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Assessment of Toxic Metals in an Open Dump Site Near PNG University of Technology, Papua New Guinea

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Abstract

Groundwater contamination near the municipal solid waste dump at the Papua New Guinea University of Technology (PNGUoT) has raised serious health concerns in the local communities. To testify these, a research study was conducted to quantify the presence of heavy metals. Water sample analyses showed Cd levels ranging from 0.0002 to 0.02 mg/L, Pb from 0.00002 to 0.094 mg/L, and Hg from 0.0001 to 0.052 mg/L, all of which exceed the World Health Organization's (WHO) safe drinking water limits. These metals are known to cause a range of health problems, including kidney disease, cancer, brain damage, and developmental delays in children. The situation calls for urgent action to safeguard the local community's health. Immediate improvements in waste management, such as better landfill designs with systems to capture and treat leachate, are needed to prevent further contamination of groundwater. Additionally, water treatment technologies like reverse osmosis should be considered to provide safe drinking water. Regular monitoring of groundwater quality and public health education in the area are also key steps in minimizing risks. These combined efforts will help ensure safer water for the community and more responsible management of the waste disposal site.

Key Words	Ground water, Municipal solid waste (MSW), Open dump site (ODS), Heavy metal contaminants, Inverse distance weight (IDW) interpolation
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Introduction

Human activities, including industrial processes, urbanization, agriculture, and the open dumping of municipal solid waste (MSW), significantly contaminate water sources, adversely affecting groundwater quality (Akinbile 2012; Usman et al. 2017). Landfills and Open Dump Sites (ODS) are major threats, with ODS referring to sites where solid waste is dumped without environmental regulations (Fatta & Loizidou 1999; Fodor & Szabo 2004). Areas near these sites are at a heightened risk for groundwater contamination due to leachate pollution (Hossain et al. 2014; Hadi 2023). When electronics, paints, batteries, and plastics are mixed with MSW, they increase heavy metal concentrations at dump sites (Maiti et al. 2016; Przydatek & Kanownik 2019). ODS remains the primary disposal method in many developing countries, contributing significantly to water and environmental pollution (Omeiza et al. 2022). It is well-documented that garbage is often dumped near borewells without proper waste management, further raising the risk of groundwater contamination. The issue of MSW is universal (Aderemi et al. 2011) and its management is an issue in underdeveloped nations, like PNG.

Research by Sugirtharan & Rajendran (2015) found that borewells near dumping sites have higher pollutant concentrations compared to those located farther away. Leachate, which accumulates at the bottoms of open dumps, percolates through soil layers, reaching groundwater and introducing toxic contaminants (Mor et al. 2006; Omeiza 2022). The high concentration and toxicity of leachate pose serious public health risks (Baderna et al. 2019). Chemical pollution remains a pressing issue globally, particularly in industrialized and developing nations. Studies link chemical exposure in drinking water to chronic health problems, including cancer and cardiovascular diseases, with children being especially vulnerable (Lin et al. 2022; Alao et al. 2023; Sankhla et al. 2019). Unsafe drinking water, inadequate sanitation, and poor hygiene create dangerous conditions, leading to water-related diseases such as diarrhea, typhoid, and cholera. In light of public concerns regarding the dump site at PNG University of Technology (PNGUoT) in Lae, this study aims to assess the impact of leachates on bore water quality in the vicinity of the dumping site.

Research Area

Lae City, the capital of Morobe Province, is the second largest city in Papua New Guinea (PNG) and hosts the largest cargo port, making it an industrial hub and home to the Papua New Guinea University of Technology (PNGUoT). Located between the Indonesian-Australian Plates and the

Pacific Plates on the South Bismarck Plate, Lae lies at coordinates 6.7155° S, 146.9999° E and features a tropical rainforest climate, with an average annual precipitation of 4,500 millimeters (Richard Stanaway et al. 2009).

The focus of this study is an open dump site situated near borewells from which Water PNG Limited extracts, treats, and distributes water for residential and commercial use across Lae City and surrounding areas. The dump site is located northeast of PNGUoT at the Second Seventh Landfill, positioned at 6.6598° S, 147.0123° E. Between March 2022 and February 2023, a survey was conducted on the borewells adjacent to the PNGUoT disposal site. The dumping sites with various disposals are shown in Figures 1 and 2. Thirteen sampling locations were established: three for dump soils, two for surface waters, and eight for bore waters (groundwater samples). Table 1 provides the coordinates of these sampling sites, while Figure 3 illustrates their actual positions within the study area.

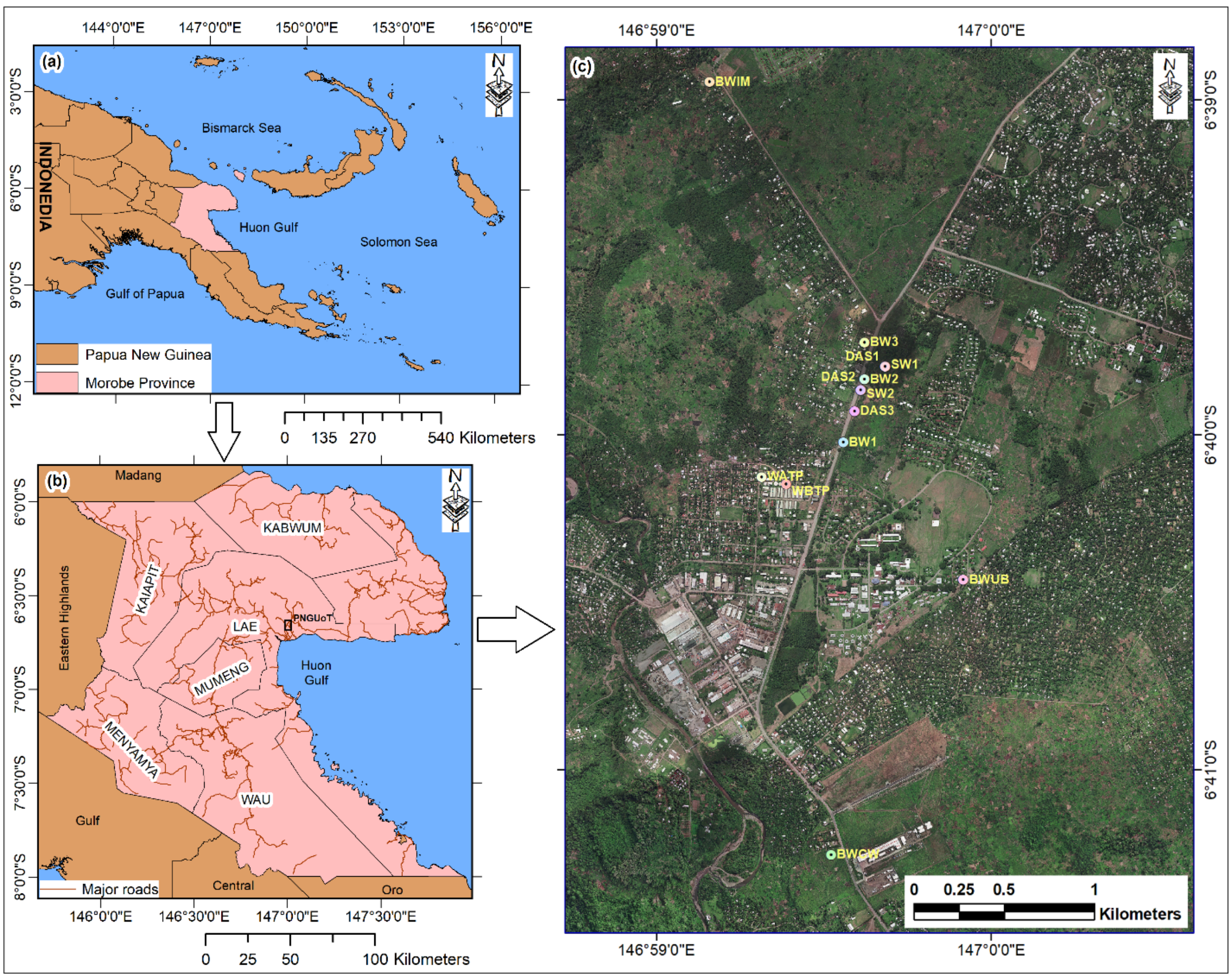

Figure 1 Location map of the study area (a) Papua New Guinea, (b) Morobe Province, and (c) Dump site and Borewells around PNGUoT.

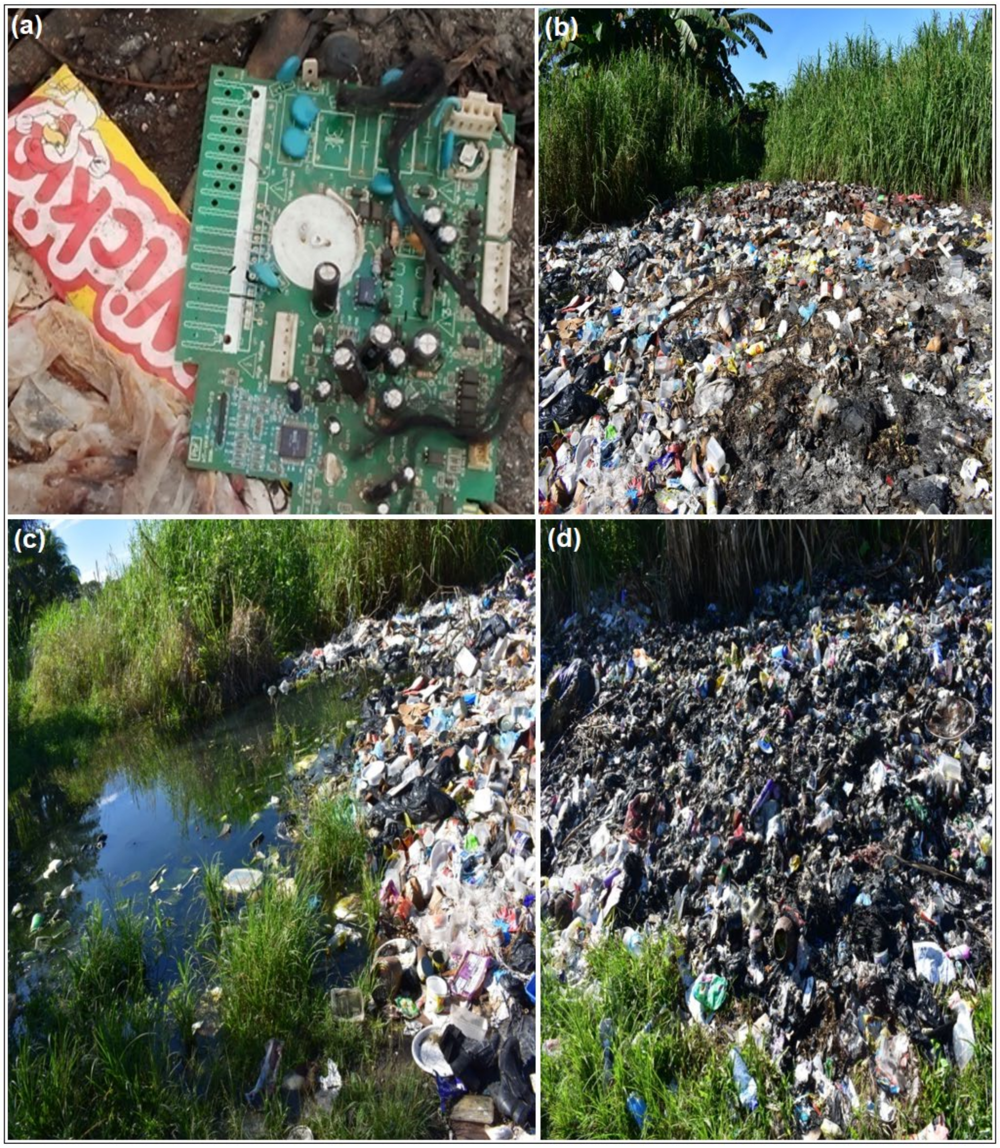

Figure 2 Types of Solid waste dumped at PNGUoT dump site, (a) Electronic Waste at Dump Site (b) Disposal of polymer (c) Pond near Dump Site, and (d) Electrical, paint waste near Dump Site.

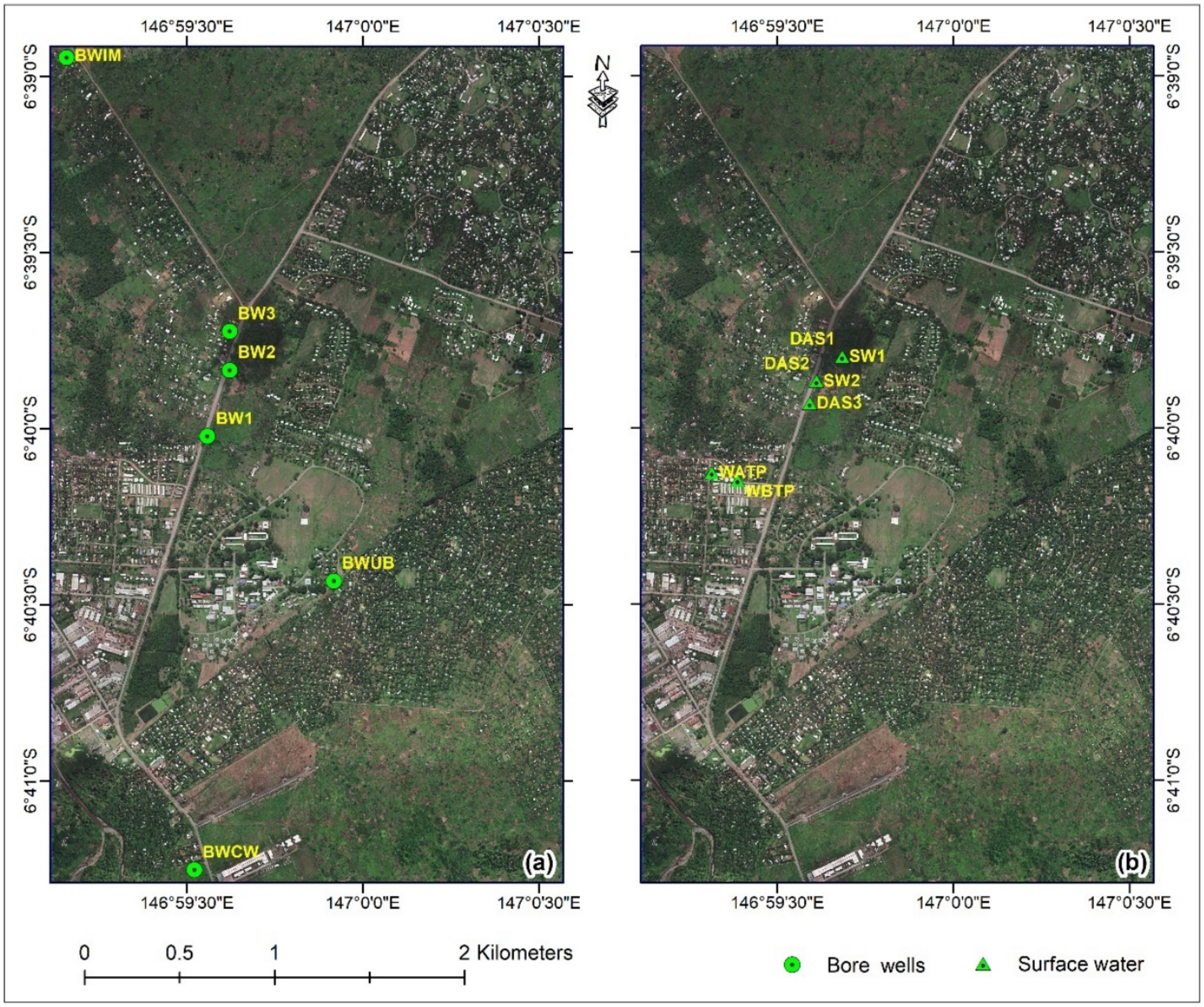

Figure 3 Location of water sample points (a) Bore wells and (b) Surface water

Table 1: Location of sampling point in the study area

Sl. No.	Station Type	Sampling point	Longitude	Latitude
1	Bore Wells (BW)	Bore Well 1 (BW1)	146.99265	-6.66704
2		Bore Well 2 (BW2)	146.99370	-6.66391
3		Bore Well 3 (BW3)	146.99370	-6.66207
4		Bore Well Uni Block (BWUB)	146.99862	-6.67388
5		Bore Well Igam Market (BWIM)	146.98597	-6.64911
6		Bore Well Carwash (BWCW)	146.99203	-6.68756
7	Ground Points (GP)	Dump Area Soil 1 (DAS1)	146.99474	-6.66327
8		Dump Area Soil 2 (DAS2)	146.99352	-6.66444
9		Dump Area Soil 3 DAS3)	146.99320	-6.66549
10		Surface Water 1 (SW1)	146.99474	-6.66327
11		Surface Water 2 (SW2)	146.99352	-6.66444
12		Water Before Treatment Plant (WBTP)	146.98980	-6.66913
13		Water After Treatment Plant (WATP)	146.98858	-6.66877

Methodology

A streamlined process was followed as below during the assessment procedures. is streamlined

Sample Collection and Storage: Water and soil samples were collected in clean bottles and stored in an icebox. They were transported to the National Analytical and Testing Services Limited (NATSL) laboratory and processed within 24 hours.

Water Sample Analysis: Toxic and heavy metals in surface and groundwater were analyzed using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Samples were acidified with 10% nitric acid, filtered through a 0.45 µm filter, and analyzed for Cadmium (Cd), Mercury (Hg), Lead (Pb), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Silver (Ag), Chromium (Cr) and Tin (Sn).

Soil Sample Digestion: Soil samples were digested using 3:1 aqua regia following Soil Chemical Methods–Australasia. The mixture was heated at 70–90°C and reduced in volume, then filtered through 0.45 µm cellulose nitrate filters. The digested samples were analyzed by ICP-MS.

Calibration Standard Preparation: ICP-Multi Elemental Solution IV (Merck KGaA) traceable to NIST SRM was used for calibration. Solutions were prepared at µg/L concentrations (50, 100, 150, 200 µg/L), with accepted calibration graph Replicate (R) values >0.95.

Spatial Interpolation and Mapping: The spatial interpolation technique predicts unknown values from a set of known values for any geographic location (Samanta et al. 2012). IDWA (Inverse distance-weighted) is one of the global spatial interpolation techniques used to interpolate the known tested values of the sample point location (Burrough & McDonnell 1998). These points are named bore wells (BW) from where the water samples were collected. Contours were generated from these interpolated raster surfaces. Both these activities were executed using the ArcGIS spatial analyst tool. The other set of points, called ground points (GP), were overlaid on the interpolated map to understand the impact or relationship of surface phenomena on the groundwater.

Results and Discussion

Groundwater in the research area is used for both residential and commercial purposes, so pollutant concentrations were compared against relevant standards. Measurements were taken at ODS and nearby borewells, with results for surface water, groundwater, and waste soils summarized in Tables 2. Using the IDW interpolation technique, results for each parameter across different time frames were used to generate thematic maps. The range of values (high to low) for each parameter is presented in Table 3.

Table 2 Analytical results of pollution sources - Dump area soils and surface waters in open dumping areas.

Sampling ID	Sampling Dates	Cd (mg/L)	Hg (mg/L)	Pb (mg/L)	Mn (mg/L)	Mo (mg/L)	Ni (mg/L)	Ag (mg/L)	Cr (mg/L)	Sn (mg/L)
DAS 1	Apr-22	0.0011	0.00086	0.08	0.471	0.0002	0.03	0.00068	0.043	0.0043
	Aug-22	0.0036	0.00004	0.013	0.277	0.0002	0.019	0.00004	0.025	0.0017
	Feb-23	0.0024	0.0007	0.01	0.384	0.0002	0.001	0.00003	0.0037	0.0034
DAS 2	Apr-22	0.00024	0.00034	0.049	0.334	0.0002	0.027	0.00034	0.034	0.0016
	Aug-22	0.0004	0.00004	0.0097	0.265	0.0002	0.011	0.00004	0.012	0.0036
	Feb-23	0.0003	0.0004	0.0084	0.247	0.0002	0.001	0.00003	0.0031	0.0028
DAS3	Apr-22	0.00015	0.00043	0.02	0.342	0.0007	0.032	0.00044	0.043	0.0011
	Aug-22	0.0005	0.00004	0.0038	0.202	0.0002	0.013	0.00004	0.012	0.0012
	Feb-23	0.0025	0.00006	0.0034	0.352	0.0005	0.001	0.00004	0.024	0.0016
WHO	**Guidelines(mg/L)**	**0.003**	**0.006**	**0.01**	**0.1**	**0.07**	**0.07**	**0.1**	**0.05**	
SW1	Apr-22	0.0029	0.0026	0.0005	0.033	1.441	0.001	0.0062	0.0002	2
	Aug-22	0.015	0.009	0.00003	0.0013	0.1	0.26	0.5	0.0019	1

Sampling ID	Sampling Dates	Cd (mg/L)	Hg (mg/L)	Pb (mg/L)	Mn (mg/L)	Mo (mg/L)	Ni (mg/L)	Ag (mg/L)	Cr (mg/L)	Sn (mg/L)
	Feb-23	0.0022	0.0054	0.0007	0.0028	1.224	0.001	0.42	0.0016	1
SW2	Apr-22	0.0024	0.0092	0.0001	0.0038	2.442	0.001	0.0078	0.0002	2
	Aug-22	0.0009	0.0026	0.071	0.0009	0.1	0.029	0.027	0.0014	0.554
	Feb-23	0.0029	0.0035	0.094	0.0021	2.134	0.001	0.0019	0.0009	2
BW1	Apr-22	0.013	0.0077	0.026	0.0074	0.1	0.001	0.0081	0.0008	0.001
	Aug-22	0.0009	0.0086	0.0005	0.0062	0.1	0.001	0.015	0.0002	0.001
	Feb-23	0.0043	0.011	0.00003	0.0084	0.1	0.001	0.00001	0.00002	0.001
BW2	Apr-22	0.02	0.0023	0.022	0.01	0.1	0.001	0.0052	0.0003	0.001
	Aug-22	0.0002	0.0038	0.0011	0.021	0.1	0.001	0.012	0.0002	0.001
	Feb-23	0.0063	0.052	0.0002	0.02	0.1	0.001	0.00001	0.0006	0.001
BW3	Apr-22	0.0002	0.0019	0.00003	0.0095	0.1	0.001	0.0048	0.0002	0.001
	Aug-22	0.0003	0.0035	0.0001	0.01	0.1	0.001	0.048	0.0002	0.001
	Feb-23	0.0033	0.029	0.0004	0.029	0.1	0.001	0.00001	0.0002	0.001
WBTP	Apr-22	0.0047	0.0012	0.018	0.0095	0.1	0.001	0.0081	0.0002	0.001

Sampling ID	Sampling Dates	Cd (mg/L)	Hg (mg/L)	Pb (mg/L)	Mn (mg/L)	Mo (mg/L)	Ni (mg/L)	Ag (mg/L)	Cr (mg/L)	Sn (mg/L)
	Aug-22	0.0047	0.0022	0.0003	0.0092	0.1	0.001	0.0071	0.0002	0.001
	Feb-23	0.00005	0.018	0.0008	0.015	0.1	0.001	0.00001	0.0002	0.001
WATP	Apr-22	0.0015	0.0012	0.00003	0.0088	0.1	0.001	0.0016	0.0002	0.001
	Aug-22	0.01	0.0018	0.0003	0.0096	0.1	0.001	0.011	0.0002	0.001
	Feb-23	0.0027	0.014	0.00003	0.035	0.1	0.001	0.00001	0.0007	0.001
BWUB	Apr-22	0.0035	0.0035	0.00003	0.0001	0.1	0.001	0.00001	0.0001	0.001
	Aug-22	0.0042	0.0051	0.0003	0.0001	0.1	0.001	0.00001	0.0002	0.001
	Feb-23	0.0006	0.0061	0.00003	0.0001	0.1	0.001	0.00001	0.0004	0.001
BWIM	Apr-22	0.0028	0.0032	0.00003	0.002	0.1	0.001	0.00001	0.0002	0.001
	Aug-22	0.0024	0.0038	0.0003	0.0015	0.1	0.001	0.00001	0.0002	0.001
	Feb-23	0.0007	0.0041	0.00003	0.002	0.1	0.001	0.00001	0.0002	0.001
BUCW	Apr-22	0.003	0.005	0.00003	0.00005	0.1	0.001	0.00001	0.0003	0.001
	Aug-22	0.0034	0.004	0.0003	0.00003	0.1	0.001	0.00001	0.0001	0.001
	Feb-23	0.0026	0.004	0.00003	0.00003	0.1	0.001	0.00001	0.0002	0.001

The values highlighted in the preceding table exceed the limits set by WHO guidelines, further corroborated by the visual comparisons presented in figures 5, 8, and 11.

Table 3 The resulting interpolated data ranges

Sl. No.	Parameters	Interpolation range value		
		April, 2022	August, 2022	February, 2023
1	Silicon dioxide (SiO_2), mg/L	8.7 - 51	9.1 - 40	9.4 – 102
2	Total dissolve solids (TDS), mg/L	59 - 295	60 - 560	55 – 290
3	Total hardness (TH), mg/L	101 - 564	123 - 639	101 – 517
4	Mercury (Hg), mg/L	0.0019 – 0.007	0.0035 – 0.0086	0.004 – 0.052
5	Lead (Pb), mg/L	0.00003 - 0.026	0.0001 – 0.001	0.00003 – 0.0003
6	Cadmium (Cd), mg/L	0.0002 – 0.02	0.0002 – 0.004	0.0006 – 0.006
7	Chromium (Cr), mg/L	0.0001 – 0.0007	0.01 – 0.02	0.00002 – 0.0006

Interpretation of Data

The data illustrates that the contamination of borewell water with heavy metals, specifically cadmium (Cd), lead (Pb), and mercury (Hg), which were detected above the permissible limits set by the World Health Organization (WHO, 2022). The permissible limits for these metals are 0.003 mg/L for Cd, 0.01 mg/L for Pb, and 0.006 mg/L for Hg. These contaminants were found in borewell samples (BW1 and BW2) near dumping sites, indicating that pollution is occurring due to the leaching of heavy metals into the groundwater and the likely sources of contamination are items such as fluorescent lamps, batteries, and electronic waste, which are disposed of in open dump sites (Figure 2). These observations coincide with earlier reported studies of Hossain et al. 2014, Waheed Ahmad Hurra & Abhilasha Bhawsar 2021. The detection of Cadmium (Cd), Lead (Pb) and Mercury (Hg) in samples collected and tested in BW1, BW2 and WBT is an indication of heavy metal contamination undiluted during dry seasons. This contamination is particularly concerning as it coincides with dry seasons when the lack of rainfall leads to minimal dilution of the contaminants. The findings align with earlier studies conducted in Tamil Nadu, India by Nagarajan et al. 2012 and Pande et al. 2015, which also reported high levels of heavy metal contamination in groundwater near dumping sites. The situation underscores the environmental and public health risks associated with improper waste disposal and the subsequent leaching of toxic substances into groundwater. A graphical representation and spatial diagrams of Cd, Pb and Hg are represented in Figures 4-12.

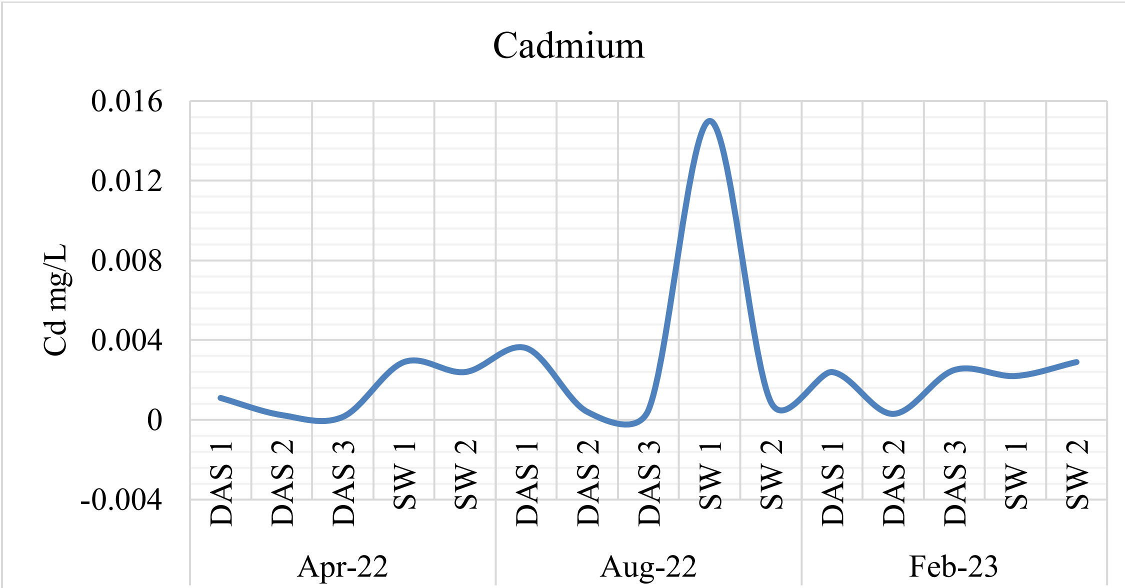

Figure 4 Temporal Variation of Cd in Surface Point

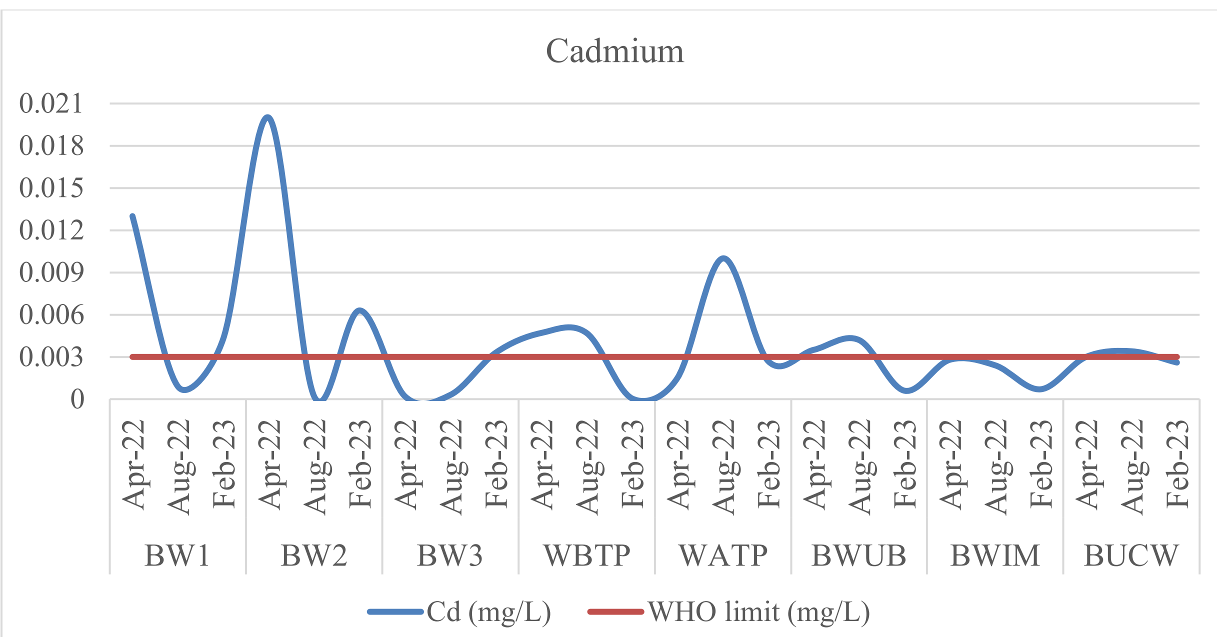

Figure 5 Temporal Variation of Cd in Borewells

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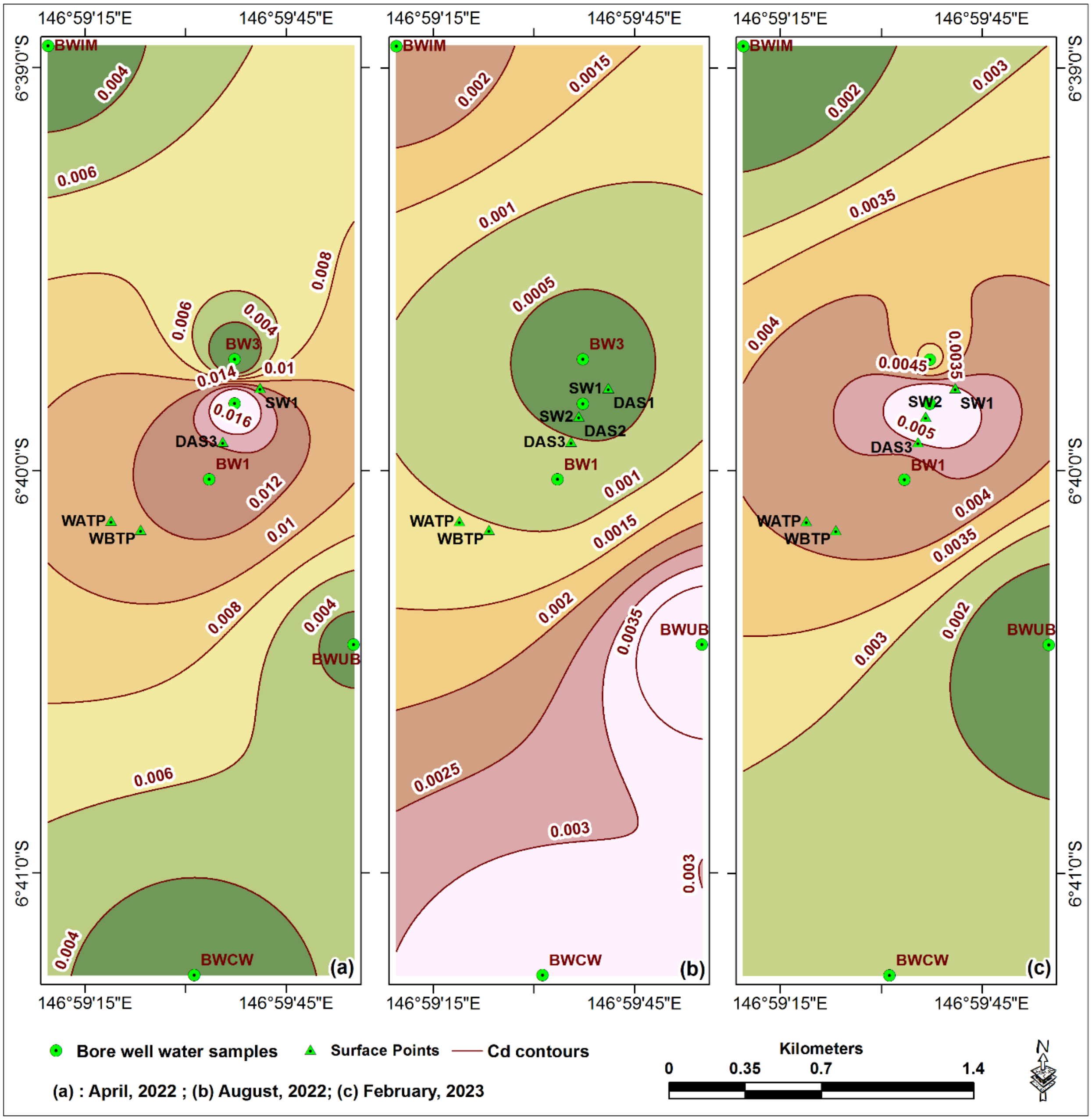

Figure 6 Spatial Variation of Cd

The highest concentration of cadmium (Cd) was detected in SW1 in August 2022, likely due to its proximity to DAS1, where leaching and percolation were particularly active during the wet season when the samples were collected. However, in April 2023, cadmium levels were found to be higher in BW1 and BW2. This increase in concentration is attributed to the samples being collected during the driest week of the month, a period when the contaminants were undiluted, leading to more concentrated levels of Cd in the groundwater. This seasonal variation highlights the impact of rainfall on the dilution and dispersion of heavy metal contaminants in groundwater systems.

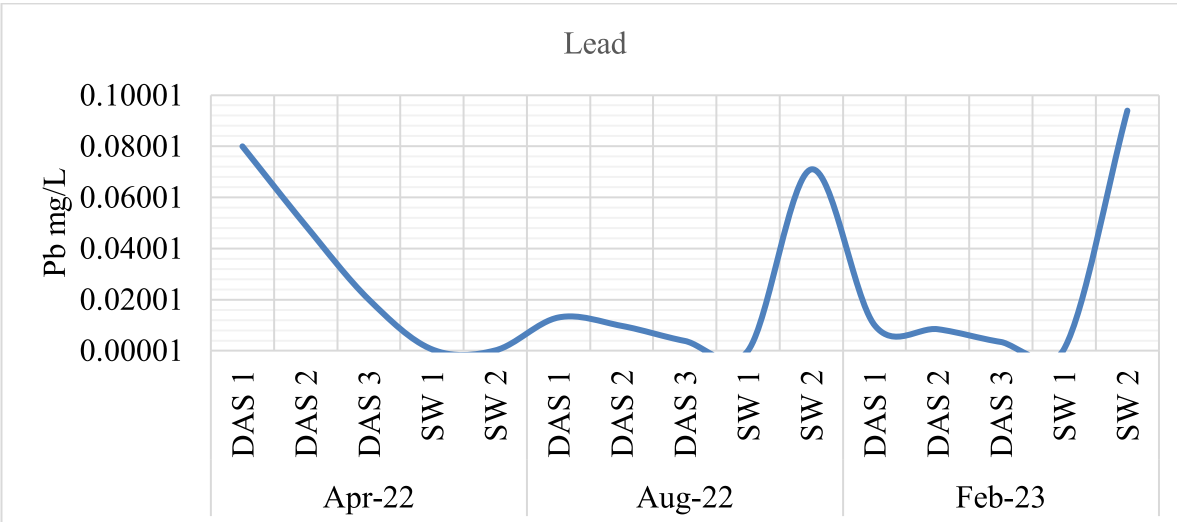

Figure 7 Temporal Variation of Pb in Surface Point

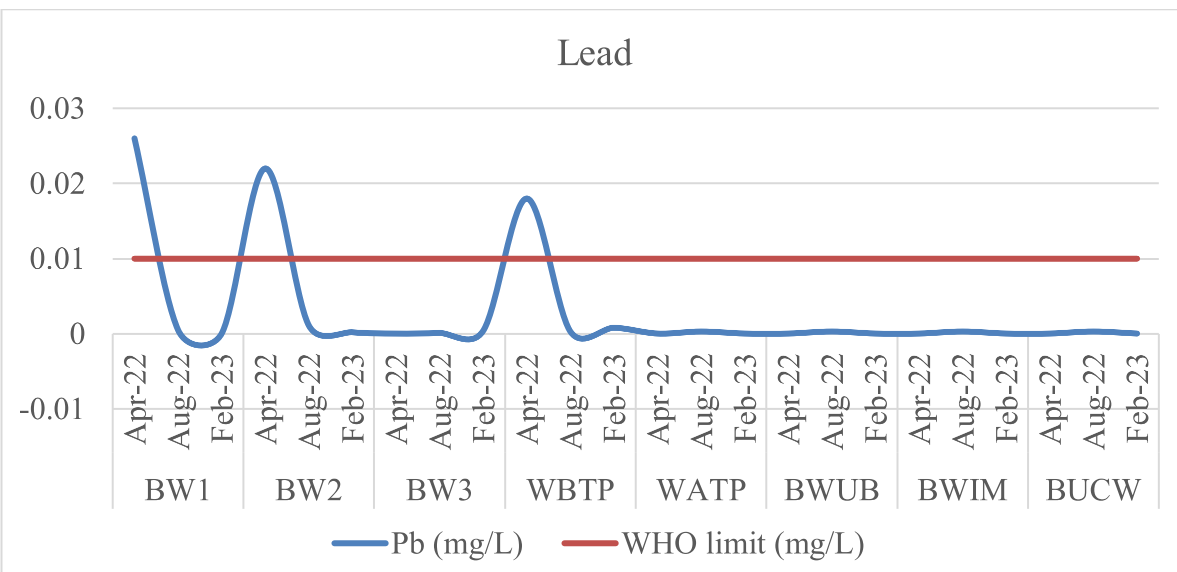

Figure 8 Temporal Variation of Pb in Borewells.

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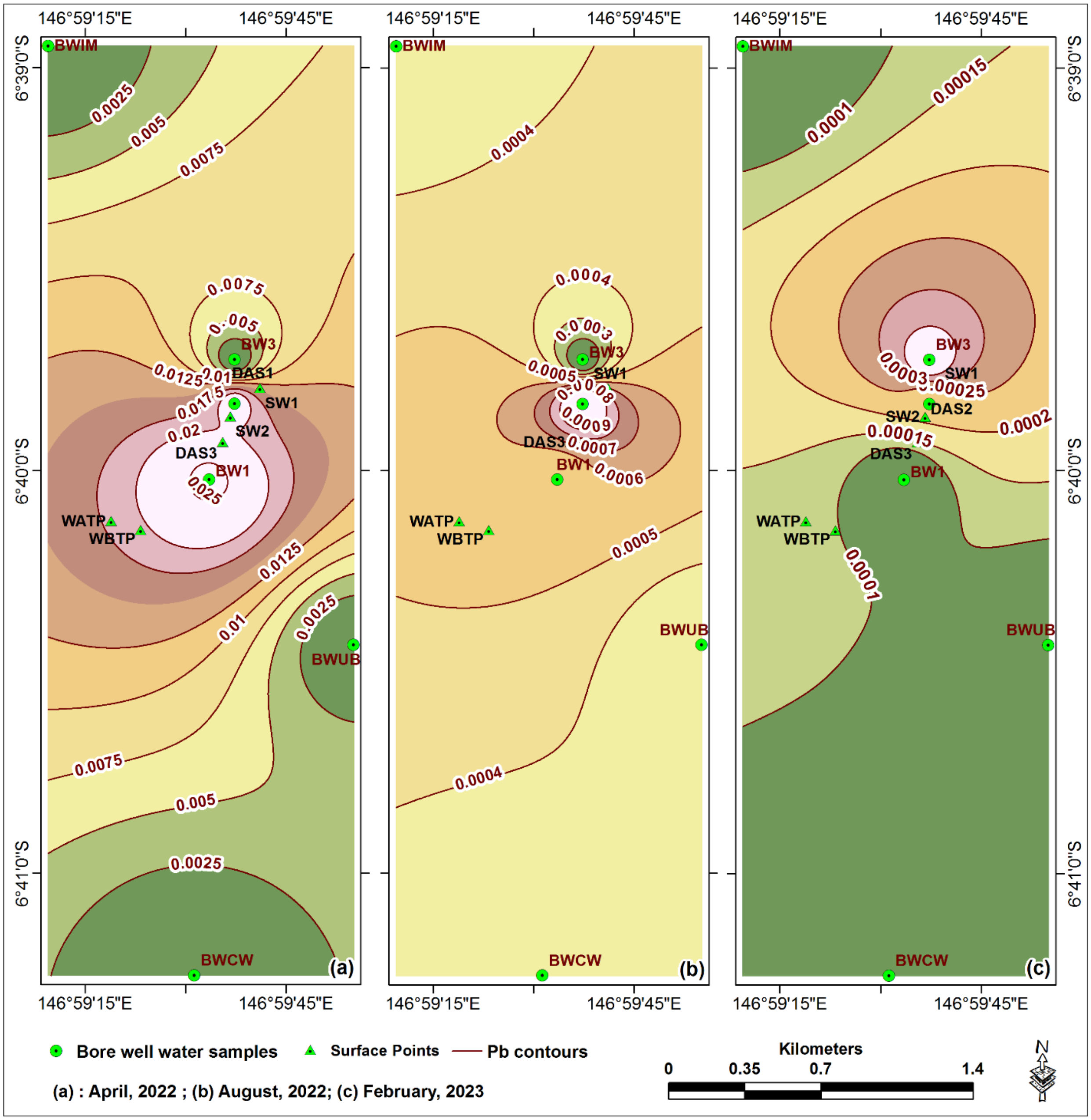

Figure 9 Spatial variation of Pb

The highest concentrations of lead (Pb) were measured in DAS1, DAS2, and SW2 in April 2022, August 2022, and February 2023, respectively. Leaching and percolation of contaminants were particularly effective during the rainy seasons in August 2022 and February 2023, which likely caused an increase in Pb levels in surface water samples collected at those times. In contrast, the highest Pb concentrations in groundwater were detected in BW1, BW2, and WBTP in April 2022, when the samples were collected during the driest week. Due to the lack of rainfall, the contaminants were not effectively diluted, leading to higher Pb levels in the groundwater. This variation emphasizes the influence of seasonal rainfall on the dispersion and concentration of lead contaminants in both surface and groundwater systems.

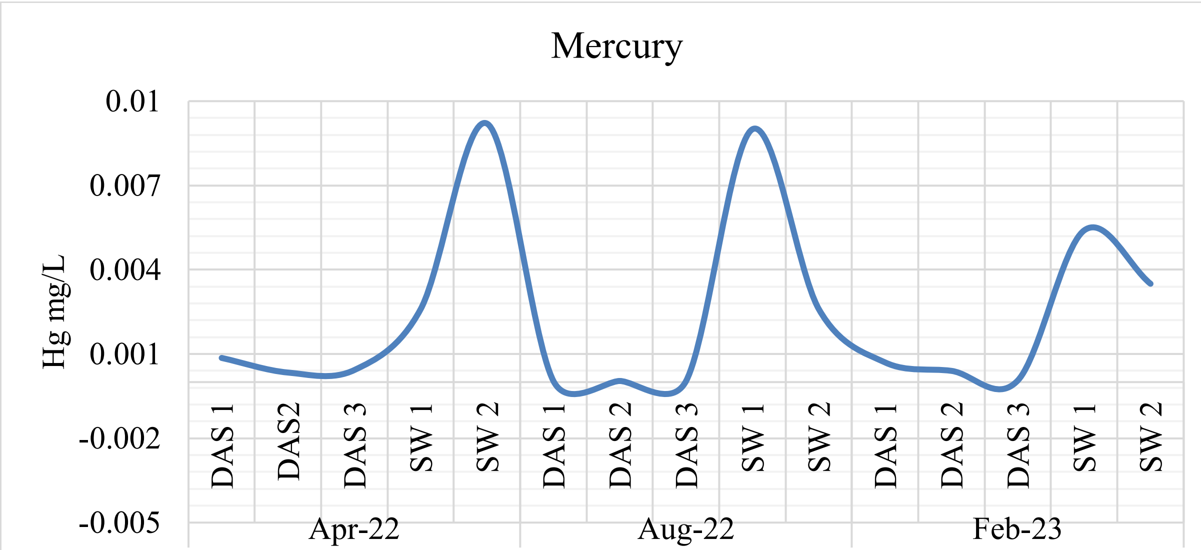

Figure 10 Temporal Variation Hg in Surface Point

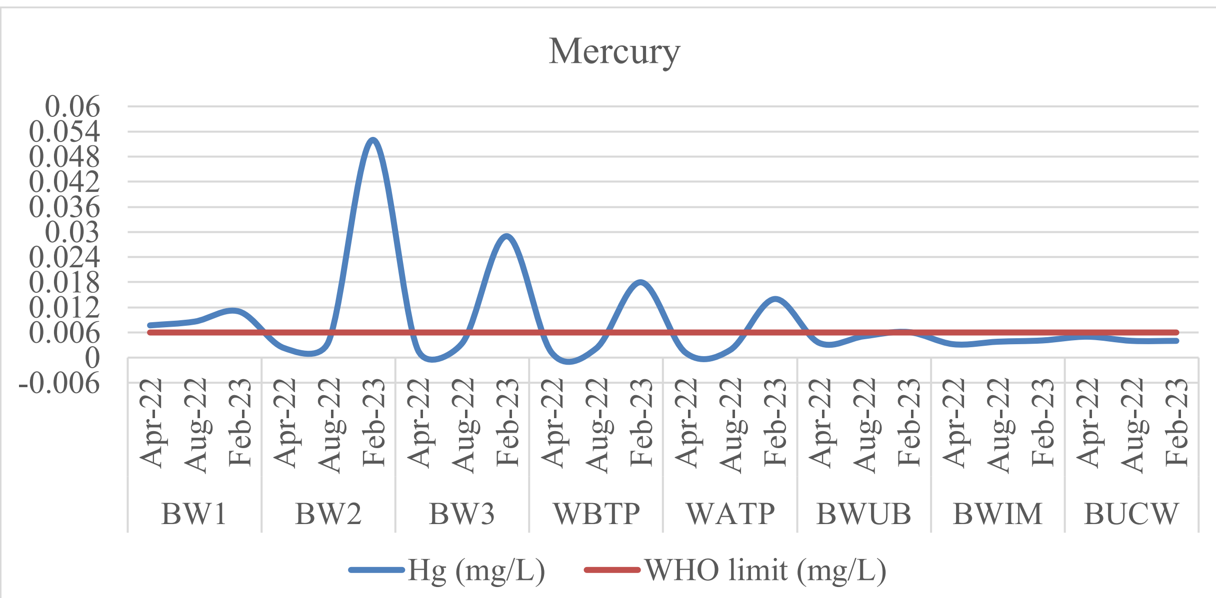

Figure 11 Temporal Variation of Hg in borewells

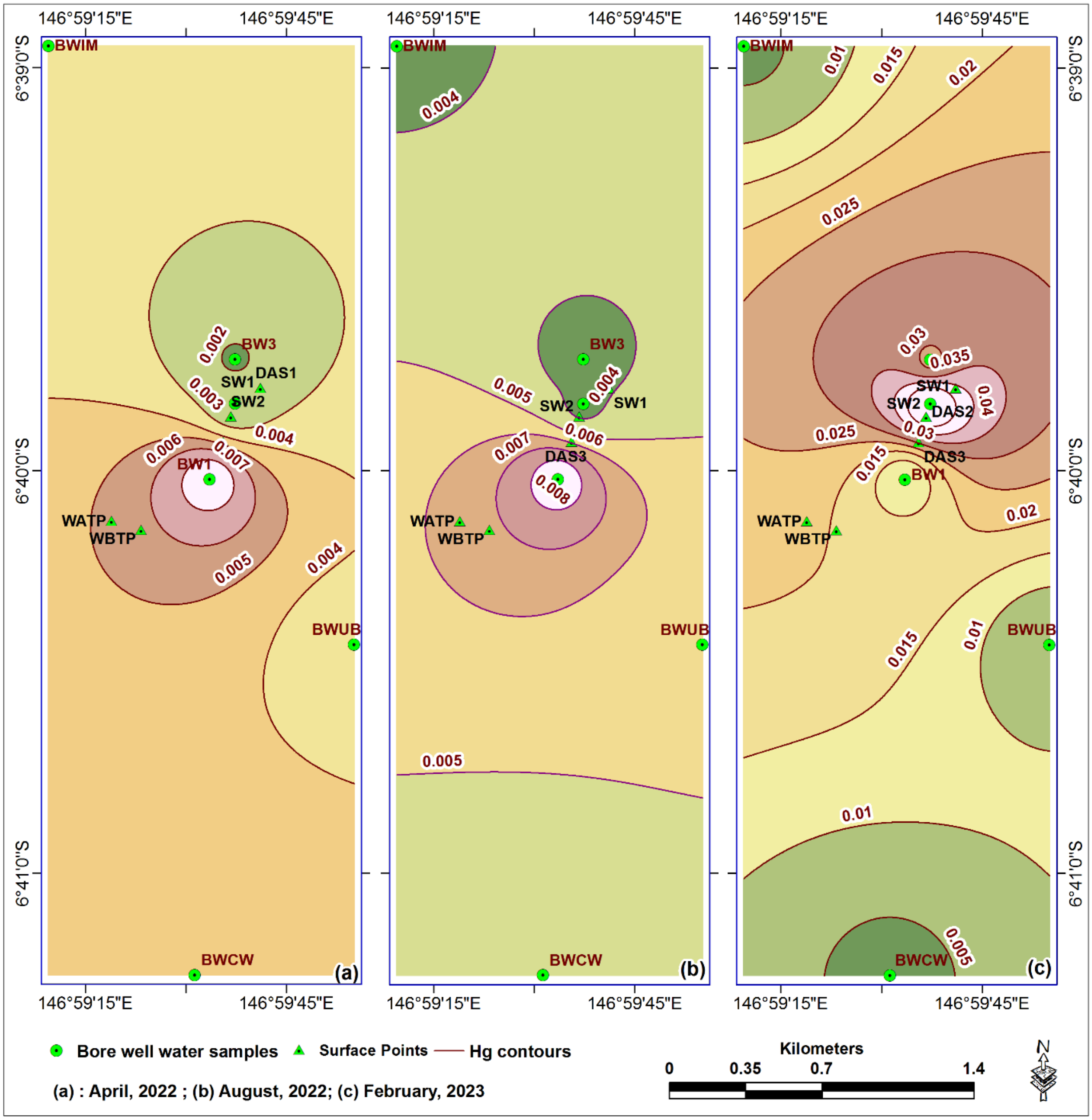

Figure 12 Spatial Variation of Hg

The maximum mercury (Hg) levels were consistently detected in SW1, SW2, and BW1 throughout the investigation period. However, the highest concentrations of Hg were measured in BW2, WB3, WBTP, and WATP in February 2023. Since mercury is known to be highly persistent in the environment, it is believed that Hg pollution in SW1 and SW2 leached into the groundwater over time. This process likely contributed to the elevated concentrations of Hg detected in the groundwater samples in February 2023. The persistence of Hg and its ability to contaminate both surface and groundwater highlight the long-term environmental risks associated with mercury pollution.

Conclusion

Confirming the concerns of pollution at the site, the study concludes that leaching of Cadmium (Cd), Lead (Pb) and Mercury (Hg) percolated through the soils and polluted the groundwater nearer to ODS. Also concluded that leaching of chemical contaminants as confirmed by Cd, Pb, and Hg concentrations at the site under investigation, heavy metals were detected in BW1 BW2 BW3, WBTP, WATP, SW1, SW2, DAS1, DAS2 and DAS3 which signifies leaching and percolating of potential pollution sources near the dumping. Borewells further away from dumping sites and BWIM. BWUB and BWCWP detected heavy metals below the permissible limit. Therefore, an ODS along the boundary has significant impacts on groundwater quality near the dumping site. Cd and Pb were detected at greater concentrations in April 2022 at BW1, BW2, SW1 SW2. The heavy metals detection in bore water seems to have resulted from the dumping of electronic waste, electrical appliances, batteries, packaging materials, and cosmetic products as per site observations coinciding with earlier reported studies.

Preventing groundwater pollution from open dumping requires a combination of regulatory measures, waste management practices, and environmental monitoring. Looking at the situation of the site, we here with recommend the following best strategies to prevent open dumping from contaminating groundwater. Firstly, proper waste management systems like improved waste collection and recycling infrastructure should be considered with designed sanitary landfills. This should be followed by implementing hazardous waste regulations with strict enforcement of laws. Further, regular monitoring of the site along with real time detection technologies would be beneficial in timely identification and remedial steps. Finally, public awareness programs should be engaged in the local communities for proper disposal and civic responsibility in maintaining public health and environmental protection. Modern environmentally friendly methods like bioremediation and phytoremediation should be considered at the site. By implementing these strategies, open dumping and its subsequent groundwater pollution can be significantly reduced, protecting both human health and the environment.

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REFERENCES

Aderemi, A.O., Oriaku, A.V., Adewumi, G. A. and Otitoloju, A. A., 2011. Assessment of groundwater contamination by leachate near a municipal solid waste landfill. *African Journal of Environmental Science and Technology,* 5, pp.933–940.

Akinbile, C.O., 2012. Environmental impact of landfill on groundwater quality and agricultural soils in Nigeria. *Soil and Water Research,* 7, pp.18–26.

Alao, J.O., Fahad, A., Abdo, H.G., Ayejoto, D.A., Almohamad, H., Ahmad, M.S., Nur, M.S., Danjuma, T.T., Yusuf, M.A., Francis, O. T. and others, 2023. Effects of dumpsite leachate plumes on surface and groundwater and the possible public health risks. *Science of The Total Environment,* 897, pp. 165469.

Baderna, D., Caloni, F. and Benfenati, E., 2019. Investigating landfill leachate toxicity in vitro: A review of cell models and endpoints. *Environment International,* 122, pp.21–30.

Burrough, P.A. and McDonnell, R.A., 1998. Principles of Geographical Information Systems" Oxford, Oxford University Press, pp. 330.

Fatta, D., Papadopoulos, A. and Loizidou, M., 1999. A study on the landfill leachate and its impact on the groundwater quality of the greater area. *Environmental Geochemistry and Health,* 21, pp.175–190.

Fodor, L. and Szabó, L., 2004. Study of heavy metal leaching in the soil. Proceedings of the 13th International Soil Conservation. Organization Conference.

Hadi, N.S., 2023. Leachate Characterization and Assessment of Soil Pollution Near Some Municipal Solid Waste Transfer Stations in Baghdad City. *Nature Environment & Pollution Technology*, *22*(4), pp. 2239-2247.

Hossain, M.L., Das, S.R., Hossain, M. K. and others, 2014. Impact of landfill leachate on surface and groundwater quality. *Journal of Environmental Science and Technology,* 7, pp.337–346.

Lin, L., Yang, H. and Xu, X., 2022. Effects of water pollution on human health and disease heterogeneity: a review. *Frontiers in environmental science,* 10, pp.1-16.

Maiti, S. K., De, S., Hazra, T., Debsarkar, A. and Dutta, A., 2016. Characterization of leachate and its impact on surface and groundwater quality of a closed dumpsite–a case study at Dhapa, Kolkata, India. *Procedia Environmental Sciences,* 35, pp.391–399.

Mor, S., Ravindra, K., Dahiya, R. P. and Chandra, A., 2006. Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environmental monitoring and assessment,*118, pp.435–456.

Nagarajan, R., Thirumalaisamy, S. and Lakshumanan, E., 2012. Impact of leachate on groundwater pollution due to non-engineered municipal solid waste landfill sites of Erode City, Tamil Nadu, India. *Iranian Journal of Environmental Health Science & Engineering,* 9, pp.1-12 .

Omeiza, A.J., Abdulwahab, O.O., Nur, M. S., Danjuma, T. T., Jaiyeoba, E., Abdullahi, D., Adekanye, O. O. and Mary, E. T., 2022. Effect of an active open dumpsite on the earth's subsurface and groundwater resource. *Asian Journal of Physical and Chemical Sciences,*10, pp. 15–24.

Omeiza, A.J., Abdulwahab, O.O., Nur, M.S., Danjuma, T.T., Jaiyeoba, E., Diya'ulhaq, A., Oluseyi, Adekanye, O. and Mary, E.T., 2022. Effect of an active open dumpsite on the earth's subsurface and groundwater resource. *Asian Journal of Physical and Chemical Science,* 10, pp.15–24.

Pande, G. S. A. A. A., 2015. Impacts of leachate percolation on groundwater quality: A case study of Dhanbad city. *Global Nest J,* 17, pp.162–174.

Przydatek, G. and Kanownik, W., 2019. Impact of small municipal solid waste landfill on groundwater quality. *Environmental Monitoring and Assessment,*191, pp.1–14.

Rayment, G.E. and Lyons, D.J. 2011. Soil chemical methods: Australasia, vol. 3, CSIRO Publishing.

Rice, E.W., Bridgewater, L., Association, A.P.H. and others, 2012. Standard methods for the examination of water and wastewater, vol. 10, American Public Health Association Washington, DC.

Samanta, S., Pal, D.K., Lohar, D. and Pal, B., 2012. Interpolation of climate variables and temperature modeling. *Theoretical and Applied Climatology*, 107, pp.35-45.

Sankhla,M.S. and Kumar, R., 2019. Contaminant of Heavy Metals in Groundwater & its Toxic Effects on Human Health & Environment. *International Journal of Environmental Sciences & Natural Resources,*18(5), pp. 00149-00153.

Stanaway, R., Wallace, L., Sombo, Z., Peter, J., Palusi, T., Safomea, B., Nathan, J., 2009. Lae, a city caught between two plates – 15 years of Deformation Measurements with GPS. 43rd Association of Surveyors PNG Congress, Lae.

Sugirtharan, M. and Rajendran, M., 2015. Groundwater quality near municipal solid waste dumping site at Thirupperumthurai, Batticaloa.*The Journal of Agricultural Sciences*, 10(1), pp.21-28.

Usman, M., Yasin, H., Nasir, D.A., Mehmood, W. and others, 2017. A case study of groundwater contamination due to open dumping of municipal solid waste in Faisalabad, Pakistan. *Earth Sciences Pakistan,*1, pp.15–16.

Waheed, A.H. and Bhawsar, A., 2021. Assessment of groundwater quality near solid waste dumping site Bhanpur, Bhopal. *International Journal of Applied Research*, 7(8), pp.314-319.

World Health Organization (WHO)., Guidelines for drinking-water quality: fourth edition incorporating the first addendum, Annex 3, 24th April 2017.