CONTAMINATION OF DUMP SOILS BY TOXIC HEAVY METALS: AN EMERGING RISK TO GROUNDWATER QUALITY

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Abstract: Heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) pose significant concerns due to their persistence in the environment and their potential risks to human health and ecosystems. Contamination of soil can jeopardize groundwater quality, as precipitation may facilitate the leaching of these metals into the water supply. Given that groundwater serves as a crucial source of drinking water, such contamination can adversely affect aquifer geochemistry, resulting in severe health and environmental consequences. This study corroborates earlier research that identified the presence of Cd, Pb, and Hg in borewell samples by assessing heavy metal concentrations in the soil surrounding the Papua New Guinea University of Technology's dump site. Utilizing Inductively Coupled Plasma Mass Spectroscopy (ICP-MS), the investigation revealed concentrations of Cd, Pb, and Hg ranging from 0.0031 to 0.0062 mg/L, 0.04 to 0.63 mg/L, and 0.0008 to 0.0018 mg/L, respectively. The findings indicate a significant increase in heavy metal concentrations in proximity to the dump site over the years.

Key Words: Ground water, Open dump site (ODS), Heavy metal contaminants, Inverse distance weight (IDW) interpolation.

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1. INTRODUCTION

The management of municipal solid waste (MSW) in Lae City is through open dumping and burning. This study assessed its impacts on groundwater quality, given that heavy metal contamination in soils can result in leaching of metals into the groundwater aquifer. Solid waste such as scrap metals, metallic devices, batteries, and electronic waste found in open dumps are some of the sources of heavy metals. Heavy metals such as Cd, Pb, and Hg are highly toxic, even at very low concentrations. As such this study evaluated Cd, Pb, and Hg in dump soil to confirm previous studies on bore wells near the dump site. Surface water and groundwater aquifer are venerable and suspectable to heavy metals contaminations as confirmed by studies over the decade.

Leachate, a waste fluid, is created when rainwater flows through a waste disposal plant and according to studies it has a high propensity to seep through soil and contaminate the water table below. These leachates containing heavy metals and or inorganic or organic substance reaching groundwater persist and degrade groundwater quality and provide a serious health risk to the consumer.

The open dump site in which this study centered is located inside the perimeter of PNG University Technology and beside it is the pump house where raw water is harvested and treated at Traka Treatment Facility by Water PNG Limited and distributed through Lae City and surrounding communities for consumption and domestic uses. Potable water is one of the basic necessities for human survival. A vital component of successful health protection measures, access to drinking water can be a fundamental right and a necessity for good health. Since improved access to clean drinking water has measurable health advantages, it is crucial. Therefore, access to clean drinking water is essential to human survival. According to The United Nations General Assembly (UNGA) has listed access to clean water and sanitation for all as one of the sustainable development goals to be attained by 2030.

To determine and validate the level of heavy metal (Cd, Pb, and Hg) contamination in the dump soil close to the borewell, this self-funded investigation was carried out.

2. THE STUDY AREA AND SITE MAP

This study was recently carried out in the industrial metropolis of Lae, Morobe Province, Papua New Guinea (PNG), located near the PNG University of Technology, illustrated on the map.

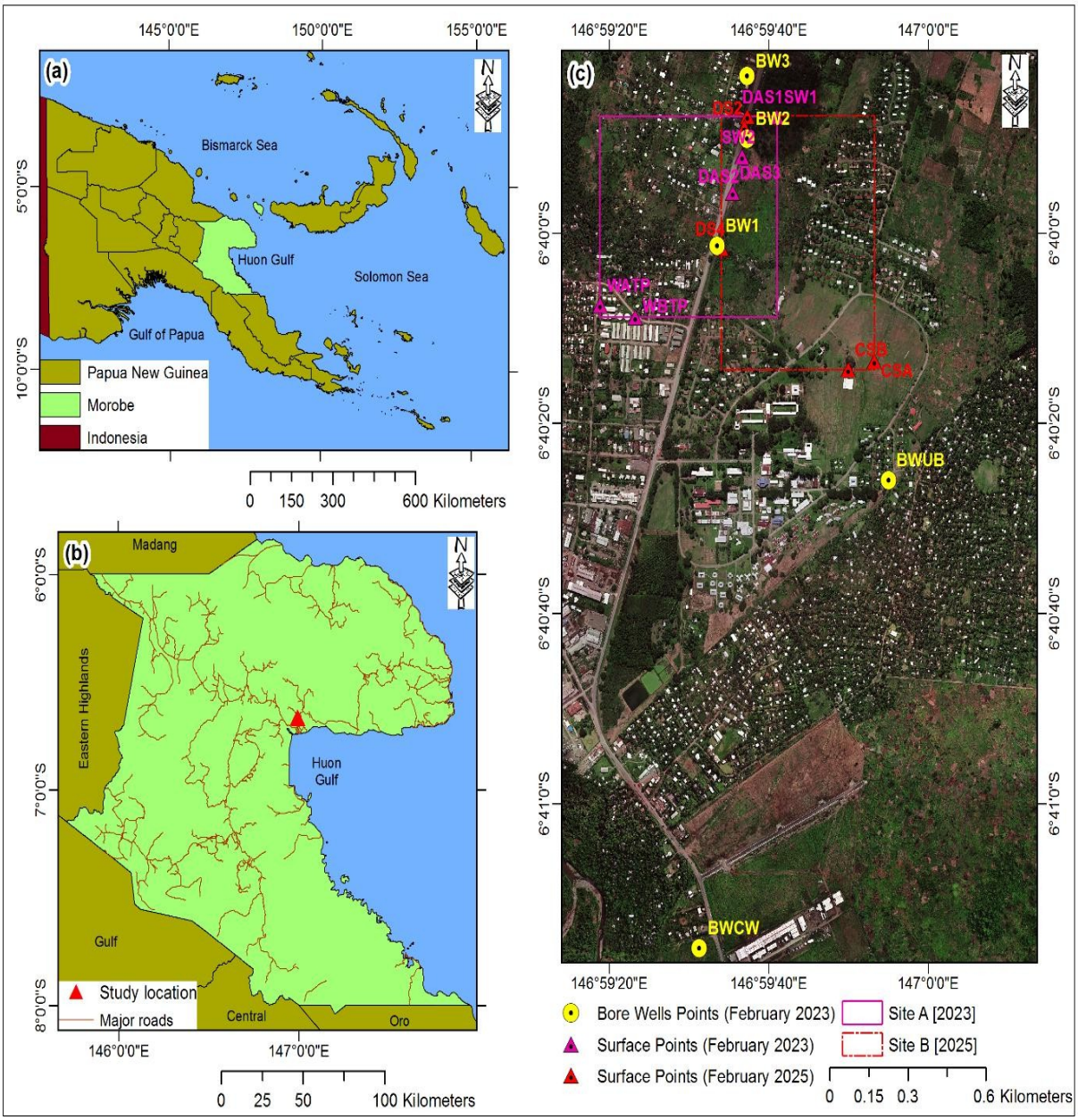

Figure 1 Map Depicting the Study Area

Six (6) soil samples were taken in total, two (2) control soils away from the dump and four (4) near the waste disposal site as tabulated below.

Table 1 Sampling Coordinates

Sl. No.	Station Type	Sampling Point	Longitude	Latitude
1	Bore well 2023	Borewell 1 (BW1)	146.9926	-6.66704
2		Borewell 2 (BW2)	146.99369	-6.66390
3		Borewell 3 (BW3)	146.99369	-6.66207
4		Borewell Igam Market (BWIM)	146.98597	-6.64910
5		Borewell Carwash (BWCW)	146.99202	-6.68756
6		Borewell Uni Block (BWUB)	146.99862	-6.67388
7		Water Before Treatment Plant (WBTP)	146.98980	-6.66913
8		Water After Treatment Plant (WATP)	146.98857	-6.66876
9	Surface Point 2023	Dump Area Soil 1 (DAS1)	146.99474	-6.66326
10		Dump Area Soil 2 (DAS2)	146.99352	-6.66443
11		Dump Area Soil 3 DAS3)	146.99320	-6.66548
12		Surface Water 1 (SW1)	146.99474	-6.66326
13		Surface Water 2 (SW2)	146.99352	-6.66443
1	Surface Points 2025	Control Soil A (CS A)	146.998145	-6.67045
2		Control Soil B (CS B)	146.997232	-6.67062
3		Dump Soil 1 (DS1)	146.993721	-6.66329
4		Dump Soil 2 (DS2)	146.993635	-6.66358
5		Dump Soil 3 (DS3)	146.993569	-6.66445
6		Dump Soil 4 (DS4)	146.992823	-6.66716

3. ANALYTICAL TECHNIQUES

Sampling and Sample Preparation: For heavy metal testing, soil samples were collected from the control and dump sites at a depth of 5 to 10 cm, and they were then taken to the National Analytical and Testing Services Laboratory. The samples were processed according to Soil Chemical Methods- Australasia by air-drying at room temperature for 4 weeks. The soils were homogenized using mortar and pestle, sieved through 0.45 µ.

Sample Treatment: For each of the homogenized soil samples, 1.0000g of soil was weighed into a 150 ml beaker that had been washed and rinsed with distilled water. The samples were acid digested overnight with aqua regia solution and processed by heating the mixture at 80ºC to boiling until the mixture volume reduced to less than 15 ml in volume. The digested solutions were removed from the hot plate, cooled, and transferred into a 100 ml polyethylene container previously washed in an acid bath and rinsed with distilled water and diluted to 50

ml with distilled water.

Sample analysis: The digested aliquots were analysed for Cd, Pb, and Hg using Inductive Couple Plasma Mass Spectroscopy (ICP-MS). Multi-Elemental Solution IV (Merck KGaA)—traceable to NIST CRM—was used to develop calibration curves and accuracy checks.

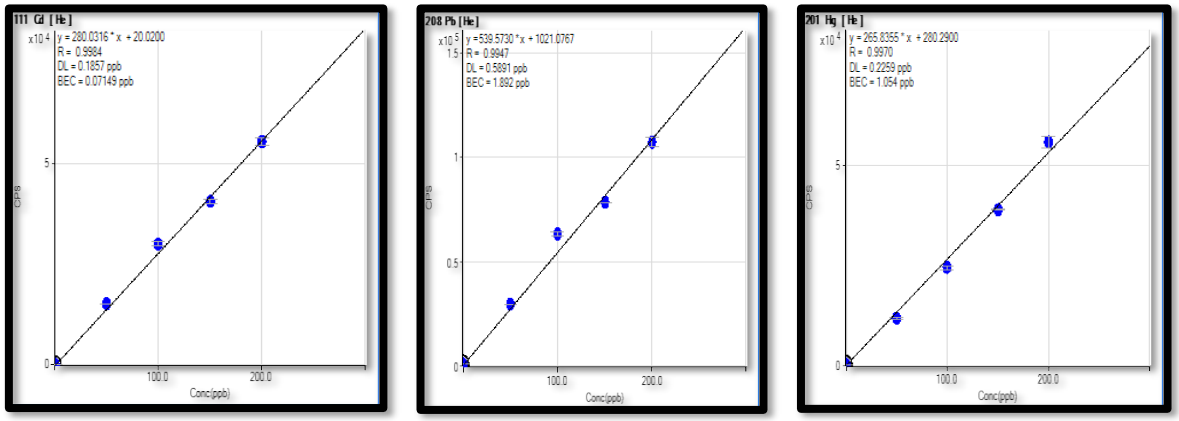

Figure 2 Calibration Curve of Cd, Pb, and Hg

Result and data processing: The spatial interpolation technique was in predicting values for cells in a raster. Inverse distance weighted (IDW) is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighbourhood of each processing cell. IDW interpolation was used to explicitly implements the assumption of concentrations in soil and water quality data that are close to one another are more alike than those that are farther apart. IDW was used to predict a value for any unmeasured location the measured values surrounding the predicted location.

4. RESULT AND DISCUSSION

The results that were obtained after the ICP- MS analysis are tabulated in Table 2. There are significant levels of heavy metals (Cd, Pb, Hg) in the recent studies of soil quality parameters in dump soils, according to the analysed results. Higher Cd, Pb, and Hg concentrations were recorded during analysis. The heavy metal content was generally higher in dump soil (DS1, DS2, DS3, DS4), borewells (BW1, BW2, BW3), and surface points (DAS1, DAS2, DAS3, SW1, SW2), as depicted in Table 2.

Table 2 Analytical Results

SI No.	Sampling Dates	Sampling ID	Cd (mg/L)	Pb (mg/L)	Hg (mg/L)
1	Surface Point Feb 2023	DAS1	0.0024	0.01	0.0007
2		DAS2	0.0003	0.0084	0.0004
3		DAS3	0.0025	0.0034	0.00006
4		SW1	0.0022	0.0007	0.0054
5		SW2	0.0029	0.094	0.0035
6		WBTP	0.00005	0.0008	0.018
7		WATP	0.0027	0.00003	0.014
8	Borewell Point Feb 2023	BW1	0.0043	0.00003	0.011
9		BW2	0.0063	0.0002	0.052
10		BW3	0.0033	0.0004	0.029

11		BWUB	0.0006	0.00003	0.0061
12		BWIM	0.0007	0.00003	0.0041
13		BWCW	0.0026	0.00003	0.004
1	Surface Point Feb 2025	CS A	0.0031	0.0500	0.0010
2		CS B	0.0026	0.0440	0.0008
3		DS1	0.0056	0.6310	0.0015
4		DS2	0.0062	0.6020	0.0018
5		DS3	0.0057	0.5810	0.0012
6		DS4	0.0061	0.5830	0.0012

4.1 Cd contamination

The results of the 2023 investigations on surface waters, borewells, and dump soils were compared to the findings of the current studies, as shown in the spatial interpolation below. The previous studies revealed that Cd ranges from 0.00005 to 0.063 mg/L, while the current studies concluded that there was a significant increase in Cd concentration at the dump site, as illustrated in the spatial interpolation diagram. The highest concentration of Cd was detected in borewells and surface points in 2023, with the concentration exceeding the WHO permissible limit of 0.003 mg/L. Additionally, Cd was detected at a higher level in dump soils (DS1-DS4) compared to control sites (CS A & CS B), which is scientifically evident as sources of Cd contamination were from the following: paint pigments, electroplated parts, Ni-Cd batteries, plastics, synthetic rubber, photographic and engraving processes, photoconductors, and photovoltaic cells, as most of the listed solid wastes were dumped at the dump site as shown below .

Figure 3 Solid Waste at the Site under Investigation.

The detection of Cd in borewells in February 2023 above the WHO maximum permissible limit is a concern for public health. Over time, exposure to low levels of Cd in drinking water can accumulate in the kidneys, leading to renal disease and brittle bones [12]. Cd tends to accumulate in the kidneys and is difficult for the body to eliminate. Therefore, kidney damage in older persons can result from lifetime low-level exposures to Cd as well as shorter, greater exposures [13]. Chest pain, coughing, vomiting, and diarrhea are some of the symptoms

that might result from drinking water with high levels of Cd.

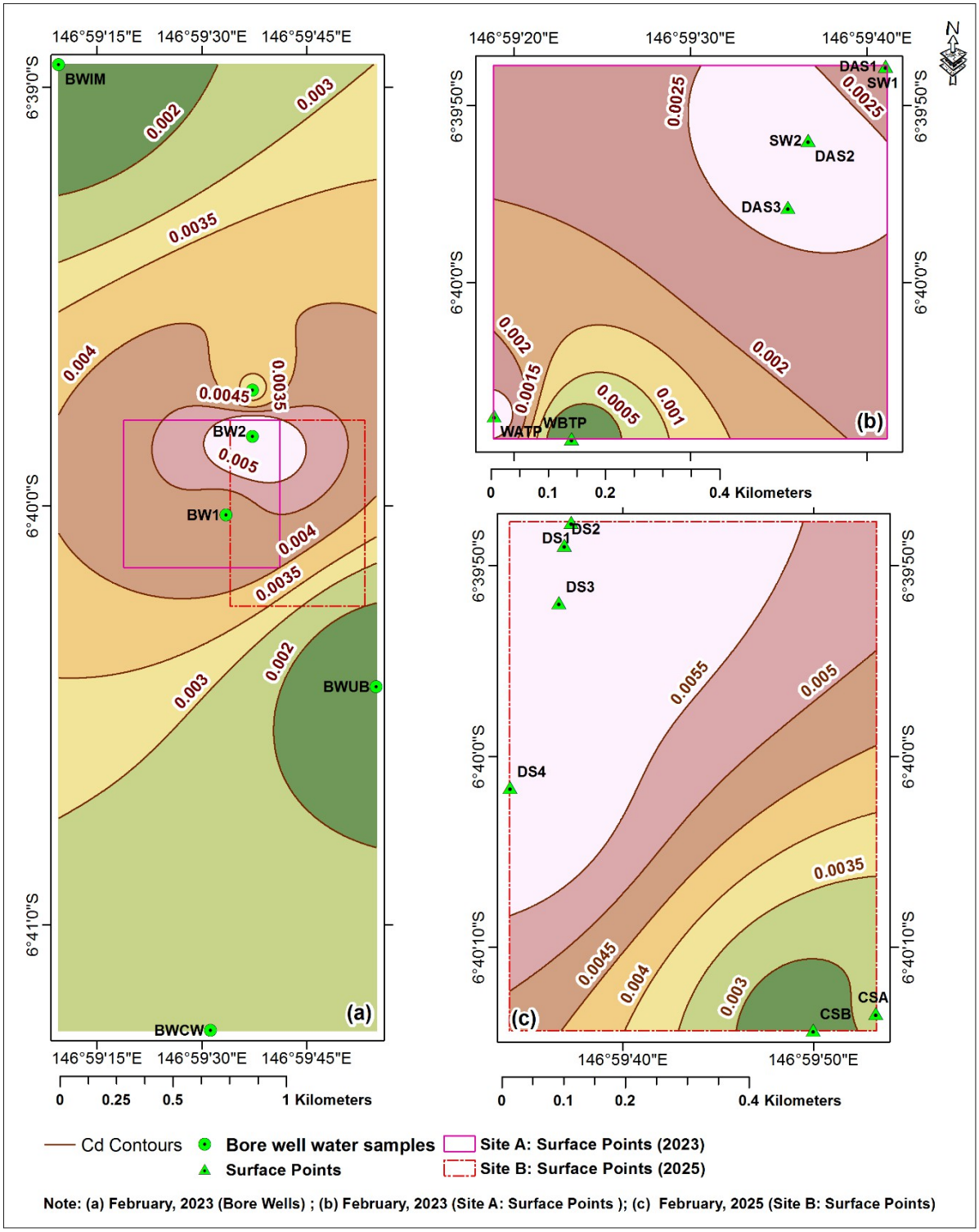

Figure 4 Spatial Interpolation of Cd in 2023 and 2025

The contaminated sites, according to the spatial distribution, are dump sites (DAS1, DAS2, DAS3, and SW2) and borewells (BW1, BW2, and BW3), according to 2023 data. The present investigation strongly confirms the previous studies, with the maximum concentration of 0.0062 mg/L detected at dump sites and a minimum of 0.0026 mg/L measured at the control site.

4.2 Pb Concentration 2023-2025

According to the spatial diagram, the most concentrated region was the ground point sampling site and BW1 and BW2, which are nearer to the dump site, as 2023 studies confirmed.

The current analytical results signify that soils at dump sites are severely contaminated, as illustrated by inverse distance weighted (IDW) interpolation; borewells (BW1, BW2, BW3), including surface waters (SW1, SW2), are within the Pb-contaminated zone.

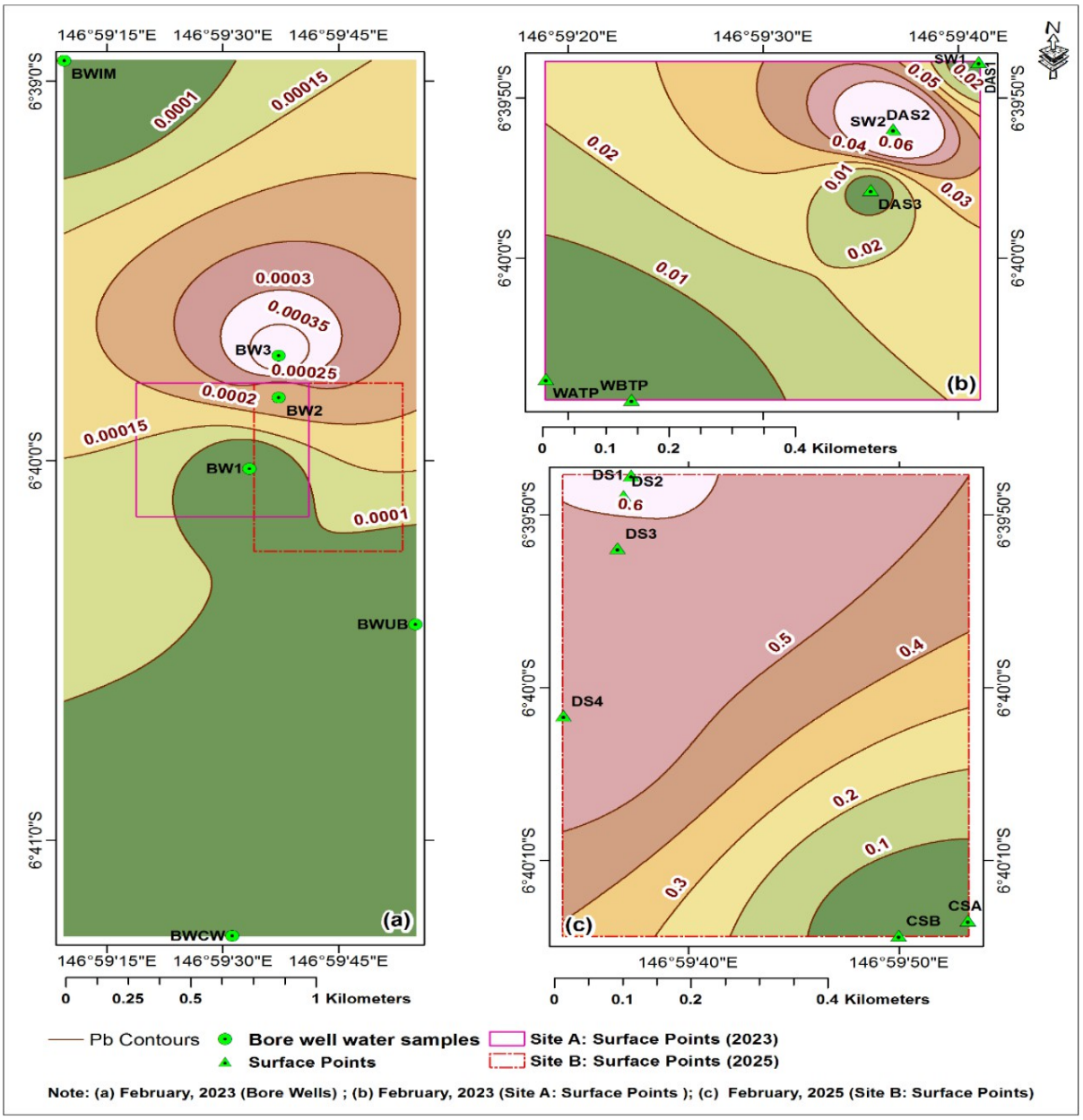

Figure 5 Spatial Interpolation of Pb in 2023 and 2025

PVC pipes used in agricultural and sanitation, recycled PVC lead paints, metal jewelry, lead batteries, lunchboxes, and other solid trash are some of the sources of lead contamination at the disposal site. As seen in the image below, the majority of the specified solid wastes are disposed of at the dump site in a way that does not safeguard the environment

Figure 6 Solid Trashed Buring at the Site Under Investigation.

According to studies done in 2023, leaching and percolation of heavy metals were significant closest to the dumping grounds and thus have affected BW in the vicinity around the dump. In comparison to soil samples from the control site (CS A & CS B), the dump soil had the greatest concentration of Pb.

Because Pb can cause major health issues if too much is consumed through drinking Pb- contaminated water, public health is concerned about the traces of Pb pollutants found in BW1, BW2, and WBTP. It may affect the synthesis of red blood cells, which deliver oxygen to every part of our body, and harm the kidneys and brain.

4.3 Hg Concentration 2023-2025

The maximum concentration of Hg was detected in DAS2 SW2, BW2 and WBTP in 2023. A range of 0.0012mg/L to 0.0018mg/L was measured in dump soils as depicted in the IDW interpolation diagram below. The WHO-permitted limit of 0.0006 mg/L Hg was exceeded at sample sites BW, SW, and DAS in the 2023 studies. Significant amounts of Hg are released close to the dump site due to improper waste segregation, as the image taken from the dump site below illustrates. Given that Hg is a persistent element in the environment, the municipal solid waste (MSW) that was disposed of may have contributed to the mercury pollution in the dump area. Batteries, measuring instruments like thermometers and barometers, electric switches and relays in machinery, lamps (including certain kinds of lights), dental amalgam, skin-lightening products, and other pharmaceutical and cosmetic items are some of the possible sources of Hg in bore wells that are being investigated

Figure 7 Solid Trash at the Site Under Investigation

According to spatial interpolation, DS1–DS4 are located within the polluted zone, as demonstrated by

recent investigations of dump soil. According to the BW data, the investigations came to the conclusion that Hg leaches out, percolates, and reaches groundwater. If Hg were present in drinking water, it may have a major negative impact on a person's health; this would be harmful. It will have an impact on the central nervous system and may harm the kidneys.

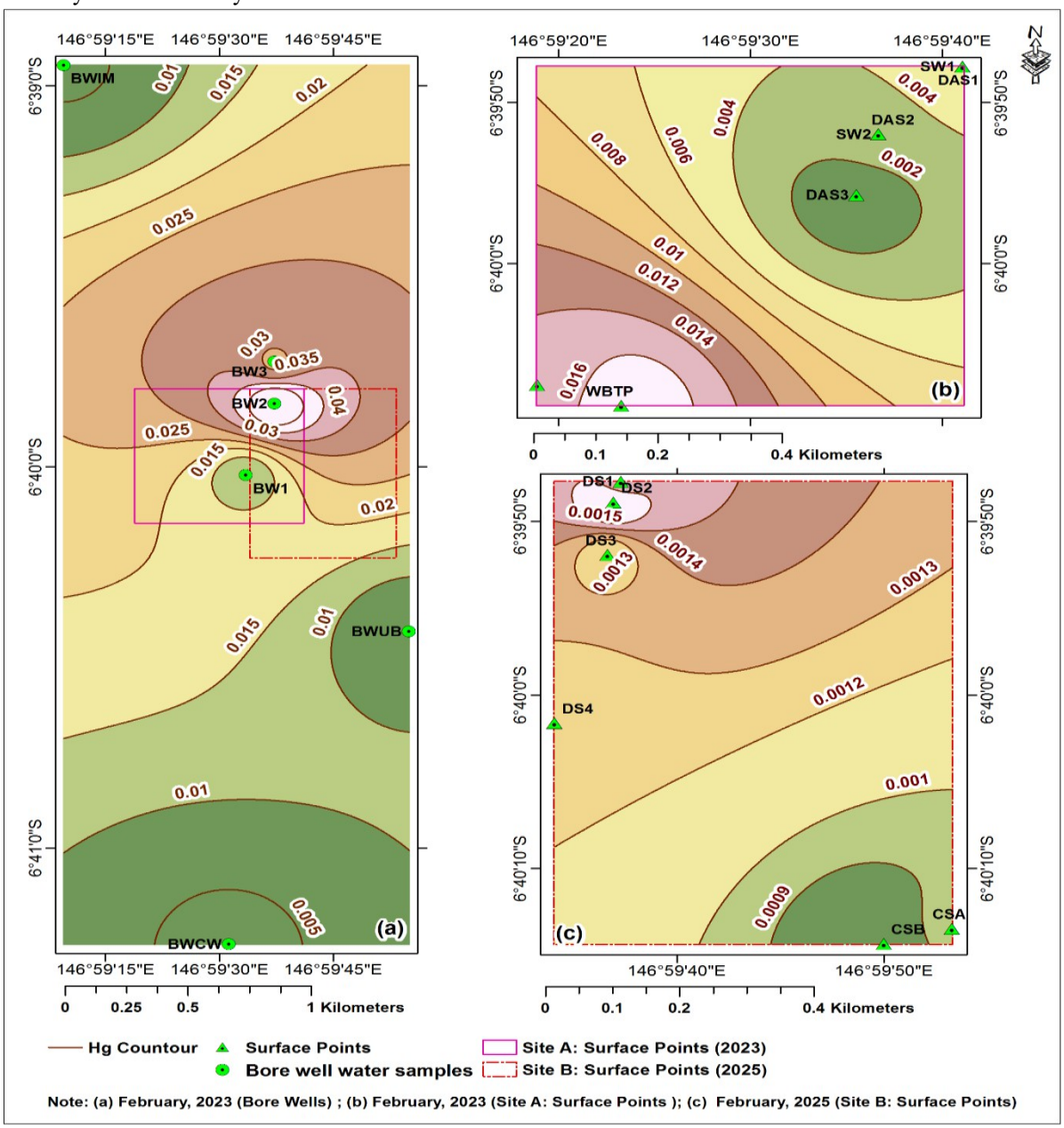

Figure 8 Spatial Interpolation of Hg in 2023 and 2025

CONCLUSION

Toxic heavy metal (Cd, Pb, Hg) investigation was conducted on the dump soils, a total of 4 soil samples from the dump site and 2 control soil samples away from the dump site were sampled. The control samples were extended from the dump site to the center of University's rugby field to enhance comparative analysis of heavy metal contamination of dump site soil and groundwater. Water and soil samples were collected in 2023, totaling 13 samples: 7 surface point samples and 6 borewell samples. Based on the analytical results from 2023, Cd, Pb, and Hg were detected in both surface points and borewells at concentrations above the WHO permissible limit. The present studies affirmed that soils at the dump site were contaminated with heavy metals, with Cd and Pb detected

at the higher concentrations, while the soil samples away from the dump site, that is university's rugby field soil, detected lower concentrations.

The investigation signifies that soils, surface and groundwater near and within the vicinity of the dump site are more prone to contamination than those away from the dump site.

The research carried out at the University of Technology dump site and borewell along the perimeter of the university campus in Lae, Morobe Province, Papua New Guinea, significantly proved that heavy metals (Cd, Pb, Hg) polluted the dump soil and thus contaminated borewells near the open dump. The notable concentration of Cd, Pb, and Hg highlights the urgent need for solid waste management disposal practices. Toxic heavy metals have the potential to threaten the environment and groundwater and put public health at risk.

RECOMMENDATION

The study highly recommends sustainable solid waste management practices and refraining from dumping at the site and near the borewell. The right thing to do is dumping at the designated area, which is the second Seven Dump, which is a CEPA-permitted dumping area in Lae City.PNG University of Technology, Morobe Provincial Health Authority, CEPA, and WPNG need to address this issue by funding further investigation and remediation processes to contain the pollution before it gets worse.

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