GEOELECTRICAL AND PHYSICOCHEMICAL CHARACTERIZATION OF GROUNDWATER CONTAMINATIONAROUND A CASSAVA PROCESSING FACTORY IN OGBOMOSO, SOUTHWESTERN NIGERIA

ABSTRACT

2D resistivity profiling and hydro-geochemical analyses were carried out to assess groundwater contamination. in and around the Cassava Processing Factory at Aarada, Ogbomoso, Southwestern Nigeria. The dipole-dipole profiling was conducted along eight traverses,trending NW-SE, using electrode spacing a = 5m and expansion factor n=1 to 4. The resistivity data were inverted using 2D inversion procedure to produce the 2D inverted resistivity sections beneath the traverses. Water samples were also taken from seven hand dug wells within and around the studyarea for physicochemical analyses to determine the pH, EC, TDS, and concentrations of cations and anions which included Fe^{2+},Zn^{2+}, Na^{+},Pb^{2+}, Cu^{2+}, K^{+}, NO_3^- and CN^-.The 2D inverted resistivity sections revealed that the study is characterized by relatively low resistive zones typical of contamination plumes beneath the traverses near the cassava processing factory and general dumpsite.The pH values range from 7.2 to 8.0 and indicate that the groundwater is basic. They are within the WHO (2011) recommended limits. The electrical conductivity (EC) and total dissolved solids (TDS) exceed the WHO limit in the wells close to the cassava processing factory and the dumpsite, indicating that the water is harmful to human health. The major indicators of groundwater contamination in the study area are the Fe^{2+} and NO_3^- caused by percolation of the dumpsite leachate, and CN^- caused by infiltration of the cassava effluent, into the aquifers.The level of contamination in the wells is closely related to proximity to the cassava processing factory and the dumpsite. The discharge of the effluents from the cassava processing factory contributes significantly to cyanide contamination of groundwater in the study area.Appropriate remediation measures should be taken to forestall further contamination of groundwater in the study area.

Keyword: Contamination, Cassava effluent, Leachate, Groundwater, Cyanide.

INTRODUCTION

The rise in the cultivation of cassava to meet the huge global demand for domestic, industrial and export purposeshas led to increase in the need for cassava processing and subsequent location of numerous cassava processing factories(Obueh and Odesiri-Eruteyan, 2016). The cassava processing industry provides employment and revenue for 30% of Nigeria's informal sector (Omotosho and Amori, 2015). Cassava processing, however, generates large amounts of effluent which are rich in soluble ions such as potassium (K^+), sodium (Na^+), nitrogen$NO_3^-$and cyanide (CN^-)(Oladele, 2014;Adewumi *et al*., 2016; Olukanni and Olatunji, 2018). The cassava effluent has high concentration of cyanide extractable from cassava tubers during processing.The solid wastes and effluents from cassava processing factoriesin rural and semi-urban area are usually disposed of without consideringspecific guidelineson waste disposal and treatment (Alrumman *et al*., 2016, Ilyas *et al*., 2019; Olurin et al., 2022; Adjei *et al*., 2023; Aweto, 2023). When these harmful substances are discharged into the environment untreated, they may leach into the soil, alter the physicochemical properties of the soil and groundwater resources (Izonfuo *et al*., 2013, Akpan *et al*., 2017, Oyewusi *et al*., 2021),and ultimatelyconstitute serious health risk to the hosting communitywhich depend solely on groundwater mostly from hand-dug wells for domestic and industrial uses (Ehilenboadiaye *et al*., 2018; dos Santos *et al*., 2018;Olukanni and Olatunji, 2018; Gomezulu *et al*., 2018).

Leachate plumes generated from cassava effluents may contain significant amount of dissolved ions that can substantially raise the conductivities or lower the resistivityof the soil and groundwater which can be detected by the electrical resistivity method (Hamzah, *et al*., 2014,lAzhar, *et al*., 2017, Osinowo *et al*., 2020).The2D electrical resistivity profiling method is particularly suitable for mapping contamination plumes beneath and around waste dumps since it is capable of revealingsubsurface variations of resistivityinduced by leachate in both lateral and vertical directions from the waste sources.The method is fast, non-invasive, cost-effective and is capable of delineating geologic structures such as fractures in the underlying rocks which may provide migration paths for leachate into neighbouring soil and groundwater environment (Oyinkuro and Wariebi, 2017).

While the ER method reveals the spatial spread of the leachate, the degree of contamination can bedetermined by physicochemical analyses for the constituent ions, conducted on groundwater samples collected from wells in the study area.The cassava processing factory at Aarada in Ogbomoso has discharged its effluents and wastes via its adjoining drainage and waste dump for over twenty-five years and the leachate generated might have largely impacted the groundwater resources in the vicinity.

This study is therefore carried out to assess the extent and degree of subsurface contamination by mapping the leachate spread and determining concentrations of the leachate constituents using a combination of 2D electrical resistivity method and physicochemical analysesforpH, ***EC***, TDS,Cu^{2+}, Fe^{2+}, Pb^{2+},Zn^{2+}, K^{+}, Na^{+}, $NO_3^{-}$and CN^{-} in the groundwater presumably impacted by the cassava processing factory. The objectives are to identify anomalous conductive zones possibly due to leachate accumulation, determine the lateral and vertical extent of the leachate plumes, reveal the possible presence of geologic structures that may have served as conduit for the transport of the leachate into groundwater in neighboring wells, and determine the physicochemical properties of the groundwater in the study area.

The study area is located within the Longitudes 04^{0} 14ˈ31” E- 04^{0} 14ˈ44” N and Latitudes 08^{0} 06ˈ51” N - 08^{0} 07ˈ01” E (Fig. 1). Itis low-lying and is relatively rugged with undulating topography. The elevation varies between 309 m and 325 m above mean sea level. The area is drained mainly by River Ora which flows in the NE-SW direction. The predominant rock underlying the area is migmatite gneiss (Fig. 2) whose outcrops were observed nearby on the eastern side. The groundwater flow direction is 107°S towards the south-east direction.Groundwater flow direction has influence on movement of groundwater contaminants such as heavy metals and cyanide into boreholes and hand-dug wells and must be considered in siting wastes disposal facilities (Aweto, 2023). The results of the study are expected to serve as useful guide for proper and sustainable management of both solid wastes and effluents generated in and around the cassava processing factory.

METHODOLOGY

The resistivity survey was conducted along eight traverses run across and around the cassava processing factory and the general dumpsite (Fig. 3). The Dipole-Dipole horizontal profiling was

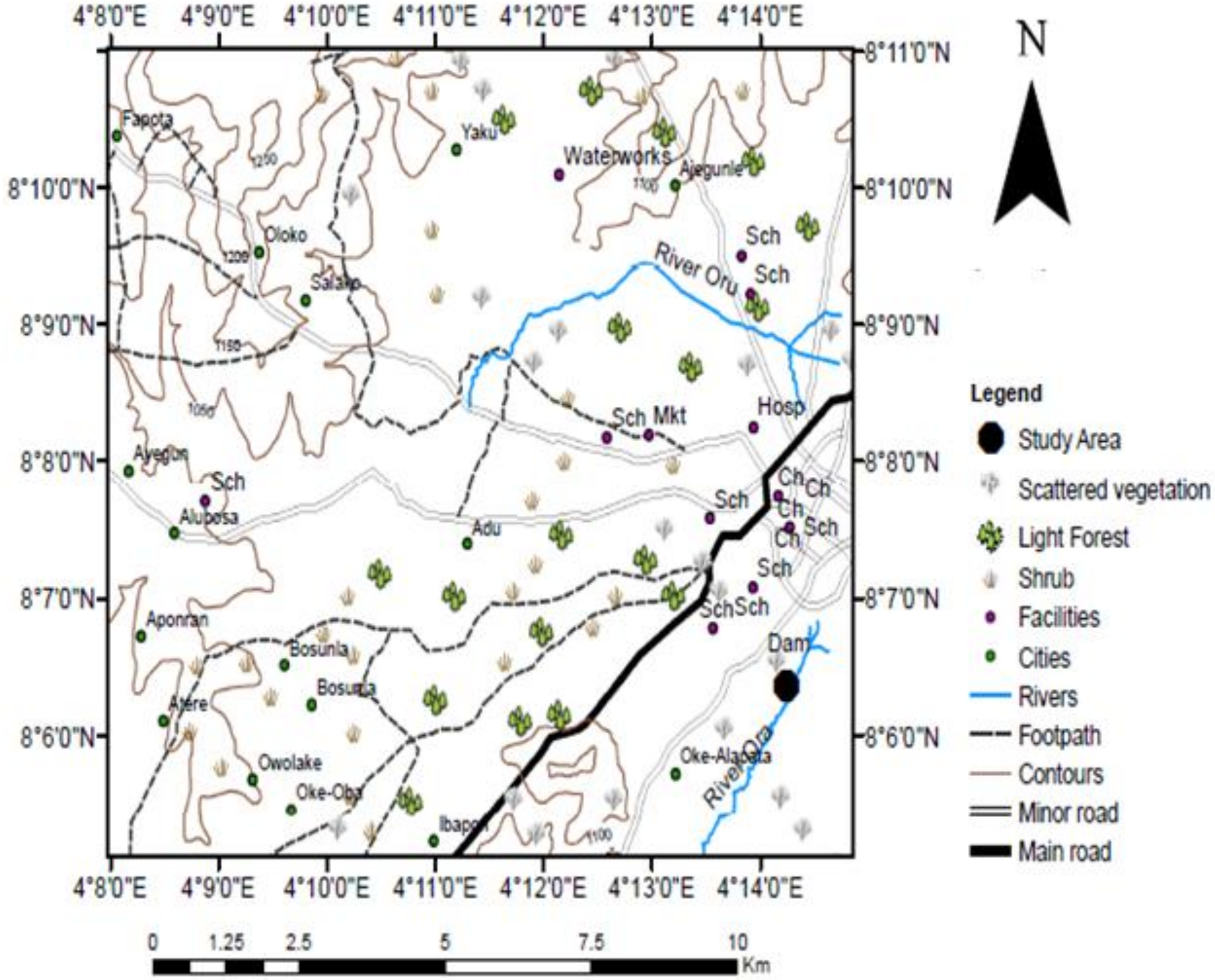

Fig.1: Location map of the study area(modified after NGSA, 2020)

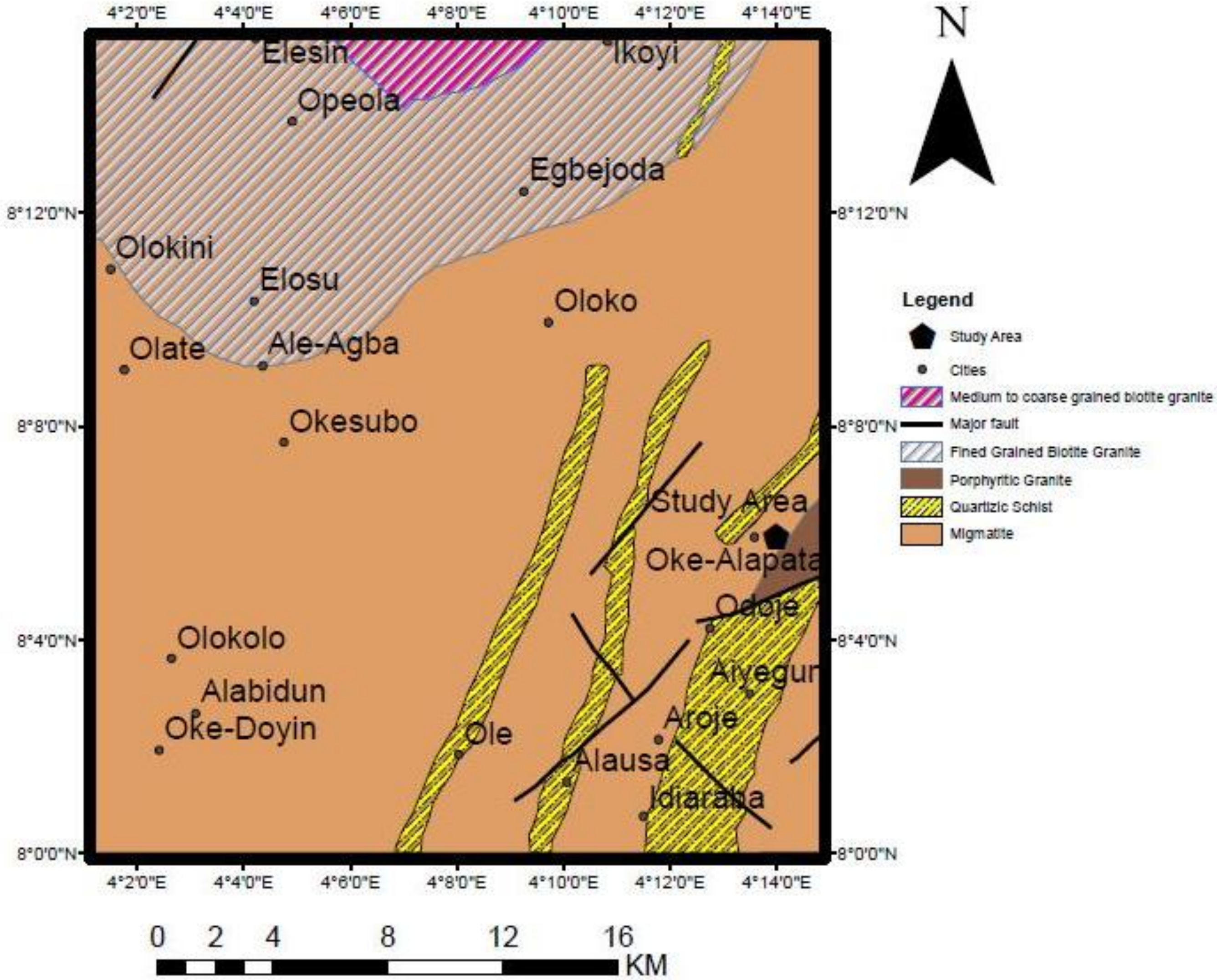

Fig. 2: Geological map of the study area (modified after NGSA, 2020)

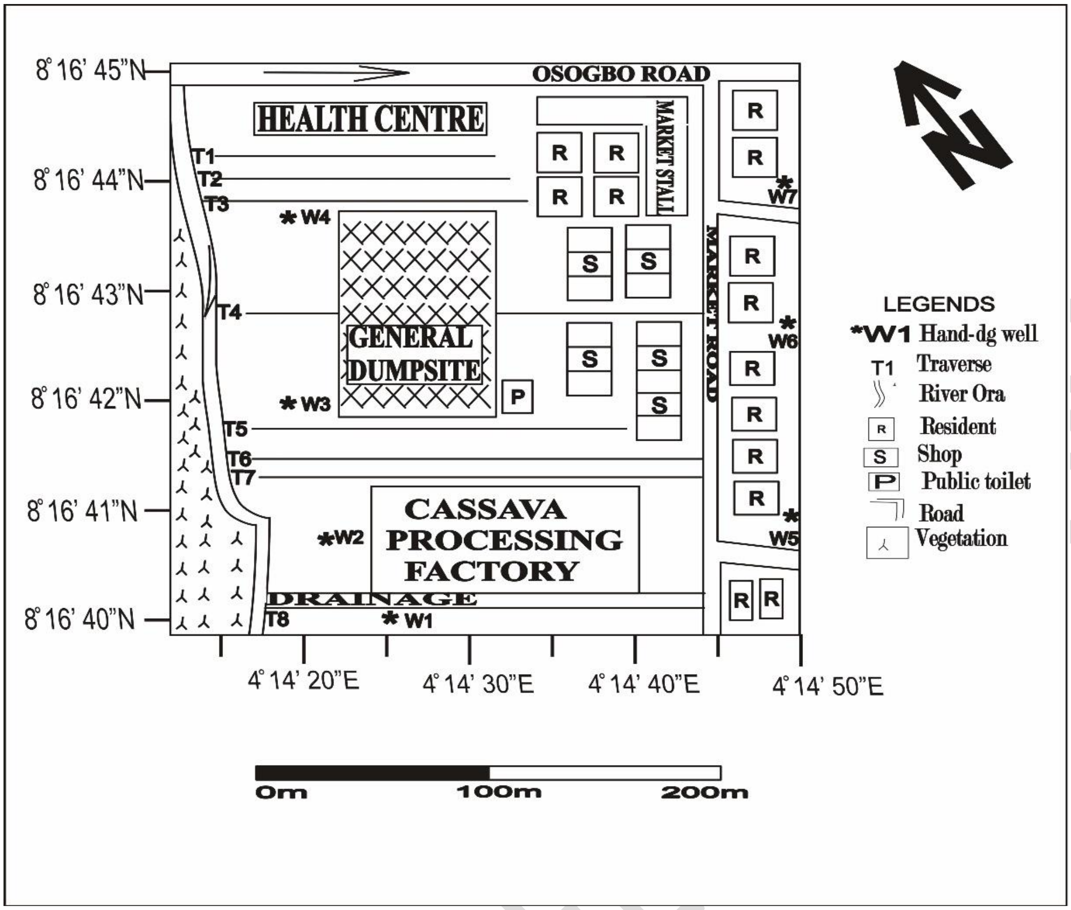

Fig. 3: Location of geophysical traverses and hand-dug wells in the study area

employed with electrode spacing a = 5m and expansion factor n=1 to 4. The data were inverted by using 2D inversion procedures (Loke, 2014), to produce the 2D inverted resistivity sections which show lateral and vertical variations of resistivity beneath the traverses. Zones of anomalously low resistivity were suggested to represent leachate accumulation and/or subsurface features supporting its migration.

Groundwater samples were collected from seven hand dug wells (W1-W7) within and around the study area for physicochemical analyses to determine thepH, EC, TDS and concentrations of Fe^{2+}, Pb^{2+}, Zn^{2+}, Cu^{2+}, K^{+}, Na^{+}, NO$_3^{-}$and CN^{-}.W1-W4 are located near the cassava processing factory and the general dumpsite while W5-W7 are further away on the eastern side of the study area. The pH, EC and TDS were measured *in situ* witha portable hand held digital Multifunction Water Quality Tester (Pen Type meter). Water samples were collected from hand-dug wells in the study area using 0.5-litre plastic containers initially rinsed with deionized water to avoid contamination during the sampling. The concentrations of the cations and anionsin water samples weredeterminedusingAtomic Absorption Spectrophotometer(AAS)in accordance with the proceduresdeveloped by the American Public Health Association (APHA, 2005). The results of the water analyses were compared with the World Health Organization (WHO, 2011) Standards to assess impact of the cassava processing factory and the waste dump on groundwater quality.

RESULTS AND DISCUSSION

The results of resistivity surveys along eight traverses run across the study area are presented as 2D inverted sections.Leachate contamination is characterized by low resistivity values, generally less than 10 Ωm, indicating the presence of high ionic content and increase in conductivity.The sections beneath Traverses 1-3 run between the Health Centre and the General Dumpsite show lateral and vertical resistivity variationsranging from 2.51 Ωm – 4101 Ωmindicating the geoelectrical strata (overburden and weathered/fresh bedrock) and zones of leachate contamination within them.The anomalously low resistivity values between 9.45 Ωm and11.6 Ωm in the topsoil beneath Traverse 1 suggest leachate contamination up to the depth of about 5 m while the lowvalues ranging from 15.6 Ωm to 37.6 Ωm indicate reduced contamination in theweathered bedrock and fresh bedrock respectively (Fig. 4).

The 2-D inverted resistivity section beneath Traverse 2 (Fig. 5) shows leachate contamination (2.51 Ωm - 10.2 Ωm)at lateral distance 15 m - 35 m fromsurface to about 4 m depth while 17.0 Ωm – 17.3 Ωm indicate reduced contamination in the clay saprolite of maximum resistivity value of 81.6 Ωm. The resistivity values 112 Ωm – 396 Ωm and 633 Ωm – 967 Ωm suggest weathered bedrock and fresh bedrock respectively.

The anomalously low resistivity values of 4.22 Ωm - 9.31 Ωm observed in the topsoil along Traverse 3 (Fig. 6), laterally spreading to about 50 m from the SE end and to 3-5 m depth fromground surface, suggest leachate contamination originating from the dumpsite. The relatively low resistivity values of 15.5 Ωm – 63.9 Ωm are characteristic of the clayey saprolite while the relatively high values of 122 Ωm – 375 Ωm and 530 Ωm - 2535 Ωm indicate weathered bedrock and fresh bedrock respectively. The degree of leachate contamination reduced with distance of the traverse from the dumpsite.

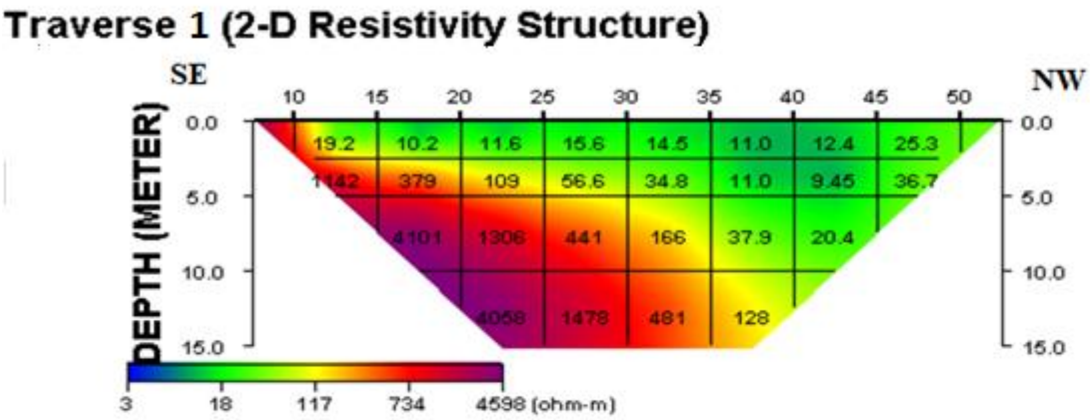

Fig 4. 2D resistivity structure for Traverse 1

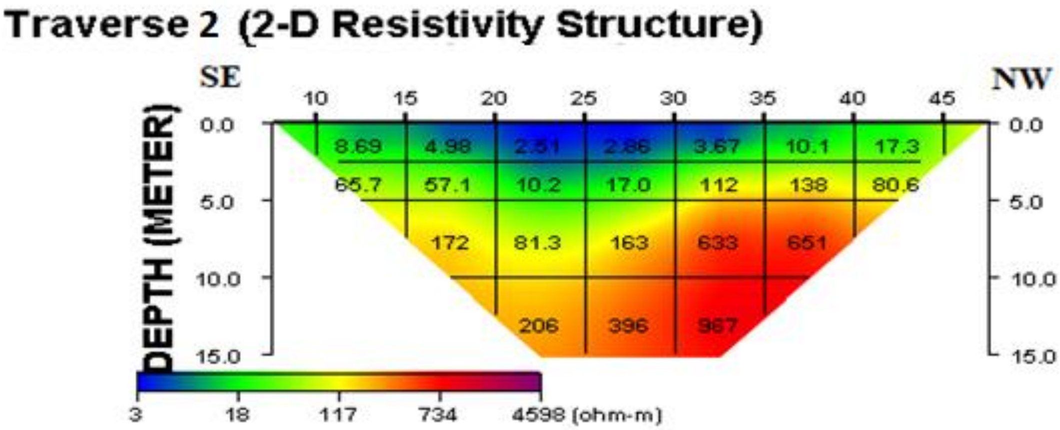

Fig 5. 2D resistivity structure for Traverse 2

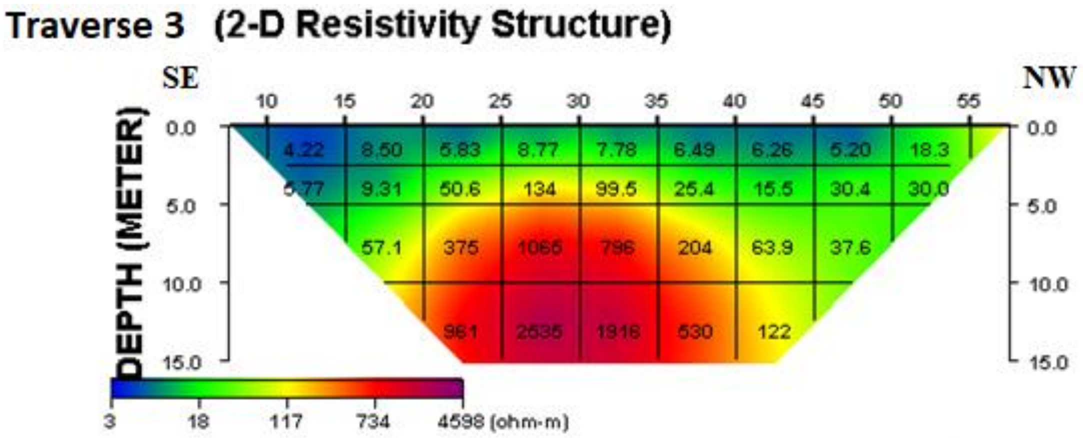

Fig. 6. 2D resistivity structure for Traverse

The 2-D inverted resistivity section beneath Traverse 4 run across the General Dumpsite shows zone of anomalously low resistivity (6.73 Ωm – 9.52 Ωm) indicating leachate contamination in the topmost layer from lateral distance 15 m to 45 m spreading up to 2.5 m depth (Fig. 7). The relatively low resistivities ranging from 12.0 Ωm to 23.7Ωm observed beneath lateral intervals 10 m - 15 m, 25 m - 30 mand 65 m – 72 m suggest reduced contamination within the clay layer of resistivity values 38.7 Ωm – 79.1 Ωm.This layer is underlain by saprolite of resistivity 102 Ωm -248 Ωm characteristic of sandy clay. The resistivities of the weathered bedrock and fresh bedrock range from 373 Ωm to 975 Ωm and 1163 Ωm -3205 Ωm.The fractured bedrock at the NW end of

the traverse may serve as conduit for spreading leachate into the groundwater beneath the study area and pose serious health risk.

The section underlying Traverse 5 run across the southern end of the dumpsite shows a topsoil with resistivity vales less than 100 Ωm typical of clay. The anomalously low resistivity (5.36 Ωm – 8.22 Ωm) suggests leachate contamination, which spreads laterally through about 40 m from the SE end of the traverse and about 2.5 m depth below ground surface (Fig. 8). The topsoil is underlain by thin saprolite of resistivity vales of 109 Ωm - 262 Ωm indicating sandy clay.

The resistivities of the weathered bedrock and fresh bedrock range from 335 Ωm – 1879 Ωm and 2148 Ωm – 5879 Ωm respectively.

The 2-D sections beneath Traverses 6, 7 and 8 in close proximity to the Cassava Processing Factory show significant leachate contamination attributable to the percolation of cassava effluent from the factory (Figs. 9 - 11). The movement and accumulation of the leachate may have been aided by the bedrock fractures beneath Traverses 6 and 7 which may have provided flow path for the cassava effluent into the ground from the source of discharge and the drainage. The resistivities of the zones of leachate contamination are much lower than for locations further away from the factory and the drainage. The values range from 0.95 Ωm to 7.60 Ωm in the bedrock fracture zonebeneath Traverse 6, 0.10 Ωm to 3.72 Ωm beneath Traverse 7, and 0.26 Ωm to 8.88 Ωm beneath Traverse 8.

The results of the physicochemiical analyses conducted on water samples collected from hand-dug wells in the study area are presented in Table 1. The pH values range from 7.1 to 7.7 and indicate that the groundwater is basic. They are within the WHO (2011) recommended limits.

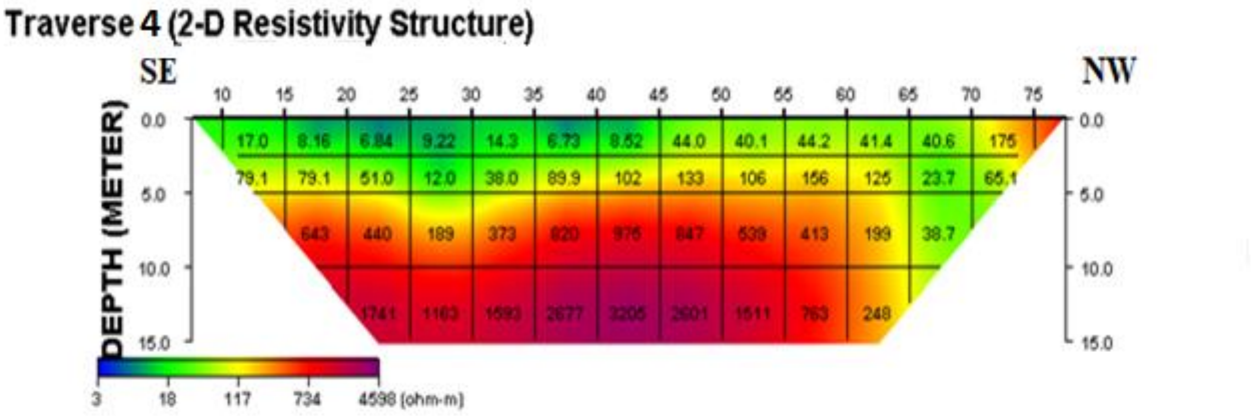

Fig 7. 2D resistivity structure for Traverse 4

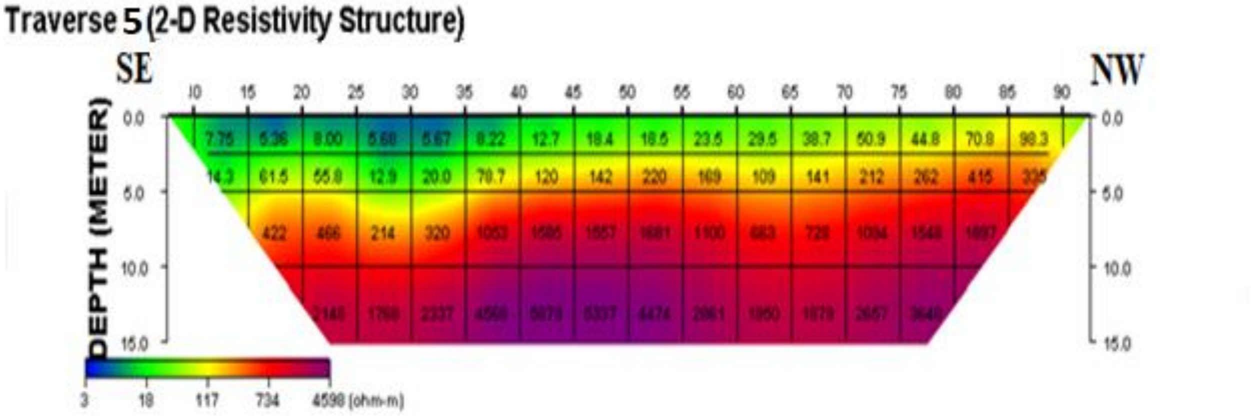

Fig 8. 2D resistivity structure for Traverse 5

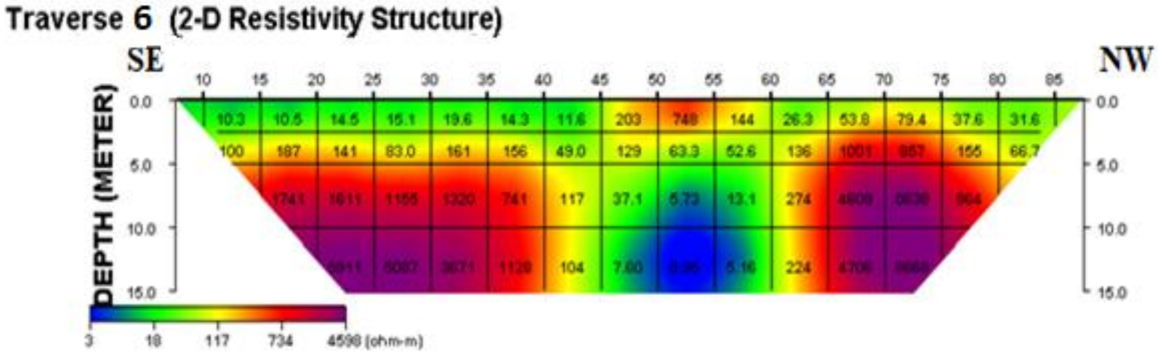

Fig 9. 2D resistivity structure for Traverse 6

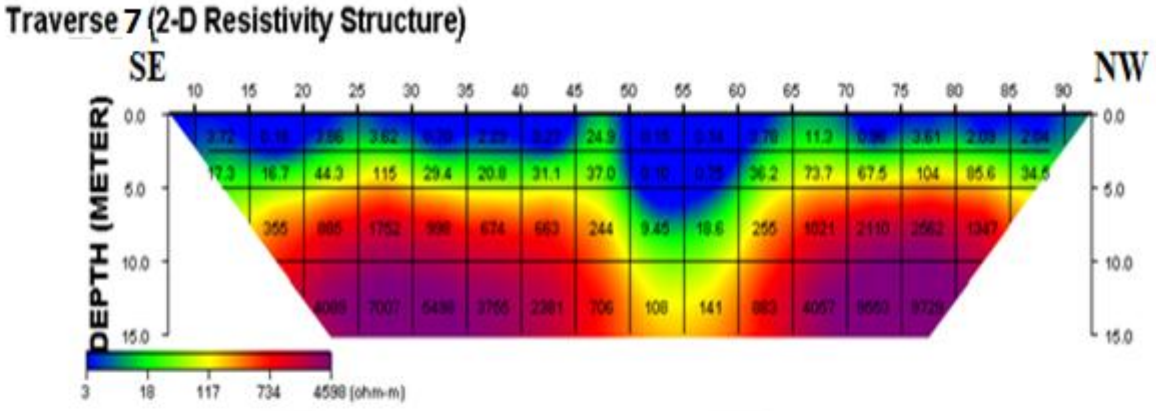

Fig 10. 2D resistivity structure for Traverse 7

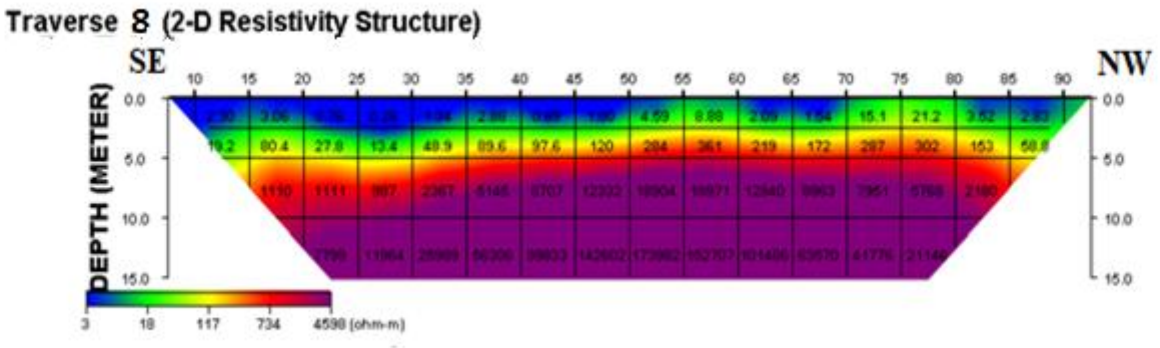

Fig 11. 2D resistivity structure for Traverse 8

The electrical conductivity (EC) ranges from 277 µS/cm to 860 µS/cm and is lower than the WHO limit in all the samples**.** Total dissolved solids (TDS) exceed WHO limit in W2-W4. They are lower and within WHO limit in W1 and W5-W7. The TDS level is excellent in W5 and W6, good in W1 and W7, and not acceptable for W2-W4. TDS levels beyond the permissible limits in drinking water indicates potential risk (Ilyas, *et al*., 2017).

The concentrations of iron (Fe^{2+})ions exceed the WHO limits significantly in all the wells sampled. The high values are attributable to weathering of the iron-bearing minerals and rocks, on the one hand, and corrosion of iron in the dumpsite wastes, on the other. Rain water dissolves the iron minerals and wash them into the aquifers where they impact the groundwater. The ingestion of high level of iron in water can cause damage to skin, hair, liver, pancreas and heart.

TABLE 1: Results of Physicochemical analysis on water samples from hand-dug wells

Parameter	W1	W2	W3	W4	W5	W6	W7	WHO 2011
pH	7.6	7.5	7.1	7.2	7.7	7.6	7.4	6.8-8.5
EC (µS/cm)	***277***	777	860	844	635	645	528	1500
TDS (mg/l)	430	1410	1450	1300	140	108	320	1000
Fe^{2+} (mg/l)	0.75	1.65	1.85	1.50	3.51	2.72	2.81	0.3
Pb^{2+} (mg/l)	0.001	0.009	0.006	0.005	0.001	0.001	0.0015	0.01
Cu^{2+} (mg/l)	0.65	0.50	1.57	1.57	0.98	0.50	0.31	1.5
Zn^{2+} (mg/l)	3.45	2.33	3.40	2.91	4.03	3.63	3.57	5
K^+ (mg/l)	36.2	20.32	41.80	51.31	20.90	17.10	14.00	55
Na^+ (mg/l)	39.20	55.20	51.90	60.20	25.31	30.20	16.33	200
NO_3^- (mg/l)	30.6	77.50	95.00	80.40	15.36	20.75	12.96	50
CN^- (mg/l)	3.76	3.15	0.96	0.83	0.42	0.35	0.35	0.2-0.5

Heavy metals like iron, copper and zinc are essential for the growth and normal function of human body but are toxic at high concentrations (Chiagu *et al*., 2022).

The concentrations of Lead (Pb^{2+}), sodium (Na^+), zinc (Zn^{2+}) and potassium (K^+), ions in all the wells sampled are within WHO limits for drinking water. The values for sodium ions (Na^+) are lower in W5-W7 which are farther from the cassava factory and general dumpsite. Common source of zinc in groundwater is corrosion of galvanized metals which are washed through the soils from ground surface.The major sources of potassium in groundwater are weathering of rocks and disposal of industrial wastewater.Lead is toxic even in low concentration (Ren *et al.*, 2022).

Copper ion (Cu^{2+}) concentrations are within WHO limits except in W3 and W4 where it is 1.57 mg/l and slightly or tolerably higher. Consumption of high level of copper in water may damage red blood cells in human, reduce their ability to carry oxygen and cause serious illness(Vargas *et at.*, 2017).

The nitrate ions (NO_3^-) levels exceed the WHO limits in W2-W4 possibly due to their closeness to dumpsite and the sewage tank of the public toilet. The values are significantly lower and within WHO permissible limits in W1 and W5-W7. Ingesting high-level nitrate in drinking water can harm human health adversely as nitrate changes into nitrite and cause methemoglobinemia, a condition which hinders the ability of blood to carry oxygen (Moeini and Azhdarpoor, 2021).

The cyanide (CN^-) levels in all the wells exceed the permissible limit of 0.2 mg/l set by the United States Environmental Protection Agency (USEPA, 2018) and indicate that water from the wells are not suitable for consumption. The higher values in W1 and W2 can be attributed to their proximity to the cassava processing factory which is the source of the cassava effluent rich in cyanide. The values are lower with distance from the cassava processing factory, and more so in W5-W7 farther away from the effluent and the dumpsite. Considering the recommendation of World Health Organization that water with cyanide level above0.5 mg/l should not be consumed for more than 5 days in order to prevent short -term health risks, the water in W5-W7 with cyanide concentration less than 0.5 mg/l is not suitable for continuous consumption.The high level of cyanide in the cassava effluents may have also led to increase in the nitrate level and the TDS.

Appropriate remediation measures should be taken to forestall further contamination/pollution of the groundwater.Heavy metals can be effectively removed from contaminated water by using adsorption, while the cassava effluents can be detoxified by alkali hydrolysis before they are discharged to the environment.

CONCLUSIONS

2D electrical resistivity profiling and physicochemical analyses were carried out to map subsurface leachate spread and assess the level of contamination caused by indiscriminate disposal of cassava effluents and solid wastes around a cassava processing factory in Ogbomoso, southwestern Nigeria. The anomalously low resistivity zones on the 2D inverted resistivity sections revealed leachate contamination while the values of the physical and chemical parameters indicated the contaminants and level of contamination when compared with WHO (2011) and USEPA (2018) standards.

The pH values indicate that the groundwater is basic and are within the WHO recommended limits. The electrical conductivity (EC) and total dissolved solids (TDS) exceed the WHO limit in the wells close to the cassava processing factory and the dumpsite, indicating that the water is harmful to human health. The major indicators of groundwater contamination in the study area are the Fe^{2+}, NO_3^- and CN^- caused by percolation of leachate from the dumpsite and cassava effluents into the aquifers. The level of contamination in the wells is closely related to proximity to the cassava processing factory and the dumpsite. The cyanide levels recorded for all the water samples exceed the acceptable limit of 0.2 mg/l for drinking water, which indicates that they are not safe for drinking. The results for the wells farther from both sources are all generally lower than those close to them.

Groundwater from wells close to the cassava factory and dumpsite has been polluted by high levels of iron, nitrate and cyanide and is not safe for human use. The discharge of the effluents from the cassava processing factory contributes significantly to cyanide pollution. Regular monitoring and appropriate remediation measures are recommended in order to forestall further contamination of the groundwater.

REFERENCES

Adjei L. P., Arthur E. K., Gikunoo E., Foli G., Quaye-Ballard J. A., Agyemang F. O., Nsiah-Gyambibi, R., Bash, D. S., 2023.Cyanide contamination assessment via target survey and physicochemical and bacteriological characterization: A case study of Akrofrom-Techiman cassava processing area in Ghana. Environ Monit Assess., 195: 482.

Adewumi, J. R., Babatola, J. O and Olayanju, O. K., 2016.The Impact of Cassava Wastewater from Starch Processing Industry on Surrounding Soil: A Case Study of Matna Foods Industry, Ogbese. FUOYE Journal of Engineering and Technology, Volume 1, Issue 1, p.31-36.

Akpan, J.F.,Eyong, M. O. and Isong, I. A., 2017. The Impact of Long-term Cassava Mill Effluent Discharge on Soil pH and Microbial Characteristics in Cross River State. Asian Journal of Soil Science and Plant Nutrition 2(1): p. 1-9.

Alrumman, S. A., El-kott, A. F. and Kehsk, M. A., 2016. Water pollution: Source and treatment. American journal of Environmental Engineering, 6(3): p. 88-98.

APHA, 2005. Standard Methods for the Examination of Water and Wastewater. 21st Edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC.

Aweto, K. E., 2023. Application of Geophysical and Geochemical Approach to Environmental Impact Assessment around Cassava Mills in Western Niger Delta, Nigeria. Nig. J. Pure & Appl. Sci. Vol. 36 (Issue 1), p. 4573-4581

Azhar, A. T. S., Ayuni, S. A., Ezree, A. M., Nizam, Z. M., Aziman, M., Hazreek, Z. A. M., Norshuhaila, M. S.,and Zaidi, E., 2017. The Use of Electrical Resistivity Method to Mapping the Migration of Heavy Metals by Electrokinetic.IOP Conference Series: International Research and Innovation Summit (IRIS2017)Materials Science and Engineering, 7p.

Chiagu, F. O., Chikezie, P. C., Ahaneku, C. C. and Chikezie, C. M., 2022. Human Exposure to Heavy Metals: Toxicity Mechanisms and Health Implications. Material Science and Engineering International Journal, Volume 6, Issue 2, p. 78-87.

dos Santos, J. D., Veit, M. T., Juchen, P. T., da Cunha Gonçalves, G., Palacio, S. M. and Fagundes-Klen, M., 2018. Use of different coagulants for cassava processing wastewater treatment. Journal of Environmental Chemical Engineering, 6, p. 1821–1827.

Ehilenboadiaye, J. I., Aigbogun, C. O.,and Osamudiamen, G., 2018. 2D and 3D Subsurface Geoelectrical Resistivity Imaging of Contaminant Plume from Cassava Processing Mill in Uzebba Area of Edo North, Edo State, Nigeria. J. Appl. Sci. Environ. Manage. vol. 22 (4), p. 539 – 543.

Gomezulu, E.S., Mwakaje, A. and Katima, H.Y., 2018. Heavy metals and Cyanide distribution in the villages surrounding Buzwagi gold mine in Tanzania. Tanzania Journal of Science, 44(1), p. 107–122.

Hamzah, U. H., Jeeva, M. and Mohd Ali, N. A., 2014. Electrical Resistivity Techniques and Chemical Analysis in the Study of Leachate Migration at Sungai Sedu Landfill. Asian Journal of Applied Sciences, 7: p. 518-535.

Ilyas, M., Khan, S., Khan, A., Amin, R., Khan, A. and Aamir, M., 2017. “Analysis of drinking water quality and health risk assessment. A case study of Dir Pakistan,” Journal of Himalayan Earth Sciences, vol. 50, p. 100–110.

Ilyas, M., Ahmad, W., Khan, H., Yousaf, S., Yasir, M. and Khan, A.2019. “Environmental and health impacts of industrial wastewater effluents in Pakistan: a review,” Reviews on Environmental Health, vol. 34, no. 2, p. 171–186.

Izonfuo, W-AL, Bariweni, P. A., George, D. M. C., 2013. Soil Contamination from Cassava Wastewater Discharges in a Rural Community in the Niger Delta, Nigeria. J. Appl. Sci. Environ. Manage. vol. 17 (1), p. 105 - 110.

Loke, M. H., 2014. Electrical Imaging Surveys for Environmental and Engineering Studies. A Practical Guide to 2-D and 3-D Surveys.

Moeini, Z and Azhdarpoor, A., 2021. Health risk assessment of nitrate in drinking water in Shiraz using probabilistic and deterministic approaches and impact of water supplyEnvironmental Challenges, Vol. 5, 100326.

NGSA, 2020. Geological Maps of Nigeria (Online). A publication ofNigerian Geological Survey Agency, Abuja, Nigeria.Available at: http://ngsa.gov.ng/geological-maps.

Obueh, H.O and Odesiri-Eruteyan, E., 2016. A Study on the Effects of Cassava Processing Wastes on the Soil Environment of a Local Cassava Mill. Journal of Pollution Effects and Control 4: 177.

Oladele, P.K., 2014. Cassava Processing and the Environmental Effect. The 4th World sustainability Forum 2014. Conference Proceedings Paper.

Olukanni, D. O. and Olatunji, T. O., 2018. Cassava waste management and biogas generation potential in selected local government areas in Ogun State. Nigeria. Recycling, 3, 58.

Olurin, O. T., Ganiyu, S. A., Ognsanwo, F.O., Ojo, A.O., Alabi, A. A., Adegbamigbe, O. K., 2022. Groundwater quality assessment around a cassava processing mill on the sedimentary terrain of Ilaro, South-western Nigeria. HydroResearch, Volume 5, p. 108-117.

Omotosho, O. and Amori, A., 2015. Caustic Hydrogen Peroxide Treatment of Effluent from Cassava Processing Industry: Prospects and Limitations. International Journal of Engineering and Technology Innovation. 5. p. 75-85.

Osinowo O.O., Agbaje M.A. and Ariyo S.O., 2020. Integrated geophysical investigation techniques for mapping cassava effluent leachate contamination plume, at a dumpsite in Ilero, southwestern Nigeria. Scientific African, 8, p. 1-12.

Oyewusi,T. F., Osunbitan, J. A. and Taiwo, A. 2021. Investigation into the suitability of well water near cassava processing areas for drinking and irrigation purposes. Environmental Challenges, p. 1-5.

Ren,Y. S., IlyasM.,Xu R. Z., Ahmad, W., Wang, R., 2022. Concentrations of Lead in Groundwater and Human Blood in the Population of Palosai, a Rural Area in Pakistan: Human Exposure and Risk Assessment. Adsorption Science and Technology. p. 1-12.

US EPA, 2018. United States Environmental Protection AgencyDrinking Water Standards and Health Advisories Tables.https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf.

Vargas, I. T., Fischer, D. A., Alsina, M. A., Pavissich, J. P., Pastén, P. A., Pizarro, G. E., 2017. Copper Corrosion and Biocorrosion Events in Premise Plumbing. Materials (Basel). 10(9): 1036.

WHO, 2011. Guidelines for drinking water quality 4th (ed.). World Health Organization, Geneva, Switzerland.ISBN 978 9241548151.