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Assessment of Water Quality for Both Surface and Groundwater in Ewhereh and Ohrerhe Towns, in Agbarho, Delta State

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Abstract
Evaluating the quality of surface and groundwater in Ewhereh and Ohrerhe Towns, Agbarho, Delta State, to determine their safety and suitability for drinking and other uses. A total of 15 water samples were collected from both towns, including groundwater from boreholes and surface water from hand-dug wells. The physio-chemical and heavy metal parameters of the water samples were analyzed. Parameters assessed included pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), salinity, color (Pt-Co), turbidity, Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), bicarbonate (HCO_3), phosphorus (P), ammonium (NH_4-N), nitrite (NO_2), nitrate (NO_3), calcium, potassium, sodium, carbonate, chloride, sulphate, magnesium, and heavy metals (manganese, iron, copper, zinc, lead, cadmium, and chromium). The pH of the water samples ranged from 5.0 to 6.2, with a mean value of 5.573, indicating slightly acidic conditions. This acidity may result from natural factors such as dissolved carbon dioxide or anthropogenic influences like industrial discharge, which can affect the solubility and bioavailability of nutrients. Elevated EC, TDS, salinity, and COD levels were observed in samples from BH 6, BH 8, and BH 12, suggesting localized contamination sources. The mean concentrations of heavy metals were as follows: iron (0.668 mg/L), manganese (0.216 mg/L), zinc (0.508 mg/L), copper (0.094 mg/L), chromium (0.034 mg/L), cadmium (0.006 mg/L) and Lead (0.013 mg/L). High levels of iron, manganese, cadmium and zinc, particularly in BH 2 EKP AGB, point to potential localized contamination sources. The elevated concentrations of iron, manganese, cadmium and zinc in multiple locations may stem from natural mineral content or industrial activities in the area. The water quality results highlight increased levels of Iron, Manganese, chromium, cadmium and lead, which could pose health and aesthetic concerns. Strong correlations between the concentrations of these metals suggest they may originate from common sources or shared geochemical processes in the study area. Regular monitoring of heavy metal concentrations is recommended to protect soil nutrients and prevent degradation, ensuring favourable conditions for crop growth. Additionally, health risk assessments are advised for areas with elevated cadmium, lead, and chromium levels to evaluate potential impacts on local communities and develop effective mitigation strategies.

Keywords
Assessment, suitability, industrial discharge, bioavailability, anthropogenic

1. Introduction

Water is an essential resource for sustaining life, health, and economic development. However, ensuring access to clean and safe water remains a significant challenge globally, particularly in developing nations where water sources are often polluted and infrastructure for purification and management is inadequate (WHO, 2011). In Nigeria, water quality issues are pervasive, largely due to human activities such as domestic pollution, industrial waste discharge, and agricultural runoff, which significantly affect surface and groundwater sources (Nwankwoala, 2011). Delta State, a region characterized by extensive industrial and agricultural activities, faces heightened vulnerability to water contamination. Surface runoff often pollutes rivers, lakes, and ponds, especially during heavy rains, exposing them to atmospheric contaminants. In cities like Ewhereh and Ohrerhe, where surface water from rivers and ponds is commonly used for domestic purposes, the proximity to agricultural areas and human settlements increases the likelihood of contamination from pesticides, fertilizers, and untreated sewage.

While groundwater, located in aquifers, is less directly exposed to pollutants, it is not immune to contamination. Industrial operations, improper waste disposal, and leaks from underground storage facilities present significant risks to the groundwater quality in Delta State (Oteri and Atolagbe, 2003). Water quality assessments are vital for determining the suitability of water for various uses and identifying potential health risks. These assessments involve analyzing physical, chemical, and biological parameters to detect contaminants like heavy metals, organic compounds, and pathogens (WHO, 2017). Such evaluations ensure compliance with safety standards established by organizations like the World Health Organization and Nigerian Standard for Drinking Water Quality (NSDWQ).

In rapidly urbanizing and industrializing regions like Agbarho in Delta State, water resources are under increasing pressure, often leading to deteriorating quality that threatens ecosystems and public health. By analyzing water quality through the measurement of physical, chemical, and microbiological characteristics, the levels and impacts of pollutants, such as heavy metals, nutrients, and pathogens, can be better understood. Water quality plays a crucial role in maintaining healthy ecosystems and providing safe drinking water. Assessments offer valuable insights into the extent and sources of contamination, enabling effective management and remediation efforts. Common contaminants, including nitrates, heavy metals, and pathogens, typically enter water systems through agricultural runoff, industrial discharges, and poor waste management practices (Ngah and Onwuka, 2020).

In the Delta Region, including the towns of Ewhereh and Ohrerhe, contamination risks are exacerbated by industrial activities and oil exploration. Asadu (2016) assessed the water quality of Agbarho area, Delta State, Nigeria, the results reveals that the cations anions, heavy metal fell below the permissible limit of the WHO standard of 1982. The water samples exhibited generally acidic conditions, with pH values ranging between 4 and 6, indicating the need for pH adjustment to meet potable water standards. Microbiological analysis showed that samples from Oseri, Uvwiamughe, Idirima, Urhoboghara, and Ogubane were contaminated with coliform bacteria, with counts ranging from 5 to 25 CFU/100 mL, suggesting fecal contamination. Additionally, samples from Erhidi, Uvwiamughe, Abavo, and Oguname had elevated Biological Oxygen Demand (BOD) levels, reflecting a high concentration of organic pollutants. Therefore, water from these sources should be properly treated and disinfected before it is considered safe for human consumption. The water quality in Ewhereh and Ohrerhe towns is shaped by both human activities and natural factors.

Udeme et al. (2021) carried out a comparative assessment of the groundwater and surface water quality for domestic water supply in rural areas surrounding crude oil exploration facilities. The results revealed that the pH of the two water sources were somewhat acidic, with values ranging from 5.19 to 6.24. Water quality indicators such as Fe, Pb, TDS, TPC, DO, BOD, F coli, and E coli, on the other hand, were found to be above the permissible tolerance in drinking water, according to the Nigerian Standard for Drinking Water Quality (NSDWQ) and the World Health Organisation (WHO). Pollutant concentrations in surface water were higher than in groundwater, which may be attributable to the presence of humans or animal excrements (from open grazing) as well as offshore activities.

Samuel et al. (2019) carried out water quality assessment of surface and groundwater sources using the water quality index method and using a peri-urban town in southwest Nigeria as a case study. The results revealed that all the physicochemical water quality parameters complied with regulatory standards. Similarly, most of the heavy metals also complied except for some sites. Faecal coliform and E. coli tested positive for all the samples except one of the tap water samples. Majority of the water samples (86%) were rated as excellent based on the physicochemical parameters. One sample each was rated as having poor and good water quality, respectively. All the samples tested positive for faecal coliform bacteria and E. coli except one (treated water). It was recommended that Microbial water quality parameters be included in all Water Quality Index (WQI) analyses in order to give the true status of the quality of a water resource.

Aigberua et al. (2021) assessed the impact of oil and gas operations on water quality in the Niger Delta. The study highlighted that surface water bodies near oil production sites contained high concentrations of heavy metals and hydrocarbons, far exceeding World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) limits. The research emphasized the urgent need for stricter regulation and monitoring to protect water resources in oil-impacted regions.

Atuanya et al. (2012) evaluated the quality of groundwater around the Udu and Ughelli areas in Delta State, finding that groundwater samples contained high levels of nitrate, iron, and microbial contaminants, often exceeding NSDWQ standards. The aim of this study is assessing the quality of surface and groundwater at Ewhereh and Ohrerhe towns, in Agbarho, Delta State, to determine their safety and suitability for drinking and other purposes.

2. Description of the Study Area

The study area, Agbarho, is a town in the Ughelli North local government area of Delta state, Nigeria. It is located near the city of Warri. It lies within latitude N5° 34' 32" to N5° 36' 11" and longitude E5° 51' 09" to E5° 52' 50" (Fig. 1). The area derives its water from the Sombreiro Warri Deltaic Plain which overlies the coastal plain sand of the highly prolific Agbada formation. The area has a shallow water table which is encountered at a minimum depth of 20 meters. The area is considerably recharged by rainfall. The area is accessible by major roads and foot paths. Agbarho is a coastal town located strategically in the Niger Delta region of Nigeria. It is also one of the kingdoms that belong to the Urhobo Tribe. The Urhobo are the main tribe living within this area. Agbarho is one of the most populated towns in Delta State, with an estimated population of over 500,000 people, 2006 population census, (Demographic and Social Statistics, 2020). Agbarho is made up of communities such as the Oguname, Ophori, Oviri, Oghara of Agbarho, Uvwiamuge, Ughrugheli, Uvwiama Ekrerhavwe, Ikwegwu Okrherhe, Orhokpokpor, Orho-Agbarho, Ekwerhe (Wikipedia, 2024).

The people of Agbarho are mainly farmers and businessmen/women. There is also a government owned and operated hospital which lies on the outskirts of the town and on the way to Ohrerhe community

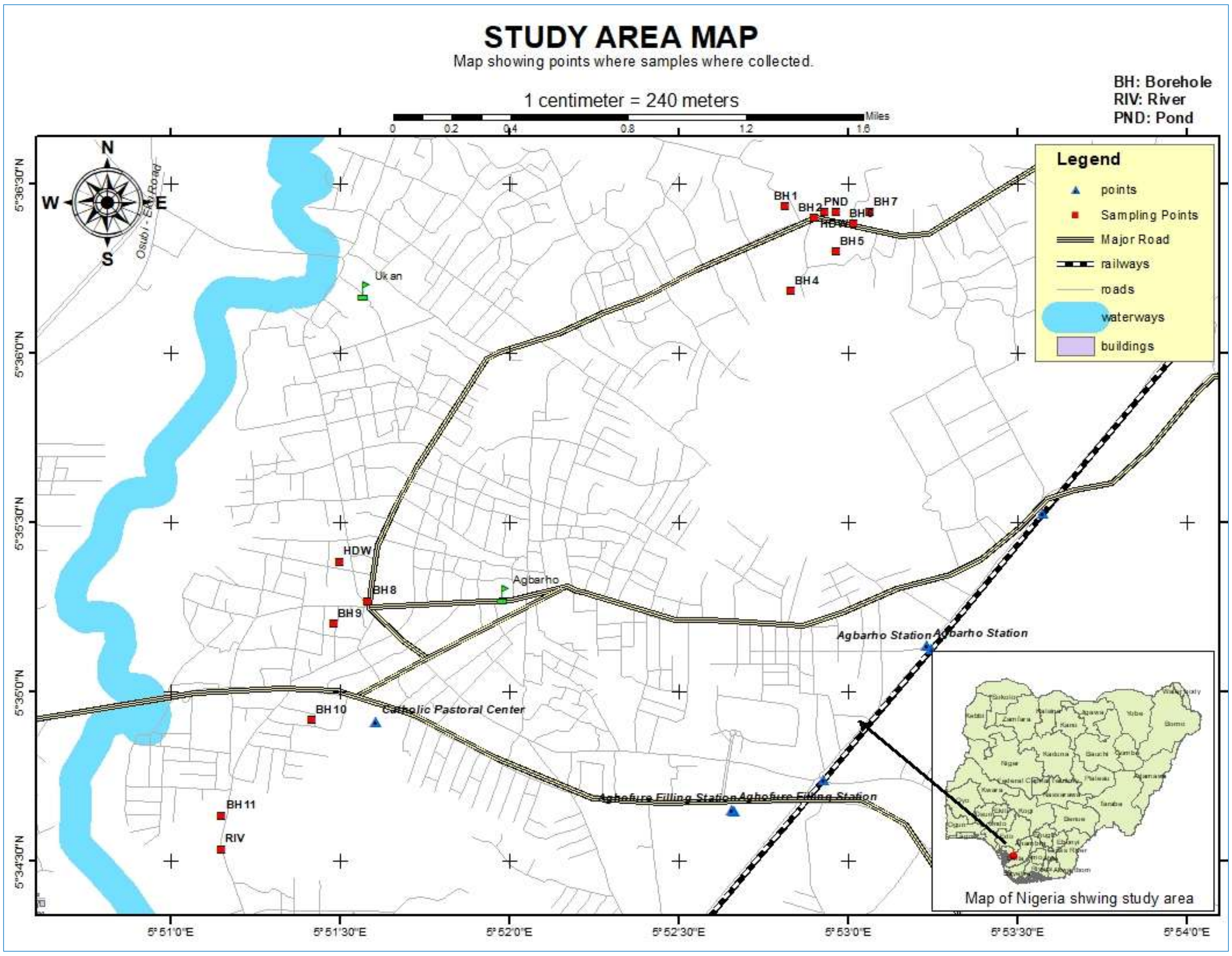

Fig. 1. Based map of the study area

It is located approximately 50 kilometres away from the Atlantic Ocean within the oil-rich provinces of Nigeria. The town is situated in a low-lying area with an average elevation of 6 meters above sea level. It features a flat landscape that gently slopes towards the Warri River and its tributaries, which ultimately discharge into the Atlantic Ocean. Agbarho has two main entry points, one from Benin in Edo State and the other from Port-Harcourt in Rivers State. These well-connected roads make it convenient to access various sampling locations within the city. The study area in Agbarho is characterized by a low-lying topography with an average height of 6 meters above sea level. The aquifer source of fresh water of the study is from the Benin Formation and Sombeiro -Warri Deltaic Plain Deposits.

The climate in Agbarho belongs to the tropical equatorial type and is characterized by two main seasons: a long, wet season from April to October and a short, dry season from November to March. The interaction of the south-west and north-east trade winds that traverse Nigeria affects these seasons. Annual rainfall typically exceeds 3000 mm, as no month of the year is devoid of rainfall. The temperature remains above 28°C, and humidity levels hover around 80% (Iloeje, 1981). The natural vegetation in the area is predominantly mangrove swamp forest, transitioning to rainforest further inland.

However, human activities like farming and logging have extensively altered the original vegetation, often leading to its replacement by grassland. An important characteristic of the Climate of Delta State is flooding (Balogun et al., 2022).
The ecological attributes of Delta State also include heavy rainfall, which makes the state, like other states in the Niger-Delta of Nigeria to be regarded as lowland rainforest,

freshwater swamp and mangrove swamp. Delta State has a mean rainfall of 36.9 mm, as well as an increase in rainfall which in the year 2015 resulted in inundation of farmlands in the state (Oyerinde, 2021). 2015 was also the year the state had the highest rainfall, amounting to 3183.6 mm. In the year 2007, the state had the lowest rainfall over an 11-year period, amounting to an annual rainfall of 2030.58 mm.

While January has the lowest rainfall in the state, in July, rainfall is very high at 423.2 mm (Oyerinde, 2021). Delta State covers a landmass of about 18, 050 km^2 (6,970 sq m), of which more than 60% is land. The state lies approximately between E5°00' and E6°45' to N5°00' and N6°30' (Ebewore, 2020). It is geographically located in Nigeria's Midwest, bounded in the north and west by Edo State for 350 km (218 miles), the east by Anambra, and Rivers States for about 93 km and about 50 km respectively, southeast by Bayelsa State across the Niger River for 17 km and the Forçados River for 198 km (Encyclopedia Britannica, 2021) and on the southern extreme is the Bight of Benin which covers about 160 kilometres of the state's coastline. Delta State is generally low-lying without any remarkable hills. The state has a wide coastal belt inter-laced with rivulets, which form part of the Niger Delta (Nigeria Information & Guide, 2012; DSMTDP, 2019; Nigeria Information & Guide, 2021).

The Niger Delta basin covers most areas of the Rivers, Bayelsa, Edo, and Delta states of Nigeria. It covers an area of approximately 75000 km^2 and consists predominantly of cretaceous to recent (Orife and Avbovbo, 1982). The Niger Delta is in the Gulf of Guinea, central West Africa, at the culmination of the Benue trough and is considered one of the most prolific hydrocarbon provinces in the world (Corredor et al., 2005). The delta consists of a broad riverine area through which the River Niger enters the Atlantic Ocean, dividing into numerous rivulets that fan out into the sea. It also includes a number of tidal creeks separating small islands less than 10 meters above sea level (Offodile, 2002)

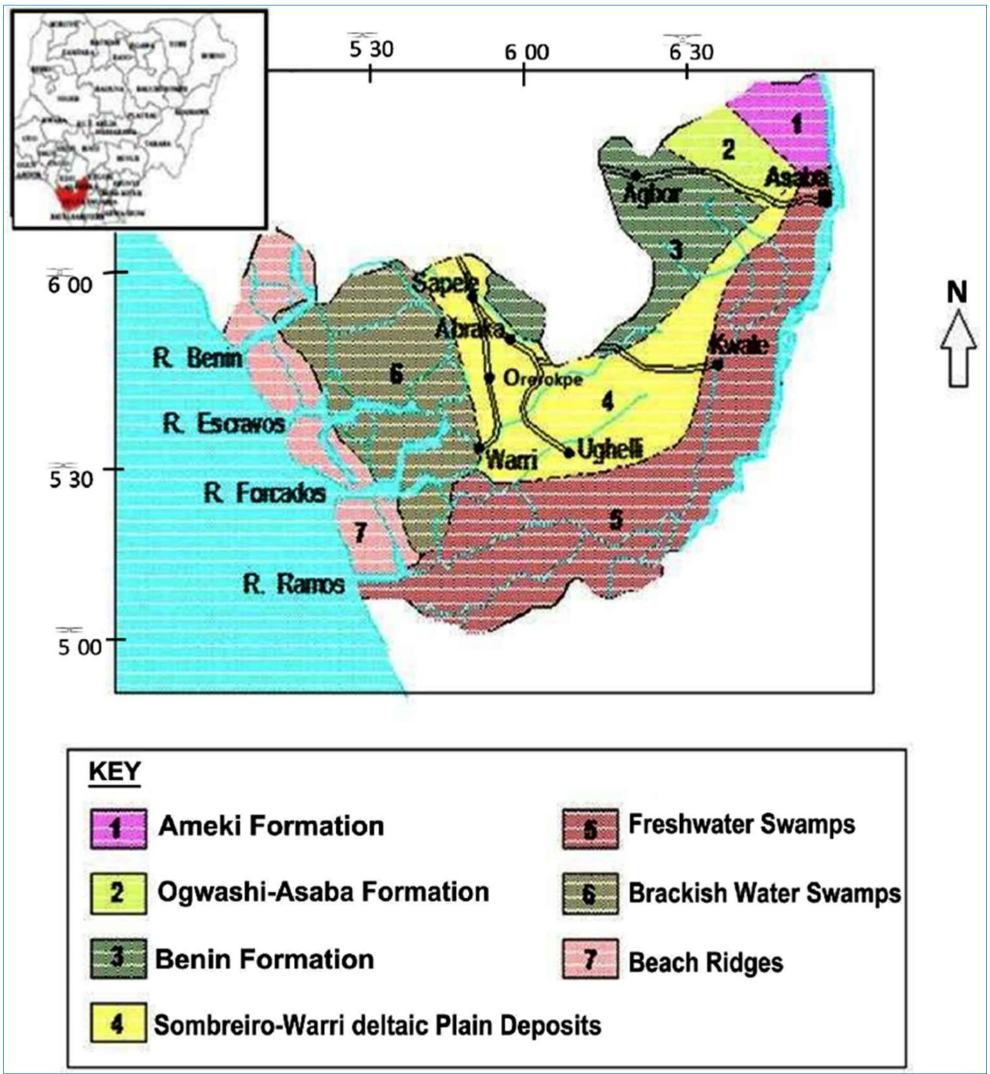

Fig. 2. Geology of the study area (modified from Akpoborie et al., 2011)

The Anambra basin and the Abakaliki high to the north, the Cameroun volcanic line to the east, the Dahomey embayment to the west, and the Gulf of Guinea to the south define the boundaries off the Niger Delta. The siliciclastic system of the Niger Delta began to prograde across the pre-existing continental slope into the deep sea during the late

Eocene and is still active today (Burke and Dewey, 1972). The town of Agbarho is underlain by a sequence of sedimentary formations with a thickness of up to 8000m, which includes, from bottom to top, the Akata formation, the Agbada formation, the Benin formation, and largely the Sombreiro-Warri Atlantic plain sands (Allen, 1965; Reyment, 1965; Short and Stauble, 1967). The Sombreiro-Warri deltaic plain sand is quaternary to recent in age and directly underlies the study area, as shown in Fig. 2, which consists of fine to medium unconsolidated sands that are often feldspathic (30–40% with feldspars) and occasionally gravelly (Wigwe, 1975). The sequence is locally stratified with peat and lenses of soft and plastic clay that could be sandy and shaly, predominantly unconfined, and generally do not exceed 120 m in thickness. The aquifer sources of fresh water in the study area are the Benin Formation and Somberio-Warri Deltaic Plain Deposits.

3. Materials and Methods

3.1. Materials

Fifteen (15) water samples were collected from Ewhereh and Ohrerhe towns, in Agbarho, groundwater from drilled boreholes, and surface water from hand-dug wells. The samples were placed in plastic bottles, kept on ice, and transported to Martlet Environmental Research Laboratory Limited for physicochemical and heavy metal analysis. Materials used are sterilized plastic bottles, cooler of ice, masking tape, GIS for coordination and bacon bag. The following parameters was analyzed: pH, Electrical conductivity, Total Dissolved Solids (TDS), Salinity, colour, (Pt-Co), Turbidity, and Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), bicarbonate (HCO_3), phosphorus (P), ammonium (NH_4N), nitrite (NO_2) and nitrate (NO_3), calcium, potassium, sodium, carbonate, chloride, sulphate, magnesium, heavy metals (manganese, Iron, copper, zinc, lead, cadmium and chromium) to evaluate the level of contamination.

3.2. Methods

The method used in analyzing water samples is Atomic Absorption Spectroscopy (AAS). Atomic Absorption Spectrophotometer analytical instrument is based on the principle of atomic absorption spectroscopy and is very useful to detect the metal ion concentration present in drinking water samples. The following apparatus was used: 250 ml digestion tube, heater, funnels, 25 ml volumetric flask, filter paper, beakers. The statistical software used to analysis the dataset is Microsoft Xcel and SPSS.

Table 1. Physiochemical parameters of groundwater samples collected from the study area

Parameters	pH	EC µS/cm	Sal. g/l	TDS	COD
BH 1 EKP AGB	5.1	120	0.054	60	22
BH 2 EKP AGB	5.8	20	0.09	10	7.7
BH 3 EKP AGB	6.1	48	0.022	24	12.1
BH 6 EKP AGB	5	367	0.166	152	34
BH 7 EKP AGB	6.2	60	0.027	30	15.3
BH 8 EKP AGB	6	353	0.159	177	33.2
BH 9 EKP AGB	5.8	66	0.03	33	21.6
BH 10 AGB	5.1	160	0.072	80	23.9
BH 12 Ohr AGB	5.1	373	0.17	154	37.9
BH 13 Ohr AGB	5	231	0.104	114	30
BH 14 Ohr AGB	6.1	44	0.02	22	9.9
AVERAGE	5.573	167.454	0.0831	77.818	22.509
MIN	5	20	0.02	10	7.7
MAX	6.2	373	0.17	177	37.9

Table 3. Comparison of Groundwater physiochemical parameters with NSWDQ (2007) and WHO (2011)

Parameters	pH	EC µS/cm	Sal. g/l	TDS	COD
BH 1 EKP AGB	5.1	120	0.054	60	22
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BH 12 Ohr AGB	5.1	373	0.17	154	37.9
BH 13 Ohr AGB	5	231	0.104	114	30
BH 14 Ohr AGB	6.1	44	0.02	22	9.9
NSWDQ 2007	6.5-8.5	1000		500	250
WHO 2011	6.6-8.5	900		1000	250

3.2.1. Sample Preparation Techniques for AAS

To prepare water samples for AAS analysis, add 25 mL of the sample to a PTFE beaker and acidify it with 2.0 mL of concentrated HNO3 and 6.0 mL of concentrated HCl (trace metal grade for AAS). Heat the mixture on a hot plate under a fume hood until it reaches just below boiling and the solution turns clear. Once cooled, transfer the contents to a 50 mL volumetric flask, rinsing the beaker's inner wall with ultrapure water (resistivity of 18.2 Ωm) and adding the rinsate to the flask. Adjust the solution's volume with ultrapure water. If needed, filter or centrifuge the solution to remove silicates and other insoluble materials that could clog the nebulizer. Ensure the filter and apparatus are cleaned thoroughly with diluted HNO_3 before filtering each sample to avoid contamination. Adjust the final volume to 100 mL with ultrapure water and ensure the final acid concentration is 10%. The sample is now ready for AAS analysis.

3.2.2. Procedure in Carrying out AAS Analysis on Water Samples

Sample Introduction: The prepared water sample is aspirated into the flame of converting them into their atomic form.

Atomization: The flame generates atomic vapours of the element being analyzed. Most of these atoms remain in their ground state, while a small fraction may become thermally excited by the flame's heat.

Absorption of Radiation: The ground-state atoms absorb light at a specific wavelength emitted by a hollow cathode lamp, which serves as the light source for the AAS. The lamp is made of the same element being analyzed (e.g., a copper lamp for copper detection), ensuring the emitted radiation matches the element's absorption wavelength.

Measurement: The amount of light absorbed by the ground-state atoms in the flame is measured. Since the absorbed radiation corresponds to the specific wavelength of the element, the level of absorption is directly proportional to the concentration of the element in the sample.

Quantification: Using a calibration curve generated from standards of known concentration, the concentration of the target element in the water sample is determined.

4. Results and Discussion

4.1. Physiochemical Parameters of Groundwater Collected around Ewhereh-Ohrehe Community

The pH values range from 5.0 to 6.2 with mean concentration value of 5.573; this indicates that the water samples are slightly acidic. The acidic water can be a result of natural processes such as the presence of dissolved carbon dioxide or due to anthropogenic factors like industrial discharge. This could affect the solubility and bioavailability of nutrients. The EC values range from 20 to 373 µS/cm, with mean concentration value of 167.454 µS/cm. Higher EC values can indicate higher concentrations of dissolved salts, which could influence plant growth and soil health. The salinity levels range from 0.02 to 0.17 mg/L, with an average of 0.0831 mg/L. The low salinity levels are generally favourable for freshwater organisms. Higher salinity could indicate influence from saltwater intrusion or other sources of dissolved salts. TDS value ranges from 10 to 177 mg/L, with mean concentration value of 77.818 mg/L. Elevated TDS can indicate a higher concentration of salts and can affect water quality. COD levels range from 7.7 to 37.9 mg/L, with an average of 22.509 mg/L. Higher COD values suggest a higher level of organic pollutants in the water, which could affect oxygen levels and aquatic life. BH 12 Ohr AGB has the highest values of EC, salinity, TDS, COD, and bicarbonate, indicating it has the most mineralized water among the samples. This may be due to natural processes or contamination sources. BH 2 EKP AGB has the lowest values of pH, EC, TDS and COD indicating less mineralization and possibly better water quality in comparison to other sampling areas. The general acidity of the water samples suggests potential issues that may require treatment, especially if used for drinking or irrigation. The variations in these parameters suggest differences in the water quality between the borehole locations, potentially due to geological factors or localized contamination (waste dumping activities and sand dredging in the study area) as shown in Table 1 and Fig. 3.

Fig. 4 shows the concentration level of physiochemical and the sampling points. Fig. 4 illustrates the surface contour of the sampling points, highlighting that BH6, BH8, BH12, and BH13 exhibit very high concentrations of electrical conductivity (EC) and total dissolved solids (TDS) as shown in Table 1.

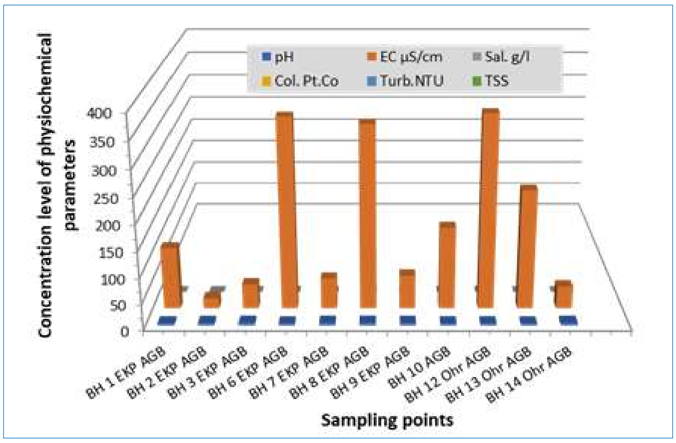

Fig. 3. Groundwater concentration level of physiochemical parameters and sampling points

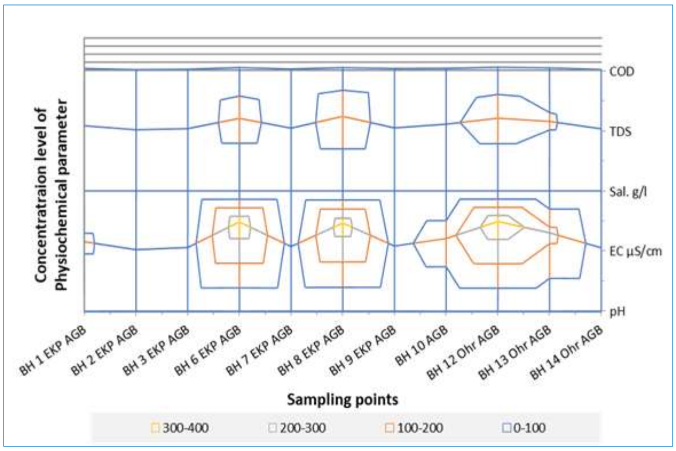

Fig. 4. Surface contour showing the groundwater concentration level of physiochemical parameters and sampling points

The pH values across the sampling points range from 5.0 to 6.2. These values indicate that the water is slightly acidic, as all samples fall below the acceptable range for drinking water (6.5–8.5, according to both NSDWQ and WHO standards). This acidity could be due to natural geological factors or pollution from industrial/agricultural activities. EC values range from 20 to 373 µS/cm. EC measures the water's ability to conduct electricity, which is influenced by the presence of dissolved salts and ions. All the samples are well below the recommended limit (1000 µS/cm for NSDWQ and 900 µS/cm for WHO), suggesting that the water has relatively low mineral content. BH 12 and BH 6 have the highest EC values, indicating these areas may have higher salinity or ion concentrations. Salinity ranges from 0.02 to 0.17 mg/L.

Although no standard limit for salinity is provided in the table, these values are generally low. The salinity levels reflect minimal salt content, which is typical for freshwater sources. BH 6, BH 8, and BH 12 show slightly higher salinity levels, which could indicate minor saline intrusion or localized contamination. TDS values range from 10 to 177 mg/L. TDS represents the total concentration of dissolved substances in the water. All samples fall far below the recommended limits (500 mg/L for NSDWQ and 1000 mg/L for WHO), indicating that the groundwater is relatively low in dissolved minerals. BH 8 and BH 12 have the highest TDS levels, hinting at higher concentrations of dissolved ions in these areas. COD values range from 7.7 to 37.9 mg/L. COD measures the amount of oxygen required to oxidize organic and inorganic matter in water. The COD values in all the samples are below the limit of 250 mg/L set by both NSDWQ and WHO, suggesting that the organic pollution levels are relatively low. However, higher values in samples like BH 12 (37.9 mg/L) and BH 6 (34 mg/L) may indicate localized organic contamination, possibly from agricultural runoff or sewage. All the samples are slightly acidic, which might pose long-term risks for infrastructure (such as pipes) and human health if untreated. The low EC and TDS values suggest that the water in these areas is low in dissolved minerals, which is generally good for drinking purposes. Sampling points like BH 6, BH 8, and BH 12 show slightly elevated EC, TDS, salinity, and COD levels, indicating potential localized sources of contamination as shown in Table 2.

Table 3. Physiochemical parameters of surface water samples collected from the study area

Parameters	HDW 4 EKP AGB	POND 5 EKP AGB	HDW 11 Orh AGB	R W 15 Ohr AGB	AVERAGE	MIN	MAX
pH	6.5	6.4	6.2	6.2	6.325	6.2	6.5
EC µS/cm	251	56	653	44	251	44	653
Sal. g/l	0.114	0.025	0.295	0.02	0.1135	0.02	0.295
Col. Pt.Co	0.001	0.8	0.001	0.5	0.3255	0.001	0.8
Turb.NTU	0.001	0.5	0.001	0.4	0.2255	0.001	0.5
TSS	0.001	1	0.001	0.8	0.4505	0.001	1
TDS	126	28	320	22	124	22	320
COD	31.1	14.3	52	8.8	26.55	8.8	52

Table 4. Comparison of Surface water physiochemical parameters with NSWDQ (2007) and WHO (2011)

Parameters	HDW 4 EKP AGB	POND 5 EKP AGB	HDW 11 Orh AGB	R W 15 Ohr AGB	NSWDQ 2007	WHO 2011
pH	6.5	6.4	6.2	6.2	6.5-8.5	6.5-8.5
EC µS/cm	251	56	653	44	1000	900
Sal. g/l	0.114	0.025	0.295	0.02		
Col. Pt.Co	0.001	0.8	0.001	0.5	15	
Turb.NTU	0.001	0.5	0.001	0.4	5	
TSS	0.001	1	0.001	0.8		
TDS	126	28	320	22	500	1000
COD	31.1	14.3	52	8.8	250	250

4.2. Physiochemical Parameters of Surface Water Collected around Ewhereh-Ohrehe Community

The pH values range from 6.2 to 6.5, with an average of 6.325, indicating that the water is slightly acidic to neutral. These pH levels are generally suitable for most freshwater organisms. Electrical conductivity (EC) shows significant variation, ranging from 44 to 653 µS/cm, with an average of 251 µS/cm. HDW 11 Ohr AGB records the highest EC, indicating a greater concentration of dissolved salts, which may impact plant growth and overall water quality. Salinity levels are low across all samples, with values between 0.02 and 0.295 mg/L and an average of 0.1135 mg/L, making them favourable for freshwater ecosystems.

Colour measurements vary, with POND 5 EKP AGB having the highest at 0.8 Pt-Co units. Increased colour can indicate the presence of organic matter or turbidity, potentially affecting water quality. Turbidity levels range from 0.001 to 0.5 NTU, with an average of 0.2255 NTU. Higher turbidity can hinder light penetration in water bodies, which impacts aquatic life. Total suspended solids (TSS) range from 0.001 to 1 mg/L, with an average of 0.4505 mg/L, and POND 5 EKP AGB exhibiting the highest concentration. Elevated TSS can contribute to increased turbidity and reduce light availability for photosynthesis. Total dissolved solids (TDS) range from 22 to 320 mg/L, with an average of 124 mg/L; HDW 11 Ohr AGB shows the highest concentration. Increased TDS can negatively affect water quality and usability. Chemical oxygen demand (COD) values range from 8.8 to 52 mg/L, with an average of 26.55 mg/L, and HDW 11 Ohr AGB displaying the highest COD, indicating a greater presence of organic matter that can deplete oxygen levels in the water as shown in Table 3 and Fig. 5.

Fig. 6 illustrates the surface contour of the sampling points, highlighting that HDW 4 and HWD 11 exhibit very high concentrations of electrical conductivity (EC) and total dissolved solids (TDS) as shown in Table 3.

The pH values range from 6.2 to 6.5. All the samples fall within or just below the acceptable range (6.5–8.5) set by NSDWQ (2007) and WHO (2011). While HDW 4 meets the minimum pH level, the rest are slightly below, indicating mildly acidic water. This slight acidity might be a concern for long-term water quality if not properly managed. EC values vary significantly; from 44 to 653 µS/cm. Electrical conductivity measures the water's ability to conduct electricity, which is related to the concentration of dissolved salts and minerals.

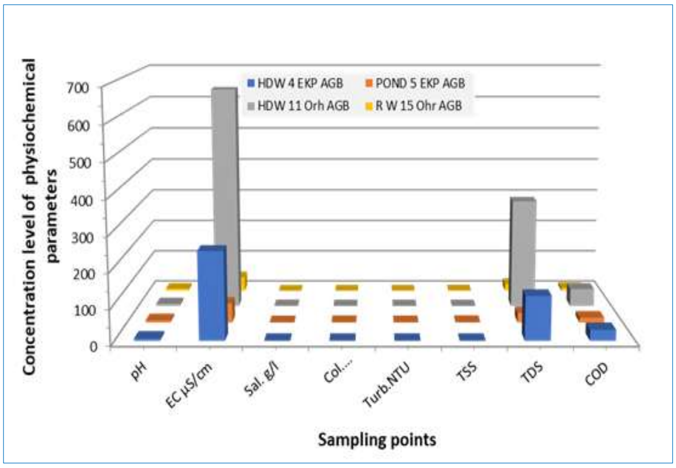

Fig. 5. Surface water concentration level of physiochemical parameter and sampling points

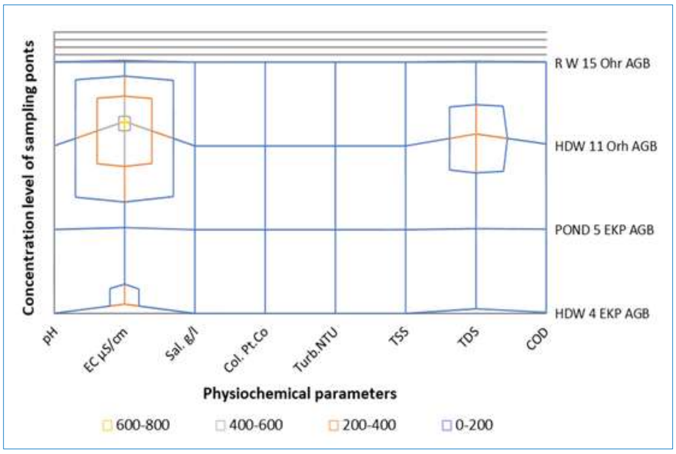

Fig. 6. Surface contour of surface water concentration level of physiochemical parameters

All samples are well below the 1000 µS/cm limit set by NSDWQ (2007) and WHO (2011). With the exception of HDW 11 (653 µS/cm), all of the others are similar. HDW 11 shows elevated ion concentrations, suggesting that it may be affected by salinity or mineralization. Salinity values range from 0.02 to 0.295 mg/L.

Although no salinity standard is specified here, the values indicate relatively low salt content, except for HDW 11 (0.295 g/l), which suggests the presence of more dissolved salts or minerals compared to other samples. This could be an indicator of localized contamination or saline intrusion. Colour values vary from 0.001 to 0.8 Pt.Co units. Colour levels are well below the NSDWQ limit of 15 Pt.Co units, indicating clear water. POND 5 shows slightly higher colour (0.8 Pt.Co), but this is still within safe limits. Turbidity values range from 0.001 to 0.5 NTU. Turbidity measures the clarity of the water, with higher values indicating more suspended particles. All samples are well below the 5 NTU limit, meaning the water is visually clear. POND 5 shows slightly higher turbidity (0.5 NTU) but still within acceptable limits. TSS levels range from 0.001 to 1 mg/L. TSS represents the concentration of solid particles in water. All the values are extremely low, with POND 5 having a slightly elevated level (1 mg/L), but still indicating very low levels of suspended particles. TDS values range from 22 to 320 mg/L. TDS indicates the total concentration of dissolved substances in the water. All the samples are well below the 500 mg/L limit set by NSDWQ (2007) and the 1000 mg/L limit set by WHO (2011). HDW 11 has the highest TDS (320 mg/L), consistent with its higher EC and salinity, suggesting more dissolved minerals at this location. COD values range from 8.8 to 52 mg/L. COD measures the amount of oxygen required to oxidize organic and inorganic matter in water.

All samples are below the 250 mg/L limit, but HDW 11 shows a higher value (52 mg/L), indicating that this sample has more organic matter or potential pollutants than the others. POND 5 (14.3 mg/L) and RW 15 (8.8 mg/L) show lower COD values, indicating cleaner water with less organic contamination.

The pH levels are slightly acidic but generally close to acceptable limits. EC, TDS, and salinity levels suggest that HDW 11 may be experiencing higher mineral or salt content than the other locations. The water is clear in all locations, with low turbidity and colour values, meaning it is visually clean. HDW 11 has elevated EC, TDS, and COD values, suggesting potential localized contamination or natural mineralization. POND 5 shows slightly higher values for colour, turbidity, and TSS, but overall, the water quality appears to be within safe limits across most parameters as shown in Table 5.

4.3. Major Cation of Groundwater and Surface Water Collected around Ewhereh-Ohrehe Community

Sodium (Na) levels range from 0.6 mg/L to 5.2 mg/L, with mean concentration value of 2.1 mg/L. BH 1 EKP AGB and HDW 11 Orh have relatively higher Na concentrations compared to other points. Sodium is an essential nutrient but can contribute to soil salinity if present in high concentrations, which might affect plant growth. The high concentration levels of these nutrients (Na), possibly from contamination sources like agricultural runoff, wastewater discharge, or soil mineral composition. Potassium concentrations range from 0.4 mg/L to 2.9 mg/L with mean concentration value of 1.22 mg/L. HDW 11 Orh has the highest K value, while BH 14 Ohr AGB and RW 15 Ohr AGB have lower values. Potassium is vital for plant growth, especially for root development and resistance to drought. Calcium values vary significantly, from as low as 3.7 mg/L to as high as 30.1 mg/L with mean concentration of 12.25 mg/L. HDW 11 Orh shows the highest concentration of calcium. Calcium is important for soil structure, helping to improve water penetration and reduce soil compaction. Magnesium ranges from 1.6 mg/L to 12.9 mg/L with mean concentration value of 5.27 mg/L. HDW 11 Orh has the highest magnesium concentration. Magnesium is a key element for chlorophyll production in plants and helps stabilize soil structure. The values of NH_4N range from 0.23 mg/L to 5.3 mg/L with mean concentration value of 1.59 mg/L. The highest NH4N concentration is in HDW 11 Orh, indicating higher nitrogen levels, which can suggest recent organic matter decomposition or fertilizer application. Phosphorus levels range from 0.015 mg/L to 0.133 mg/L with mean concentration value of 0.0581 mg/L. HDW 11 Orh has the highest phosphorus concentration, followed by BH 6 EKP AGB and BH 12 Ohr AGB. Phosphorus is crucial for plant energy transfer and root development but can cause environmental issues if it leaches into water bodies. HDW 11 Orh stands out as having the highest concentrations of Na, K, Ca, Mg, NH4N, and P. This could be due to localized conditions such as higher mineral content in the soil or water contamination from organic waste or human activities (fertilizer usage). The variability in cation and nutrient levels suggests differences in soil or water chemistry across the sample locations. Lower values of Na, K, Ca, and Mg in certain locations like RW 15 Ohr AGB indicate a lower mineral content or less human influence as shown in Table 5 and Fig. 7.

Table 5. Major Cation of water samples collected from Ewhereh-Ohrehe community

Parameter	Na	K	Ca	Mg	NH_4N	P
BH 1 EKP AGB	1.9	0.9	11.2	4.8	1.39	0.074
BH 2 EKP AGB	0.6	0.4	3.7	1.6	0.23	0.015
BH 3 EKP AGB	1.1	0.7	6.3	2.7	0.42	0.033
HDW 4 EKP AGB	2.6	1.5	15.2	6.5	2.08	0.061
PD 5 EKP AGB	1.2	0.8	7.1	3.1	0.48	0.038
BH 6 EKP AGB	3.2	1.8	18.7	8	3	0.087
BH 7 EKP AGB	1.3	0.7	7.4	3.2	0.52	0.047
BH 8 EKP AGB	2.9	1.7	17	7.3	2.4	0.077
BH 9 EKP AGB	1.5	0.9	8.5	3.7	0.61	0.053
BH 10 AGB	2.3	1.5	13.3	5.7	1.49	0.055
HDW 11 Orh	5.2	2.9	30.1	12.9	5.3	0.133
BH 12 Ohr AGB	3.7	2	21.4	9.2	3.32	0.102
BH 13 Ohr AGB	2.4	1.4	14.1	6.1	1.94	0.058
BH 14 Ohr AGB	0.9	0.6	5.5	2.4	0.32	0.021
RW 15 Ohr AGB	0.7	0.5	4.3	1.8	0.3	0.018
AVERAGE	2.1	1.22	12.253	5.2667	1.5867	0.0581
MIN	0.6	0.4	3.7	1.6	0.23	0.015
MAX	5.2	2.9	30.1	12.9	5.3	0.133

Table 6. Comparison of Major Cation with NSWDQ (2007) and WHO (2011)

Parameter	Na	K	Ca	Mg	NH4N	P
BH 1 EKP AGB	1.9	0.9	11.2	4.8	1.39	0.074
BH 2 EKP AGB	0.6	0.4	3.7	1.6	0.23	0.015
BH 3 EKP AGB	1.1	0.7	6.3	2.7	0.42	0.033
HDW 4 EKP AGB	2.6	1.5	15.2	6.5	2.08	0.061
PD 5 EKP AGB	1.2	0.8	7.1	3.1	0.48	0.038
BH 6 EKP AGB	3.2	1.8	18.7	8	3	0.087
BH 7 EKP AGB	1.3	0.7	7.4	3.2	0.52	0.047
BH 8 EKP AGB	2.9	1.7	17	7.3	2.4	0.077
BH 9 EKP AGB	1.5	0.9	8.5	3.7	0.61	0.053
BH 10 AGB	2.3	1.5	13.3	5.7	1.49	0.055
HDW 11 Orh	5.2	2.9	30.1	12.9	5.3	0.133
BH 12 Ohr AGB	3.7	2	21.4	9.2	3.32	0.102
BH 13 Ohr AGB	2.4	1.4	14.1	6.1	1.94	0.058
BH 14 Ohr AGB	0.9	0.6	5.5	2.4	0.32	0.021
RW 15 Ohr AGB	0.7	0.5	4.3	1.8	0.3	0.018
NSWDQ 2007	200		75	50	35	
WHO 2011	200		200	100	35	

Figs. 8 and 9 illustrate the surface contour of the sampling points, highlighting that BH6, BH8, BH12, BH13, HDW 4 and HDW 11 exhibit very high concentrations of Calcium (Ca) as shown in Table 5.

The Sodium levels range from 0.6 to 5.2 mg/L. All sodium concentrations are well below the NSDWQ and WHO limits of 200 mg/L, indicating no significant sodium contamination. HDW 11 Orh AGB has the highest sodium concentration (5.2 mg/L), but it is still very low and safe for drinking purposes. Potassium concentrations range from 0.4 to 2.9 mg/L. No standard limits are provided for potassium, but these levels are relatively low, with HDW 11 Orh AGB having the highest concentration (2.9 mg/L). Potassium is generally not harmful at these levels. Calcium levels vary significantly, from 3.7 to 30.1 mg/L. All samples are well below the NSDWQ limit of 75 mg/L and the WHO limit of 200 mg/L. However, HDW 11 Orh AGB shows the highest concentration of calcium (30.1 mg/L), which is higher than the other samples but still within safe drinking water standards. Elevated calcium could suggest harder water in this location. Magnesium concentrations range from 1.6 to 12.9 mg/L. All magnesium levels are below the NSDWQ (50 mg/L) and WHO (100 mg/L) limits, with HDW 11 Orh

AGB showing the highest concentration (12.9 mg/L). Magnesium contributes to water hardness, but these levels are not high enough to cause concern. NH4-N concentrations range from 0.23 to 5.3 mg/L. The NH4-N concentrations are all below the 35 mg/L guideline by NSDWQ and WHO, but HDW 11 Orh AGB has a significantly elevated concentration (5.3 mg/L). While still within safe limits, elevated ammonium nitrogen can be a sign of organic pollution or contamination from agricultural runoff or wastewater. Phosphorus concentrations range from 0.015 to 0.133 mg/L. No specific standard is provided for phosphorus in drinking water at this table. However, phosphorus in water can indicate nutrient pollution, possibly from fertilizers or detergents. HDW 11 Orh AGB has the highest concentration (0.133 mg/L), which may indicate localized contamination or nutrient input. HDW 11 Orh AGB consistently shows the highest concentrations across all parameters, including Na, K, Ca, Mg, NH4-N, and P. Although these values remain within the safe drinking water limits, the elevated levels suggest the presence of natural mineralization or anthropogenic contamination (agricultural runoff). BH 6 EKP AGB and BH 12 Ohr AGB also show elevated levels of calcium, magnesium, and ammonium nitrogen, indicating that these sites may also have mineral-rich groundwater or be influenced by external sources of contamination. All locations remain within the NSDWQ and WHO safe limits for sodium, calcium, magnesium, and ammonium nitrogen, indicating that; overall, the water quality is suitable for drinking, though localized monitoring may be required for areas like HDW 11. This analysis highlights the importance of continuing to monitor nutrient levels, particularly at sites with elevated concentrations, as these can indicate potential contamination sources as shown in Table 6.

4.4. Major Anion of Groundwater and Surface Water Samples Collected in Ewhereh-Ohrehe Community

The concentration of nitrite (NO_2) ranges from 0.09 mg/L to 2.02 mg/L with mean concentration value of 0.604 mg/L. HDW 11 Orh AGB has the highest concentration of nitrite, while BH 2 EKP AGB and BH 14 Ohr AGB have the lowest values. High nitrite levels can be toxic in water and usually indicate contamination from agricultural runoff, wastewater discharge, or decaying organic matter. Nitrate (NO_3) concentrations vary significantly, ranging from 0.8 mg/L to 18.2 mg/L with mean concentration value of 5.45 mg/L.

HDW 11 Orh AGB shows the highest concentration of nitrate, which may indicate potential contamination from fertilizers or other nitrogen sources. Nitrate is a common nutrient in agricultural runoff and can lead to water quality issues like eutrophication in high amounts. Sulphate (SO_4) levels range from 0.5 mg/L to 11.28 mg/L with mean concentration value of 3.38 mg/L. The highest concentration of sulphate is observed in HDW 11 Orh AGB, followed by BH 12 Ohr AGB. High sulphate concentrations can affect the taste of water and may indicate the presence of gypsum or other sulphate-bearing minerals. Chloride (Cl) concentrations show a wide range, from 33 mg/L to 610.1 mg/L with mean concentration value of 203.14 mg/L.

HDW 11 Orh AGB again has the highest value, which could be a sign of contamination from sources like seawater intrusion, industrial discharge, or road salts. Elevated chloride levels can lead to increased salinity, affecting soil and water quality. Bicarbonate (HCO_3) levels range from 17.8 mg/L to 121 mg/L with mean concentration value of 54.85 mg/L. The highest bicarbonate concentration is found in HDW 11 Orh AGB, indicating high alkalinity, which helps buffer the pH of the water. Bicarbonate is important in regulating the pH of natural waters and its presence can be linked to carbonate rock dissolution in the area.

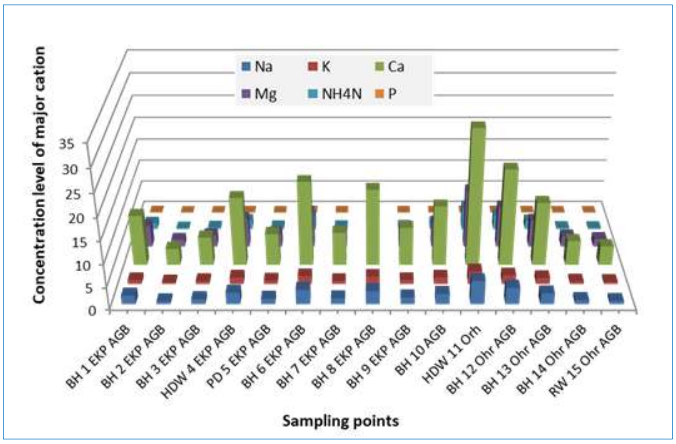

Fig. 7. Concentration level of Major Cation and sampling points

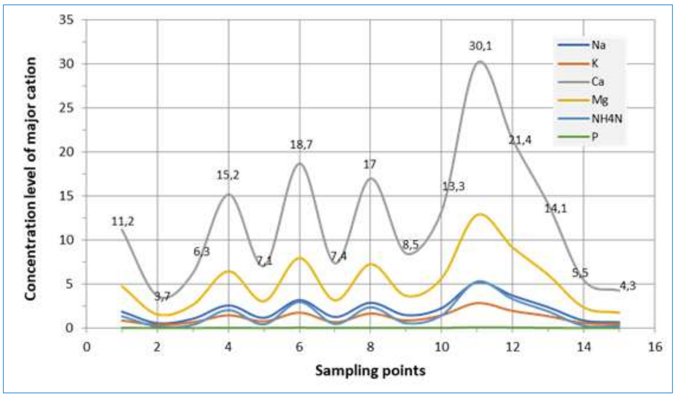

Fig. 8. Scatter diagram of concentration level of Major Cation and sampling points

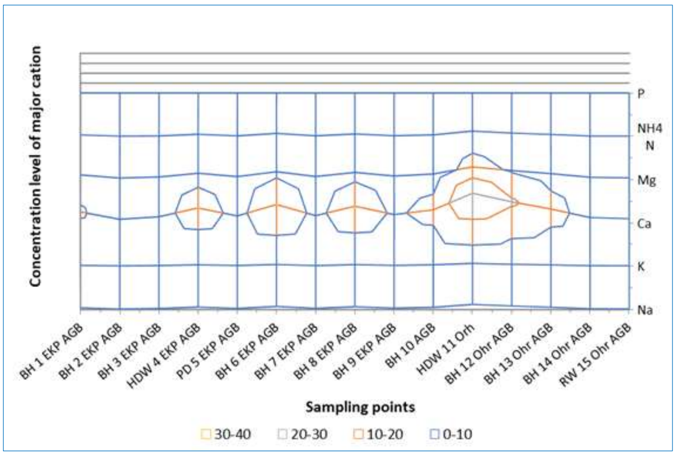

Fig. 9. Surface contour showing the concentration level of Major Cation and sampling points

HDW 11 Orh AGB stands out with significantly higher concentrations of NO_2, NO_3, SO_4, Cl, and HCO_3 compared to other sample locations, suggesting possible contamination or natural mineral enrichment in that area. The variations in nitrate and sulphate concentrations suggest differences in anthropogenic or natural sources, such as agricultural activities or industrial influences. Elevated levels of chloride in HDW 11 Orh AGB might indicate a strong influence of external contaminants, possibly from saltwater intrusion or industrial activities. The lower concentrations of these anions in locations like BH 2 EKP AGB and RW 15 Ohr AGB may indicate less exposure to pollution or different geological conditions as shown in Table 7 and Fig. 10.

Figs. 11 and 12 illustrate the surface contour of the sampling points, highlighting that BH6, BH8, BH12, BH13, HDW 4 and HDW 11 exhibit very high concentrations of chloride (Cl) as shown in Table 7.

Table 7. Major Anion of Groundwater and Surface water samples collected in Ewhereh-Ohrehe community

Parameters	NO_2	NO_3	SO_4	Cl	HCO_3
BH 1 EKP AGB	0.53	4.77	2.96	163.1	51.2
BH 2 EKP AGB	0.09	0.8	0.5	33	17.8
BH 3 EKP AGB	0.16	1.44	0.89	44.7	28.1
HDW 4 EKP AGB	0.79	7.14	4.43	310.1	72.3
PD 5 EKP AGB	0.18	1.66	1.03	51	33.3
BH 6 EKP AGB	1.14	10.3	6.39	333.2	79.1
BH 7 EKP AGB	0.2	1.78	1.1	66.5	35.5
BH 8 EKP AGB	0.91	8.22	5.1	317.2	77.3
BH 9 EKP AGB	0.23	2.11	1.31	80.4	50.2
BH 10 AGB	0.57	5.12	3.17	271	55.6
HDW 11 Orh AGB	2.02	18.2	11.28	610.1	121
BH 12 Ohr AGB	1.26	11.41	7.07	401.2	88.1
BH 13 Ohr AGB	0.74	6.66	4.13	288	69.7
BH 14 Ohr AGB	0.12	1.1	0.68	41	23.1
R W 15 Ohr AGB	0.12	1.04	0.64	36.6	20.4
AVERAGE	0.604	5.45	3.378667	203.14	54.84667
MIN	0.09	0.8	0.5	33	17.8
MAX	2.02	18.2	11.28	610.1	121

Table 8. Comparison of Major Anion with NSWDQ (2007) and WHO (2011)

Parameters	NO_2	NO_3	SO_4	Cl	HCO_3
BH 1 EKP AGB	0.53	4.77	2.96	163.1	51.2
BH 2 EKP AGB	0.09	0.8	0.5	33	17.8
BH 3 EKP AGB	0.16	1.44	0.89	44.7	28.1
HDW 4 EKP AGB	0.79	7.14	4.43	310.1	72.3
PD 5 EKP AGB	0.18	1.66	1.03	51	33.3
BH 6 EKP AGB	1.14	10.3	6.39	333.2	79.1
BH 7 EKP AGB	0.2	1.78	1.1	66.5	35.5
BH 8 EKP AGB	0.91	8.22	5.1	317.2	77.3
BH 9 EKP AGB	0.23	2.11	1.31	80.4	50.2
BH 10 AGB	0.57	5.12	3.17	271	55.6
HDW 11 Orh AGB	2.02	18.2	11.28	610.1	121
BH 12 Ohr AGB	1.26	11.41	7.07	401.2	88.1
BH 13 Ohr AGB	0.74	6.66	4.13	288	69.7
BH 14 Ohr AGB	0.12	1.1	0.68	41	23.1
R W 15 Ohr AGB	0.12	1.04	0.64	36.6	20.4
NSWDQ 2007	3	50	100	250	250
WHO 2011	3	50	250	250	250

The concentrations of nitrite range from 0.09 mg/L (BH 2 EKP AGB) to 2.02 mg/L (HDW 11 Orh AGB). The NSDWQ and WHO guideline for nitrite in drinking water is 3 mg/L. All the sampling points are below this limit. However, HDW 11 Orh AGB (2.02 mg/L) and BH 12 Ohr AGB (1.26 mg/L) have relatively high concentrations of nitrite, which could indicate contamination from organic waste, agricultural runoff, or other anthropogenic sources. Nitrate concentrations range from 0.8 mg/L (BH 2 EKP AGB) to 18.2 mg/L (HDW 11 Orh AGB). Both NSDWQ and WHO set the maximum allowable concentration of nitrate in drinking water at 50 mg/L. All the values are well below this limit, with an average of 5.45 mg/L. The highest concentration is at HDW 11 Orh AGB, which, while within limits could indicate agricultural runoff or waste discharge. Elevated nitrate levels may pose risks to human health, particularly for infants (blue baby syndrome). Sulphate concentrations range from 0.5 mg/L (BH 2 EKP AGB) to 11.28 mg/L (HDW 11 Orh AGB). The WHO limit for sulphate is 250 mg/L, and all the values fall well below this threshold. Sulphate concentrations are not a major concern in this area, and the relatively low levels suggest limited industrial or agricultural sulphate inputs. Chloride concentrations range from 33 mg/L (BH 2 EKP AGB) to 610.1 mg/L (HDW 11 Orh AGB). Both NSDWQ and WHO set a limit of 250 mg/L for chloride. Several sites exceed this limit, particularly HDW 11 Orh AGB (610.1 mg/L), BH 12 Ohr AGB (401.2 mg/L), BH 6 EKP AGB (333.2 mg/L), and

BH 8 EKP AGB (317.2 mg/L). These elevated chloride levels could indicate saltwater intrusion or contamination from industrial or agricultural sources. High chloride levels can affect water taste and lead to corrosion of pipes and equipment. Bicarbonate concentrations range from 17.8 mg/L (BH 2 EKP AGB) to 121 mg/L (HDW 11 Orh AGB).

Bicarbonate plays a key role in buffering water pH and is typically derived from natural sources such as carbonate minerals. There is no specific guideline for bicarbonate in the NSDWQ or WHO standards, but the levels reported here suggest normal geological contributions, with the highest concentrations in HDW 11 Orh AGB and BH 12 Ohr AGB, which might indicate higher mineral content in these areas. HDW 11 Orh AGB consistently shows the highest levels of NO_2, NO_3, SO_4, Cl, and HCO_3, which suggests a localized source of contamination. Potential sources could be agricultural runoff, industrial discharges, or saltwater intrusion. BH 12 Ohr AGB and BH 6 EKP AGB also show elevated chloride levels, indicates contamination. BH 2 EKP AGB and RW 15 Ohr AGB consistently report the lowest values for most parameters, suggesting that these areas are less impacted by contamination as shown in Table 8.

4.5. Heavy Metal Concentration Level of Groundwater and Surface Water in Ewhereh-Ohrehe Community

Iron (Fe) concentrations range from 0.411 mg/L to 0.901 mg/L with mean concentration value of 0.669 mg/L. BH 2 EKP AGB and RW 15 Ohr AGB have the highest levels of iron, while HDW 11 Orh AGB has the lowest. Elevated iron levels can cause discoloration, a metallic taste, and staining in water. It is often a result of natural mineral deposits or industrial pollution. Manganese (Mn) levels vary from 0.13 mg/L to 0.35 mg/L with mean concentration value of 0.216 mg/L. RW 15 Ohr AGB has the highest concentration of manganese, indicating potential influence from natural sources or industrial discharge. High manganese concentrations can affect the taste and colour of water and might also impact health if above regulatory limits. Zinc (Zn) concentrations range from 0.316 mg/L to 0.694 mg/L with mean concentration value of 0.508 mg/L . The highest zinc levels are observed in BH 2 EKP AGB and RW 15 Ohr AGB.

Zinc is generally not toxic in drinking water at low concentrations, but elevated levels might suggest industrial contamination or corrosion of galvanized pipes. Copper (Cu) levels vary between 0.057 mg/L and 0.147 mg/L with mean concentration value of 0.094 mg/L. RW 15 Ohr AGB shows the highest copper concentration. Excess copper can be toxic to aquatic life and may cause gastrointestinal issues in humans if levels exceed the drinking water standards. Chromium (Cr) concentrations range from 0.021 mg/L to 0.053 mg/L with mean concentration value of 0.006 mg/L with mean concentration value of 0.034 mg/L. RW 15 Ohr AGB has the highest chromium concentration, which could be indicative of industrial pollution or natural deposits.

Chromium is a toxic heavy metal, and high levels in water may pose serious health risks. Cadmium (Cd) levels are relatively high, ranging from 0.004 mg/L to 0.009 mg/L with mean concentration value of 0.006 mg/L. The highest levels are found in RW 15 Ohr AGB, which may indicate contamination from industrial waste or other anthropogenic activities.

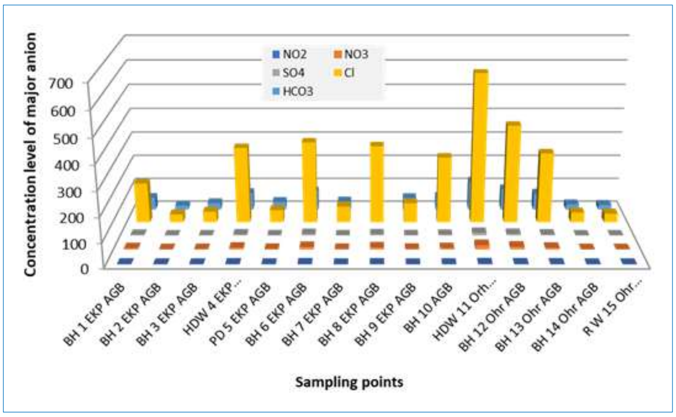

Fig. 10. Concentration level of Major Anion and sampling points

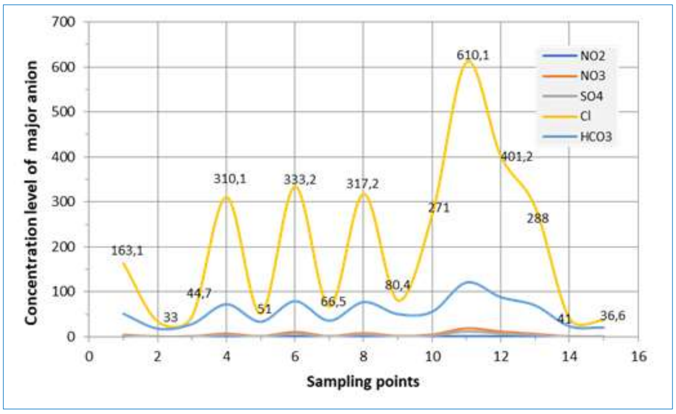

Fig. 11. Scatter diagram of concentration level of Major Anion and sampling points

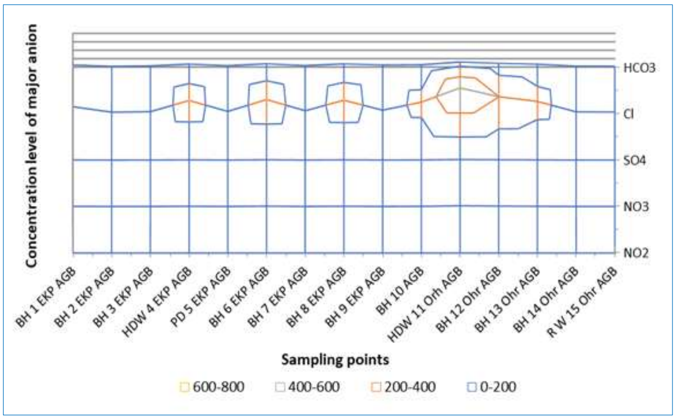

Fig. 12. Surface contour of concentration level of Major Anion and sampling points

Even small amounts of cadmium in water are hazardous and can have serious health effects. Lead (Pb) concentrations range from 0.008 mg/L to 0.021 mg/L with mean concentration value of 0.013 mg/L. RW 15 Ohr AGB again has the highest lead concentration. Lead is highly toxic and should ideally be absent from drinking water due to its severe health effects, especially on children. RW 15 Ohr AGB consistently shows elevated concentrations of heavy metals, which suggests possible contamination from industrial or anthropogenic sources as Table 9.

BH 14 Ohr AGB, and RW 15 Ohr AGB. Elevated Iron levels may result from natural geological formations or contamination from industrial and agricultural activities. While Iron is not highly toxic, excessive amounts can lead to undesirable taste, staining, and pipe corrosion. Manganese concentrations vary from 0.13 mg/L at HDW 11 Orh AGB to 0.35 mg/L at RW 15 Ohr AGB. The NSDWQ guideline for manganese is 0.2 mg/L, while the WHO allows a higher limit of 0.4 mg/L. Some sampling points, particularly RW 15 Ohr AGB (0.35 mg/L) and BH 14 Ohr AGB (0.28 mg/L), slightly exceed the NSDWQ limit. Elevated manganese can affect water taste and stain plumbing fixtures and laundry, but it is not considered highly toxic unless consumed in extremely high amounts. Zinc concentrations range from 0.316 mg/L at HDW 11 Orh AGB to 0.694 mg/L at BH 2 EKP AGB. These levels are well below the NSDWQ (3 mg/L) and WHO (5 mg/L) standards, indicating that zinc is not a significant concern regarding water quality in the study area. Zinc is an essential trace element and poses no health risks at these concentrations.

Copper levels range from 0.057 mg/L at HDW 11 Orh AGB to 0.147 mg/L at RW 15 Ohr AGB. Both the NSDWQ and WHO set limits for copper in drinking water at 1 mg/L and 2 mg/L, respectively, and all sampling points have copper concentrations well below these limits, indicating that copper is not a major concern for water quality. At this level, copper is unlikely to cause health or aesthetic issues.

Table 9. Heavy metal concentration level of Ewhereh-Ohrehe Community

Parameters	Fe (mg/L)	Mn (mg/L)	Zn (mg/L)	Cu (mg/L)	Cr (mg/L)	Cd (mg/L)	Pb (mg/L)
BH 1 EKP AGB	0.666	0.21	0.513	0.093	0.033	0.006	0.013
BH 2 EKP AGB	0.901	0.284	0.694	0.125	0.045	0.008	0.018
BH 3 EKP AGB	0.841	0.266	0.648	0.117	0.042	0.007	0.016
HDW 4 EKP AGB	0.521	0.164	0.401	0.072	0.026	0.004	0.01
PD 5 EKP AGB	0.781	0.247	0.601	0.108	0.039	0.007	0.015
BH 6 EKP AGB	0.483	0.152	0.372	0.067	0.024	0.004	0.009
BH 7 EKP AGB	0.773	0.244	0.595	0.107	0.039	0.007	0.015
BH 8 EKP AGB	0.511	0.161	0.393	0.071	0.026	0.004	0.01
BH 9 EKP AGB	0.687	0.217	0.529	0.095	0.034	0.006	0.013
BH 10 AGB	0.654	0.206	0.504	0.091	0.033	0.006	0.013
HDW 11 Orh AGB	0.411	0.13	0.316	0.057	0.021	0.004	0.008
BH 12 Ohr AGB	0.447	0.141	0.344	0.062	0.022	0.004	0.009
BH 13 Ohr AGB	0.577	0.182	0.444	0.08	0.029	0.005	0.011
BH 14 Ohr AGB	0.887	0.28	0.583	0.123	0.044	0.008	0.017
R W 15 Ohr AGB	0.888	0.35	0.684	0.147	0.053	0.009	0.021
AVERAGE	0.668	0.216	0.508	0.094	0.034	0.006	0.013
MIN	0.411	0.13	0.316	0.057	0.021	0.004	0.008
MAX	0.901	0.35	0.694	0.147	0.053	0.009	0.021

Table 10. Comparison of Heavy Metals with NSWDQ (2007) and WHO (2011)

Parameters	Fe (mg/L)	Mn (mg/L)	Zn (mg/L)	Cu (mg/L)	Cr (mg/L)	Cd (mg/L)	Pb (mg/L)
BH 1 EKP AGB	0.666	0.21	0.513	0.093	0.033	0.006	0.013
BH 2 EKP AGB	0.901	0.284	0.694	0.125	0.045	0.008	0.018
BH 3 EKP AGB	0.841	0.266	0.648	0.117	0.042	0.007	0.016
HDW 4 EKP AGB	0.521	0.164	0.401	0.072	0.026	0.004	0.01
PD 5 EKP AGB	0.781	0.247	0.601	0.108	0.039	0.007	0.015
BH 6 EKP AGB	0.483	0.152	0.372	0.067	0.024	0.004	0.009
BH 7 EKP AGB	0.773	0.244	0.595	0.107	0.039	0.007	0.015
BH 8 EKP AGB	0.511	0.161	0.393	0.071	0.026	0.004	0.01
BH 9 EKP AGB	0.687	0.217	0.529	0.095	0.034	0.006	0.013
BH 10 AGB	0.654	0.206	0.504	0.091	0.033	0.006	0.013
HDW 11 Orh AGB	0.411	0.13	0.316	0.057	0.021	0.004	0.008
BH 12 Ohr AGB	0.447	0.141	0.344	0.062	0.022	0.004	0.009
BH 13 Ohr AGB	0.577	0.182	0.444	0.08	0.029	0.005	0.011
BH 14 Ohr AGB	0.887	0.28	0.583	0.123	0.044	0.008	0.017
R W 15 Ohr AGB	0.888	0.35	0.684	0.147	0.053	0.009	0.021
NSWDQ 2007	0.3	0.2	3	1	0.05	0.003	0.01
WHO 2011	0.3	0.4	5	2	0.05	0.003	0.01

Chromium concentrations range from 0.021 mg/L at HDW 11 Orh AGB to 0.053 mg/L at RW 15 Ohr AGB. The permissible limit for chromium, according to both NSDWQ and WHO standards, is 0.05 mg/L. RW 15 Ohr AGB slightly exceeds this limit, while BH 14 Ohr AGB (0.044 mg/L) and BH 2 EKP AGB (0.045 mg/L) are approaching it. Elevated chromium levels can have serious health effects, particularly as certain forms are carcinogenic, warranting further investigation into their sources. The cadmium concentrations in the water samples range from 0.004 mg/L to 0.009 mg/L, which means all recorded values exceed the maximum allowable limit of 0.003 mg/L set by both the NSDWQ and the WHO. This indicates that cadmium contamination is present at unsafe levels across all sampled locations, posing potential health risks to consumers if the water is used for drinking or domestic purposes.

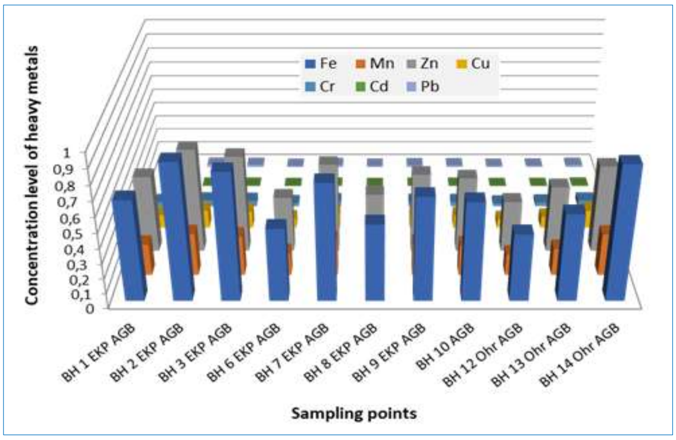

Fig. 12. Groundwater concentration level of heavy metals and sampling points

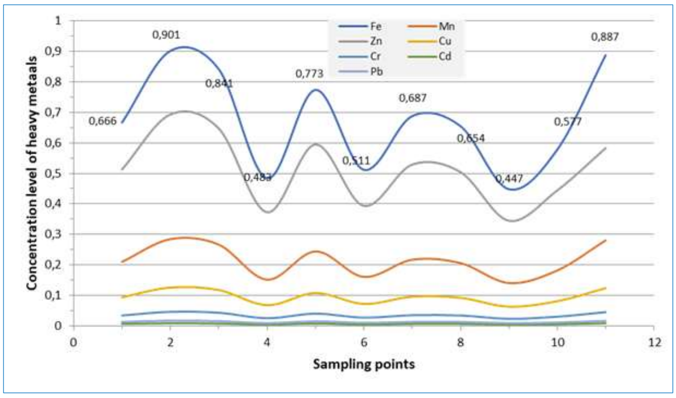

Fig. 13. Scatter diagram of groundwater concentration level of heavy metals and sampling points

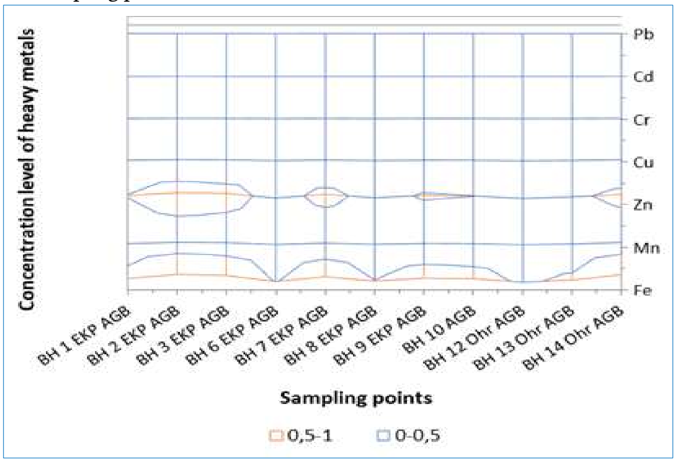

Fig. 14. Surface contour showing groundwater concentration level of heavy metals and sampling points

Lead concentrations vary from 0.008 mg/L at HDW 11 Orh AGB to 0.021 mg/L at RW 15 Ohr AGB. The NSDWQ and WHO limit for lead is 0.01 mg/L, with RW 15 Ohr AGB (0.021 mg/L) and BH 14 Ohr AGB (0.017 mg/L) exceeding this limit. Several other points are near this threshold. Lead is a highly toxic metal that can lead to severe health issues, particularly in children, making its presence concerning and necessitating measures to mitigate exposure. The high levels of iron and manganese, particularly in BH 2 EKP AGB, BH 14 Ohr AGB, and RW 15 Ohr AGB, may indicate natural mineral deposits or contamination from industrial activities.

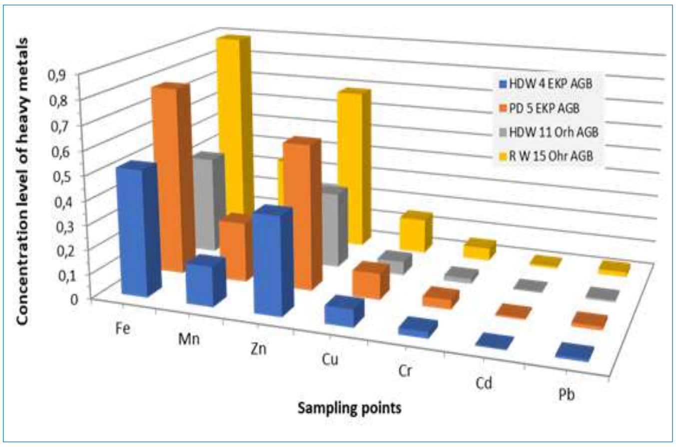

Fig. 15. Surface water concentration level of heavy metals and sampling points

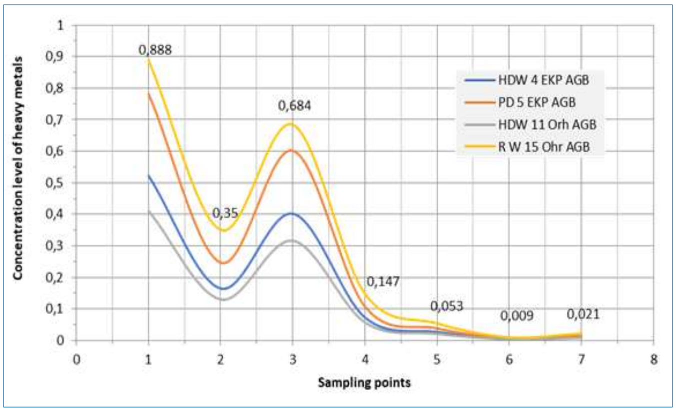

Fig. 16. Scatter diagram of surface water concentration level of heavy metals and sampling points

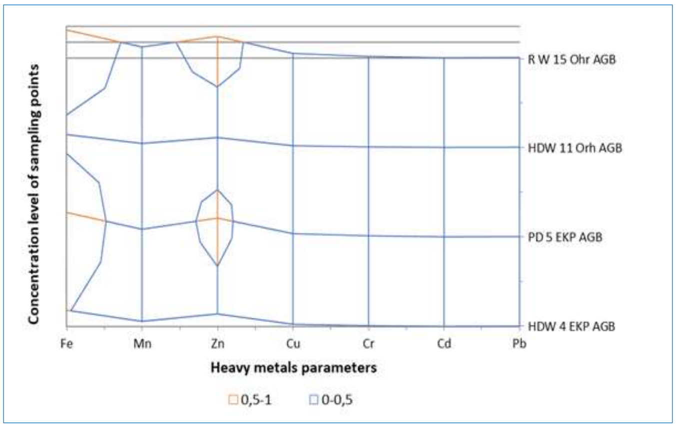

Fig. 17. Surface contour showing surface water concentration level of heavy metals and sampling points

RW 15 Ohr AGB displays slightly elevated levels of both chromium and lead, which can have significant health impacts. Remediation efforts and source identification are crucial in these areas. Zinc and copper concentrations are well within acceptable limits, indicating no immediate concern regarding these metals in the water supply, as shown in Table 10.

Table 12. Correlation of heavy metals of the study area

	Fe	Mn	Zn	Cu	Cr	Cd	Pb
Fe	1						
Mn	0.9634	1					
Zn	0.9811	0.9569	1				
Cu	0.9762	0.9985	0.9673	1			
Cr	0.9748	0.9984	0.9675	0.9995	1		
Cd	0.9733	0.9809	0.9569	0.9850	0.9848	1	
Pb	0.9678	0.9971	0.9627	0.9974	0.9974	0.9849	1

BH 2 EKP AGB also exhibits elevated levels of Iron, Manganese, Cadmium, Zinc, and other metals, pointing to a potential localized source of contamination. The relatively high concentrations of Iron, Manganese, Cadmium and Zinc across several locations could be attributed to natural mineral content or the influence of industrial activities in these areas. Although cadmium and lead levels are lower in comparison, their presence is still concerning due to their toxicity and associated health risks, as indicated in Table 9 and Fig. 12.

Figs. 13 and 14 reveal that all groundwater samples contain elevated levels of Iron, with particularly high Zinc concentrations in BH1, BH2, BH3, BH7, BH9, and BH14. This suggests that groundwater in the study area is significantly contaminated with both Iron and Zinc, likely due to anthropogenic activities and agricultural runoff, as depicted in Fig. 14.

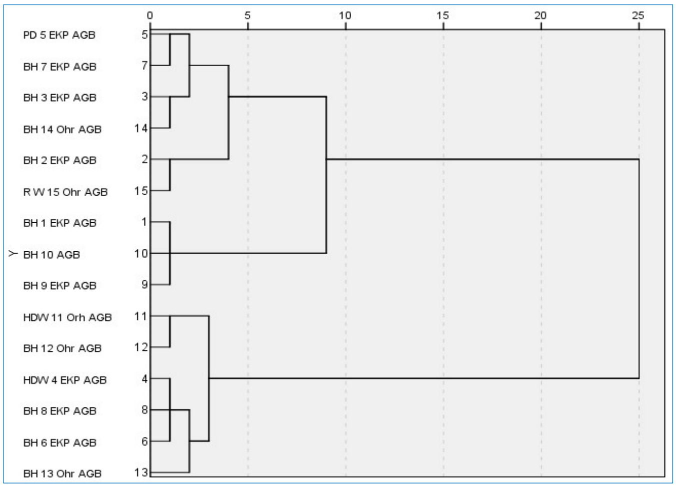

Fig. 18. Dendrogram using average linkage (between groups) to show the relationship between sampling points

R W 15 Ohr AGB has the highest concentrations across multiple parameters, including manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), and lead (Pb), suggesting this site may be more heavily impacted by contaminants. HDW 11 Ohr AGB shows the lowest concentrations for almost all heavy metals, indicating relatively better water quality at this location. The elevated levels of iron, manganese, zinc, cadmium and lead in certain locations may indicate contamination, potentially from anthropogenic sources such as industrial or agricultural runoff, or natural leaching from rocks and soil. Lead and Cadmium levels, although not extremely high, are of concern due to their toxicity, even at low concentrations as Figs. 15 and 16.

Iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd) and lead (Pb) is plotted to illustrate the concentration levels across different sampling points. Iron and lead generally exhibit more consistent concentrations throughout the sites, while Manganese and Zinc show greater variability based on location. Zinc concentrations are notably the highest among all the metals, especially in samples from R W 15 Ohr AGB (yellow) and PD 5 EKP AGB (orange). Manganese also displays significant levels, particularly in PD 5 EKP AGB (orange) and R W 15 Ohr AGB (yellow). Iron maintains moderate concentrations across all sites, with HDW 4 EKP AGB (blue) showing a relatively higher level. The surface contour plot (Fig. 17) facilitates a quick comparison of heavy metal concentrations across different sampling locations, highlighting which metals are present in higher amounts at specific sites. Notably, spikes in zinc and manganese suggest that these two metals are of particular concern regarding concentration levels at certain locations.

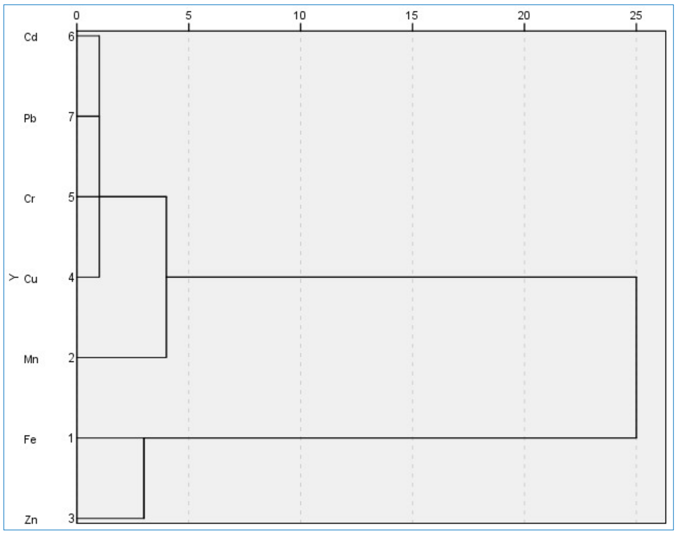

Fig. 19. Dendrogram using average linkage (between groups) to show the relationship between heavy metals.

4.6. Heavy Metals Correlation Matrix and Hierarch Cluster

The following heavy metals display very strong positive correlations with one another: Fe and Mn (0.9634), Fe and Pb (0.9678), Zn and Fe (0.9811), Zn and Mn (0.9569), Mn and Cu (0.9985), Cr and Fe (0.9748), Cr and Mn (0.9984), Cr and Zn (0.9675), Cr and Cu (0.9995),Mn and Pb (0.9970), Zn and Cu (0.9673), Cd and Fe (0.9733), Cd and Mn (0.9809), Cd and Zn (0.9569), Cd and Cu (0.9850), Cu and Fe (0.9762), Cd and Cr (0.9845), Cd and Pb (0.9849), Pb and Cu (0.9974), Pb and Cr (0.9974), Pb and Fe (0.9678), Pb and Mn (0.9971), and Pb and Zn (0.9627). These high correlation values indicate a strong connection between the presence of these metals, suggesting that their concentration may be influenced by common sources or combined geochemical processes in the study area, as shown in Table 11.

The dendrogram analysis reveals two distinct clusters among the sampling points. Cluster 1 consists of BH 1, BH 2, BH 3, BH 4, PD 5, BH 7, BH 9, BH 10, BH 11, BH 14, and RW 15. The strong correlation among these points suggests a shared source of contamination, indicating that they are affected by similar factors or activities. Cluster 2 includes BH 6, BH 8, BH 12, BH 13, HDW 4, and HDW 11, which also show a strong correlation, implying that these points share a different yet similar source of contamination, as depicted in Fig. 18.

In the dendrogram analysis of the heavy metals, two clusters are identified. Cluster 1 includes Pb, Cr, Cu, Mn, and Cd, which exhibit strong correlations, suggesting a common contamination source that may be linked to industrial or anthropogenic activities. Cluster 2 consists of Zn and Fe, which are also strongly correlated and likely originate from a similar source, as illustrated in Fig. 19.

5. Summary and Recommendation

The water quality assessment reveals variation across boreholes, with most parameters falling within NSDWQ and WHO safe limits. While the water generally appears clean and suitable for consumption and irrigation, certain sites particularly HDW 11 and RW 15 Ohr AGB show elevated levels of electrical conductivity (EC), total dissolved solids (TDS), chemical oxygen demand (COD), chloride, and heavy metals like cadmium, lead, and chromium, indicating possible contamination from human activities or natural mineralization.

Nutrient levels (nitrite, nitrate, sulphate) remain within safe limits, but localized spikes in ammonium nitrogen and phosphorus call for attention to prevent eutrophication. High concentrations of Iron, Manganese, Zinc, Cadmium and Chromium also raise concerns and suggest common contamination sources or geochemical processes.

I recommend that there should be continuous monitoring of heavy metals, nutrients, and anions investigating contamination sources, especially at high-risk sites like HDW 11, implementing treatment methods (reverse osmosis, chemical precipitation). Continuous conducting health risk assessments in areas with elevated toxic metals and taking preventive steps to safeguard soil and water quality, particularly for agricultural use.

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