

Geophysical and geochemical site investigation of eastern part of Lagos metropolis, southwestern Nigeria

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Abstract Geophysical and geochemical studies were carried out in the eastern part of Lagos metropolis to determine the possible contamination of subsurface soils and groundwater as a result of dumping of waste into the canal. The geophysical method involved the use of 2D electrical resistivity imaging which was acquired along five (5) traverses, while the geochemical method involved the physicochemical analysis of water samples from nine (9) wells within the study area. The geochemical study includes the analysis of physical parameters like total dissolved solids (TDS), electrical conductivity (EC), pH and temperature. Seventy elements which include trace elements (such as As, B, Ba, Cd, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, U and Zn), major cations (such as Ca, K, Mg and Na) and anions (Cl and Br) were analysed, and the concentrations of the elements were compared with the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) permissible level for drinking water. Geophysical results show that the lithology is composed of topsoil, clayey sand, peat and sand. 2D electrical resistivity tomography revealed that the leachate and polluted water from the canal have percolated to the subsurface soil down to a depth of about 37 m with low resistivity values of 1–13 Ω m. In addition to this, result of physicochemical analysis of water samples shows that Mn, Br, TDS, and EC were high in some wells, above the WHO and NSDWQ standard. It was deduced that the subsurface has been invaded by the polluted water from the canal consequently, making the groundwater unsuitable for human consumption.

Keywords Contamination · Geochemical analysis · Physicochemical analysis · Lithology · Electrical resistivity tomography · Leachate · Canal

Introduction

Groundwater is the prime source of water for domestic use. It is often unpolluted due to restricted movement of pollutants in the soil layers. However, shallow and permeable water table aquifers are most susceptible to contamination. Contamination of groundwater results in poor water quality, high cleanup costs, high costs for alternative water supplies and/or potential health problems. As worldwide extraction of groundwater is accelerated to meet increasing demand, the significance of chemical quality of groundwater also increases, relative to its economic value and usefulness (Adhikari et al. 2009).

Over the years, water especially in canals, rivers, lagoons and ocean has traditionally served as a means of waste disposal. One of the major challenges in Lagos state refuse disposal management is the dumping of waste generated by human activities into the numerous canals located in the state. The proliferation of urban settlements and slums in the city of Lagos has also meant increased generation of domestic waste, which eventually finds their way via drainages into the Lagos Lagoon. The lagoon receives a complex mixture of domestic and industrial waste via drainages and has served as the ultimate sink for the domestic sewage since the latter part of the nineteenth century (Oshisanya et al. 2011).

Electrical resistivity method is the most commonly applied geophysical method to identify contamination plumes. 2D electrical resistivity tomography (ERT) is now a well-established tool for environmental and engineering site investigation and is routinely applied to the detection of pollution (Daily et al. 1998; Goes and Meekes 2004), geologic characterization (Meads et al. 2003), engineered structures (Daily

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and Ramirez 2000) and hydrogeologic studies (Binley et al. 2002; Sandberg et al. 2002).

By examining the physical and chemical composition of groundwater, one can make predictions about the environment. Although natural weathering processes can take various trace elements into the subsurface groundwater, human activities such as indiscriminate dumping of waste materials also contribute to the gross groundwater pollution. During their transport, the trace metals undergo numerous changes in their speciation due to dissolution, precipitation, hydrolysis and redox processes (Samarghandi et al. 2007; Zvinowanda et al. 2009).

The Coker/Aguda canal is a typical Lagos canal characterized by both decomposable and non-decomposable waste materials (Fig. 1). As the waste decomposes, it mixes with water and finds its way into the aquifer, through the process of infiltration and can migrate from there to affect a very wide area.

This research work therefore seeks to determine the level of pollution to the subsurface and its hydrogeological units as a result of waste disposal into the canal.

The study area

The study area (Coker/Aguda Canal) is located in the southeastern part of Surulere within the Lagos metropolis, southwest Nigeria (Fig. 2). It lies within the geographical coordinates $6^{\circ} 30' - 6^{\circ} 50' 0''$ N and $3^{\circ} 35' - 3^{\circ} 21' 0''$ E and has an area extent of about 23 km². Surulere is densely populated with a population density of 21,864 inhabitants per square kilometre (Wikipedia 2011). This dense population has resulted to the generation of large volumes of waste (both domestic and industrial).

Geologically, the study area falls within the sedimentary basin of southwestern Nigeria popularly called the Dahomey Basin (Fig. 2). The Dahomey Basin constitutes part of the system of West African precratonic (marginal sag) basin

developed during the commencement of rifting, associated with the opening of the Gulf of Guinea in the early Cretaceous to late Jurassic. The Basin is very extensive and consists of Cretaceous Tertiary sedimentary sequence that thins out on the east and are partially cut off from the sediment of the Niger Delta Basin by the Okitipupa ridge. In general, rocky outcrops are poor due to the thick vegetation and soil cover. The knowledge of the geology of this basin had been improved through the availability of boreholes and recent road cuts. Major lithological sequences associated with the Basin are Abeokuta Formations (Ise, Afowo and Araromi Formations), and Ewekoro, Akinbo, Oshoshun, Ilaro and Benin Formations. The lithology is composed of loose sediment ranging from silt, clay and fine to coarse grained sand, called coastal plain sand. The exposed surface consists of poorly sorted sands with lenses of clays. The sands are in part cross-bedded and show transitional characteristics (Jones and Hockey 1964; Omatsola and Adegoke 1981; Agagu 1985; Enu 1990; Nton 2001).

Methods of study

Electrical resistivity method and hydrochemical analysis of water samples from wells and boreholes were used for the investigation of possible contamination of groundwater as a result of waste disposal into the canal. A detailed reconnaissance survey of the study area was carried out to determine site selection, line of survey, well selection, setting of the equipment and measurement parameters.

Geophysical method

A 2D electrical resistivity data were acquired using Super Sting R8 Earth Resistivity/IP metre along five traverses (Fig. 3) using a multi-electrode system. The ERT employed Wenner configuration with an inter-electrode spacing of 3 m and a maximum spread length of 249 m per profile. Traverses

Fig. 1 The Coker/Aguda canal characterized by both decomposable and non-decomposable waste materials



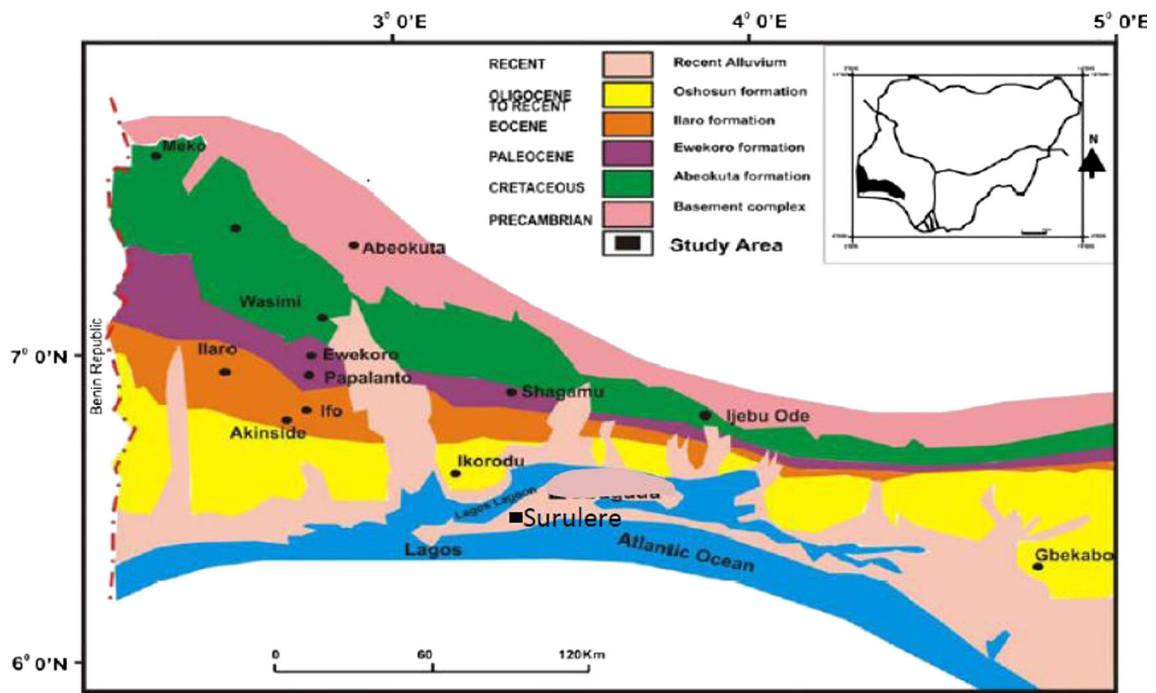


Fig. 2 Geological map of eastern Dahomey Basin showing the study area (modified after Billman 1992)

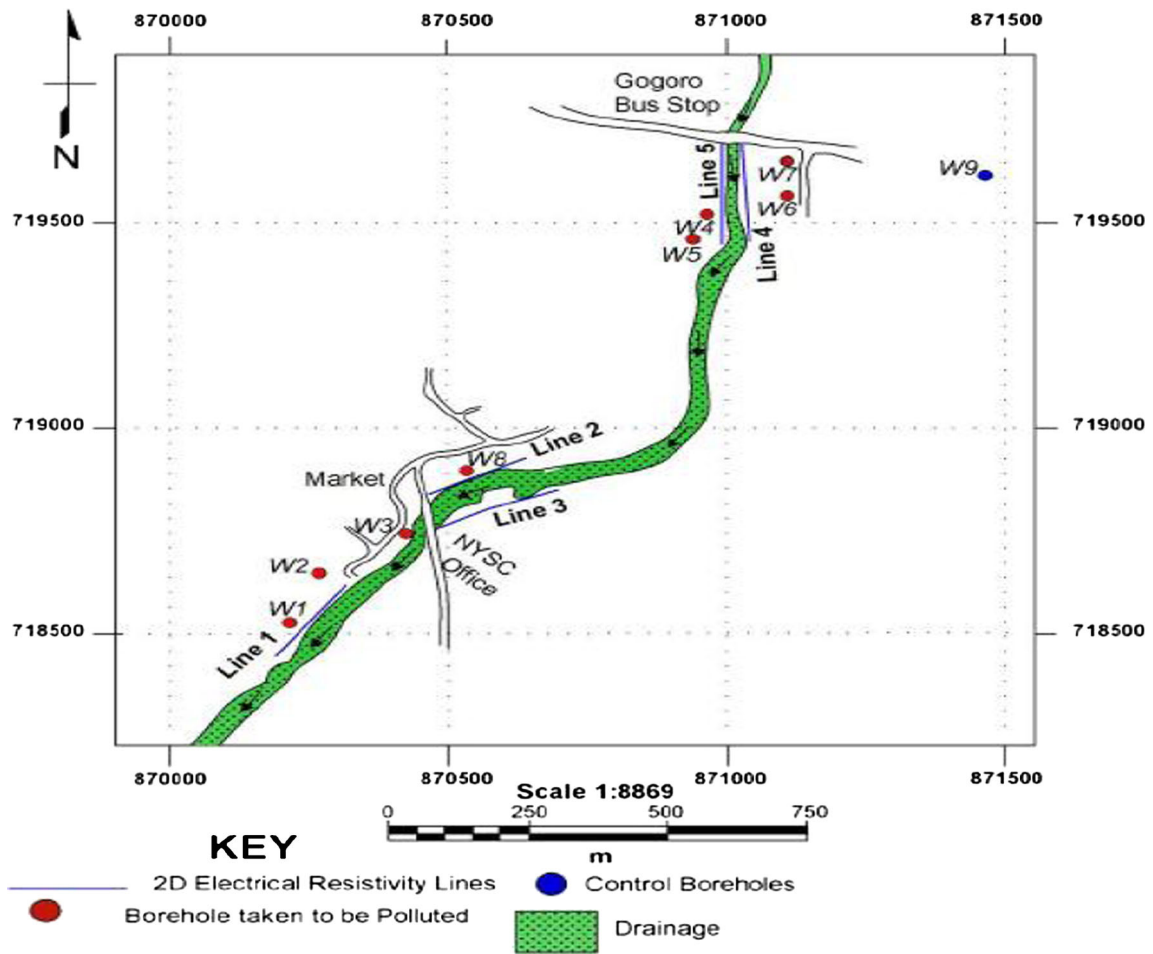


Fig. 3 Data acquisition map

1–3 were acquired in the northeast-southwest direction and are within the non-concretized area of the canal while traverses 4 and 5 were acquired in the north-south direction and within the concretized area of the canal (Fig. 3).

The 2D data were processed and inverted using the Earth Imager inversion algorithm. The algorithm calculates the apparent resistivity values using forward modelling subroutine (AGI 2003). It generates the inverted resistivity-depth image for each profile line based on an iterative smoothness constrained least-squares inversion algorithm (Loke and Barker 1996). Generally, the programme automatically creates a 2D model by dividing the subsurface into rectangular blocks (Loke and Barker 1996), and the resistivity of the model blocks was iteratively adjusted to reduce the difference between the measured and the calculated apparent resistivity values (a measure of this difference is given by the root mean squared (RMS) error). The apparent resistivity values were calculated by the finite-difference method. The program calculates the apparent resistivity values and compares these to the measured data for consistency (i.e. if the processed pseudosection varies significantly from the measured, then the forward model is assumed to be inaccurate, and the model is rejected). During iteration, the modelled resistivity values will be adjusted until the calculated apparent resistivity values of the model agree with the actual measurements. The iteration is stopped when the inversion process converges (i.e. when the RMS error either falls to acceptable limits, usually less than 5 %, or when the change between RMS errors for consecutive iterations becomes infinitesimally small).

However, the model with the lowest possible RMS error can sometimes show large and unrealistic variations in the model resistivity values and might not always be the “best” model from a geological perspective. In general, the most prudent approach is to choose the model at the iteration after which the RMS error does not change significantly.

Geochemical method

Nine water samples were collected for chemical analysis from wells and boreholes within the study area (Fig. 3). Eight water samples (W1–W8) were collected from hand-dug wells proximally located to the 2D resistivity lines, while a control water sample (W9) was collected from a borehole at a distance away from the drainage (Fig. 3). The water samples obtained from the different wells/borehole were well labelled in situ, prepared in accordance with standard practice and sent to ACME Laboratory, Vancouver, Canada, for analysis. Some in situ data collected on the water samples include conductivity (EC), total dissolved solids (TDS), pH, temperature (T).

Results and discussion

Electrical resistivity tomography results

The results of ERT for the five traverses are displayed as resistivity-depth sections (Figs. 4 and 5). Each of the five

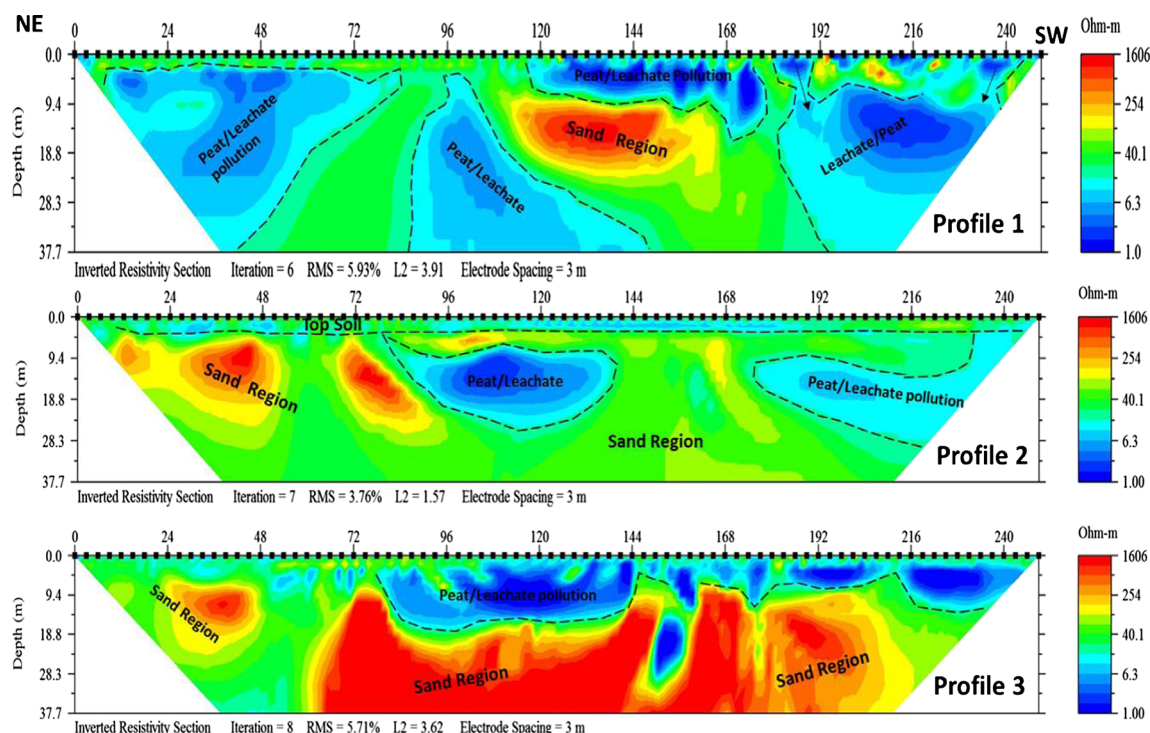


Fig. 4 The resistivity-depth models along the ERT lines for profiles 1–3

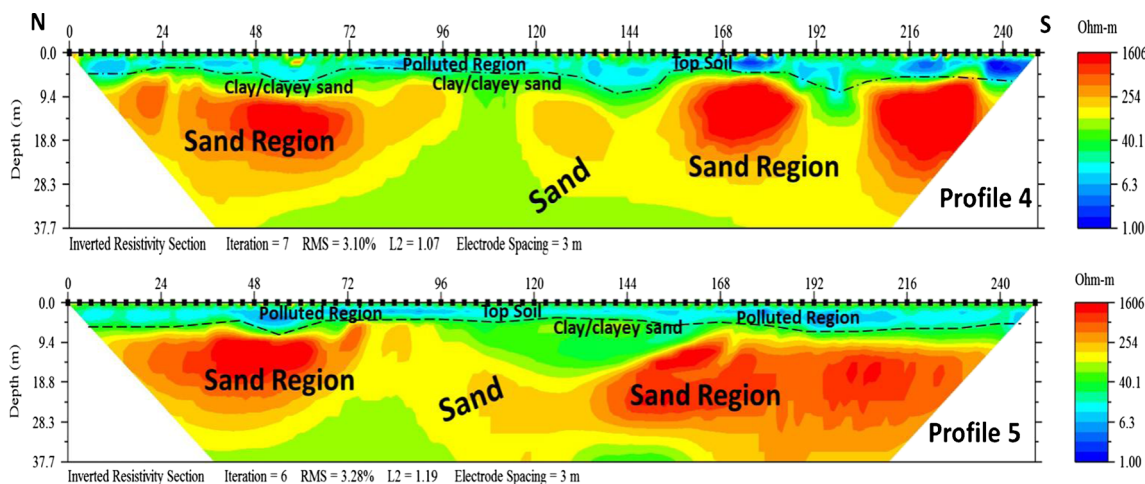


Fig. 5 The resistivity-depth models along the ERT lines for profiles 4 and 5

traverses has a maximum spread length of 249 m using an inter-electrode spacing of 3 m. The subsurface was investigated to a maximum depth of 37.7 m with resistivity values ranging from 1.0 to 1606 Ω m (Figs. 4 and 5). Profiles 1 to 3 are located in the non-concretized part of the canal, while profiles 4 and 5 are located in the concretized part of the canal.

The results of the standard constrain inversion technique for the Wenner array configuration with the 3-m electrode spacings are presented as model sections shown in Figs. 4 and 5. The RMS errors of 5.93, 3.76, 5.71, 3.10 and 3.28 % obtained for profiles 1–5, respectively, are in accord with the expected level of noise in our data.

In profile 1 (Fig. 4), the top layer is characterized by electrical resistivity value range of 1.0–166 Ωm from the

surface to a depth of about 4.7 m. Materials with low values of electrical resistivity (range of 1–13 Ω m) were identified below the top soil at lateral distances of 6–84, 87–126 and 117–246 m to a depth of about 37.7 m. This suggests the presence of peat lithology (with low resistivity values ranging from 1 to 6.3 Ω m to a depth of 18 m as deduced by Longe et al. 1987) or possible leachate infiltration of the subsurface; hence, groundwater pollution of the first aquifer (since the average water table is about 11 m within the study area) by polluted water from the canal which probably represent the recharge unit for the aquifer along its line. Materials with high resistivity values (range of 40–1606 Ω m) within this profile may be reflective of sand.

Table 1 Trace elements analysis

Elements	MDL	W1	W2	W3	W4	W5	W6	W7	W8	W9	WHO 2004 Standard	NSDQW 2007 Standard
As	0.5	<0.5	<0.5	0.7	0.5	<0.5	0.6	<0.5	<0.5	<0.5	10	10
B	5	60	110	53	42	19	23	11	29	7	300	N/G
Ba	0.05	155.17	120.40	144.54	90.59	127.35	38.05	264.41	88.16	80.1	300	700
Cd	0.05	0.31	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	3	3
Cr	0.5	3.5	12.2	9.3	4.3	<0.5	9.9	1.2	3.7	<0.5	50	50
Cu	0.1	6.4	2.5	1.9	1.3	0.6	0.6	0.7	1.0	0.5	2000	1000
Hg	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1	1
Mn	0.05	208.09	0.89	1.41	560.96	48.54	45.26	89.66	17.79	25.40	500	200
Mo	0.1	<0.1	0.3	0.8	0.7	<0.1	0.2	<0.1	0.9	<0.1	70	N/G
Ni	0.2	2.8	1.9	0.9	0.5	0.6	0.4	0.4	2.2	0.7	20	20
Pb	0.1	2.4	0.3	<0.1	<0.1	<0.1	0.2	0.9	<0.1	2.1	10	10
Sb	0.05	<0.05	0.12	0.34	0.14	0.06	0.08	<0.05	0.09	0.21	200	N/G
Se	0.5	4.4	1.6	4.0	0.9	1.2	0.9	<0.5	0.8	<0.5	10	N/G
U	0.02	0.03	0.04	0.36	<0.02	<0.02	0.02	<0.02	<0.02	0.03	1400	N/G
Zn	0.5	67.7	33.3	4.3	2.2	7.8	1.8	67.1	5.7	8.9	3000	2000

Elements in ppb

MDL maximum detection limit, W well, NG not given

Table 2 Analysis of cations and anions

Elements	MDL	W1	W2	W3	W4	W5	W6	W7	W8	W9	WHO 2004 Standard	NSDQW 2007 Standard
Cations												
Ca	0.05	32.62	36.79	76.27	83.10	31.94	47.34	5.19	51.47	2.56	N/G	N/G
K	0.05	9.23	13.94	17.63	11.71	6.55	21.59	1.96	12.59	1.27	N/G	N/G
Mg	0.05	10.12	16.48	12.32	5.45	3.15	4.75	7.32	5.94	1.60	N/G	N/G
Na	0.05	71.01	100.91	86.39	49.37	40.62	49.26	8.67	43.25	34.88	200	200
Anions												
Cl	1	58	92	74	42	23	44	24	19	15	250	250
Br	0.005	0.594	0.527	0.422	0.277	0.451	0.230	0.136	0.241	0.129	0.01	N/G

Elements in ppm

MDL maximum detection limit, W well, NG not given

The resistivity-depth model of profile 2 (Fig. 4) reveals a subsurface with electrical resistivity values range of 2.6–520 Ω m. The topsoil is represented by electrical resistivity value range of 8.7 to 96 Ω m and average thickness of about 4.7 m. Regions of low electrical resistivity values (8.7–13 Ω m) within the top soil suggest possible subsurface groundwater contamination by the infiltrating water from the canal. Beneath the top soil, at lateral distance of 84–138 m and depth range of 9.4–24 m, the subsurface is characterized by materials with low values of electrical resistivity (range of 2.6–13 Ω m). Likewise, materials with low values of resistivity (8.7–13 Ω m) are represented at lateral distance of 175–246 m from a depth of about 9.4–28 m. This suggests possible groundwater contamination from the leachate and waste water from the canal, and/or the presence of peat lithology. Relatively higher resistivity materials with resistivity value range of 40–520 Ω m within the profile is suggestive of sand that has not been affected by infiltration from the canal.

The 2D electrical resistivity model beneath profile 3 (Fig. 4) shows that the subsurface is composed of low resistivity material, from lateral distance of 48–246 m, at a depth range of 0–19 m with resistivity values ranging from 1.0–13 Ω m. The low resistivity values are suggestive of peat lithology or may be due to possible pollution as a result of infiltrations from the canal into the subsurface. High resistivity materials with resistivity value range of 158–1600 Ω m were identified at lateral distances of 24–48 and 69–216 m at a

depth range of 4–23 and 10–37.7 m respectively. These high resistivity values are indicative of unpolluted sand materials.

The 2D resistivity model beneath profiles 4 and 5 (Fig. 5) shows similar lithology and structural disposition. These two profiles were acquired within the concretized area of the canal. The resistivity-depth models for the two traverses (Fig. 5) reveal a top soil having an average thickness of about 4.7 m from the surface. Low values of electrical resistivity (<13 Ω m) within this layer possibly reflects the impact of pollution as a result of infiltration of leachate from the decomposing waste deposited on the canal. The subsurface beneath the top soil from a depth of about 5–37.7 m is characterized by materials with high resistivity (>40 Ω m). This layer is composed of sand/clayey sand, and the aquifer in this region appears not to have been polluted by the incursion from the drainage (since the water table is about 11 m). The low level of pollution observed in profiles 4 and 5 is also reflective of low accumulation of waste materials and/or concretization of this part of the canal, and possibly due to the direction of ground water flow (southwards).

Hydrogeochemical study

Seventy (70) elements which include trace elements such as As, B, Ba, Cd, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, U and Zn (Table 1); major cations such as Ca, K, Mg and Na; and anions such as Cl and Br (Table 2) were analysed in nine (9) water

Table 3 Analysis of physical parameters

Parameters	W1	W2	W3	W4	W5	W6	W7	W8	W9	WHO 2004 Standard	NSDQW 2007 Standard
TDS (mg/l)	477	521	780	230	313	284	265	390	48	500	500
EC (μ S/cm)	957	1048	1570	462	627	568	488	780	102	1500	1000
pH	5.81	6.51	5.54	6.38	6.54	7.29	6.88	4.35	6.92	6.5–8.5	6.5–8.5
Temp. ($^{\circ}$ C)	27.8	28.7	28.8	27.5	27.3	28.9	27.8	26.6	29.2	N/G	Ambient

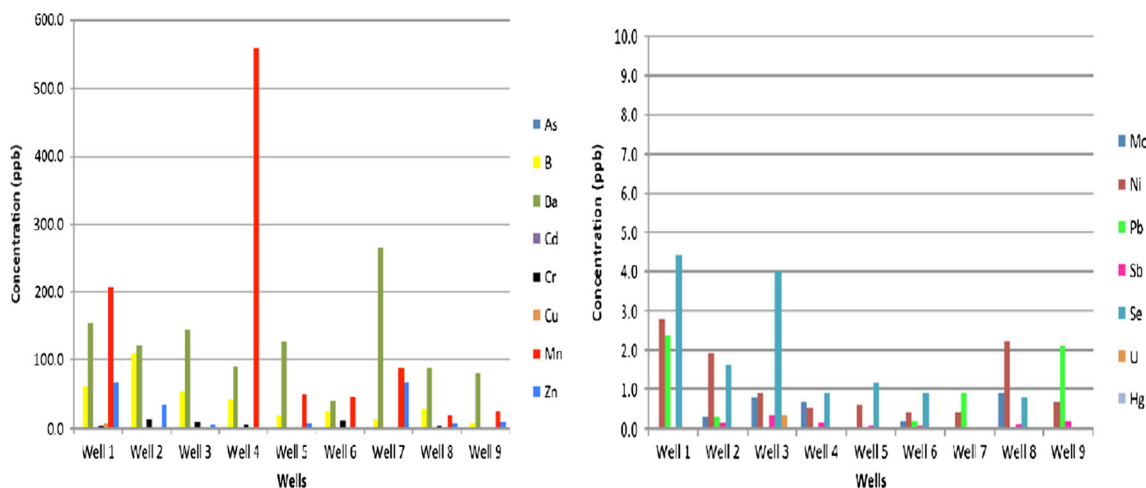


Fig. 6 Plot of trace elements against sample location

samples within and outside the study area. The parameters below detection limit in all the wells include (Ag, Au, Bi, Ga, Ge, Hf, Hg, In, Nb, P, Pd, Pt, Re, Ru, Sn, Ta, Te, Th, Ti and W). Also, physical parameters, which include pH, temperature (in °C), electrical conductivity (in $\mu\text{S}/\text{cm}$) and total dissolved solid (in mg/l) were measured in situ (Table 3). The results were compared with the maximum contamination level provided by World Health Organization for drinking water (WHO 2004) and Nigerian Standard for Drinking Water Quality (NSDQW 2007).

Analysis of trace element

The trace element analysis for the water samples in the study area is presented in Table 1. The concentration of Mn in well 4 was observed to be high (560.96 ppb), above WHO and NSDQW standards for drinking water threshold values of 500 and 200 ppb, respectively, while the Mn concentration in well 1 (208.09 ppb) was above the NSDQW standard for drinking water. However, high concentration of Mn is hazardous to human health and can cause neurological disorder.

Although trace elements such as As, Ni, Pb and Se were seen to be of low concentration and below the maximum allowable concentration stipulated by the WHO and NSDQW, however, long term exposure and continuous drinking of water from the wells may lead to the accumulation of these elements within the human system and may result to adverse health condition. The plot of trace element against sample location is shown in Fig. 6.

Analysis of major cations and anions

Table 2 presents the concentrations of the major cations (Ca, K, Mg and Na) and anions (Cl and Br) determined in the water samples. The concentrations of the cations are within WHO and NSDQW standards for drinking water. However, the concentration of Cl was observed to be below WHO and NSDQW standards of 250 ppm while the concentration of Br was observed to be above the 0.01 ppm WHO standard for drinking water in all the wells. The plots of these major cations and anions against sample locations are shown in Fig. 7.

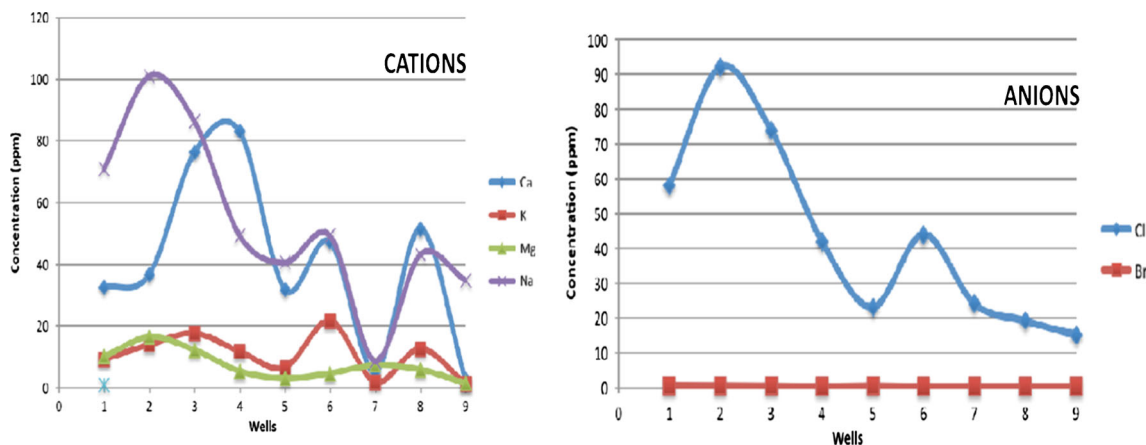


Fig. 7 Plot of major ions against sample location

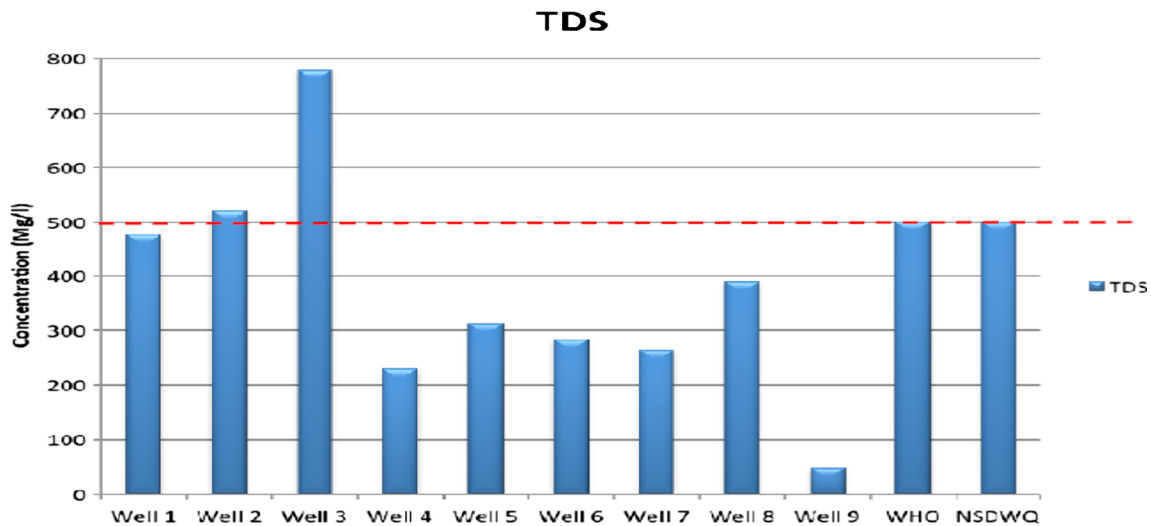


Fig. 8 Distribution of TDS of water samples within the study area

Analysis of physical parameters

The physical parameters (TDS, EC, pH and temperature) taken at different well locations in the study area along with their WHO and NSDWQ standards are presented in Table 3. Values of TDS measured in the wells were observed to vary from 48 to 780 mg/l. With all the values less than 1000 mg/l, the water can be classified as fresh. However, TDS value in wells 2 and 3 exceeds WHO and NSDWQ permissible limit of 500 mg/l having concentration values of 521 and 780 mg/l, respectively (Fig. 8). The high value of TDS (477–780 mg/l) in wells 1–3 correlate well with low resistivity (1–13 Ω m) values obtained for the 2D ERT around this area.

Conductivity values were observed to vary from 102 to 1570 μ S/cm (Fig. 9). Well 3 exceeded both the WHO and NSDWQ standards of 1500 and 1000 μ S/cm, respectively, with conductivity value 1570 μ S/cm while well 2 was above NSDWQ standard with conductivity value of 1048 μ S/cm. It was generally observed that conductivity values are higher in

wells at the part of the canal with high accumulation of dump. The high value of electrical conductivity (957–1570 μ S/cm) corroborated the low value of electrical resistivity obtained for the 2D ERT around this area.

The pH value ranges from 4.35 to 6.92. WHO and NSDWQ specified pH range of 6.5 to 8.5 as permissible for drinking. Water samples 1, 3 and 8 fall below the WHO and NSDWQ standard range. Generally, the water in all the wells can be described as acidic with pH values less than 7. Health implications of acidic water include stomach disorder and increased risk of complicating gastro illness such as ulcer.

Conclusion

A geophysical and geochemical study was carried out at eastern part of Lagos metropolis to investigate subsurface and groundwater pollution due to the contamination of the canal. The geophysical method used is 2D electrical resistivity

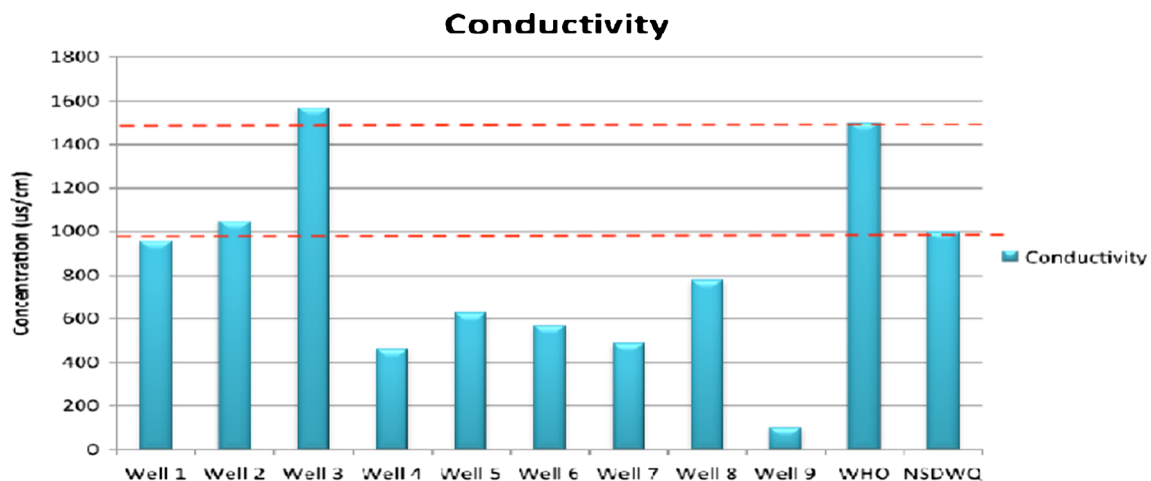


Fig. 9 Distribution of electrical conductivity of water samples in the study area

imaging, while geochemical parameters analysed include trace elements, major cations, anions, pH, temperature, total dissolved solids and electrical conductivity. The geophysical results show that the lithology is composed of topsoil, clay, clayey sand, peat and sand. The inverted 2D electrical tomography revealed that the decomposing refuse material in the canal and the waste water flowing through the canal may possibly have polluted the subsurface soil down to a depth of about 37 m and with resistivity values as low as between 1–13 Ω m especially at the non-concretized areas of the canal which is also characterized with high accumulation of dump. High resistivity values $>70\Omega$ m in the area are reflective of sand/clayey sand that has not been contaminated by the leachate from the canal. Physiochemical characterization of the water from the wells indicates possible infiltration of leachate from the canal into some of the wells as concentrations of Mn and Br were observed to be higher than WHO and NSDWQ permissible level in some wells. TDS and electrical conductivity values in some of the wells also show high concentration of dissolved substances while pH values are generally low (<7) which is an indication of acidic water. These correlate well with the low resistivity value obtained for the 2D ERT along profiles 1–3 within the study area.

In view of the above, water found in wells within the area of investigation may have been polluted by the infiltrations from the canal to a depth of about 37 m, hence, are unsuitable for human consumption.

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