An Assessment of the Effects of Groundwater Quality Parameters in Proximity to the Open Dump Site in the Perimeter of PNG University of Technology

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Abstract : The study, which investigated physical, chemical, and biological characteristics of drinking water quality, was carried out near the dumpsite. The physical parameters were conductivity and total dissolved solids (TDS), the chemical parameters were silica (SiO_2), nitrate (NO_3), sulfate (SO_4), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), and total hardness (TH), and the biological parameters were coliform bacteria. The study utilized the use of cutting-edge equipment, including an inductively coupled plasma mass spectrometer (ICP-MS), an ultraviolet-visible spectrophotometer, and a colony counter. Coliform bacteria maxima are 760,000 cfu/100 ml, conductivity and TDS range from 80 to 785 µS/cm and 5 to 560 mg/L, respectively, and the chemical properties analysed in bore wells near the dumpsite were noteworthy, according to the investigation's findings. High levels of microbiological and chemical contaminants may spread through soils and contaminate groundwater, which is the source from which Water PNG Limited extracts, treats, and distributes water, according to the results of the groundwater analysis.

Keywords: Groundwater resource management, contamination, ICP-MS, Open dump site (ODS), physico-chemical parameters, Inverse distance weight (IDW) interpolation.

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1. INTRODUCTION

Water is essential to the survival of all living things, including tiny insects and enormous creatures. As is known to all, humans can live for three weeks without food, but only for three to four days without water. About 97% of the water is believed to reside in the oceans, as shown in Figure 1.1. The remaining 3% is fresh water, which includes lakes, swamps, rivers, and icecaps and glaciers (20.06%). Washing, cooking, bathing, food production, cattle rearing, and creating and preserving the environment that forms the basis of all life are examples of both direct and indirect uses for this.

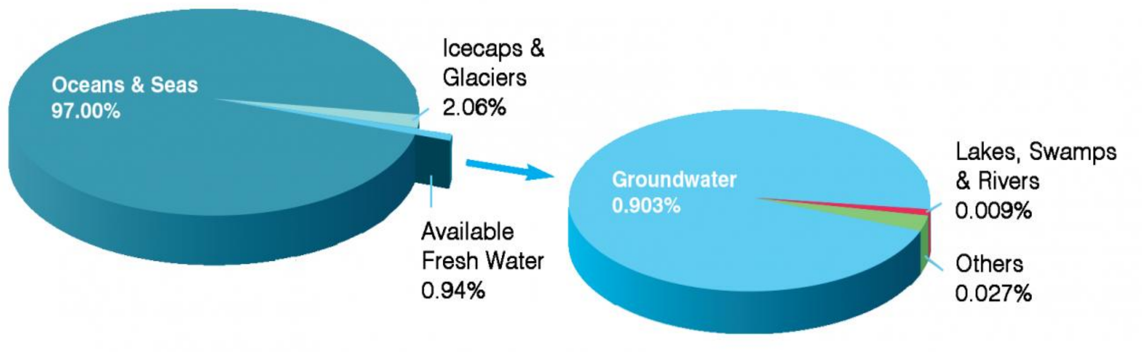

Fig 1. Distribution of water (Supply, 2014).

The limited supply of freshwater is continuously threatened by pollution and over-harvesting brought on by human activity. Growing urbanization, increased personal demand, and population growth are the causes of these pressures. Therefore, protecting this important yet limited resource is essential. Among all the different types of pollution, open dumping remains one of the main causes of contamination for soils, groundwater, surface water, and the atmosphere (Akinbile, 2012, Alao et al., 2023, Ahmad & Bhawsar, 2021). Since water can dissolve more compounds than any other liquid on Earth, it is particularly susceptible to pollution.

Papua New Guinea is a developing country in the Pacific region and has been identified as one of the thirty-seven (WHO/UNICEF, 2022) hot spot countries in the world with extremely high vulnerability to waterborne diseases according to an analysis released by UNICEF globally ahead of World Water Day (WWD) on 22nd March 2022.

The bore wells investigated are abstracted, treated and distributed by Water PNG Limited through Lae City and the surrounding communities for domestic and commercial purposes at the rate of 30 million liters of treated water each day. The water required to meet the demand is drawn from the bore along the perimeter and dumping at the vicinity of the bore pump is a threat to groundwater quality. Therefore, samples were drawn from bore wells, surface waters and dump soils to assess the presence of biological and physicochemical contaminants. Given the context and concerns of the dump site, an investigation was conducted on the bore wells along the perimeter of The Papua New Guinea University of Technology (PNGUoT).

2. MATERIALS AND METHODS

2.1 Study Area

The oldest landfill, the Second Seventh dump site, is located northeast of PNGUoT and is where Lae City's Municipal Solid Waste (MSW) generation is disposed of. It is situated between 6.6598^{o}S and 147.0123^{o}E. Nonetheless, MSW, paint, used batteries, plastic, electronic debris, and other waste materials are already routinely disposed of by PNGUoT catering services, the estate and project service department, and the university community is being investigated

A survey was conducted in the study region on the bore wells that border the PNGUoT disposal site between March 2022 and February 2023 as depicted on the spatial map below.

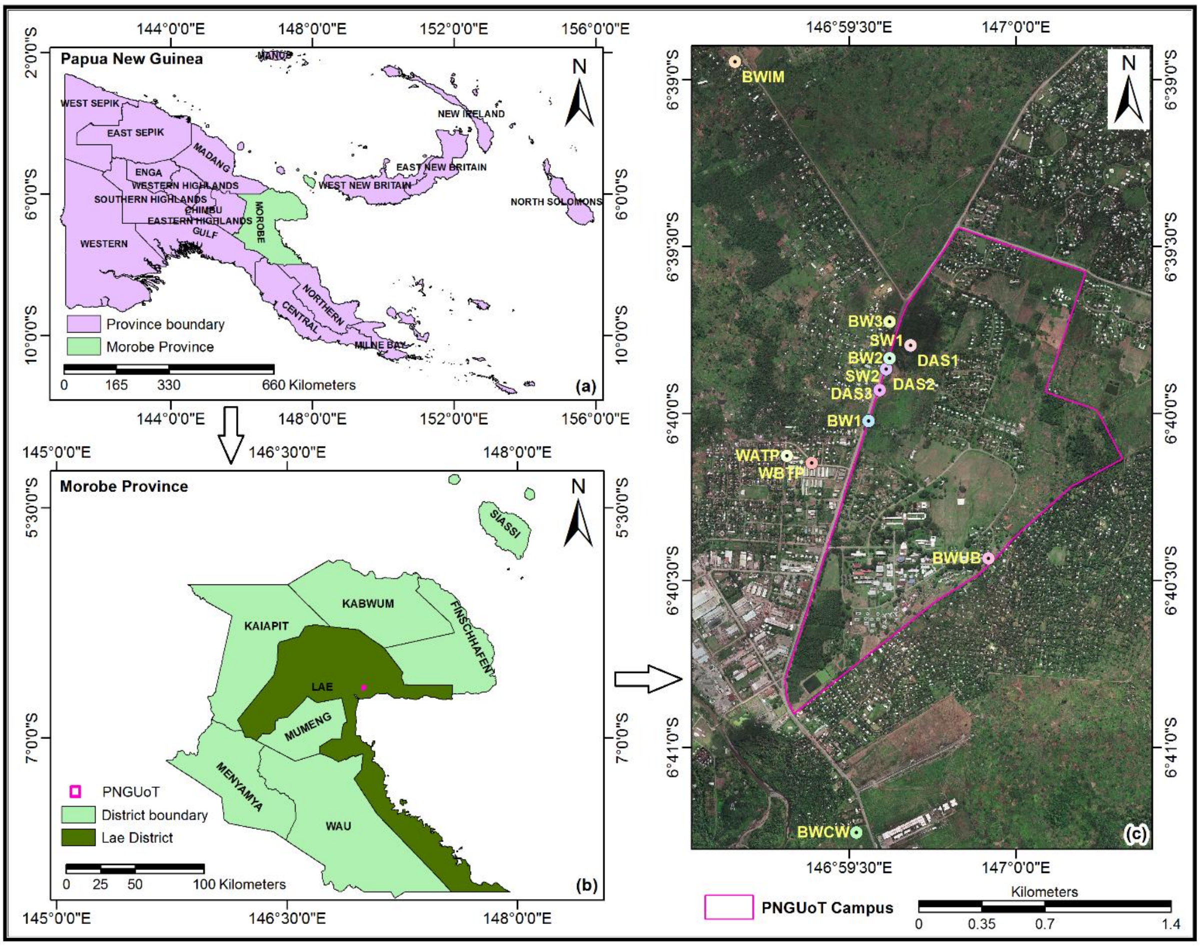

Fig 2 . Sampling Stations and Dump Site: (a) Papua New Guinea with Provinces, (b) Morobe province with districts, and (c) PNGUoT Campus with the location of sampling stations and dump sites.

2.2 Microbiological and Physicochemical Water Quality Assessment

Thirteen (13) sampling locations were identified for the study; two were surface waters, three were dump soils, and eight were bore waters (groundwater samples) as tabulated.

Table 1 Shows Sampling Stations and Coordinated

SI. No	Station Type	Sampling Point	Longitude	Latitude
1	Bore well	Bore Well 1 (BW1)	146.99264	-6.66704
2		Bore Well 2 (BW2)	146.99369	-6.66390
3		Bore Well 3 (BW3)	146.99369	-6.66207
4		Bore Well Igam Market (BWIM)	146.98597	-6.64910
5		Bore Well Carwash (BWCW)	146.99202	-6.68756

6		Bore Well Uni Block (BWUB)	146.99862	-6.67388
7	Ground Point	Water Before Treatment Plant (WBTP)	146.98980	-6.66913
8		Water After Treatment Plant (WATP)	146.98857	-6.66876
9		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

Samples were collected in sterilized sampling bottles and stored in an icebox. Samples were immediately transported to the National Analytical and Testing Services Laboratory (NATSL) for analysis using a standard testing procedure. All sample preparation procedures were followed within 24 hours of collection time and analyzed for biological and physicochemical contaminants including TC, EC, TDS, major anions (SiO_2, NO_3, SO_4,) and cations (Ca, Mg, Na, K) and TH.

The Standard Method of Examination of Water and Wastewater is employed to analyze the physicochemical and microbiological properties of surface and groundwater samples. The water samples were prepared according to the standard testing method by field spiked with 10% nitric acid to preserve the analyte of interest, the samples were taken to the laboratory within an hour, filtered using a 0.45µm filter, acidified with 2% HNO_3 and analyzed using an Inductive Couple Plasma-Mass Spectroscopy (ICP-MS) following basic clean room protocols. The microbiological and physicochemical parameters measured during the investigation are shown in Table 2.

Table 2 The microbiological and physicochemical parameters measured during the investigation.

Sampling ID	Sampling Dates	TC (cfu/100mL)	SiO_2 (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	Conductivity (EC) (µS/cm)	TDS (mg/L)	TH (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)
DAS 1	Apr-22	5242	278	1.2	28	160	280	210	698	42	612	18
	Aug-22	5780	255	1.1	28	150	272	237	538	23	77	15
	Feb-23	5880	281	1.2	32	154	350	252	640	39	88	17
DSA 2	Apr-22	6258	309	1.3	25	80	265	182	688	44	595	17
	Aug-22	6320	309	1.1	34	140	300	209	592	25	197	10
	Feb-23	6545	310	1.1	37	125	315	248	703	41	245	12
DAS3	Apr-22	5389	395	1.2	24	150	340	265	697	40	628	19
	Aug-22	5600	377	1.1	26	240	365	279	709	39	312	13
	Feb-23	5480	389	1.1	30	220	220	289	190	44	414	15
SW1	Apr-22	146000	43	1.0	27	189	220	202	42	8	5	22
	Aug-22	310000	36	2.2	23	194	340	189	338	32	23	12
	Feb-23	278000	44	2.1	29	192	302	167	43	29	13	20
SW2	Apr-22	680000	39	2.3	34	538	110	138	20	2	11	5
	Aug-22	760000	51	7.4	38	734	130	145	65	23	10	10
	Feb-23	750000	49	4.5	30	785	125	129	45	31	15	8
BW1	Apr-22	120	45	3.4	1.6	368	120	159	51	8	0.4	12
	Aug-22	100	32	3.2	3.3	335	560	136	39	9	0.4	14
	Feb-23	0.0	102	9.6	1.6	358	250	134	42	7	0.3	11
BW2	Apr-22	500	51	2.6	2.5	322	120	126	39	7	0.5	15
	Aug-22	0.0	40	1.1	1.6	344	180	127	35	10	0.6	19
	Feb-23	0.0	55	12	2.5	323	200	117	34	8	0.4	15
BW3	Apr-22	0.0	42	2.2	2.5	322	160	141	44	8	0.5	14
	Aug-22	0.0	38	1.2	1.3	305	140	123	34	9	0.5	17

Sampling ID	Sampling Dates	TC (cfu/100mL)	SiO_2 (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	Conductivity (EC) (µS/cm)	TDS (mg/L)	TH (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)
	Feb-23	88	81	4.7	5.8	323	190	122	36	8	0.4	13
WBTP	Apr-22	0.0	54	2.8	4.9	353	180	147	47	7	0.4	13
	Aug-22	0.0	47	1.7	2.5	301	210	146	42	10	0.6	17
	Feb-23	0.0	112	25	2.9	342	220	125	37	8	0.4	12
WATP	Apr-22	0.0	46	2.7	2.1	180	180	159	51	8	0.5	13
	Aug-22	0.0	46	2.0	1.9	200	200	155	44	11	0.6	18
	Feb-23	0.0	102	6.1	7.4	180	180	127	38	8	0.4	12
BWUB	Apr-22	130	36	2.5	2.1	180	250	564	178	29	1.0	55
	Aug-22	125	32	2.1	1.8	200	294	639	167	54	2.0	62
	Feb-23	120	34	6.3	1.0	180	280	517	156	31	2.0	47
BWIM	Apr-22	114	9	2.5	2.0	250	59	101	29	7	1.0	1.3
	Aug-22	112	9	2.2	1.7	294	60	136	44	6	1.0	1.2
	Feb-23	110	9	1.0	1.0	280	55	101	31	6	2.0	1.5
BUCW	Apr-22	0.0	29	2.4	2.1	295	295	494	142	34	7.0	47
	Aug-22	0.0	27	2.2	1.8	289	289	497	151	29	7.0	40
	Feb-23	0.0	26	1.0	1.0	290	290	450	139	25	8.0	35

2.3 Water Quality Data Analysis Tool of ArcGIS and Temporal Variation Technique

The Spatial Interpolation Method and Temporal Variation Techniques were employed to analyze data collected over the investigation period.

The spatial analyst tool of ArcGIS, inverse distance weighing (IDW) and Contour Raster Surface techniques were used to interpolate water quality data collected during the study period. The spatial interpolation technique was used in predicting values for cells in a raster from a limited number of sample data points. It was used to predict unknown values for the physicochemical concentration of the water quality data.

3. RESULTS AND DISCUSSION

3.1 Coliform Bacteria

Total Coliform, Fecal Coliform, and Escherichia Coli (E-Coli) are among the hazardous bacteria. which are frequently found in the environment. Total Coliform bacteria at the ground point sampling sites depicted in Figure 3 indicate environmental contamination, particularly from the dumping site. The findings suggest that there might be other disease-causing pathogens in the dump site. There is a limit to the coliform bacteria's weak infectiousness. Additional bacteria from the disposal site or surrounding area may be connected to and accountable for infections such as urinary tract infections, lung infections, fever, emesis, dyspepsia, and hemorrhagic diarrhoea.

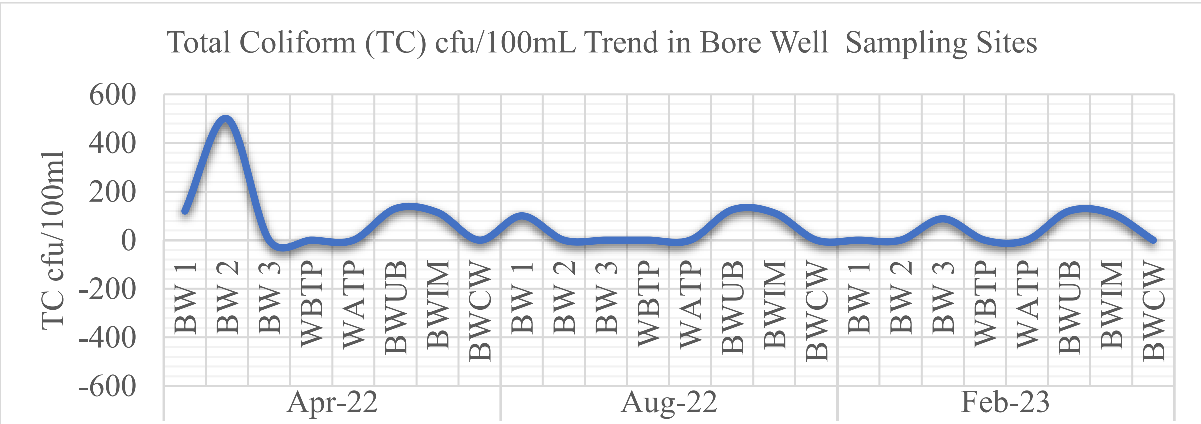

Fig 3. Temporal Variation of TC

3.2 Electrical Conductivity (EC)

The presence of inorganic and dissolved solids, such as sodium, magnesium, calcium, iron, aluminum (cations) and chloride and nitrate (anions), affects the EC in water; a higher EC indicates a larger concentration of contaminants. In comparison to other sampling sites, it can be inferred that SW2 has higher levels of contaminants. The increasing TDS in BW1 throughout the study could be caused by pollutants seeping from SW2, a pond next to the BW1 pump house. As a general indication of water quality, the EC is helpful, and variations in the EC may indicate that discharges or other sources of contamination have reached the water body. As the EC rises, water becomes less palatable. At greater EC, the water is unfit for human consumption (Figure 4).

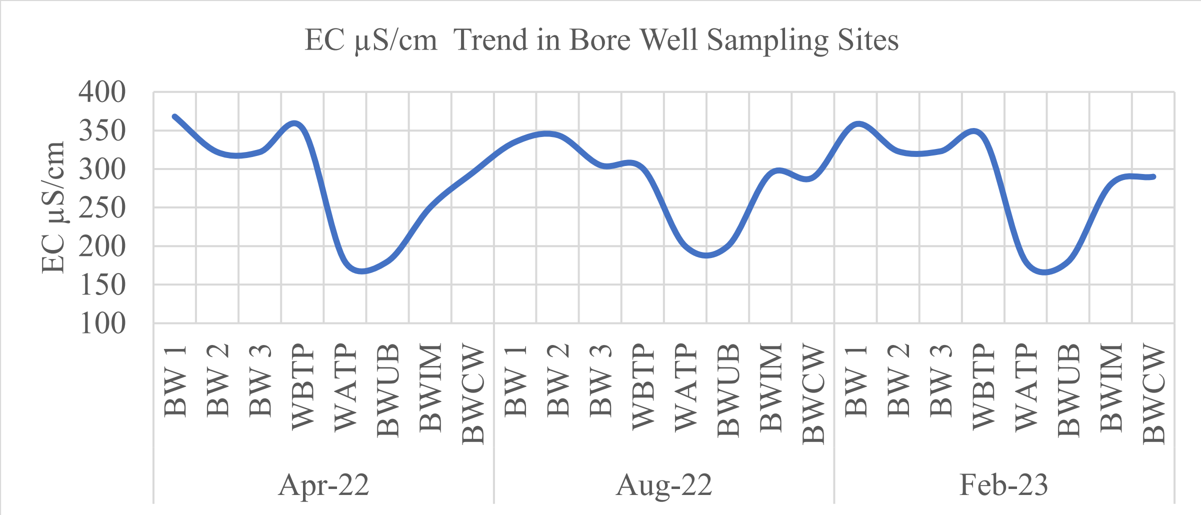

Fig 4. Temporal Variations of Electrical Conductivity

3.3 Total Dissolved Solids (TDS)

The TDS level at BW1 increased from April 2022 to August 2022 and decreased in February 2023, which signifies the leaching and percolating of dissolved organic and inorganic substances. The TDS result in BW2 increased slightly from 120mg/L to 200mg/L during the investigation periods. The TDS in drinking water originates from natural sources, sewage, urban runoff, industrial wastewater and ODS or Landfills according to the World Health Organization (WHO, 2004). However, TDS concentration at BW3, WBTP, WATP, BWUB, BWIM and BWCW were slightly uniform or constant and did not vary much shown in Figure 5 this may be due to leaching and percolating effective near the dump site.

The TDS comprise inorganic and organic salts and small amounts of organic matter that are dissolved in water. The palatability of water with a TDS level of less than about 600mg/l is generally considered to be acceptable; drinking water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000mg/l. No health-based guideline value for TDS has been proposed according to the World Health Organization (WHO, 2022). The high concentrations of TDS decrease palatability may cause gastrointestinal irritation in humans and may also have a laxative effect, particularly upon transits. However, associations between various health effects and hardness, rather than TDS content, have been investigated in many studies and some of the effects of higher TDS in drinking water, in extreme cases, caused kidney disease, liver disease and even death (Awoyemi et al., 2014).

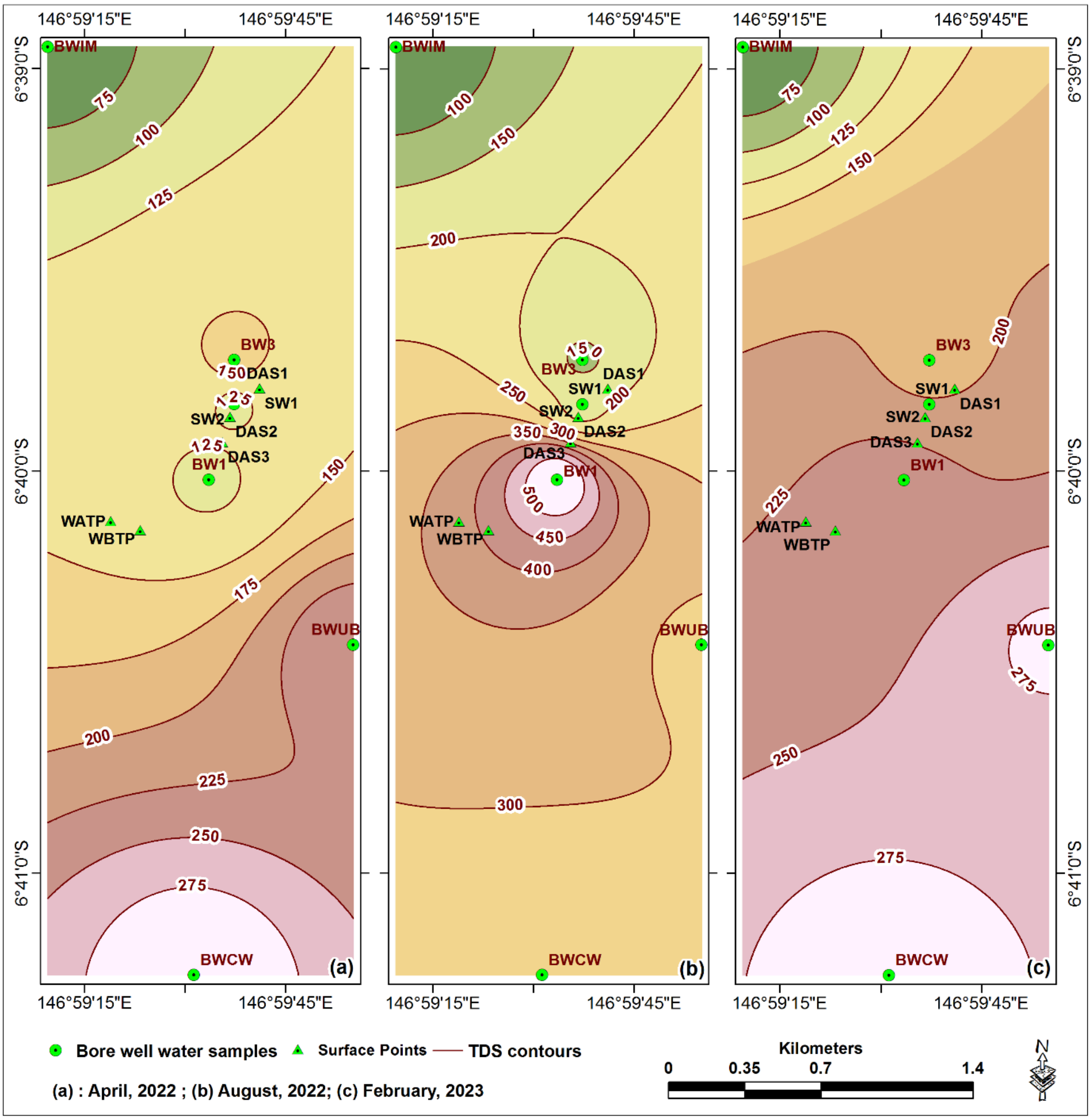

Fig 5. Spatial Variation of TDS during (a) April, 2022, (b) August, 2022, and (c) February, 2023.

3.4 Silica (SiO_2)

The highest concentration of silica was detected in BW1, BW2 WBTP and WATP in February 2023, such that DAS2 and DAS3 are nearer to BW1 and BW2. Therefore, leaching and percolating of silica was effective near the dump site, thus detected at the treatment plant. These may be due to leaching and percolation high near the dump site as studies confirmed (Pandey. et al., 2015), Rawlings & Seghosime, 2022) that the groundwater nearer the dump site does not conform to drinking water qualities standard.

Silica is found in all types of soils, and it is the most abundant common element. As leachate moves through soils, silica is carried away by leachate and ends up in groundwater. Silica creates a mineral film on glassware, faucets, glass shower doors, and sinks. Silica also causes scale build-up in boilers and water heaters. Concentrations above 10mg/L of silica tend to be problematic (Figure 6).

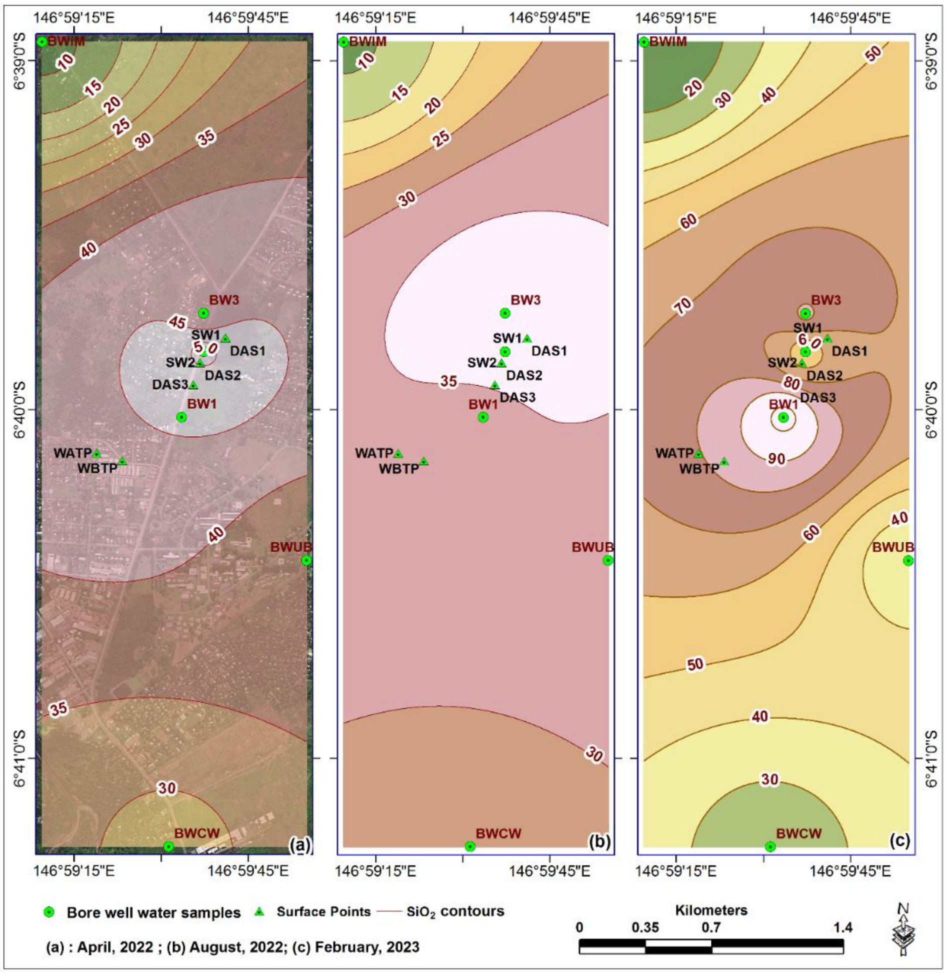

Fig 6. Spatial Variation of Silica during (a) April, 2022, (b) August, 2022, and (c) February, 2023.

3.5 Nitrate (NO_3)

Nitrate leaching into soil and into the water supply from various sources. High levels of nitrates in surface and groundwater are the result of the natural processes of atmospheric fixation, lightning storms through anthropogenic activities fertilizer applications, septic tanks and solid waste dumping in a manner that does not protect the environment, (Landfills and open dumping), feedlots and urban drainage. The natural groundwater nitrate concentration is generally low; concentrations greater than 1mg/L can be due to anthropogenic activities (Akinbile, 2012, Dubrovsky & Hamilton, 2010). Nitrate was reported to be one of the most alarming and widespread contaminants of water resources. The main sources of nitrate contaminants are agricultural and anthropogenic activities like unsafe dumping of solid waste and trash in the environment. These are the reasons behind the elevated level of nitrate in groundwater.

Nitrate can have a negative health significant effect if consumed at greater than 50 mg/L in drinking water. This can cause various health effects such as methemoglobinemia, cancer and diabetes in humans based on a long-term effect (WHO, 2022, National Health and Medical Research Council, 2011) (Figure 7)

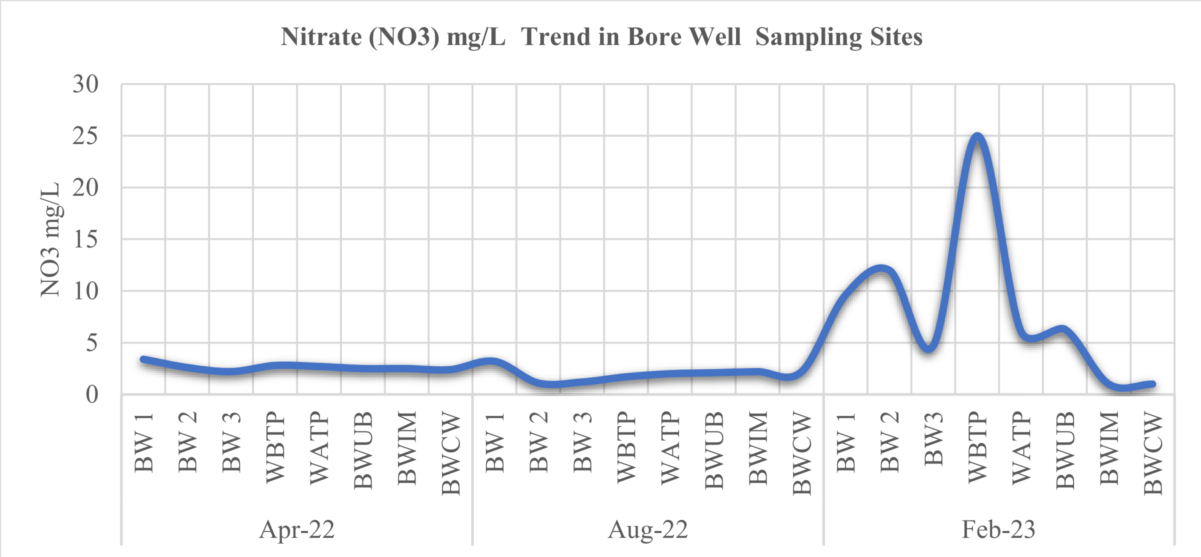

Fig 7. Temporal Variation of Nitrate

3.6 Sulfate (SO_4)

Naturally occurring in water, sulfate is one of the main dissolved elements of rain. Moreover, human activity has the potential to contaminate water with sulfates. The current investigations' sulfate concentration was lower than the 250–500 mg/L stated taste threshold limits in drinking water (WHO, 2022). According to the Australian Drinking Water Standard and the WHO (GDWQ), too much sulfate can corrode steel pipes and scavenge residual chlorine, which can interfere with disinfection efficacy and reduce the acceptability of drinking water. Dehydration and diarrhoea can occur when drinking water with high sulfate content, according to the EPA (Al Raisi et al., 2014, US Environment Protection Agency, 2003) (Figure 8).

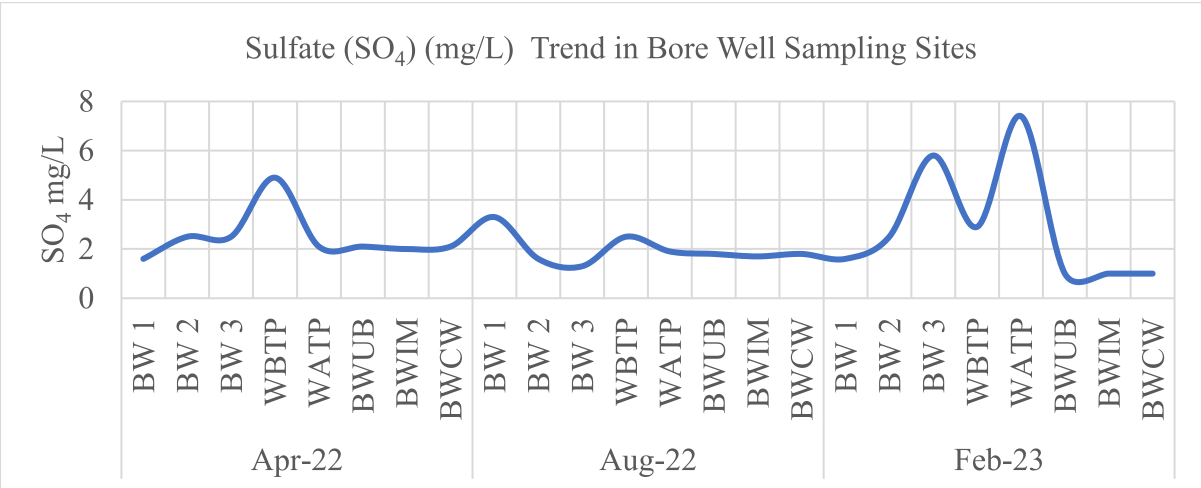

Fig 8. Temporal Variation of Sulfate

3.7 Calcium (Ca)

The maximum calcium was measured in the bore well at BWUB and BWCW at concentrations approximately above 150mg/L. The BW1, BW2, BW3 and BWIM trend below 50mg/L during various periods of testing water samples as illustrated in Figure 9. A report published by WHO on the role and possible health benefits of calcium in drinking water to be included in global dietary calcium intake was not harmful to most people. However, some people may be more susceptible to the adverse effects of calcium including, kidney stones, high blood pressure, arrhythmias (abnormal heart rhythms), bone problems, muscular problems and gastrointestinal issues (WHO, 2004, Nerbrand et al., 2003).

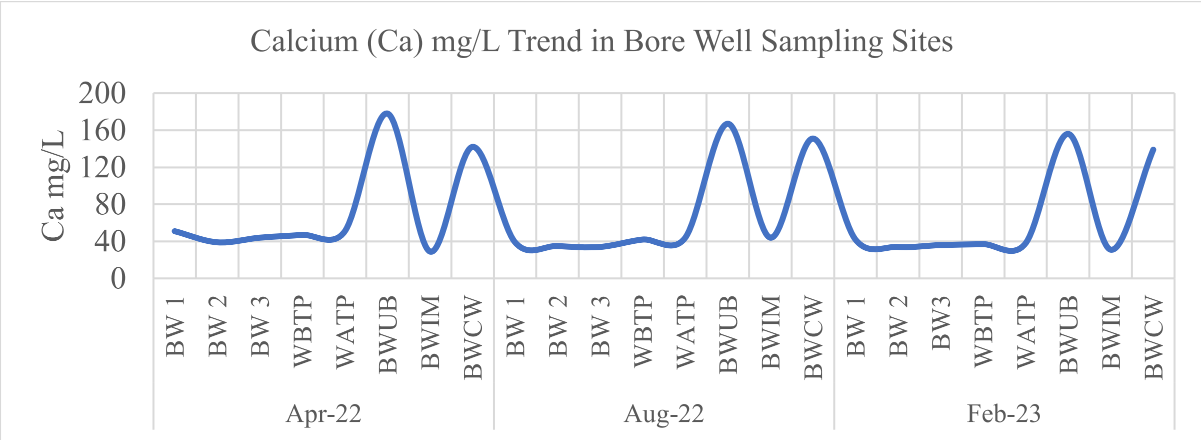

Fig 9. Temporal Variation of Calcium

3.8 Magnesium (Mg)

The magnesium concentration ranges from 2mg/L to 44mg/L in ground point sampling location According to WHO, Magnesium in drinking water can have a positive effect on health. Magnesium is essential in maintaining the balance between magnesium intake from different sources to optimal health outcomes (Nerbrand et al., 2003). However, magnesium is responsible for water hardness and its health effects are discussed in Total Hardness (TH) throughout the study period (Figure 10).

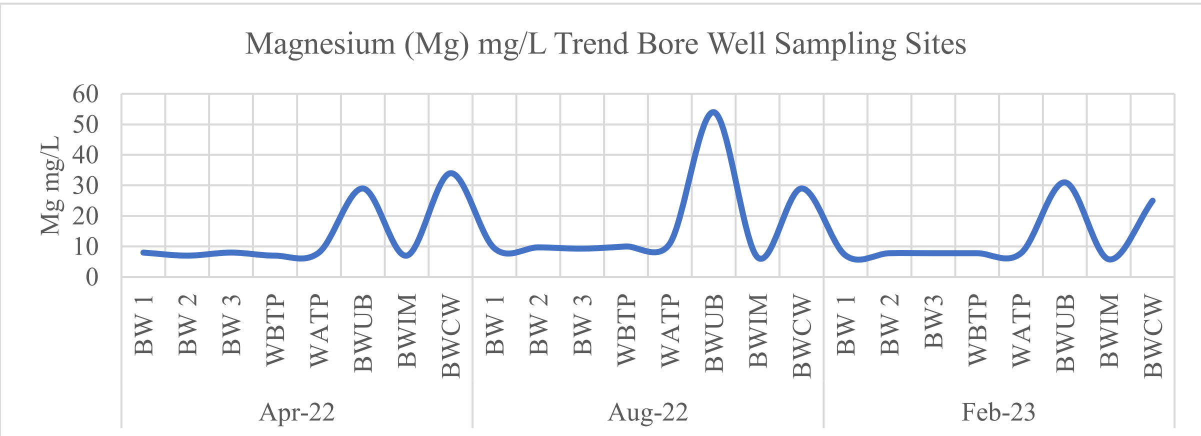

Fig 10. Temporal Variation of Magnesium

3.9 Potassium (K)

Because potassium is naturally abundant in mineral form maximum concentration was tested in all the dumps soil samples as shown in Figure 11.

Potassium in bore well samples was very low and based on WHO literature there was no established guideline for potassium in drinking water. According to WHO (GDWQ), potassium occurs in drinking at a concentration well below those of health concerns, however, intake from drinking water primarily affects individuals in high-risk groups, such as those with kidney dysfunction, heart disease, hypertension, and other specific conditions (WHO, 2022, National Health and Medical Research Council, 2011).

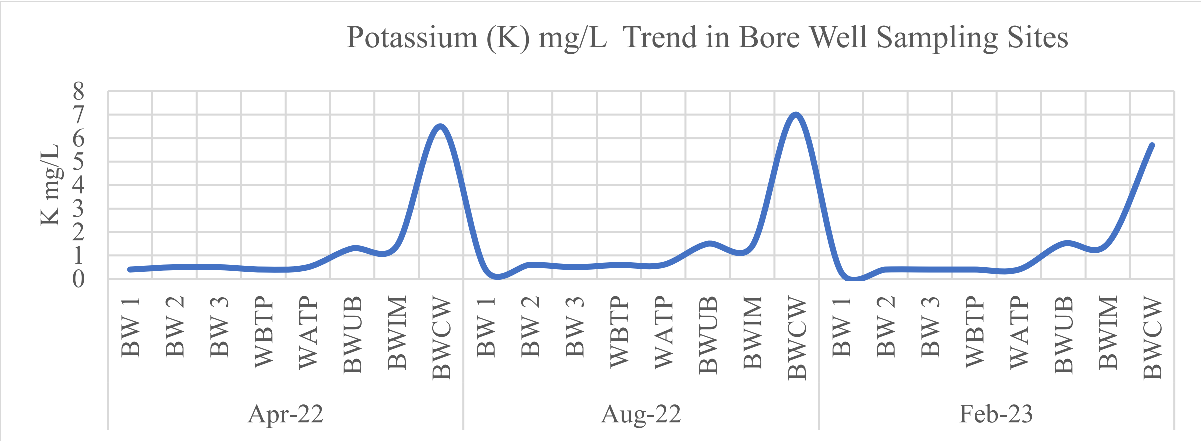

Fig 11. Temporal Variation Potassium

3.10 Sodium (Na)

The sodium level in bore well water ranges from 1.5mg/L to 62mg/L over the period. The maximum concentrations were measured in BWUB and BWCW as trended in Figure 1.12 in various periods. The sodium concentration was tested at maximum level in BWUB and BWCW throughout the investigation period. As explained by WHO the taste threshold concentration of sodium in drinking water is about 200mg/L. Excessive sodium intake in drinking water can lead to high blood pressure which can result in heart disease and stroke, diabetes, and kidney disease. However, no health-based guideline has been derived (WHO, 2004).

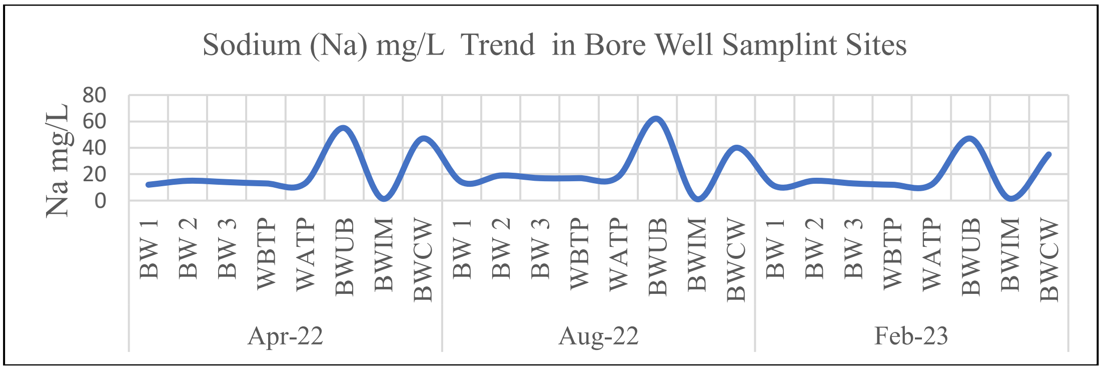

Fig 12. Temporal Variation of Sodium

3.11 Total Hardness (TH)

The concentrated sampling sites were BWUB and BWCW according to spatial interpolation shown in Figure 13. This may be due to the type of rocks the aquifer or water table is made of as confirmed (Usman et al., 2017) that could be due to a substantial contribution from the weathering of more basic rocks in the vicinity and also this may be due to dissolution of polyvalent metallic ions from sedimentary rocks, seepage, and runoff from the soils. Most consumers tolerate water hardness of more than 500mg/L and according to WHO total hardness values of 200mg/L cause scale deposition and no health-based guideline value for hardness in drinking water was proposed. However, calcium is responsible for hardness in drinking water, as such kidney stones, high blood pressure, arrhythmias bone problems, muscular problems and gastrointestinal issues are associated with drinking hard water.

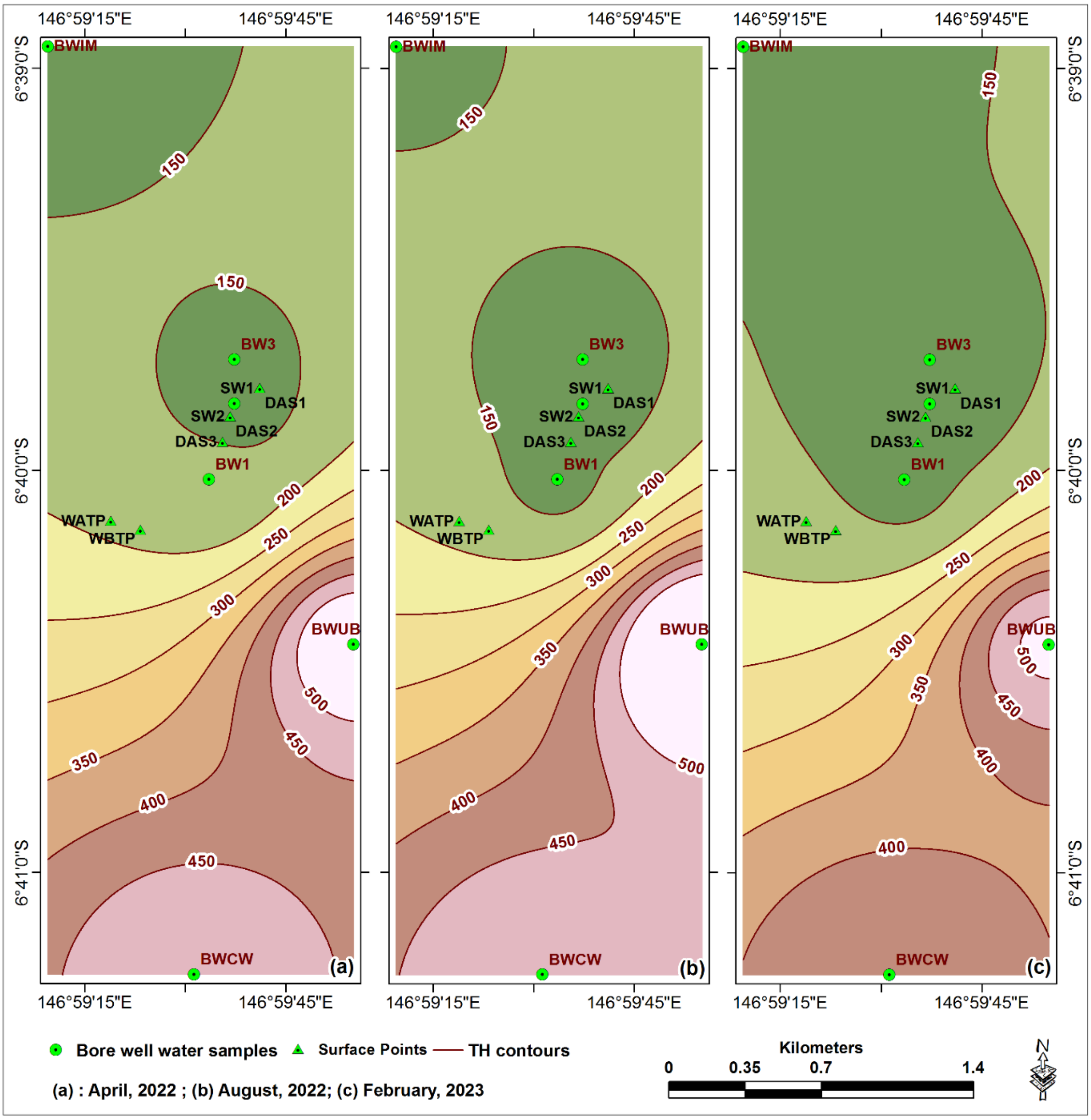

Fig 13. Spatial Variation of Total Hardness during (a) April, 2022, (b) August, 2022, and (c) February, 2023.

4. CONCLUSION

The findings led to the conclusion that the data ranges for parameters including TDS, TH, and silica (Silicon dioxide) in each of the three seasonal variations (April 2022, August 2022, and February 2023).

The Total Coliform bacteria was detected in bore well stations BW1, BW2, BWUB and BWIM in various periods. Station BW1 and BW2 are situated nearest to ground point stations DAS2, DAS3 and SW2. The maximum Silicon dioxide concentration of 102mg/L was measured during February 2023 at Bore Well Station BW1, which is situated to the nearest ground station DAS3. A spike in TDS of approximately 560mg/L was found at the bore well station BW1 in August 2022. The nearest ground sample station is also DAS3. The highest TH of 639mg/L was observed in August 2022 around bore well station BWUB.

Overall, the bore well station-BW1, which is situated closer to ground station DAS3, is more vulnerable as higher concentrations are observed in this location and they are situated in the middle of the study area.

The study concludes that the leaching of coliform bacteria and metal cations percolated through the soils and polluted the bore wells nearer to ODS as demonstrated through analytical results obtained from the analysis. Coliform bacteria were detected in BW1 and BW2 which signifies leaching and percolating of potential pollution sources near the dumping. Bore wells further away from dumping sites and WBTP and WATP detect no coliform bacteria and are below the permissible limit for drinking water standards.

The detection of coliform bacteria in bore wells near the dump site was related to the dumping of MSW and trash at the dump site near the bore wells.

This study concludes that ODS along the boundary has significant impacts on groundwater quality near dumping sites. Microbial contaminants contamination in drinking water is a concern for public health, especially the residents of Lae city and the surrounding communities.

RECOMMENDATION

Leachate slowly percolates through the soil and pollutes the groundwater resource. Therefore, there is a need to have an effective waste management program for existing open dumping sites and landfills in Lae City to control environmental pollution. This study recommends sustainable solid waste management because a proper waste management system can protect the surrounding environment from the pollution of groundwater. The findings from the research conducted at the designated site suggest the following recommendations:

- ✓ Address the existing contamination present in the soil, thoroughly assess the potential hazards that could compromise the groundwater quality.
- ✓ Take prompt measures to protect the bore wells and ensure that waste is disposed of at a safe distance from these wells.
- ✓ Conduct additional investigations to gain further insights.

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