



Geoelectrical and Physicochemical Characterization of Groundwater Contamination around a Cassava Processing Factory in Ogbomoso, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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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 $a = 5\text{m}$ 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 study area 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

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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.

Keywords: Contamination; cassava effluent; leachate; groundwater; cyanide.

1. INTRODUCTION

The rise in the cultivation of cassava to meet the huge global demand for domestic, industrial and export purposes has led to increase in the need for cassava processing and subsequent location of numerous cassava processing factories [1]. The cassava processing industry provides employment and revenue for 30% of Nigeria's informal sector [2]. 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^- [3-5]. The cassava effluent has high concentration of cyanide extractable from cassava tubers during processing. The solid wastes and effluents from cassava processing factories in rural and semi-urban area are usually disposed of without considering specific guidelines on waste disposal and treatment [6-10]. 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 [11-13], and ultimately constitute serious health risk to the hosting community which depend solely on groundwater mostly from hand-dug wells for domestic and industrial uses [14-16,5].

Leachate plumes generated from cassava effluents may contain significant amount of dissolved ions that can substantially raise the conductivities or lower the resistivity of the soil and groundwater which can be detected by the electrical resistivity method [17-19]. The 2D electrical resistivity profiling method is particularly suitable for mapping contamination plumes beneath and around waste dumps since it is capable of revealing subsurface variations of resistivity induced 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.

While the ER method reveals the spatial spread of the leachate, the degree of contamination can be determined 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 analyses for pH, 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.

1.1 Study Area

The study area is located within the Longitudes $04^\circ 14'31''$ E - $04^\circ 14'44''$ N and Latitudes $08^\circ 06'51''$ N - $08^\circ 07'01''$ E (Fig. 1). It is 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 [10]. 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.

2. MATERIALS AND METHODS

2.1 2D Electrical Resistivity Method

The 2D resistivity survey was conducted with the aid of a resistivity meter connected to four steel electrodes by means of conducting cables. Resistivity measurements were made along eight

traverses run across and around the cassava processing factory and the general dumpsite (Fig. 3). The Dipole-Dipole horizontal profiling was employed with electrode spacing $a = 5\text{m}$ and expansion factor $n=1$ to 4. The data were inverted by using 2D inversion procedures [21] 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.

2.2 Physicochemical Analyses

Groundwater samples were collected from seven hand-dug wells (W1-W7) within and around the study area for physicochemical analyses to determine the physical properties: pH, EC, TDS and concentrations of cations and anions namely: Fe^{2+} , Pb^{2+} , Zn^{2+} , Cu^{2+} , K^+ , Na^+ , NO_3^- and CN^- .

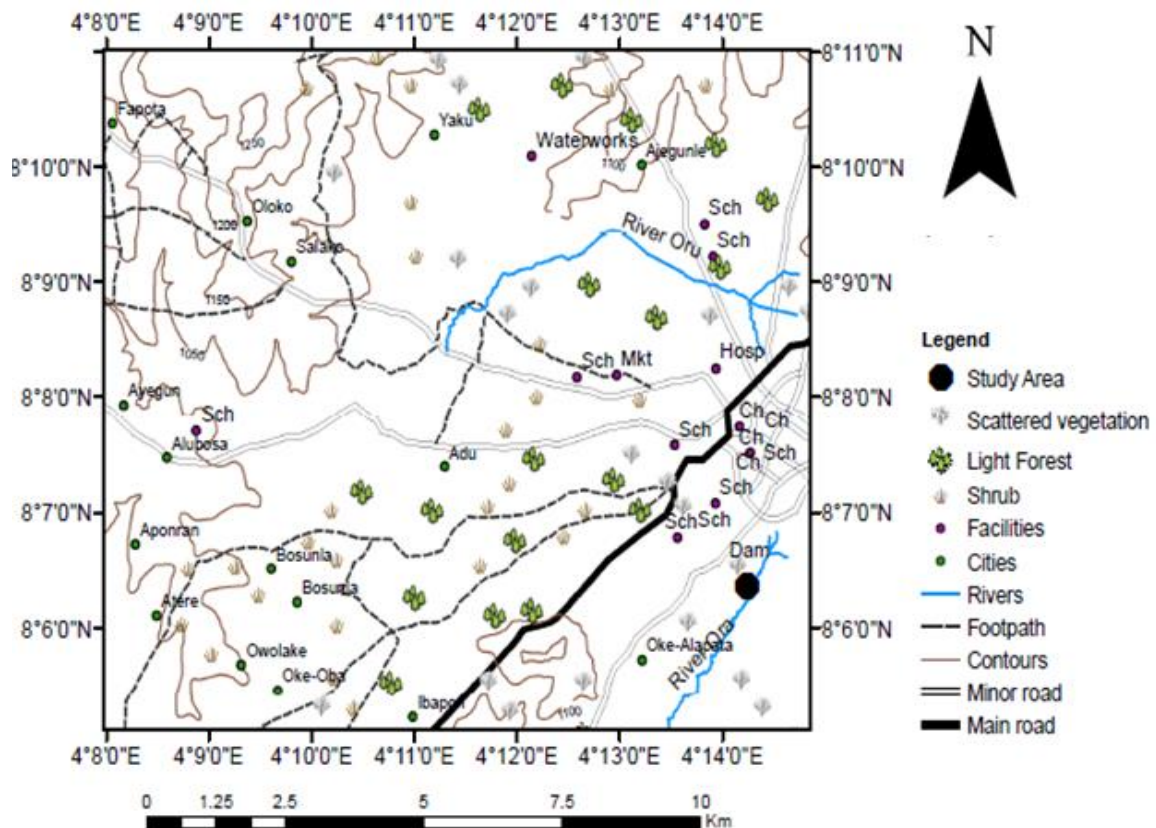


Fig. 1. Location map of the study area (modified after[20])

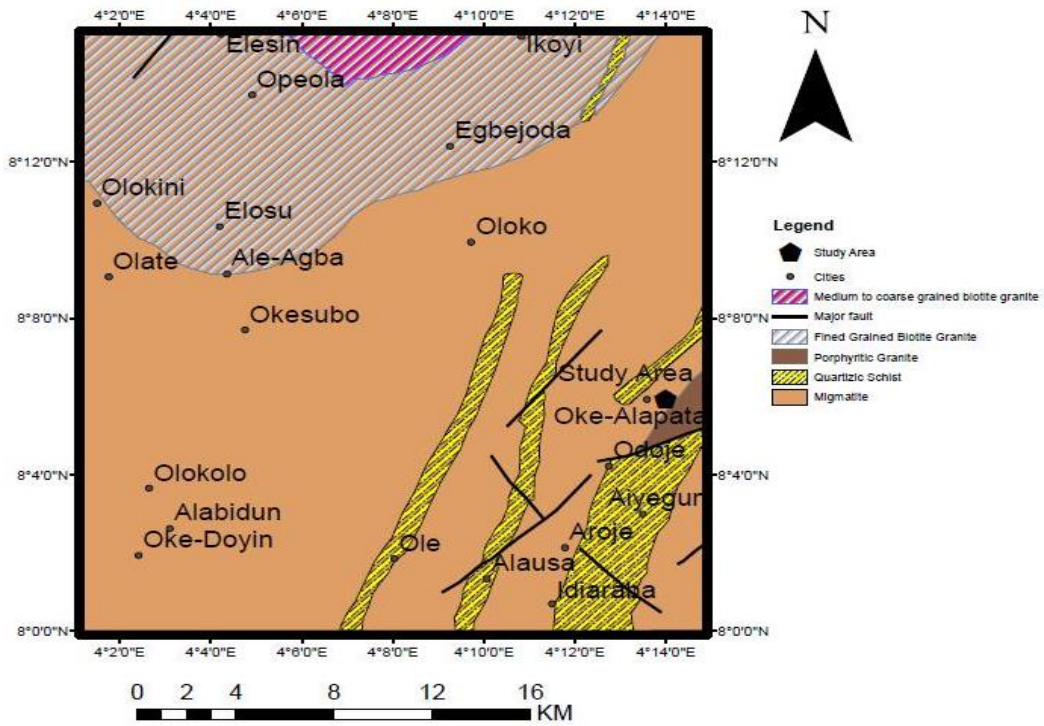


Fig. 2. Geological map of the study area (modified after [20])

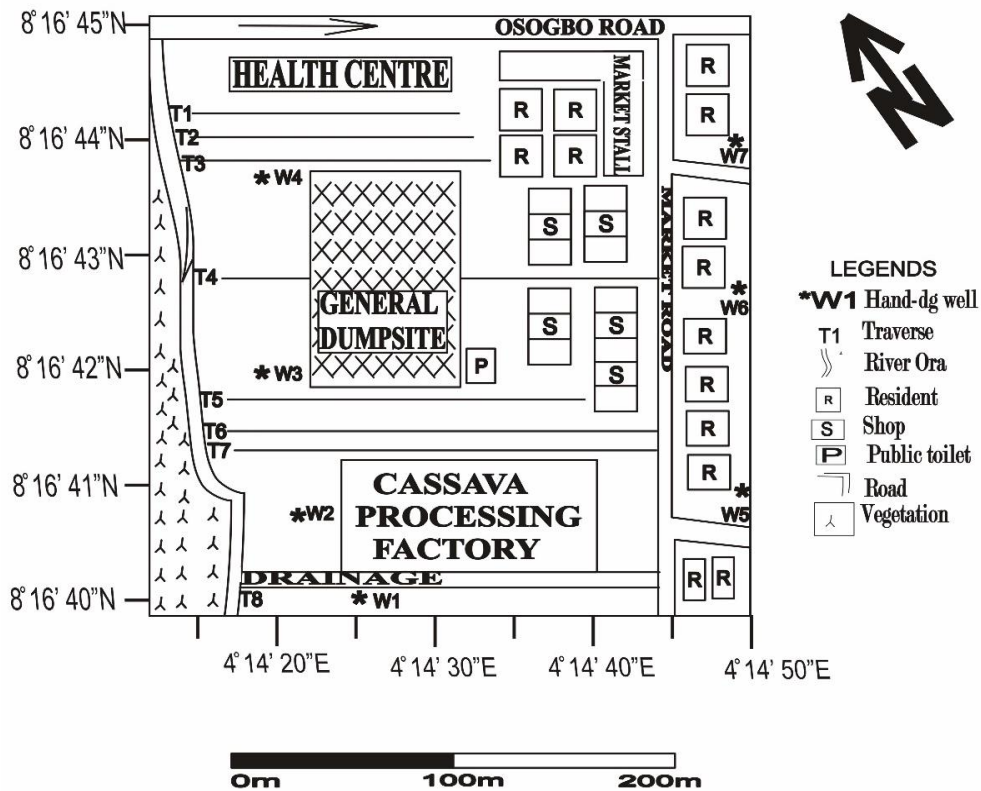


Fig. 3. Location of geophysical traverses and hand-dug wells in the study area

2.3 Sample Collection and *in-situ* Measurements

The sampling was carried out in the seven wells, at an average depth of 3.95 m, by using 0.5-litre plastic containers initially rinsed with deionized water to avoid contamination during the sampling. 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* with a portable hand held digital Multifunction Water Quality Tester (MW 602 Milwaukee Model - Pen Type meter). The probe was dipped into the water samples and was read when stable readings were obtained.

2.4 Laboratory Chemical Analyses

The water samples were subjected to chemical analyses to determine the concentrations of the cations and anions using Atomic Absorption Spectrophotometer (AAS). The analyses were conducted in accordance with the procedures developed by the American Public Health Association [22]. The results of the water analyses were compared with the World Health Organization [23] Standards to assess impact of the cassava processing factory and the waste dump on groundwater quality in the study area.

3. RESULTS AND DISCUSSION

3.1 2D Resistivity Imaging

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 Ω m, 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 variations ranging from 2.51 Ω m – 4101 Ω m indicating the geoelectrical strata (overburden and weathered/fresh bedrock) and zones of leachate contamination within them. The anomalously low resistivity values between 9.45 Ω m and 11.6 Ω m in the topsoil beneath Traverse 1 suggest leachate contamination up to the depth of about 5 m while the low values ranging from 15.6 Ω m to 37.6 Ω m indicate reduced contamination in the weathered bedrock and fresh bedrock respectively (Fig. 4).

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

The anomalously low resistivity values of 4.22 Ω m - 9.31 Ω m 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 from ground surface, suggest leachate contamination originating from the dumpsite. The relatively low resistivity values of 15.5 Ω m – 63.9 Ω m are characteristic of the clayey saprolite while the relatively high values of 122 Ω m – 375 Ω m and 530 Ω m - 2535 Ω m indicate weathered bedrock and fresh bedrock respectively. The degree

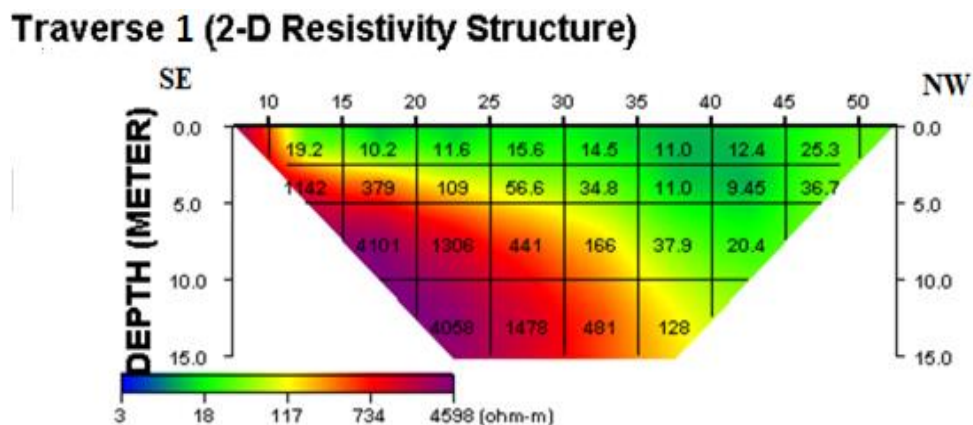


Fig. 4. 2D resistivity structure for Traverse 1

of leachate contamination reduced with distance of the traverse from the dumpsite.

The 2-D inverted resistivity section beneath Traverse 4 run across the General Dumpsite shows zone of anomalously low resistivity (6.73 Ω m – 9.52 Ω m) 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 Ω m to 23.7 Ω m observed beneath lateral intervals 10 m - 15 m, 25 m - 30 m and 65 m – 72 m suggest reduced contamination within the clay layer of

Traverse 2 (2-D Resistivity Structure)

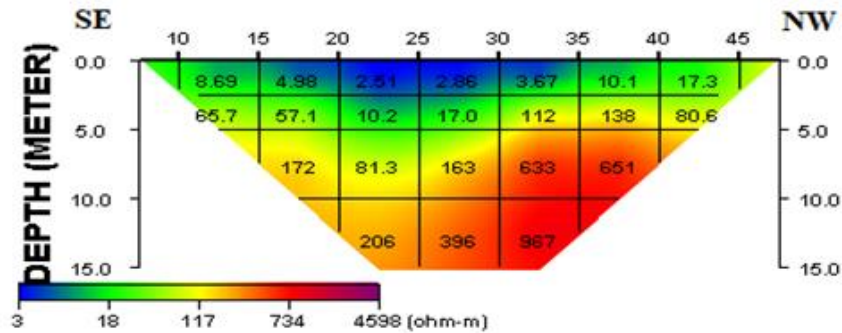


Fig. 5. 2D resistivity structure for Traverse 2

Traverse 3 (2-D Resistivity Structure)

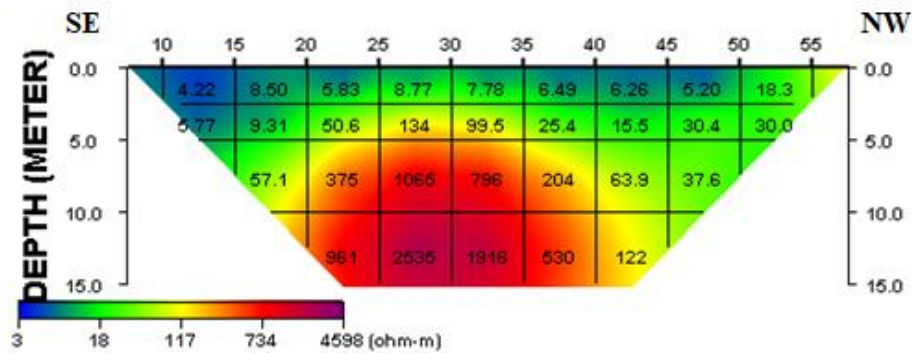


Fig. 6. 2D resistivity structure for Traverse 3

Traverse 4 (2-D Resistivity Structure)

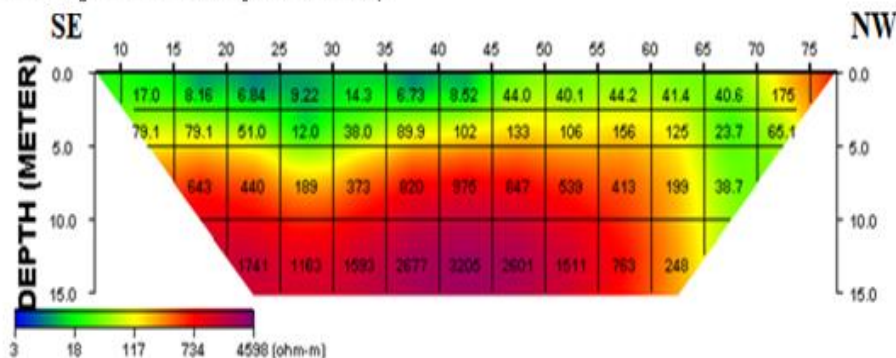


Fig. 7. 2D resistivity structure for Traverse 4

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 zone beneath Traverse 6, 0.10 Ωm to 3.72 Ωm beneath Traverse 7, and 0.26 Ωm to 8.88 Ωm beneath Traverse 8.

Traverse 5 (2-D Resistivity Structure)

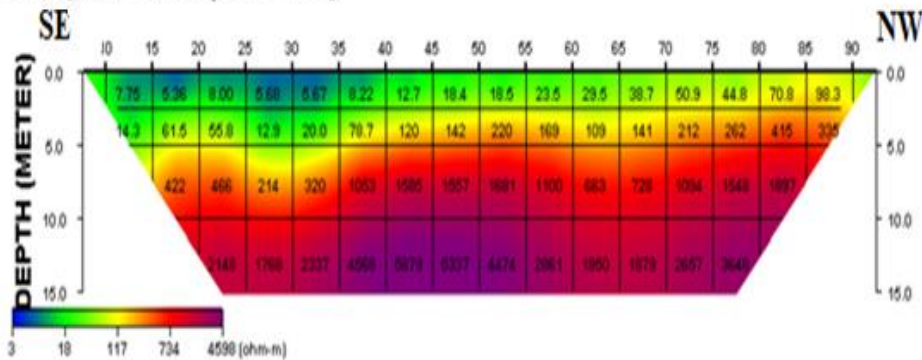


Fig. 8. 2D resistivity structure for Traverse 5

Traverse 6 (2-D Resistivity Structure)

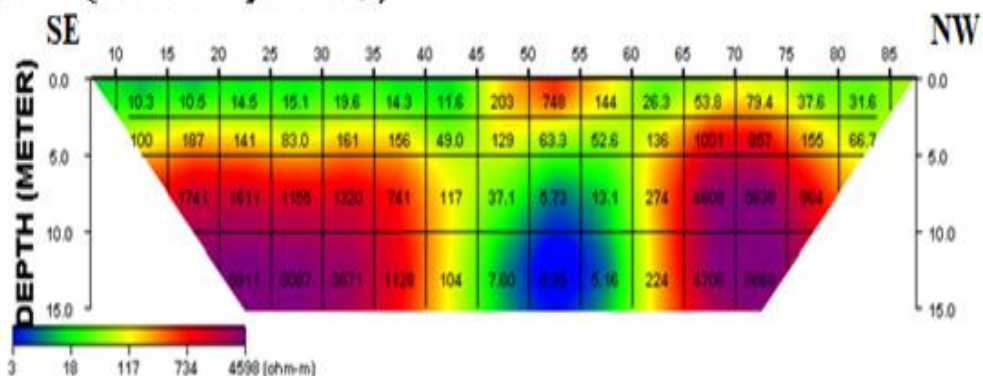


Fig. 9. 2D resistivity structure for Traverse 6

Traverse 7 (2-D Resistivity Structure)

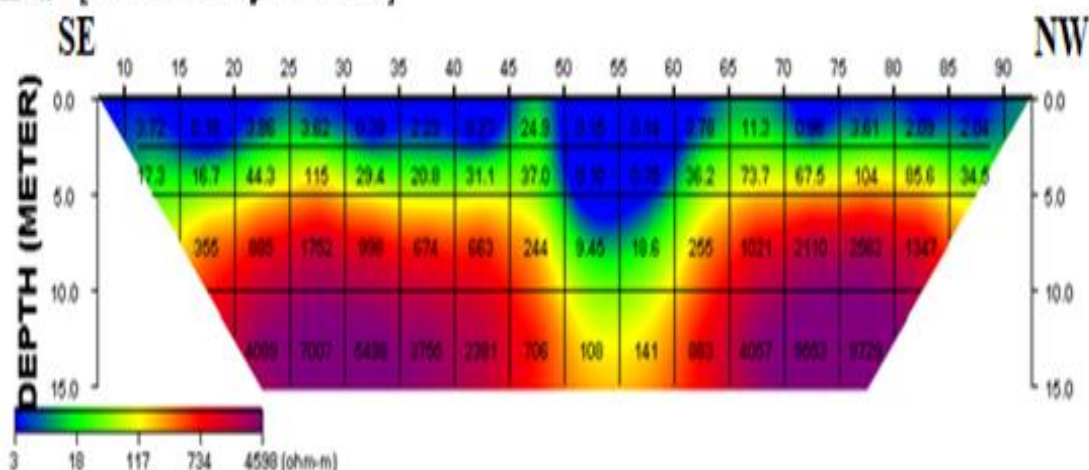


Fig. 10. 2D resistivity structure for Traverse 7

Traverse 8 (2-D Resistivity Structure)

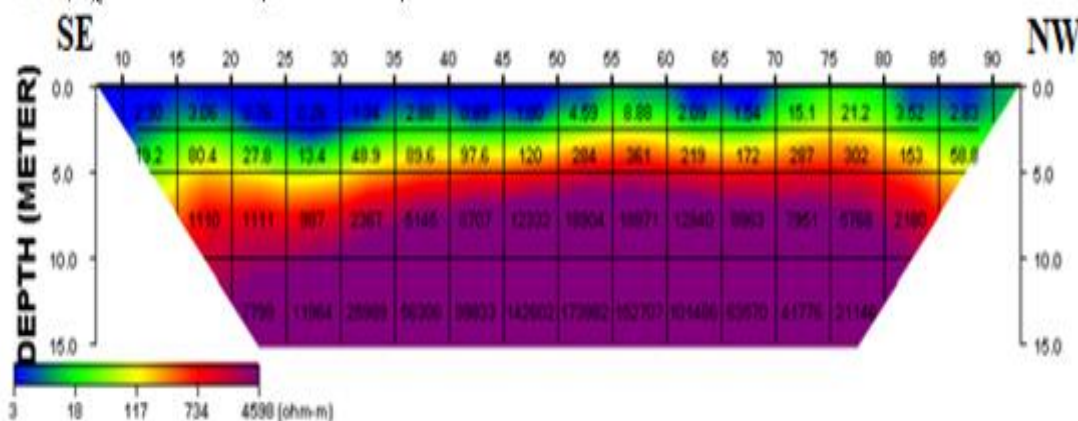


Fig. 11. 2D resistivity structure for Traverse 8

3.2 Physicochemical Evaluation

The results of the physicochemical 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 [23] recommended limits.

The electrical conductivity (EC) ranges from 277 $\mu\text{S}/\text{cm}$ to 860 $\mu\text{S}/\text{cm}$ 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 [24].

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.

Heavy metals like iron, copper and zinc are essential for the growth and normal function of

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 ($\mu\text{S}/\text{cm}$)	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

human body but are toxic at high concentrations [25,30].

The concentrations of Lead (Pb²⁺), sodium (Na⁺), zinc (Zn²⁺) 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 [26].

Copper ion (Cu²⁺) 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 [27].

The nitrate ions (NO₃⁻) 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 [28].

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 [29] 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 above 0.5 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.

4. 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 [23] and US EPA [29] 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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