values of HPI and MI for all 12 sites and their corresponding threshold values. 2 samples out of 12 fall under the unsuitable category and two other samples have values between 26-50 which

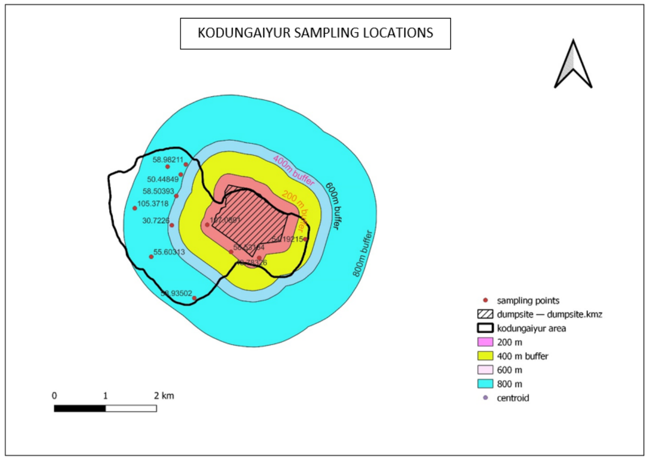

Fig 2. Kodungaiyur Sampling locations

can be treated as Good. All other samples can be regarded as a very poor category of groundwater.

Table 6. Heavy Metal Pollution Index and Metal Index

	HPI	Category	Metal Index	Category
Site 1	105.3718	Totally unsuitable	2.746667	Moderately affected
Site 2	107.0891	Totally unsuitable	2.816667	Moderately affected
Site 3	58.93502	Poor	2.906667	Moderately affected
Site 4	58.53134	Poor	3.983333	Strongly affected
Site 5	43.78326	Good	2.956667	Moderately affected
Site 6	54.19215	Poor	2.786667	Moderately affected
Site 7	58.50393	Poor	2.94	Moderately affected
Site 8	50.44849	Poor	2.816667	Moderately affected
Site 9	56.69918	Poor	2.816667	Moderately affected
Site 10	58.98211	Poor	3.056667	Moderately affected
Site 11	55.60313	Poor	3.096667	Moderately affected
Site 12	30.7226	Good	2.956667	Moderately affected

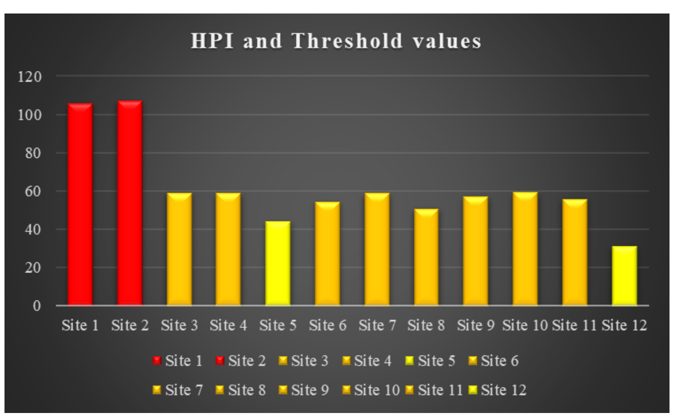

Fig 3. Representation of HPI and Threshold

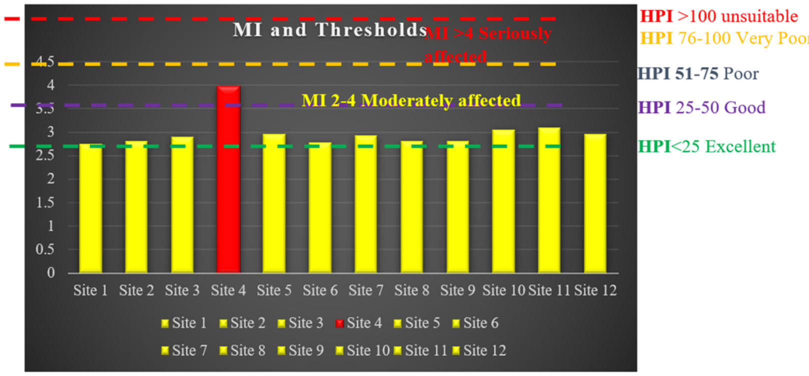

Fig 4. Representation of MI and Threshold

A similar study [15] was conducted to determine the heavy metal contamination in groundwaters using an indexing approach around the dump site. The metal index values were more than 6 for all three boreholes and water was reported to be unsuitable for drinking purposes.

3.2 Correlation analysis

To find the interrelation between HPI, MI and all heavy metals, the Pearson Correlation analysis is performed and presented in Table 7. It is evident that MI is strongly correlated with the presence of Iron in the groundwater and is least affected by the presence of Nickel. Higher the presence of iron in the groundwater, the metal index is significantly increased. The correlation matrix shows that lead and cadmium are strongly negatively correlated which exemplifies that as the quantity of lead in the water increases, the presence of cadmium decreases. HPI is less negatively correlated with Ni, CU, and Fe. This is because the mean values of the heavy metals as given in Table 1 lie within the BIS-prescribed limits. The correlation coefficient of other eco-toxic metals has a value almost equal to zero which shows that there is no interrelationship between each other.

Table 7. Correlation analysis of HPI, MI and eco-toxic metals

	Nickel (mg/L)	Copper (mg/L)	Cadmium (mg/L)	Lead (mg/L)	Iron (mg/L)	MI	HPI
Nickel (mg/L)	1						
Copper (mg/L)	0.48209	1					
Cadmium (mg/L)	-1.6E-15	4.62E-16	1				
Lead (mg/L)	1.63E-15	-4.8E-16	-1	1			
Iron (mg/L)	-0.06958	-0.27413	-5.5E-17	5.94E-17	1		
MI	0.146963	-0.02895	8.18E-16	-8.2E-16	0.963367	1	
HPI	-0.22978	-0.53245	2.94E-16	-3.9E-16	-0.06506	-0.1973	1

[16] A study conducted on the heavy metal analysis of leachate in the Kodungaiyur dumpsite shows that the leachate contains heavy. The Geo-chemical index contamination factor derived in that study indicates the leachate is polluted by the heavy metals in the order of Cd > Fe > Cr > Zn > Cu >Pb. This result can be correlated to our studies from table 1. The average level of Cadmium in our water sample is observed to be 0.015 which is higher than the BIS value of 0.01. It is evident that the leachate passes through the groundwater and carries eco-toxic metals. Also, the leachate in the study quoted was classified as Low concentration in heavy metals. As the concentration of other heavy metals is lesser than the stipulated value, our study's MI indicated groundwater fall in the moderately affected category. While the HPI and MI are used to index the groundwater, [17] it is found that a new indexing approach called modified HPI is derived for the analysis of surface water. The m-HPI expresses water pollution on a pair of positive and negative indices. Therefore, the implementation of m-HPI for groundwater indexing can be recommended for further studies.

The following conclusions are drawn from the study:

- The average concentration of cadmium in the study area is 0.015>0.01 which is the BIS-prescribed limit.
- Though the concentration of other heavy metals is within the BIS-prescribed limits, the indexing method proposed indicates the eco-toxic metal pollution in the groundwater.
- The mean value of HPI is 61.57, a figure in the range of 51-75 classified as a poor category.
- Based on mean concentration, the value of MI is 2.99 and, all of the groundwater samples fell under the moderately affected category (MI values above 2-4).
- MI of Site 4 is 3.98 (close to 4) which is considered as strongly affected.
- Based on figure 4, Site 2 which is totally unsuitable for drinking based on HPI and site 4 which is regarded as Poor according to HPI and 3.98 (strongly affected) as per MI are within a buffer of 200m from the dump site.

4 Conclusion

It is found that the groundwaters around the dumpsite are affected by heavy metal pollution which will exacerbate the residents' health issues. Two household units are regarded to have unsuitable drinking water and 8 sites are exposed to very poor-quality water while 2 sites possess good-quality water based on HPI. Metal index concludes that all the sites are moderately affected by heavy metals. Therefore, a unified index which collectively compares both indices may be useful for decision-making authorities. An important conclusion drawn from the study is that the groundwaters around the landfill should always be tested for both physicochemical parameters and heavy metals due to leachate infiltration. The limitation of the study is that the sites that have high values of HPI are either close to or far away from the dump site. It is difficult to draw conclusions based on the distance of the sampling point from the dump site. Therefore, the groundwater flow patterns must be studied to arrive at useful results. During sample collection, it was observed that the residents use metro water from Chennai corporation for domestic and drinking purposes. Heavy metal pollution study in the groundwater is recommended to be carried out for pre-monsoon and post-monsoon seasons as rainwater infiltration has more effect on groundwater pollution. Measures must be taken to treat the groundwater for minimum usage for domestic purposes as the colour of the water is found to be straw yellow. Strict pollution inspection efforts need to be initiated thorough enforcement of law-making to ensure proper function and maintenance of the landfill site.

References

1) Ramaswamy A. Impact of the Kodungaiyur dump hard on health: findings from the health service provider's study. Citizen consumer and Civil Action group. *Blogs*. 2019. Available from: https://www.cag.org.in/blogs/impact-kodungaiyur-dump-hard-health-findings-health-service-providers-study.
2) Aishwarya R. Assessment of Spatial Distribution of Physico-Chemical Parameters of Groundwater around Kodungaiyur Dump yard. *Journal of Physics: Conference Series*. 2021;2070(1):012215. Available from: https://iopscience.iop.org/article/10.1088/1742-6596/2070/1/012215.
3) Issa BR, Birma GJ, Muhammed FA, Ikpesu JE, Tawari-Fufeyin P. Index Model Approach of Heavy Metals Pollution Assessment in Soil Quality of some Selected Solid Waste Dumpsites in Warri and Environs, Delta State. *Nigeria Direct Research Journal of Public Health and Environmental Technology*. 2022;7(1):1–8. Available from: https://doi.org/10.26765/DRJPHET871635105.
4) Munagala S, Jagarapu DCK, S RRBS. Determination of water quality index for ground water near municipal dump site in Guntur. *Materials Today: Proceedings*. 2020;33(1):724–727. Available from: https://doi.org/10.1016/j.matpr.2020.06.030.
5) Briffa J, Sinagra E, Blundell R. Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*. 2020;6(9):e04691. Available from: https://doi.org/10.1016/j.heliyon.2020.e04691.
6) Anjanapriya S, Sureka M, Sasirekha N. Heavy metal pollution in soil and Water around landfill dumpsite. *International Journal of Zoology and Applied Biosciences*. 2021;6(6):299–304. Available from: https://doi.org/10.55126/ijzab.2021.v06.i06.030.
7) Aishwarya R, Faizuneesa A, Hemamathi A, Ramshankar P, Yuvaraj M. Correlation Study of Physico-Chemical Parameters and Water Quality Index Around Kodungaiyur Dumping Ground. *IOP Conference Series: Earth and Environmental Science*. 2022;1084(1):012061. Available from: https://doi.org/10.1088/1755-1315/1084/1/012061.
8) Khan A. Destruction of marshlands due to garbage dumping, Citizen consumer and Civil Action group. *Newsletter*. 2020. Available from: https://www.cag.org.in/newsletters/public-newsense/destruction-marshlands-due-garbage-dumping.
9) Fang H, Wang X, Xia D, Zhu J, Yu W, Su Y, et al. Improvement of Ecological Risk Considering Heavy Metal in Soil and Groundwater Surrounding Electroplating Factories. *Processes*. 2022;10(7):1267. Available from: https://doi.org/10.3390/pr10071267.
10) Kamel LH, Al-Zurfi SKL, Mahmood MB. Investigation of Heavy Metals Pollution in Euphrates River (Iraq) By Using Heavy Metal Pollution Index Model. *IOP Conference Series: Earth and Environmental Science*. 2022;1029(1):012034. Available from: https://doi.org/10.1088/1755-1315/1029/1/012034.
11) Shimod KP, Vineethkumar V, Prasad TK, Jayapal G. Effect of urbanization on heavy metal contamination: a study on major townships of Kannur District in Kerala, India. *Bulletin of the National Research Centre*. 2022;46(1). Available from: https://doi.org/10.1186/s42269-021-00691-y.
12) Mohan SV, Nithila P, Reddy SJ. Estimation of heavy metals in drinking water and development of heavy metal pollution index. *Journal of Environmental Science and Health Part A: Environmental Science and Engineering and Toxicology*. 1996;31(2):283–289. Available from: https://doi.org/10.1080/10934529609376357.
13) Mekuria DM, Kassegne AB, Asfaw SL. Assessing pollution profiles along Little Akaki River receiving municipal and industrial wastewaters, Central Ethiopia: implications for environmental and public health safety. *Heliyon*. 2021;7(7):e07526. Available from: https://doi.org/10.1016/j.heliyon.2021.e07526.

14) Asim M, Rao KN. Assessment of heavy metal pollution in Yamuna River, Delhi-NCR, using heavy metal pollution index and GIS. *Environmental Monitoring and Assessment*. 2021;193(2). Available from: https://doi.org/10.1007/s10661-021-08886-6.
15) Kwame T, Boateng F, Opoku O, Akoto. Heavy metal contamination assessment of groundwater quality:a case study of Oti landfill site. *Applied Water Science*. 2019;9:33. Available from: https://doi.org/10.1007/s13201-019-0915-y.
16) Babu AH, Swamy NK, Krishnaiah S, Senthil MS. A Study on Physico-Chemical analysis of Ground Water and Heavy Metal Analysis of Leachate in Kodungaiyur Landfill Site, Chennai. *IOP Conference Series: Materials Science and Engineering*. 2021;1112(1):012030. Available from: https://doi.org/10.1088/1757-899X/1112/1/012030.
17) Sahoo MM, Swain JB. Modified heavy metal Pollution index (m-HPI) for surface water Quality in river basins, India. *Environmental Science and Pollution Research*. 2020;27(13):15350–15364. Available from: https://doi.org/10.1007/s11356-020-08071-1.