

## INTEGRATED GEOPHYSICAL AND HYDROCHEMICAL INVESTIGATIONS OF SUBSOIL AND GROUNDWATER POLLUTION AROUND THREE CASSAVA PROCESSING FACTORIES AT IRETI-AYO COMMUNITY, ILESHA, SOUTHWESTERN NIGERIA

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(Received: 10th September, 2017; Accepted: 18th September, 2017)

### ABSTRACT

Integrated geophysical and hydrochemical investigations were carried out within the vicinity of three cassava processing factory sites at Ireti-Ayo Community in Ilesha, Southwestern Nigeria. This was with a view to assessing the impact of the cassava effluent on the soil/subsoil and the groundwater quality within the study area. Fourteen Vertical Electrical Soundings (VES) data were acquired using the Schlumberger array while 2-D Dipole-Dipole data were acquired along six traverses. Hydrochemical analysis was also carried out on the cassava effluent and well water samples for cyanide, pH, TDS, electrical conductivity, acidity, alkalinity, cations and anions concentrations. The VES data were quantitatively interpreted using the partial curve matching and 1-D computer assisted forward modeling while the 2-D Dipole-Dipole data were inverted into 2-D resistivity structures. The elemental concentrations were compared with the WHO (2006) standard for potable water. The VES derived geoelectric sections identified four lithological layers which comprised the topsoil (8 – 638  $\Omega\text{m}$ ), laterite (278 – 2468  $\Omega\text{m}$ ), weathered basement (32 – 1004  $\Omega\text{m}$ ) and fresh basement (536 – 20883  $\Omega\text{m}$ ). The thin topsoil was underlain by a relatively thick lateritic layer (up to 12.2 m). The sampled cassava effluent resistivity was 6.5  $\Omega\text{m}$ . The topsoil and part of the underlying laterite at and around the vicinity of the three cassava processing factory sites had relatively low resistivity values (6 - 112  $\Omega\text{m}$ ) diagnostic of cassava effluent impacted zones. The pollution plumes depth extents were estimated to range from 2.5 to 5 m with a migration rate of about 0.24 m/year. The migration of the pollution plume may have been inhibited by the relatively thick column of laterite underlying the topsoil. Cyanide was detected (0.8 mg/L) in the cassava effluent, but not in the analysed well water samples. For both the upstream and downstream well water samples respectively, the physico-chemical parameters were all within the WHO permissible levels. The study concluded that the groundwater in the vicinity of the factory sites investigated had not been polluted by the cassava effluent. However, the subsoils within the sites have been polluted to depth of up to 5 m.

**Keywords:** Geophysical Investigation, Hydrochemical Analysis, Cassava Effluents, Groundwater Quality.

### INTRODUCTION

Water is an indispensable requirement that sustains life. Most human activities such as agriculture, industries and domestic needs depend upon the availability of water resources (Awomeso *et al.*, 2010). Water can exist both as surface and groundwater. The groundwater reserve of the world is about  $5.0 \times 10^{24}$  litres and thus constitutes a significant proportion of the earth's water resources (Buchanan, 1983). However, the quality of groundwater is as important as its enormous quantity (Todd, 1980). The quality of drinking water is determined by its physical, chemical and microbiological characteristics. (Olawajaju *et al.*, 1997). In Nigeria, only 48% of urban dwellers and 39% of rural dwellers have access to potable water (Federal Republic of Nigeria, 2002). Wastes generated from agricultural farmland and industries have

contributed immensely to water pollution when contaminants percolate into the groundwater (Forster *et al.*, 1998). Drinking contaminated water could result into a variety of water borne diseases such as Diarrhoea, Cholera, Dysentery and Typhoid. Geophysical methods involving Vertical Electrical Sounding (VES) and 2D electrical resistivity imaging are relevant in the mapping of subsurface lithology and pollution plume (Amidu and Olayinka, 2006; Atakpo *et al.*, 2011; Bayowa *et al.*, 2012 and Orakwe, 2016). Hydrochemical analysis involving the determination of physicochemical parameters of water samples is also essential in area(s) of suspected groundwater contamination (Olawajaju *et al.*, 1997; Akoteyon *et al.*, 2011). The Ireti-Ayo Community, in Ilesha SW Nigeria, is noted for cassava processing. The community has three (3) cassava processing units where effluents are directly discharged within the

immediate vicinities. Disposal of cassava liquid waste to the environment directly pollute the soil/subsoil while groundwater may be polluted indirectly through infiltration. This study intends to investigate the impact of the effluents on the soil/subsoil and the groundwater.

### Description of the Study Area

The study area is located at Ireti-Ayo, in Ilesha, Osun State, SW Nigeria. It lies between Northings 845200 and 846000 mN and Eastings 694300 and 694900 mE using the Universal Traverse Mercator (UTM) Zone 31 coordinate system (Fig. 1), with a total area of about 540 km<sup>2</sup>. The area is drained by some seasonal streams flowing in the Northwest-Southeast direction (Fig. 2). It falls within the tropical climatic region with an average daily temperature that varies between about 20°C and 35°C and an annual rainfall of about 1600 mm within the raining season (OSSADEP, 1997). The vegetation is the tropical rain forest type. The area is entirely underlain by Amphibolite Schist (Fig. 3) and it is located on a relatively flat to gently undulating terrain with elevation that ranges from 374 m to 387 m.

### MATERIALS AND METHODOLOGY

The GARMIN 12 channel personal navigator GPS unit was used to acquire the coordinates of relevant features and these were used to generate the base map of the study area (Fig. 4). The base map was used to establish geophysical traverses and points for water sample collection. The investigation involved integration of geophysical and hydrochemical methods.

#### Geophysical Investigation

The geophysical investigation involved the electrical resistivity method which employed the 2-D Dipole-Dipole imaging and 1-D Vertical Electrical Sounding (VES) techniques. The 2-D Dipole-Dipole imaging technique was adopted along established geophysical traverses at the three cassava processing factory sites. Five meter (5 m) dipole length and dipole expansion factor (n)

varying from 1 to 5 were adopted for the 2-D data acquisition. The Dipole-Dipole data were inverted into 2-D resistivity structures (images) using the DIPRO for window Software. The resulting 2-D resistivity images were used to delineate pollution plumes and also used to constrain the locations of the VES points along each traverse.

The 1-D Vertical Electrical Sounding (VES) data were acquired using the Schlumberger array. The current electrode spacing (AB/2) was varied from 1 to 100 m. The acquired data were plotted as VES curves and interpreted quantitatively using the method of partial curve matching and computer assisted 1-D forward modeling with the WinResist software. The VES interpretation results were used to generate geoelectric sections along the established traverses.

#### Hydrochemical Analysis

The pH, Electric Conductivity, Total Dissolved Solids (TDS) and Temperature of cassava effluent sample collected at the oldest cassava processing unit (Unit 3 which had been active for over 20 years) and well water samples collected at both the upstream and downstream sides of the processing site were measured insitu at the oldest cassava processing factor site. The samples were labeled appropriately and immediately sent to the laboratory to test for the concentration of Cyanide, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Fe<sup>2+</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and PO<sub>4</sub><sup>3-</sup>. The results obtained from the hydrochemical analyses were compared with WHO drinking water standard so as to establish the groundwater quality.

### RESULTS AND DISCUSSION

#### VES Type Curves

Three (3) VES type curves including the KH, HKH and KHKH type (Table 1) were identified from the fourteen (14) Vertical Electrical Sounding (VES) stations that were occupied along six (6) established geophysical traverses within the study area. The KH type curve is the dominant type curve.

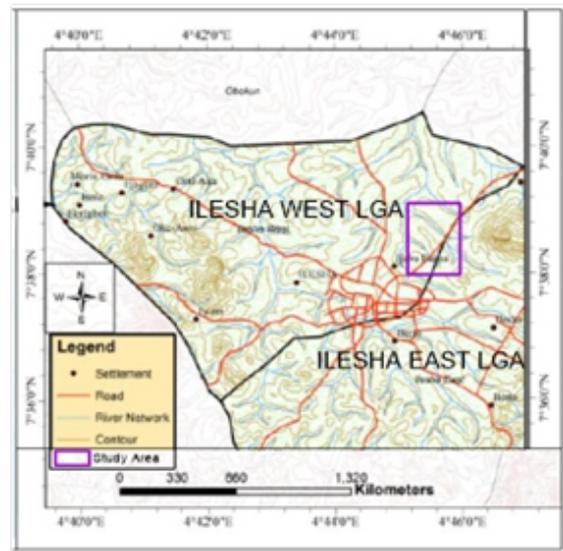
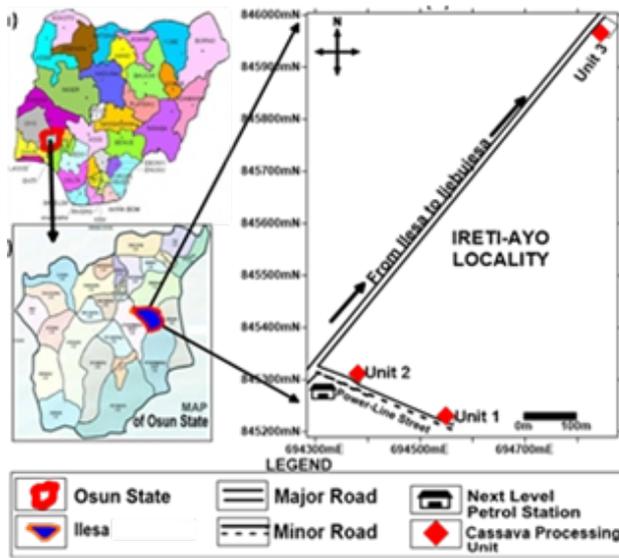


Fig. 1: Map of Osun State Showing the Three Cassava Processing Factories within the Ire-Ayo Study Area in Ilesha Town.

Fig. 2: Topographic Map of Ilesha Area showing the Study Area (Adapted from Felix and Olusola, 2016)

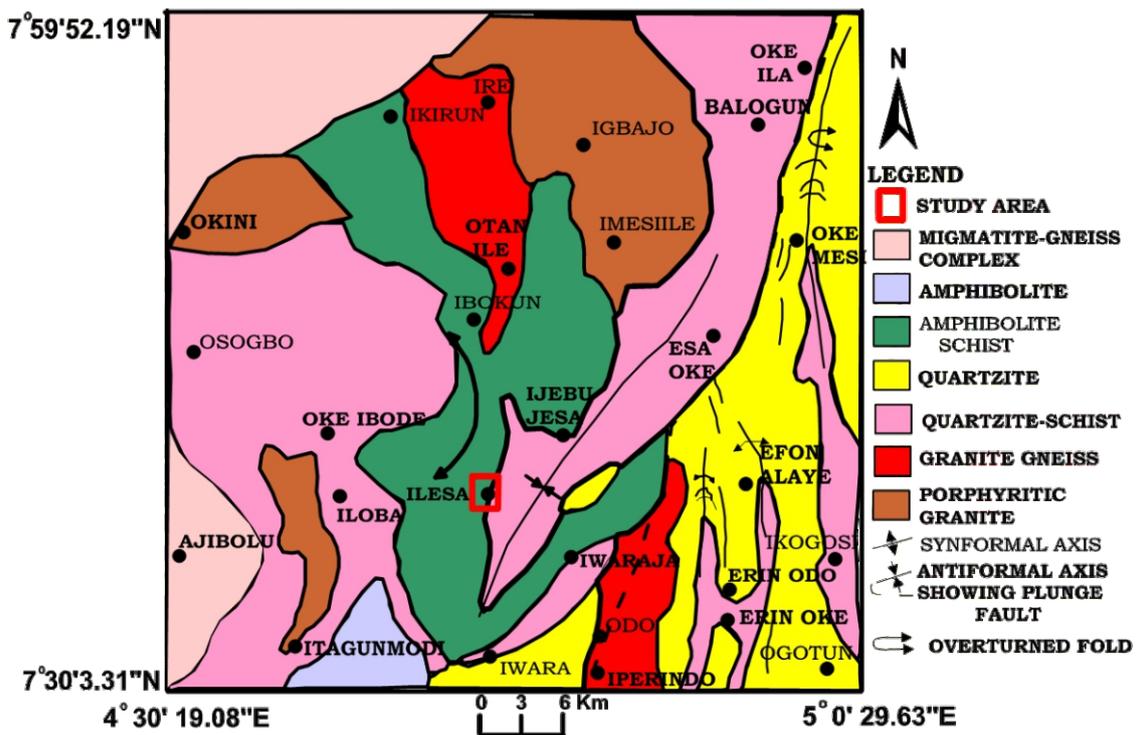


Fig. 3: Geological Map of Area around Ilesha Showing the Study Area (Adapted from Odeyemi, 1993)

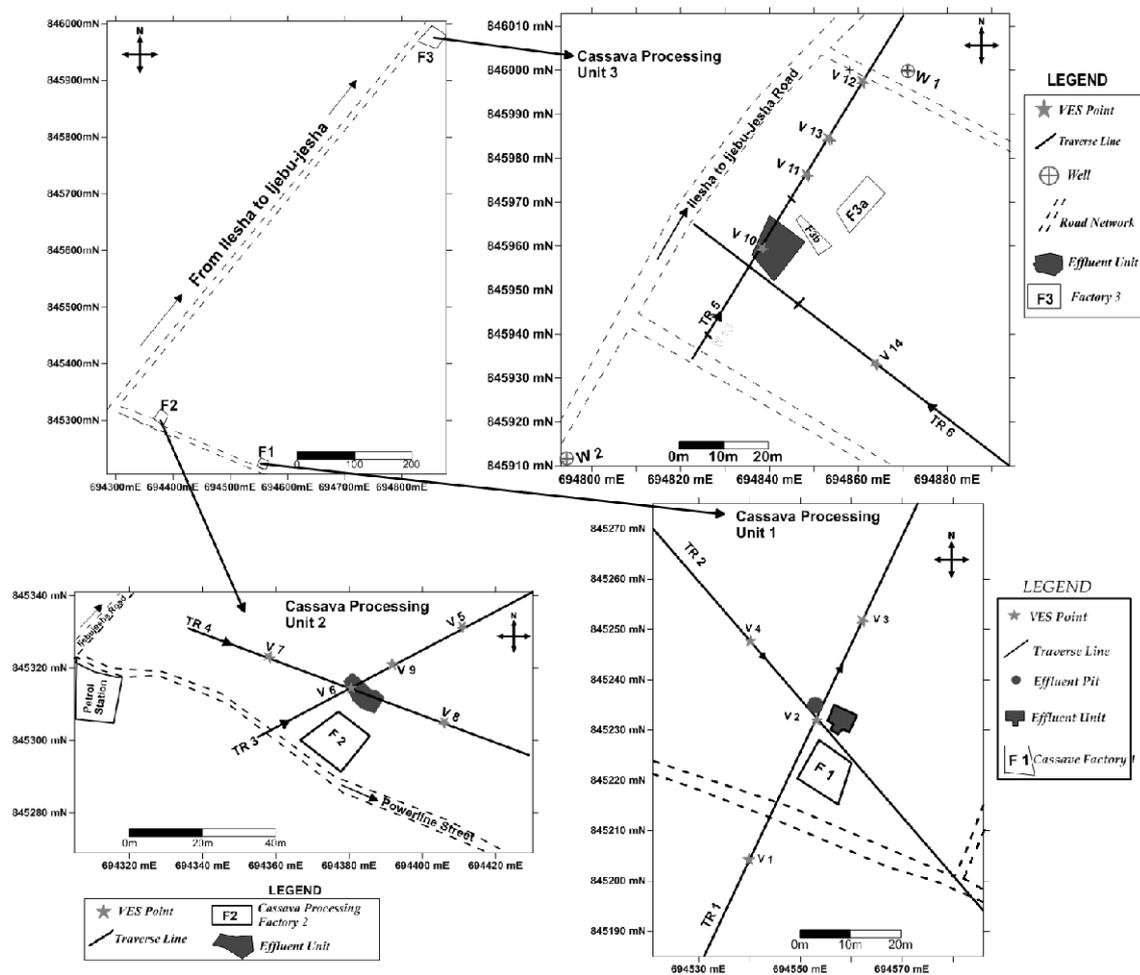


Figure 4: Map of the Study area Showing the Geophysical Traverses, VES Points and Well Locations.

**Geoelectric Sections**

**Geoelectric Section along Traverse 1 (At Site 1)**

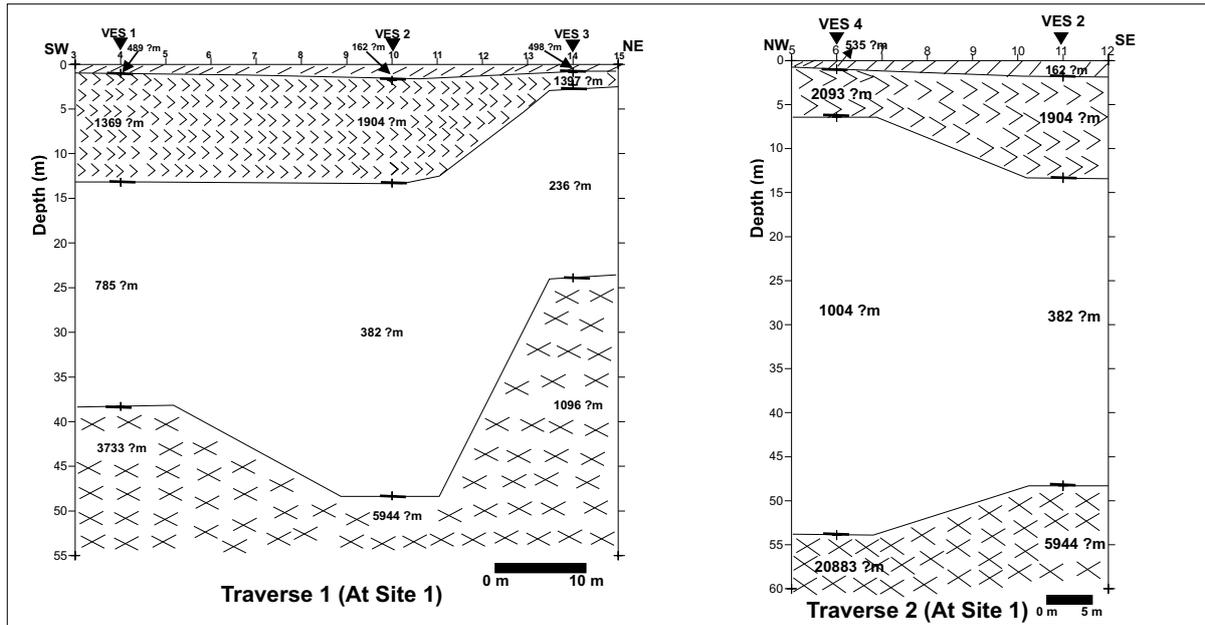
This section relates VES 1, 2, and 3 (Fig. 5a). The topsoil resistivity values range from 162 – 498  $\Omega\text{m}$  while the thickness ranges from 0.9 – 1.8 m. The lateritic layer constitutes the second layer with much higher resistivity values which range from 1369 – 1904  $\Omega\text{m}$  and thicknesses varying from 1.4 – 12.2 m. The third layer is the weathered layer having resistivity values ranging from 236 – 785 ohm-m and thicknesses of between 21.6 – 35.0 m. The fresh basement has resistivity values ranging from 1096 – 5944  $\Omega\text{m}$ . The depth to the basement bedrock ranges from 23.9 – 48.3 m.

**Geoelectric Section along Traverse 2 (At Site 1)**

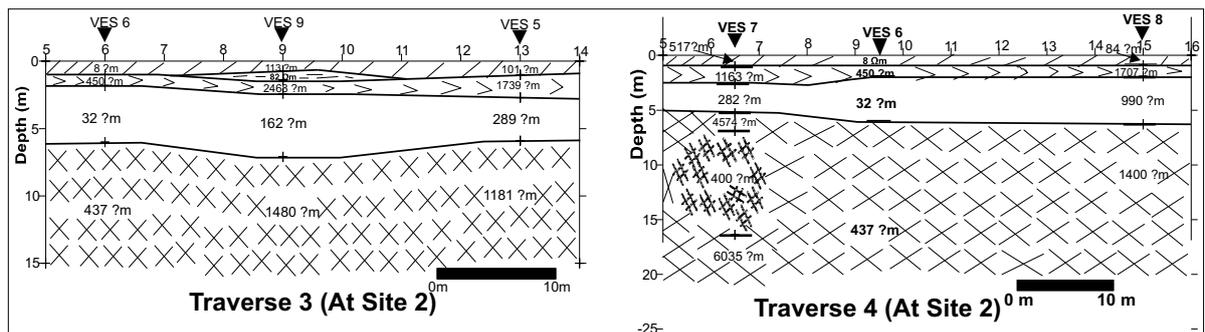
This section relates VES 4 and 2 (Fig. 5a). The topsoil resistivity values range from 162 – 535  $\Omega\text{m}$  while the thickness ranges from 1.0 – 1.8 m. The lateritic layer constitutes the second layer with a higher resistivity range of 1904 – 2093  $\Omega\text{m}$  and thicknesses varying from 5.4 – 11.5 m. The third layer is the weathered layer having resistivity values ranging from 382 – 1004 ohm-m and thicknesses of between 35.0 – 47.5 m. The basement bedrock has resistivity values range from 5944 – 20883  $\Omega\text{m}$ . The depth to the basement bedrock ranges from 48.3 – 53.9 m.

Table 1: Summary of VES Interpretation Result and their Lithologic Unit Classification

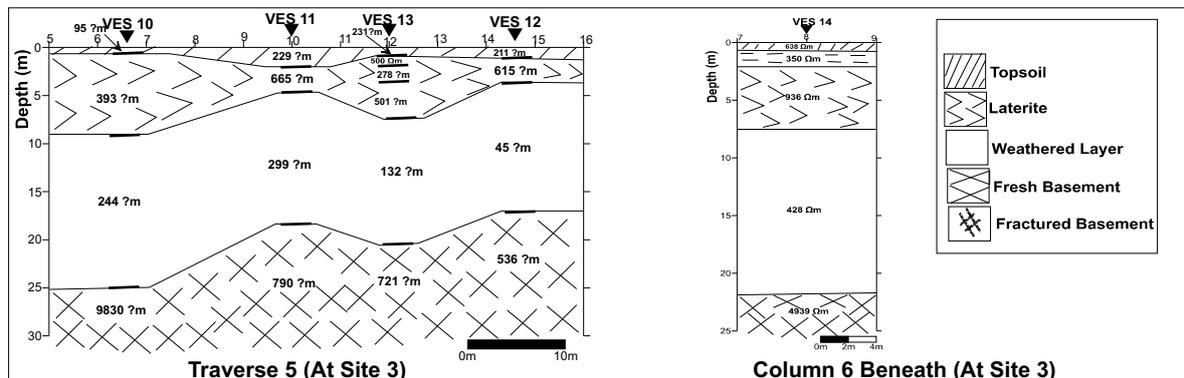
VES	Curve Type	Layer	Thickness (m)	Depth (m)	---	-	Lithologic Units
1	KH	1	1.0	1.0	489		Topsoil
		2	12.2	13.2	1369		Laterite
		3	25.2	38.3	785		Weathered Layer
		4	-	-	3733		Fresh Basement
2	KH	1	1.8	1.8	162		Topsoil
		2	11.5	13.3	1904		Laterite
		3	35.0	48.3	382		Weathered Layer
		4	-	-	5944		Fresh Basement
3	KH	1	0.9	0.9	498		Topsoil
		2	1.4	2.3	1397		Laterite
		3	21.6	23.9	236		Weathered Layer
		4	-	-	1096		Fresh Basement
4	KH	1	1.0	1.0	535		Topsoil
		2	5.4	6.4	2093		Laterite
		3	47.5	53.9	1004		Weathered Layer
		4	-	-	20883		Fresh Basement
5	KH	1	1.0	1.0	101		Topsoil
		2	1.7	2.7	1739		Laterite
		3	3.2	5.9	289		Weathered layer
		4	-	-	1181		Fresh Basement
6	KH	1	1.0	1.0	8		Topsoil *
		2	0.8	1.8	450		Laterite
		3	4.2	6.0	32		Weathered Layer
		4	-	-	437		Fresh Basement
7	KHKH	1	1.0	1.0	517		Topsoil
		2	1.6	2.6	1163		Laterite
		3	2.7	5.3	282		Weathered Layer
		4	1.6	6.9	4574		Fresh Basement
		5	9.5	16.4	400		Fractured Basement
		6	-	-	6035		Fresh Basement
8	KH	1	0.9	0.9	84		Topsoil
		2	1.0	1.9	1707		Laterite
		3	4.3	6.3	990		Weathered Layer
		4	-	-	1400		Fresh Basement
9	HKH	1	0.7	0.7	113		Topsoil
		2	0.7	1.4	82		Clay
		3	1.0	2.4	2468		Laterite
		4	4.7	7.1	162		Weathered Layer
		5	-	-	1480		Fresh Basement
10	KH	1	0.3	0.3	95		Topsoil
		2	8.7	9.0	393		Laterite
		3	16.0	25.0	244		Weathered Layer
		4	-	-	9830		Fresh Basement
11	KH	1	1.9	1.9	229		Topsoil
		2	2.7	4.6	665		Laterite
		3	13.7	18.2	299		Weathered Layer
		4	-	-	790		Fresh Basement
12	KH	1	1.0	1.0	211		Topsoil
		2	2.6	3.6	615		Laterite
		3	13.5	17.0	45		Weathered Layer
		4	-	-	536		Fresh Basement
13	KHKH	1	0.7	0.7	231		Topsoil
		2	0.7	1.5	500		Laterite
		3	1.6	3.1	278		Laterite
		4	4.3	7.4	501		Laterite
		5	12.9	20.3	132		Weathered Layer
		6	-	-	721		Fresh Basement
14	HKH	1	0.8	0.8	638		Topsoil
		2	1.4	2.1	350		Clay
		3	5.5	7.6	936		Laterite
		4	14.1	21.8	428		Weathered Layer
		5	-	-	4939		Fresh Basement



Figs. 5a: Geoelectric Sections along Traverses 1 and 2 at the Cassava Processing Site 1



Figs. 5b: Geoelectric Sections along Traverses 3 and 4 at the Cassava Processing Site 2



Figs. 5c: Geoelectric Sections along Traverse 5 and Beneath VES 14 along Traverse 6 at the Cassava Processing Site 3

### Geoelectric Section along Traverse 3 (At Site 2)

This section relates VES 6, 9 and 5 (Fig. 5b). The topsoil resistivity values range from 8 – 113  $\Omega\text{m}$  while the thickness ranges from 0.7 – 1.4 m. The lateritic layer constitutes the second layer with higher resistivity values of 450 – 2468  $\Omega\text{m}$  and thicknesses varying from 0.8 – 1.7 m. The weathered layer resistivity values range from 32 – 289  $\Omega\text{m}$  with thicknesses of between 3.2 and 4.7 m. The basement bedrock has resistivity values ranging from 437 – 1480  $\Omega\text{m}$ . The depth to the basement bedrock ranges from 5.9 – 7.1 m.

### Geoelectric Section along Traverse 4 (At Site 2)

This section relates VES 7, 6 and 8 (Fig. 5b). The topsoil resistivity values range from 8 – 517  $\Omega\text{m}$  while the thickness ranges from 0.9 – 1.0 m. The lateritic layer constitutes the second layer with higher resistivity values of 450 – 1707  $\Omega\text{m}$  and thickness varying from 0.8 – 1.6 m. The third layer is the weathered layer having resistivity values ranging from 32 – 990  $\Omega\text{m}$  and thicknesses of between 2.7 – 4.3 m. The basement bedrock has resistivity values ranging from 437 – 6035  $\Omega\text{m}$ . The basement bedrock is fractured beneath VES 7 with resistivity value of 400  $\Omega\text{m}$  and thickness of 9.5 m. The depth to the basement bedrock ranges from 5.3 – 6.3 m.

### Geoelectric Section along Traverse 5 (At Site 3)

This section relates VES 10, 11, 13 and 12 (Fig. 5c). The topsoil resistivity values range from 95 – 231  $\Omega\text{m}$  while the thickness ranges from 0.3 – 1.9 m. The lateritic layer constitutes the second layer with a resistivity range of 393 – 665  $\Omega\text{m}$  and thicknesses varying from 2.6 – 8.7 m. The weathered layer resistivity values range from 45 – 299  $\Omega\text{m}$  with thicknesses of between 12.9 and 16.0 m. The basement bedrock has resistivity values ranging from 536 – 9830  $\Omega\text{m}$ . The depth to the basement bedrock ranges from 17.0 – 25.0 m.

### Geoelectric Section along Traverse 6 (At Site 3)

This section (Fig. 5c) shows the subsoil sequence beneath VES 14. The topsoil resistivity values vary from 350 - 638  $\Omega\text{m}$  while the thickness is 2.2 m.

The lateritic second layer has a higher resistivity value of 936  $\Omega\text{m}$  and thickness of 5.5 m. The third layer is the weathered layer having resistivity value of 428  $\Omega\text{m}$  and thickness of 14.1 m. The basement bedrock has resistivity value of 4939  $\Omega\text{m}$ . The depth to the basement bedrock is 21.8 m.

## 2-D Dipole-Dipole Images at Site 1

### 2-D Resistivity Image beneath Traverse 1

The 2-D resistivity structure beneath Traverse 1 (Figs. 4d & 6a) images the upper 15 m of the subsurface sequence. The topsoil (in green/yellow/brownish red colour) has variable resistivity values of between 264 and 2000  $\Omega\text{m}$  and thicknesses too thin ( $< 1$  m) to be differentiated from the underlying layer (Fig. 6a). The second layer (in brownish red/purple colour) corresponds to the lateritic layer with resistivity values ranging from 358 - 5771  $\Omega\text{m}$  and thicknesses ranging from 4 m to greater than 15 m. The third layer (in yellowish/green colour) corresponds to the weathered layer with resistivity values ranging from 102 - 509  $\Omega\text{m}$ . The cassava effluent-impacted zone has not been clearly imaged by the resistivity structure. If any, the effect of the effluent may have been very limited.

### 2-D Resistivity Image beneath Traverse 2

The 2-D resistivity structure beneath Traverse 2 (Figs. 4d & 6b) images the upper 15 m of the subsurface sequence. The topsoil (in blue/green/brownish colour) has variable resistivity values ranging from 100 to 1884  $\Omega\text{m}$  and thicknesses of  $< 1.0$  m. The second layer (in green/brownish red/purple colour) corresponds to the lateritic layer with resistivity values ranging from 351 - 16887  $\Omega\text{m}$  (the zone with extremely high resistivity values lies directly beneath the cassava processing centre) with thicknesses greater than 15 m. The third layer (in green colour) corresponds to the weathered layer with resistivity values ranging from 391 - 1298  $\Omega\text{m}$ . The structure images the cassava effluent-impacted zone between stations 9.5 and 12 (in blue colour) with relatively low resistivity values ranging from 94 to 220  $\Omega\text{m}$  and depth extent of maximum of about 2.5 m.

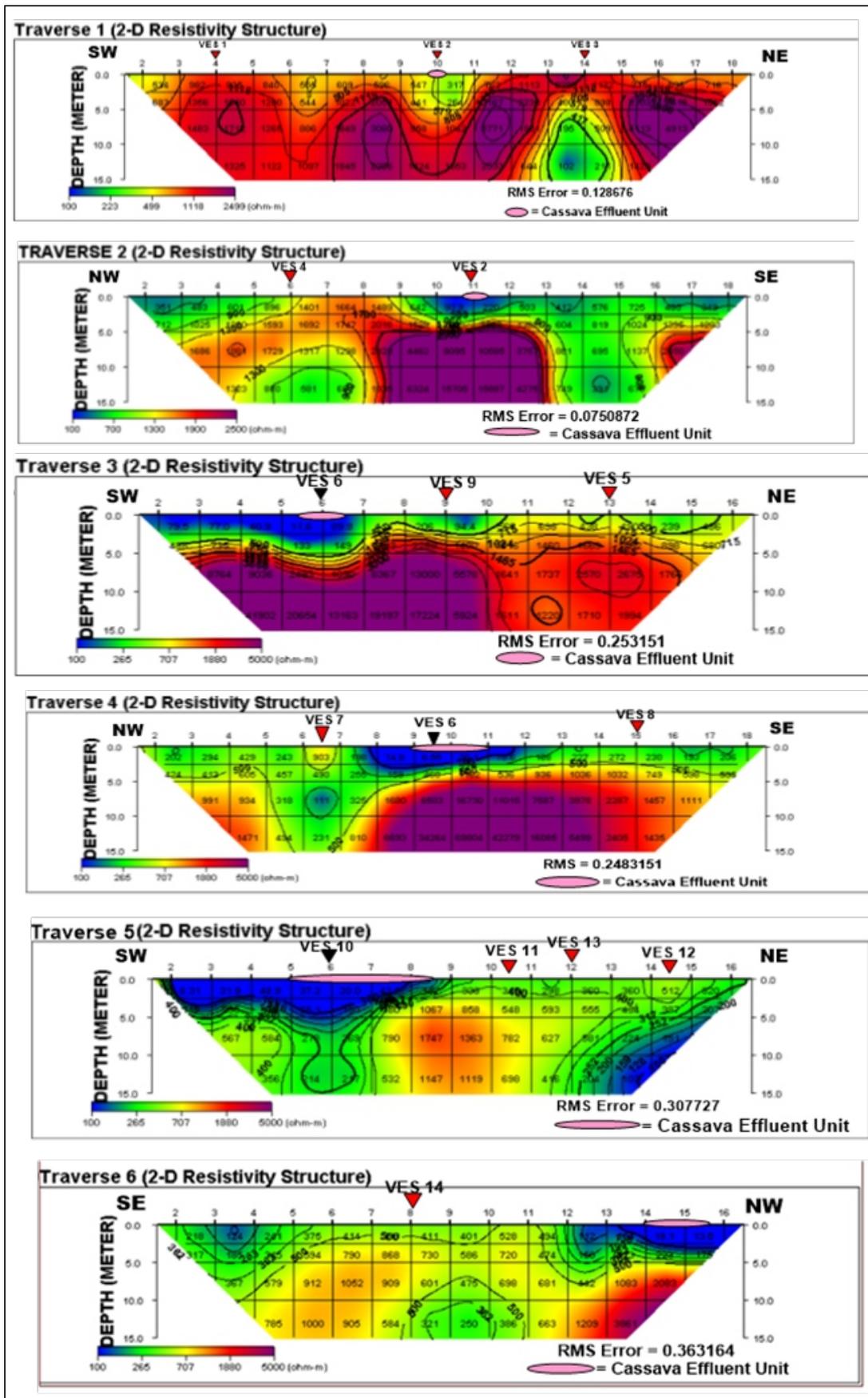


Fig 6: 2-D Resistivity Structure along Traverses 1, 2, 3, 4, 5, and 6

## 2-D Dipole-Dipole Images at Site 2

### 2-D Resistivity Image beneath Traverse 3

The 2-D resistivity structure beneath Traverse 3 (Figs. 4c & 6c) images the upper 15 m of the subsurface sequence. The topsoil (in blue/green colour) has variable resistivity values ranging from 94 to 466  $\Omega\text{m}$  and thickness of < 2.5 m. The resistivity values of the second layer (laterite) appear to have merged with that of the third layer (weathered layer). The lateritic/weathered layer (in green/ yellow colour) resistivity values range from 133 - 898  $\Omega\text{m}$  and with a combined thickness ranging from 2 - 5 m. The forth layer (in red/purple colour) corresponds to the fresh basement with resistivity values ranging from 1460 - 20654  $\Omega\text{m}$ . The structure images the cassava effluent-impacted zone (in blue colour) as relatively low resistivity zone (12 – 90  $\Omega\text{m}$ ) with the first boundary at station 7 and the second boundary beyond station 0. The depth extent of the suspected impacted zone ranges from 2.0 – 3.5 m.

### 2-D Resistivity Image beneath Traverse 4

The 2-D resistivity structure images the upper 15 m of the subsurface sequence (Figs. 4c & 6d). The topsoil (in blue/green colour) has resistivity values ranging from 15 to 505  $\Omega\text{m}$  and thickness of < 1.0 m. The resistivity values of the second layer (laterite) appear to have merged with that of the third layer (weathered layer). The lateritic/weathered layer (green/yellow colour) resistivity values range from 457 - 1036  $\Omega\text{m}$  with thickness ranging from 2 to 6 m. The forth layer (in red/ purple colour) corresponds to the fresh basement with resistivity values ranging from 991 - 69804  $\Omega\text{m}$ . The structure images the cassava effluent-impacted zone (in blue colour) as relatively low resistivity zone (7 – 79  $\Omega\text{m}$ ) between stations 7.5 and 12.5. The depth extent of the suspected impacted zone ranges from 2.0 – 4.0 m.

## 2-D Dipole-Dipole Images at Site 3

### 2-D Resistivity Image Beneath Traverse 5

The 2-D resistivity structure images the upper 15 m of the subsurface sequence (Figs.4b & 6e). The topsoil (in blue/green colour) has variable

resistivity values ranging from 6 to 593  $\Omega\text{m}$  and thicknesses of < 2.0 m. The resistivity of the second layer (laterite) seems to have merged with that of the third layer (weathered layer). The lateritic/weathered layer (in green/yellow/red colour) has resistivity values ranging from 100 - 1747  $\Omega\text{m}$  and a combined thickness of up to 12 m. The structure images the cassava effluent pollution plume (in blue colour) as a relatively low resistivity zone (6 – 68  $\Omega\text{m}$ ) between stations 1.5 and 8.5. The depth extent of the impacted zone ranges from 2.0 – 6.0 m.

### 2-D Resistivity Image beneath Traverse 6

The 2-D resistivity structure images the upper 15 m of the subsurface sequence (Figs. 4b & 6f).The topsoil (in blue/green colour) has variable resistivity values ranging from 124 to 494  $\Omega\text{m}$  and thicknesses of < 3.0 m. The second layer (in yellow/red colour) corresponds to the lateritic layer with resistivity values ranging from 500 - 3861  $\Omega\text{m}$  and thickness ranging from 5 - 13 m. The third layer (in green colour) corresponds to the weathered layer with resistivity values ranging from 250 - 500  $\Omega\text{m}$ . The structure images the cassava effluent pollution plume (in blue colour) as a relatively low resistive zone (14 -112  $\Omega\text{m}$ ) which begins from station 12 and extends beyond station 16. The depth extent of the plume ranges from 2.0 – 4.0 m.

## Hydrochemical Analysis Result

The results of the geochemical analyses (Table 2) were compared with the World Health Organization (WHO) drinking water standards (2006). The well waters are slightly acidic (pH: 6.52-6.85) but within WHO (2006) maximum permissible level of 6.5-9.5 pH range while the cassava effluent is very acidic with pH value of 4.2. For both well waters, the physico-chemical parameters are below WHO (2006) highest desirable/maximum permissible levels (see Table 2), indicating the waters are unpolluted and potable. However, the cassava effluent, apart from being very acidic has relatively high conductivity of 1540 $\mu\text{s}/\text{Cm}$ (or relatively low resistivity of about 6.5  $\Omega\text{m}$ ) and contains 0.8 mg/L of cyanide and relatively high TDS of 924 mg/L which makes the effluent toxic.

Table 2: Hydrochemical Analysis Result of the Cassava Effluent and the Two Well Water Samples collected at the Cassava Processing Unit 3; and the WHO Drinking Water Standards (2006)

S/ N	Physicochemical Parameters	Cassava Effluent	Downstream Well (W2)	Upstream Well (W1)	WHO Drinking Water Standards (2006)	
		694840mE 845960mN 383 m	694793 mE 845911 mN 381 m	694871 mE 846000 mN 386 m	Highest Desirable Level	Maximum Permissible Level
1	Temperature, °C	26.9	27.4	26.8		
2	pH	4.2	6.85	6.52	7.0 – 8.5	6.5 - 9.5
3	TDS, mg/L	924	18.0	4.5	500	1000
4	Electrical Conductivity, $\mu\text{S}/\text{cm}$	1540	31.3	7.48		1480
5	Cyanide, mg/L	0.8	ND	ND		0.07
6	Total Hardness, mg/L		72.6	80.7	100	200
7	Carbonate ( $\text{CaCO}_3$ ), mg/L		0.07	0.02	100	500
8	Acidity, mg/L		0.1	0.6		
9	Alkalinity, mg/L		0.8	0.1	100	
10	Calcium ( $\text{Ca}^{2+}$ ), mg/L		58.80	1.10	75	200
11	Magnesium ( $\text{Mg}^{2+}$ ), mg/L		1.94	0.85	50	150
12	Sodium ( $\text{Na}^+$ ), mg/L		3.40	1.60	175	200
13	Potassium ( $\text{K}^+$ ), mg/L		4.88	0.53	13.48	100
14	Iron ( $\text{Fe}^{2+}$ ), mg/L		0.14	0.10	0.3	1.0
15	Chloride ( $\text{Cl}^-$ ), mg/L		17.80	27.60	200	600
16	Manganese ( $\text{Mn}^{2+}$ ), mg/L		ND	ND	0.05	0.5
17	Nitrate ( $\text{NO}_3^-$ ), mg/L		0.2	0.5	45	50
18	Sulphate ( $\text{SO}_4^{2-}$ ), mg/L		1.2	1.5	200	400
19	Phosphate ( $\text{PO}_4^{3-}$ ), mg/L		0.3	0.4	50	

ND = Not Detected

WHO = World Health Organisation

## DISCUSSION OF RESULTS

An electrical conductivity value of  $1540\mu\text{Scm}^{-1}$  was obtained for raw cassava effluent sample. This value corresponds to a low resistivity value of  $6.5\ \Omega\text{m}$  suggesting that a cassava effluent impacted soil/subsoil should display anomalously low resistivity values.

The geoelectric sections revealed that the topsoil beneath VES stations directly located on cassava-effluent dumping units have relatively low resistivity values ( $162\ \Omega\text{m}$  beneath VES 2 at site 1 (Fig. 5a);  $8\ \Omega\text{m}$  beneath VES 6 at site 2 (Fig. 5b); and  $95\ \Omega\text{m}$  beneath VES 10 at site 3 (Fig. 5c)).

The 2-D resistivity structures (Figs. 6a – f) also confirm that the topsoil and the underlying lateritic layer at zones beneath and around the cassava-effluent dumping sites (in pink colour) down to depth of about 6 m are characterised by anomalously low resistivity values ( $12 - 90\ \Omega\text{m}$  beneath Traverse 3 (Fig. 6c);  $7 - 79\ \Omega\text{m}$  beneath Traverse 4 (Fig. 6d);  $6 - 68\ \Omega\text{m}$  beneath Traverse 5 (Fig. 6e); and  $14 - 112\ \Omega\text{m}$  beneath Traverse 6 (Fig. 6f)).

The lateral and vertical migration of the pollution plumes in the soil/subsoil along the six (6) traverses was revealed by the 2-D resistivity images (Figs. 6a – f). At the Cassava Processing Factory Site 1 (1 year old), the suspected pollution plume along Traverse 1 (Fig. 6a) is between stations 9.3 and 11.3 (about 10 m). However along Traverse 2 (Fig. 6b), the delineated suspected impacted zone is between stations 9.5 and 12.5 with a maximum depth extent of about 2.5 m. The pollution plume has a maximum width extent of 10 m at this Site. At the Processing Site 2 (13 years old), the pollution plume along Traverse 3 (Fig. 6c) has its first boundary at station 7, and may have migrated beyond station 0 ( $> 35\ \text{m}$ ) towards the southwestern direction. The maximum depth extent of the plume is about 3.0 m. The pollution plume along Traverse 4 (Fig. 6d) is between stations 7.5 and 12.5 with a maximum depth extent of about 3.0 m. The pollution plume has a maximum width extent of 27 m at this Site.

At the Processing Site 3 (established 20 years ago), the pollution plume along Traverse 5 (Fig. 6e) has its boundaries at stations 8.5 and 1.5 (about 35 m) with a depth extent of up to 6 m. Beneath Traverse

6 (Fig. 6f). The pollution plume has one of its boundaries at station 12, but has extended beyond station 18 ( $> 30$  m) (Fig. 4.13) with a depth extent of up to 4.0 m. The pollution plume has a maximum width extent of 35 m at this Site.

It was however revealed by the geoelectric sections (Figs. 5a–c) and 2-D resistivity structures (Figs. 6a–f) beneath the six (6) traverses that the topsoil in the study area is generally underlain by thick layer of laterite which is up to about 12.2 m thick at some locations. This thick impervious lateritic layer (which is characterised by low permeability) has the capacity to impede the downward migration of the pollution plumes and could explain the reason why the hydrochemical analysis conducted on water samples collected from two wells located within the vicinity of the oldest cassava processing site (one at the upstream direction with Static Water Level of 9.5 m and the other at the downstream direction with Static Water Level (SWL) of 7.0 m) show no traces of groundwater contamination. This is an indication that water from all other wells in the community will also be safe for drinking as at the time of the investigation.

The ages of the three cassava processing factories (Table 3) were plotted against the mean depth extents of the pollution plumes (Fig. 7) and empirical relationship (Eq. 1) was established. The equation shows that the depth extents of the pollution plume increases with increasing age of factories.

$$Y = 6.4286X - 11.167 \quad (1)$$

Where Y is Age of Factories and X is Depth Extent.

However, the depth migration rate of 2.5 m per year (Table 3) at the cassava processing site 1 (one year old) seems much higher than expected and may have been influenced by the effluent pit that was dug at the site (Fig. 4d). The depth migration rates of 0.23 m/year and 0.25 m/year of the pollution plumes at processing sites 2 and 3 are more realistic. A regression line fitted through data from sites 2 and 3 gives a linear equation:

$$Y = 4.0882X \quad (2)$$

with a correlation coefficient,  $R = 0.998$  and an intercept at the origin. This is more realistic since at age 0 pollution depth extent should also be 0.

If an average SWL of 8.25 m below the ground level is assumed within the vicinity of the factory site 3 (established 20 years ago), with an average migration rate of 0.24 m/year, it will take about 34 years (from the inception of the factory) using equation 2, for the cassava effluent pollution plume to reach the level of the Static Water Level and pollute the groundwater. This explains the reason why the groundwater in the vicinity of the cassava processing units has not been polluted.

## CONCLUSION

Integrated geophysical and hydrochemical investigations were carried out within the vicinity of three cassava processing factory sites at Irete-Ayo Community in Ilesha, Southwestern Nigeria as a means of assessing the impact of the cassava effluent on the soil/subsoil and the groundwater quality within the study area. The results of the geoelectric investigation indicate that the topsoil at and around the cassava effluent dumping units within the vicinity of the three cassava processing factory sites has relatively low resistivity values (6–112  $\Omega$ m) diagnostic of the cassava effluent impacted zones. The cassava effluent is characterized by relatively low resistivity value (6.5  $\Omega$ m). The pollution plumes have depth extents that range from 2.5 m to 5 m. This depth extent may have been limited by the relatively thick (up to 12.2 m) column of low permeability laterite which may have acted as a natural filter. The estimated migration rate is about 0.24 m/year.

All the physicochemical parameters of the two analyzed well water samples are below the WHO maximum permissible standards for drinking water, indicating that the groundwater within the study area has not been polluted by the effluent generated by the cassava processing activities. However, the subsoils up to depth of about 5 m have been polluted by the cassava effluent.

Table 3: Estimated Depth Extents of Cassava Effluent Plume at the three Processing Factory Sites.

Factory	Factory Age (year)	Traverse	Pollution Plume Depth Extent (m)		Depth Migration Rate Per Site (m/year)
			Depth Extent Per Traverse (m)	Mean Depth Extent Per Site (m)	
1	1	1	-	2.5	2.5 *
		2	2.5		
2	13	3	3	3	0.23
		4	3		
3	20	5	6	5	0.25
		6	4		

\*: Abnormal Migration Rate

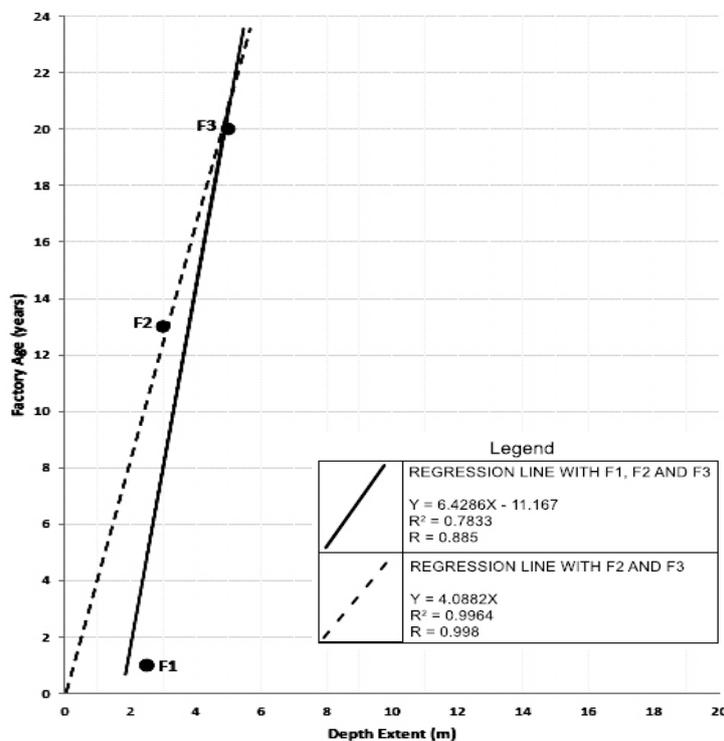


Fig. 7: Graph of the Factory Ages (year) Against the Pollution Plume Depth Extent (m)

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