

Application of Geophysical and Geochemical Approach to Environmental Impact Assessment around Cassava Mills in Western Niger Delta, Nigeria

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Date Received: 09-01-2023

Date Accepted: 29-04-2023

DOI: <https://doi.org/10.48198/NJPAS/23.A06>

ABSTRACT

Cassava mill effluent (CME) contains a significant concentration of different hazardous inorganic components, especially cyanide (CN), which can result in environmental problems. This study seeks to evaluate the impacts of CME on groundwater around Eku. A 2D electrical resistivity survey, geochemical analysis and groundwater modelling were adopted for this study. The Zones impacted by CME imaged by the inverted resistivity structure were distinguished by low resistivity ranging between 0.46 – 21.05 Ω m. Geochemical analysis of CME indicated high concentrations of Total Dissolved Solids (TDS), Electrical Conductivity (EC), CN, and heavy metal components and have the capability to contaminate surrounding groundwater. The groundwater model showed flow in the Southeast – Northwest (SE – NW) direction with a velocity of 54.24 m/year. The pH value, the concentration of CN, TDS, EC, and heavy metals in groundwater samples, when compared with the WHO drinking standard, revealed that groundwater in only one hand dug well about 20 m away from a cassava mill indicated a significant degree of contamination. A pattern of decreasing CN concentration with distance from the mill was observed in groundwater; areas with CN concentration greater than 0.2 mg/l after 1 year was 30 m away from the cassava mill but extended to about 75 m after 5 years.

Keywords: Cassava mill effluent, groundwater model, resistivity, cyanide, heavy metals

Introduction

Several communities in the central portion of Delta State are noted for cassava processing which is the fourth largest staple food in Southern Nigeria. These communities have several cassava randomly sited processing mills. Cassava requires processing before consumption due to lethal cyanogenic glucosides that are deleterious to the environment (Padmaja, 1995). Processing of cassava usually involves grinding and fermentation, which generate large volumes of CME (Izah *et al.* 2017).

The collection of these cassava mill effluents (CMEs) need to be adequately managed, however, most disposal sites are open, thus creating severe threats to the environment. Leachate from CMEs can be inorganic chemical constituents comparable to those from landfills; they contain highly toxic substances that often are indiscriminately released in untreated form into the immediate environment, thus contaminating the subsurface and may pollute groundwater indirectly through infiltration.

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Most groundwater supplies in the western Niger Delta come from mostly shallow and unconfined aquifers made up of loose sandy materials. Threats to groundwater from these uncontrolled disposals from cassava mills exist in several parts of the western Niger Delta, where these hazardous wastes are disposed of without adequate protection for the aquifer. Pollutants from these randomly sited cassava mills most often infiltrate the vadose zone and substantially pollute the groundwater beneath. According to MacDonald *et al.* (2012), leachates are the worst-known source of shallow groundwater contamination. Several studies have indicated the presence of leachate in groundwater within the vicinity of disposal sites in the western Niger Delta. Obueh and Odesiri (2016) noted that incessant disposal of CME into the soil changes the microbiological, mineral, and physicochemical compositions of the soil environment surrounding the mills. The CMEs may also migrate to other places depending on the hydraulic conductivity of the geologic material. According to Nwakauda *et al.* (2012), Igbinosa and Igiehon, (2015); Igbinosa, (2015) the presence of heavy metals like Fe, Zn, Mn, Al, Pb and Cu were significantly higher in soils around cassava mills. Osakwe (2012) also noted that CME decreased soil pH and led to higher levels of available phosphorus, total organic carbon, total nitrogen, electrical conductivity, and cation exchange capacity of the soils.

Electrical resistivity technique is a non-invasive means of delineating contaminant plumes from the point source because leachate diminishes the resistivity of the strata that contains them (Aweto, 2017). While the use of electrical resistivity and geochemical investigations in delineating CME in the Niger Delta is limited. The use of 2D electrical resistivity in mapping subsurface lithology, contaminant plume, and hydrogeochemical analysis in assessing the physicochemical parameters in the area(s) suspected to be contaminated with organic and inorganic substances have been carried out by numerous researchers. They include Amidu and Olayinka,

2006; Atakpo *et al.*, 2011; Akoteyon *et al.*, 2011; Bayowa *et al.*, 2012; Orakwe, 2016; Adigun and Olorunfemi, 2017; Olawale *et al.*, 2020. This study intends to investigate the impact of CMEs on the soil/subsoil and the groundwater using geophysical and geochemical methods and groundwater modeling.

Materials and Methods

Location and Geology of the Study Area

The study area, Eku is located within longitudes 5°58' E and 6°00' E and latitudes 5°44' N and 5°45' N. The lithostratigraphic framework of the Cenozoic Niger Delta includes three major units: Akata, Agbada and Benin Formations. The Akata Formation is made up of shales while the Agbada Formation is made up of shales and sandy sequence. The Benin Formation is indistinguishable from the younger Holocene deposits of the Sombreiro – Warri Deltaic Plain (SWDP), which is between 40 – 150m. thick. The SWDP deposits consist of fine to medium-grained sands, coarse sands, silts and thin discontinuous clay layers that merge conformably below the surface with the sands and gravels of the Benin Formation. The Benin Formation and the Sombreiro – Warri Deltaic plain deposits represent the aquifers in the Niger Delta basin. (Aweto, 2019).

2D Geophysical Technique

A 2D resistivity technique using Wenner array was conducted at five (5) sites around cassava mills using ABEM SAS 1000 Terameter. Electrode spacing of $a = 3$ m, 5 m and 15 m were used for the profiles, while the "n" factor was increased progressively from 1 to 2 and then up to 3 so as to increase the depth of investigation (Aweto, 2017; Ohwoghere-Asuma *et al.*, 2020). The acquired resistivity data were analyzed and interpreted using the RES2DINV program, to produce a 2D image/structure beneath the surface from the measured resistivity data.

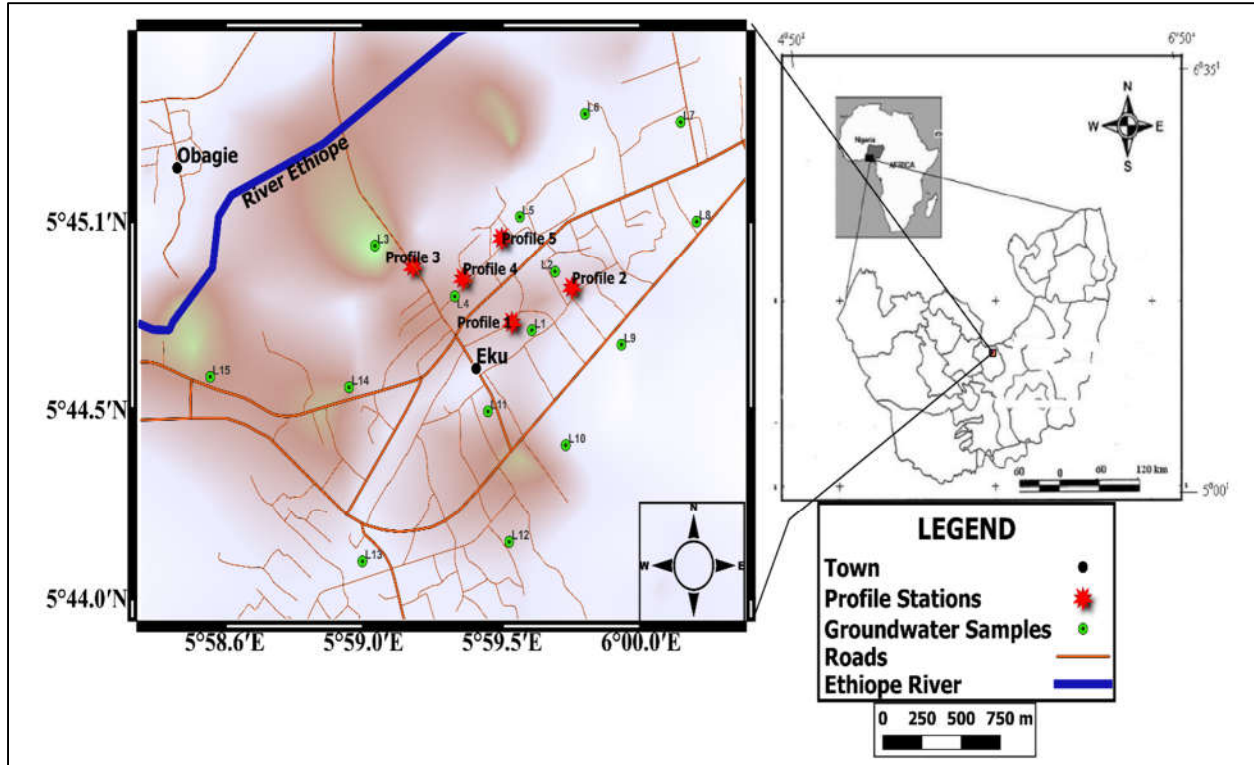


Fig. 1: Map of study area showing groundwater sampling and 2 D profiles locations

Geochemical Analysis

Leachates were taken at five (5) cassava processing mills within Eku (Fig. 1). The leachate samples were collected from a depth of 0.6 m at the cassava mills. Fifteen (15) groundwater samples were also taken from hand-dug wells close to the cassava mills and at other locations as control (Fig. 1). The pH, EC and TDS were measured in-situ using a Schott Gerate model pH meter and HACH Conductivity/TDS meters respectively. The samples collected were digested and examined in the Laboratory to test for; cyanide (CN), zinc (Zn), copper (Cu), lead (Pb), manganese (Mn), cadmium (Cd) and iron (Fe). The samples were analyzed using Atomic Absorption Spectrophotometry (AAS) by methods described by APHA (2011).

Groundwater Flow

The groundwater flow direction of the study area was simulated using the MODFLOW package, which performs both steady-state and transient

analyses. The x, y and z coordinates for gridding were estimated from the Digital Elevation Model (DEM) of the study area, and calibration was done with ten (10) heads measured from wells.

Solute Transport

As contaminants flow through a pervious medium, there is dilution of the contaminant by a process called dispersion. If the concentration at a point source is C_0 then the concentration, C after time, t at distance, L from the source as given by Ogata (1970) is shown in the equation 1 below:

$$C = \frac{C_0}{2} \left[\operatorname{erfc} \left(\frac{L - V_x t}{2\sqrt{D_L t}} \right) + \exp \left(\frac{V_x L}{D_L} \right) \operatorname{erfc} \left(\frac{L + V_x t}{2\sqrt{D_L t}} \right) \right] \dots \dots \dots (1)$$

Where erfc is the complementary error function,

D_L is longitudinal coefficient of dispersion, and

V_x is average linear velocity of groundwater.

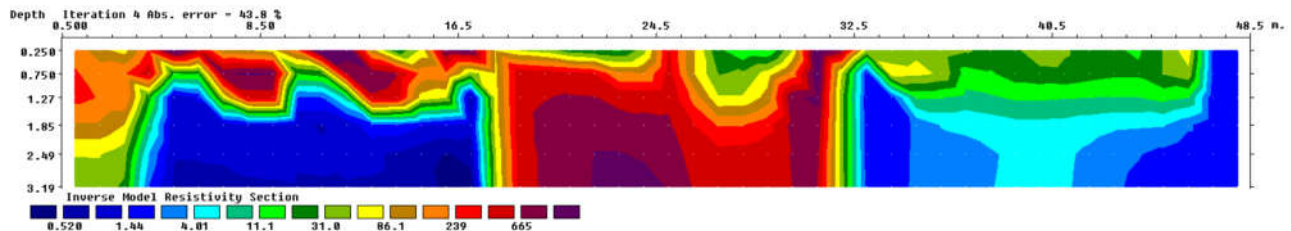
Equation 1 was used in this study to determine the concentration of cyanide in CME at distances away from the cassava mill with time

Results

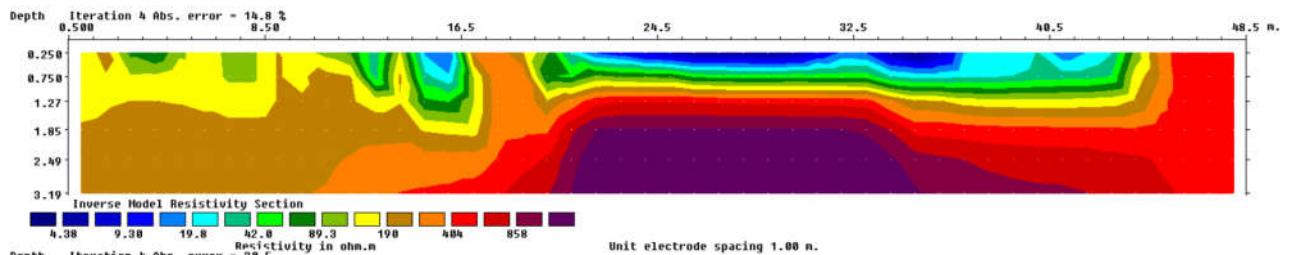
2D Resistivity Structure

The 2D resistivity structures obtained from the inversion of measured resistivity data are shown in Fig 3; zones impacted by CME was depicted by the inverted resistivity structure and were distinguished by low resistivity (depicted by shades of blue and green colour). In profile 1 (fig. 3a), zones impacted by CMEs lie between lateral distances 3.5 – 17 m and 32.5 – 48.5 m with relatively low resistivity values ranging from 0.46 – 31.0 Ωm. In profile 2 (fig. 3b), low resistive zones with a resistivity range of 2.19 – 30.9 Ωm

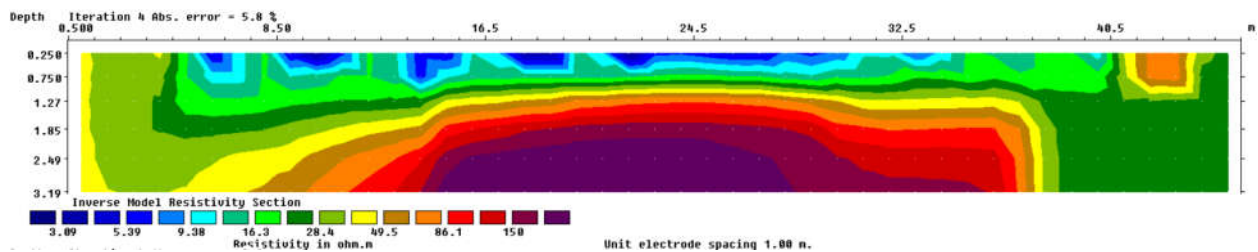
indicated the presence of the CME. They are found between a lateral distance of 11 – 16.5 m, 20 – 43 m and at a depth of up to 1 m. Profile 3 (fig. 3c) show only one zone impacted by CME from the mill; the zone is characterized by resistivity values of 1.15 – 28.4 Ωm. It is located between lateral distances of 4 – 40.5 m with a depth of 1.9 to greater than 3 m. The resistivity structure along profile 4 (fig. 3d) shows an area with low resistivity values of 1.16 – 38.3 Ωm indicative of a conductive medium and is suspected of having been impacted by cassava effluent. The low resistivity zone is between lateral distances of 18 – 48.5 m; the depth extent varies from 1.3 m to more than 3 m. The low resistivity zones correlated with the actual locations beneath waste pits.



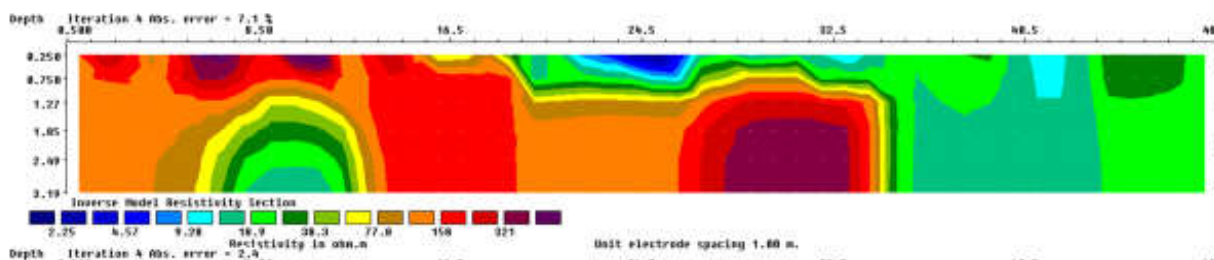
(a)



(b)



(c)



(d)

Fig. 2: 2D resistivity images at cassava mills in Eku.

The low resistivity zones coincided with the actual location of the cassava mills, with the zones invaded laterally ranging between 6 – 36 m. Resistivity values generally increase with depth, implying that the contaminant plume at the cassava mill is concentrated primarily in the topsoil. There is attenuation of the contaminant as it infiltrates into the groundwater. The extent of migration is limited because of age; profile 1 showed a greater extent of migration of CMEs, being the oldest. Under favourable hydrogeological conditions, the plumes will slowly migrate into the aquifer with time.

Physiochemical Characteristics of CME and Groundwater Samples

The geochemical analyses presented in Table 1 show that pH in CME at Eku ranged from 3.1 to 4.5; Izah *et al.* (2017) reported pH values less than 5.0 in CME. The pH of the effluent indicated it was acidic, and this was due to high hydrogen cyanide (HCN) content in the CME. Total Dissolved Solids (TDS) ranged from 6800 – 15100 mg/l; EC ranged from 5275 – 30300 $\mu\text{S}/\text{cm}$ while CN values ranged from 3.14 – 29.31 mg/l. The results for heavy metals in CME show a variation of between 0.81 – 4.47 mg/l, 1.01 – 3.82 mg/l, 0.95 – 7.35 mg/l; 0.3 – 2.17 mg/l; 0.52 – 8.84 mg/l and 0.02 – 1.01 mg/l for Zn, Cu, Mn, Pb, Fe and Cd. All samples of CMEs analyzed had high concentrations of TDS, EC, cyanide, and heavy metal components; this is an indication that the

CME has the capability to contaminate surrounding groundwater. The abundance of Mn, Pb and Fe in groundwater could be attributed to the abrasion of cassava machinery parts; these metals are used in making parts of the machinery used in cassava mills and may find their way into the CME via wears and tears as the machine is used. The low pH has also affected metals' solubility, resulting in an approximately two-fold increase in metal content. Nwakauda *et al.* (2012), Igbinsosa and Igiehon (2015), and Igbinsosa (2015) reported similar high concentrations of heavy metals in CME in southern parts of Nigeria.

The levels of chemical parameters in groundwater samples was lesser in magnitude than those found in the CMEs. The pH values for groundwater ranged from 4.7 – 7.1; TDS and EC values were 13 – 223 mg/l and 29 – 446 $\mu\text{S}/\text{cm}$, respectively; the pH values indicate mostly acidic groundwater. The acidic nature of groundwater may not be entirely related to CME discharge; according to Eto-Efeotor and Odigi (1983), low pH in groundwater is a primary attribute of shallow aquifers in the Niger Delta. Values of CN in groundwater samples were below detectable limits except at a shallow hand-dug well about 20 m away from a cassava mill, where the value was 0.2 mg/l. Furthermore, heavy metals depicted values for Zn (0.00 – 0.83 mg/l), Cu (0.0008 – 0.5 mg/l), Mn (0.002 – 0.14 mg/l), Pb (0.00 – 0.03 mg/l), Fe (0.00 – 0.45 mg/l) and Cd (0.00 – 0.005 mg/l). Comparing these results with guidelines set by

World Health Organization (WHO) shows that most parameters indicated values within stipulated

limits except for Mn, Pb and Fe at locations 2 and 3.

Table 1: Physiochemical parameters and Heavy metals concentrations in CME and groundwater samples

Parameters	pH	TDS	EC	CN	Zn	Cu	Mn	Pb	Fe	Cd
CME1	3.1	10120	30300	29.31	4.47	3.82	3.37	0.30	0.74	0.31
CME2	4.3	6800	13600	11.94	1.23	2.12	5.51	0.45	0.81	0.15
CME3	3.2	15100	17400	28.00	2.12	3.31	0.95	0.78	0.52	1.01
CME4	3.7	9365	15832	21.84	0.81	3.35	6.32	2.17	8.84	0.21
CME5	4.5	7545	5275	3.14	0.89	1.01	7.35	0.54	0.91	0.02
1	6.5	20	39	0.00	0.02	0.01	0.00	0.00	0.002	0.00
2	4.7	223	446	0.20	0.08	0.03	0.14	0.011	0.45	0.005
3	5.8	94	188	0.00	0.10	0.01	0.02	0.007	0.001	0.00
4	7.1	29	32	0.00	0.00	0.5	0.00	0.002	0.00	0.00
5	5.2	107	48	0.00	0.03	0.008	0.01	0.03	0.002	0.00
6	5.4	120	241	0.00	0.11	0.042	0.07	0.007	0.32	0.00
7	7.0	118	94	0.00	0.83	0.05	0.015	0.00	0.00	0.002
8	5.9	45	98	0.00	0.22	0.20	0.05	0.00	0.013	0.001
9	6.1	57	115	0.00	0.18	0.15	0.08	0.003	0.02	0.00
10	5.9	15	29	0.00	0.001	0.00	0.00	0.00	0.01	0.00
11	6.3	185	352	0.00	0.16	0.09	0.08	0.003	0.02	0.00
12	6.1	31	64	0.00	0.09	0.11	0.015	0.0001	0.03	0.00
13	4.6	13	37	0.00	0.10	0.07	0.002	0.00	0.35	0.001
14	6.9	32	58	0.00	0.31	0.025	0.04	0.003	0.05	0.00
15	6.6	77	148	0.00	0.09	0.021	0.03	0.00	0.40	0.00
16	6.4	74	115	0.00	0.035	0.00	0.00	0.004	0.10	0.0025
WHO	6.5 – 8.5	500	1000	0.2	4.0	2.0	0.10	0.01	0.30	0.003

Notes: CME – Cassava mill effluent collected from the waste pit. WHO – World Health Organization drinking water standard

Groundwater in a hand-dug well (location 3) about 20 m away from a cassava mill indicated the occurrence of Mn, Pb and Fe at concentrations of 0.14 mg/l, 0.011 mg/l and 0.45 mg/l. The concentration of these heavy metals was above the WHO requirements; the abundance of Mn, Pb and Fe in groundwater could be attributed to the impact of CME. The occurrence of Fe in other locations void of cassava processing mills (locations 6, 13 & 15) indicates that the source may not be solely linked with CME. Another plausible reason for the high Fe content can be related geology of the area. According to Etu-Efeotor (1981), the source of iron can be adduced to the leaching of Fe^{2+} into the groundwater from iron-bearing minerals such as hematite, limonite and goethite that are abundant within sediments of the deltaic plain sands underlying the study area. High iron may also be probably due to acid solubilization under the prevailing acidic conditions of the soils in the Niger Delta (Amajor, 1985). Groundwater in Niger Delta tends to have more concentrations of heavy metals such as; lead, iron, cadmium, manganese and copper as acid rain readily leaches

potentially toxic metals from soils, transferring them to groundwater supplies. Ohwohere-Asuma *et al.* (2020) highlighted the high content of Fe in groundwater, consequently leading to the abandoning of many boreholes in the Niger Delta.

Groundwater flow model

Groundwater heads from the model of the study area ranged from 5.50 – 9.68 m, as shown in fig 3. Groundwater flow in a SE – NW direction towards the Ethiopie River with a velocity of 0.1485m/day (54.24 m/year). This value is similar to 53.46 m/year in the Niger Delta observed by Agharanya and Chidozie (2018). The aquifer in the area is recharged mainly by rainfall; from the model, the groundwater infiltrates downward and changes its direction towards the river as it infiltrates deeper into the layers. The cassava mill at profile 3 releases effluent with CN concentration of 28 mg/l. Groundwater model for a stress period of 1 year (fig. 4a) showed that at distances 10 m, 20 m, 25 m and 30 m, the CN concentration in groundwater at location 2 were 9.92 mg/l, 0.69 mg/l, 0.1 mg/l and 0.02 mg/l respectively.

However, after 5 years, the model (fig. 4b) showed that the concentration of CN in groundwater at 10 m, 20 m, 30 m, 40 m, 60 m, 70 m and 80 m to be 19.1 mg/l, -, 12.4 mg/l, 6.12 mg/l, 2.3 mg/l, 0.67 mg/l, 0.016 mg/l and 0.01 mg/l.

A pattern of decreasing CN concentration with distance was observed in groundwater; the decreasing concentration of the CN with distance

away from the cassava mills explains the attenuation of the CN by natural filtration and hydrodynamic dispersion. However, a continuous source of CME will yield a plume that grows with time, as seen in fig. 4; areas with concentrations of CN greater than 0.2 mg/l after 1 year were 30 m away from the cassava mill but extended to about 75 m after 5 years.

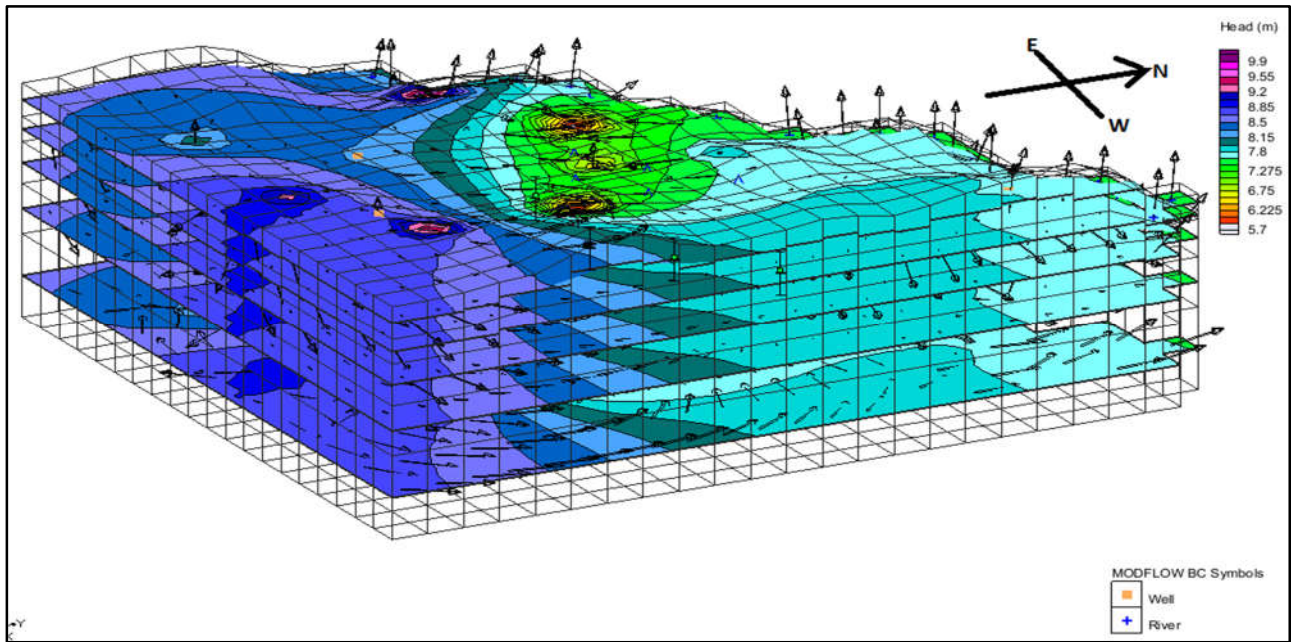


Fig. 3: Groundwater flow direction model at Eku.

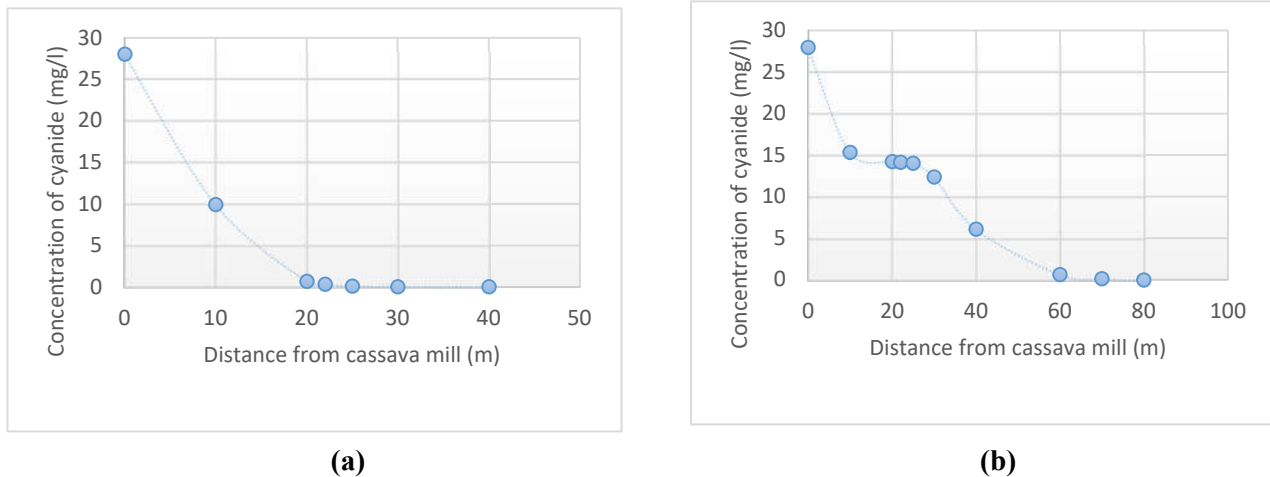


Fig. 4: Concentration of CN with distance from cassava mill after (a) 1 year (b) 5 years

Conclusion

The spread of CMEs in the aquifer at Eku has been shown by integrating 2D electrical resistivity, geochemical analyses and groundwater modelling. Electrical resistivity images showed a localized impact area by CME and infiltration through the vadose zone into the aquifer up to depths greater than 3 m. All samples of CME analyzed have high concentrations of TDS, EC, CN, and heavy metal components and thus have the potential to contaminate surrounding groundwater.

It was observed from groundwater models a pattern of decreasing CN concentration with distance due to attenuation and hydrodynamic dispersion that grew with time. Groundwater within the distance of 80 m away from cassava mills is unsafe; hence remediation processes and preventive measures to the spread should be put in place, such as treating wastewater by bioremediation and siting of pumping wells at least 150 m away from the cassava mills.

The results of this study have shown that the groundwater has been affected by the CMEs in the area and this provides a gloomy prognosis for the future, which include the following: aquifer contamination that already exists will gradually spread, and groundwater not presently known not to be impacted by CMEs will become contaminated.

Conflict of interest

The author declared no competing interest.

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