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The urban informal sector's activities and its influence on soil and water quality of some Southern Nigerian Cities

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A B S T R A C T

The magnitude of informal sector events and activities may pose serious environmental consequences which may affect soil and water quality. This study investigated the effects of informal sector activities on the physicochemical, microbiological properties, and total metal levels of soil and water in Port Harcourt and Owerri, Southern Nigeria. Composite soil and water samples were taken from sites where informal sector activities are carried out in each study location. The samples were analyzed to establish their physicochemical and microbial quality by standard methods. The data obtained were subjected to further treatments using some environmental models to establish the degree of contamination and overall quality. Results showed pH levels were normal (within 6–8). The electrical conductivity, cation exchange capacity, exchangeable acidity, and organic matter in the soils were higher than in the control samples. The trend for metals in the soils was Fe > Cr > Cd > Pb > As, with Cd and Pb showing high contamination. The microbial counts in soil samples were higher than the control soils except for TFC in Owerri (3.5×10^4 cfu/g). Water samples showed low contamination with most physicochemical properties within the permissible limits. However, the water quality index of some samples (33% in Port Harcourt and 100% in Owerri) indicates unsuitability of the water for consumption. Microbial load in water was very high in all samples in Owerri while only 17% showed significant contamination in Port Harcourt. The principal component analysis suggested that both geogenic and anthropogenic factors contributed to the accumulation of metals determined in the investigated soils and water samples. The study was able to expose the consequences of activities of this sector on the quality of soil and water as well as the associated risks. Hence, it is recommended that activities of the informal sector should be regulated to forestall environmental degradation.

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Introduction

The informal sector is an expansive term that alludes to the numerous part of a nation's economy that is not observed firmly by any type of government or its organization [1]. The informal sector is a significant part of the economic activities of many countries due to the rationalization and restructuring of the public sector, in addition to the deregulation of the labor market [2]. This sector includes maintenance and repair services as well as other informal economic activities.

Employment in developing countries like Nigeria is heavily dependent on the activities of the informal sector. The importance of informal economic activities is obvious in the creation of employment and poverty alleviation by providing income to unskilled and semiskilled workers who otherwise would have been unemployed [3]. The use of this sector to foster growth and development is common in most developing countries [4]. It is estimated that in Sub-Saharan Africa about 70% of the workforce in most of the countries are in informal economic activities [5]. Similarly, employment in the informal sector in Nigeria increased from 27.3% in 1970 - 38.2% in 1989 and contributed over 90% to the food supply in Nigeria. According to the International Monetary Fund (IMF), the informal sector contributed to about 65% of Nigeria's Gross Domestic Product (GDP) in 2017 [6]

The importance of the informal sector economy in supporting the jobless populace represents an extensive test of urban land use administration in most part of the world and Nigeria in particular. Specifically, urban communities keep on falling apart quickly from ecological issues arising from enormous waste generation. The extent of informal sector events may pose serious environmental consequences affecting the soil, water, and air quality [7,8]. Some informal sector activities such as auto-mechanic activities have resulted in the degradation of soil and groundwater sources in Southern Nigeria due to elevated heavy metal levels [9–11]. The informal sector activities serve as the major pollution source of heavy metals in the environment [12,13]. Abattoir-related waste products have been shown to increase microbial population, influence soil and water physicochemical properties, and introduce heavy metals into the environment [14].

Heavy metal toxicity in the ecosystem is still a problem for scientists [14,15]. In humans, chronic exposure to toxic metals may result in plumbism, anemia, nephropathy, gastrointestinal colic, and central nervous system ailments [16,17]. Therefore, monitoring the influence of the urban informal sector activities on water and soil physicochemical properties, as well as heavy metal levels, is of great importance to prevent ecological and human health-related problems.

As activities in this sector are largely unregulated, people working in this sector assume that they are not considered responsible for the activities that may corrupt environmental quality. The study is very important as it exposes the impact of this sector on the qualities of surrounding soil and water. The study will enhance the awareness on the consequences of improper management of the sector on soil and water quality as well as the attendant human health problems associated with activities of this sector.

There is a paucity of studies mainly focusing on the effects of various activities of the informal sector on physicochemical and microbial properties of soil, groundwater, and surface water in Southern Nigeria. This study is particularly important due to increased human population in Port Harcourt and Owerri cities, where large wastes are generated daily by artisans and others in the unregulated sector [18,19]. The current study therefore, was set to provide additional data about the informal sector activities in the study area.

Materials and method

Study area

The areas studied include Port Harcourt and Owerri in River State and Imo State respectively, all in the Southern part of Nigeria generally referred to as the Niger Delta area of Nigeria. These areas geographically lie within latitude 4.8156° N and longitude 7.0498° E and latitude 5.4891° N and longitude 7.0176° E respectively (Fig. 1). Port Harcourt city is the capital of River State, as Owerri is the capital of Imo State. These two areas are among the main cities in the Niger Delta area of Nigeria known for petroleum industry-related activities, with a massive presence of informal sectors activities and its attendant environmental consequences. The population count of Port Harcourt and Owerri were projected at 1,148,665 and 458,514 respectively in 2020 [19].

Sampling and pretreatment of samples

To determine the impact of activities of the informal sector on the environment; samples of soil and water were collected in the premises where informal sector activities are carried out as indicated in Tables 1 and 2. The sampling details for soil were shown in Table 1, while water samples were indicated in Table 2. The sampling materials used for sample collection were previously soaked and rinsed in 10% HNO_3 overnight. Soil samples were collected following a simple random sampling technique at a particular site where the informal activity is being carried out in a bid to spread the sampling point unbiased. Homogenized soil samples (from 5 sub-samples following a "W" formed plan) were gathered from the various sites at topsoil (0–10 cm) utilizing a soil auger and introduced into dark plastic bags. Overall, 12 composites (including control samples which were collected from areas with no known anthropogenic activities) samples were gathered from the sites in Port Harcourt and Owerri. The samples were tied and transported to the laboratory for analysis. In the lab, soil samples were air-dried and unwanted material like rubber, nylon, and plant materials were removed from the samples. The soils were

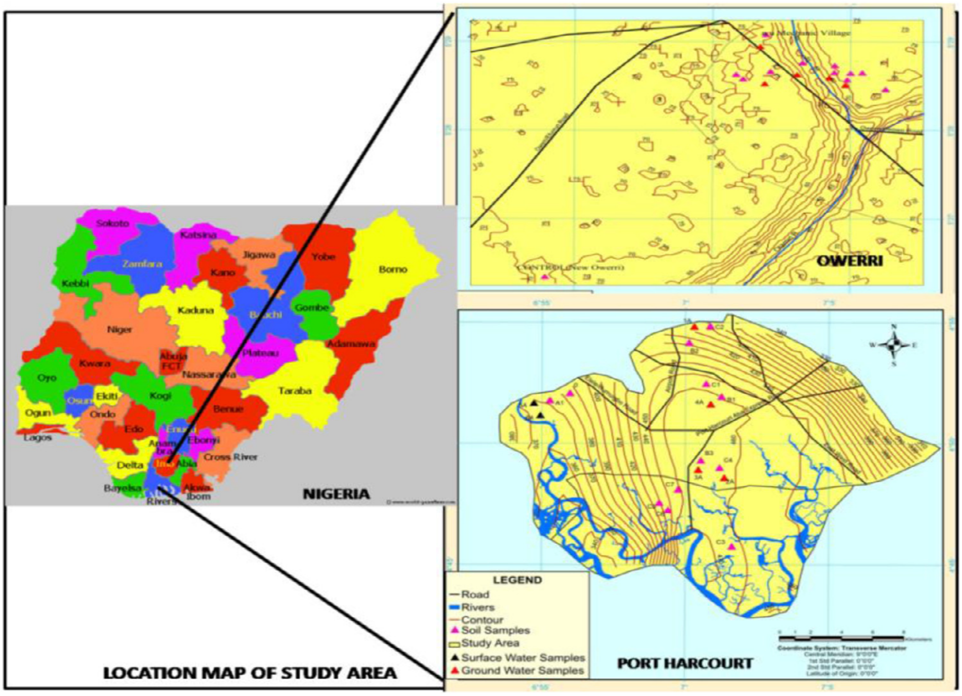

Fig.1. Map of the study area showing sample points.

Table 1
Soil sampling details for the study.

S/N	Sample code	Location	Type of activity
Port Harcourt			
1	A1	Choba	Livestock
2	B1	Eliozu	Welding/metal works
3	B2	Rukpokwu	Welding/metal works
4	B3	Trans-Amadi	Welding/metal works
5	C1	Eliozu	Auto-repairs
6	C2	Rukpokwu	Auto-repairs
7	C3	Old town	Auto-repairs
8	C4	Elekahia mechanic village	Auto-repairs
9	C5	Mile 3	Auto-repairs
10	C6	Diobu mechanic village	Auto-repairs
11	C7	Ikoku	Auto-repairs
12	Control	Residential area	No anthropogenic activities
Owerri			
1	PL1	Relief market	Livestock
2	PL2	Egbu road beside young motors	Livestock
3	PL3	Government abattoir Somachi	Livestock
4	PW1	Welding section, Naze market	Welding/metal works
5	PW2	Naze Poly junction industrial cluster	Welding/metal works
6	PA1	Orji-Mbieri axis UkwuUkor	Auto-repairs
7	PA2	Matrix workshop Orji	Auto-repairs
8	PA3	FHE/Chwukwuma Nwoha	Auto-repairs
9	PA4	Oduobi crescent	Auto-repairs
10	PA5	Egbu Road by Mobile filling station	Auto-repairs
11	PA6	Avu mechanic village	Auto-repairs
12	Control	PH road reserve area	No anthropogenic activities

crushed and sieved with a 2 mm work strainer and saved for additional investigation. All the techniques employed for soil sample collection and examination carefully adhered to the standard method according to Van Reeuwijk [20].

Three borehole water sub-samples were collected from taps connected to the groundwater at an interval of 2 h to form a composite sample for the particular site investigated. The same was applied to all groundwater samples collected in Port Harcourt and Owerri. For surface water samples, the grab sampling techniques were applied for collection to avoid col-

Table 2
Water sampling details for the study.

S/N	Sample code	Location	Type of activity
Port Harcourt			
1	1A	Borehole at Rukpokwu mechanic workshop	Auto repairs
2	2A	Borehole at Elekahia mechanic workshop	Auto repairs
3	3A	Borehole at Trans Amadi mechanic workshop	Welding/metal works
4	4A	Borehole at Eliozu auto mechanic workshop	Auto repairs
5	5A	Surface water from Choba, Abbatoir (5 m from new Calabar river)	Livestock/abattoir
6	6A	Surface water from sample at Choba (Control: headwater of the new Calabar river)	No anthropogenic activities
Owerri			
1	M1	Relief market	Livestock slaughter
2	M2	Government abattoir Somachi	Livestock slaughter
3	M3	Welding section, Naze market	Welding/metal works
4	M4	Naze Poly junction industrial cluster	Welding/metal works
5	M5	Avu mechanic village	Auto-repairs
6	M6	Borehole water from Imo State University	No significant anthropogenic activities

lecting surface scum. Surface water samples were collected at the depth of about 0.3 m. All safeguarding and examination techniques for water carefully adhered to the standard method.

Physicochemical analysis of the soil samples

The physicochemical properties of the soil samples were determined using standard and reported strategy [21]. The pH was determined using Jenway 3510 pH meter. Groline EC/TDS meter was utilized in deciding soil electrical conductivity in μS/cm. Moisture content, organic carbon (OC), and soil organic matter (SOM) were determined based on weight reduction at 105 °C and 440 °C with drying oven (DHG – 9023A). The organic matter content was calculated as a weight loss by weighing the sample before and after two hours of heating at 440 °C. Particle size distribution (% sand,% silt, and% clay) was determined by the hydrometer method. The available phosphorus (AP) was determined using the multiparameter bench photometer (HANNA H1832007) and% nitrogen by the micro-kjeldahl procedure [20]. Two grams of each sample was mixed with 20 mL of 4 M HNO_3 at 90 °C for 4 h. The blends were separated into 25 mL standard flasks and the solution made up to mark with ionized water. Appropriate standard solutions were made and concentrations of metallic elements and cations in the digest were determined with Agilent 240FS Fast Sequential Flame atomic absorption spectrophotometer and Jenway clinical PFP7 Flame photometer for Na and K. The effective cation exchange capacity (ECEC) was determined by summing the exchangeable (K^+, Na^+, Ca^{2+}, $Mg^{2+}$and acidity).

Analysis of water samples

The pH of water samples was determined utilizing a Jenway 3510 pH meter. The total dissolved solids (TDS) and electrical conductivity (EC) were established with Groline EC/TDS meter by HANNA instruments. Total hardness (TH), turbidity, total suspended solids (TSS), dissolved oxygen (DO), and biological oxygen demand (BOD) were determined as described in previous publications [21,22]. For metal concentration analysis, 10 mL of a given water sample was processed with 20 mL of HNO_3 and made up to mark with deionized water. The processed samples were investigated for heavy metal and cations utilizing Agilent 240FS Fast Sequential Flame atomic absorption spectrophotometer.

Microbial analysis

About 1 g of soil sample was collected and transferred into 10 mL autoclaved sterile water. A triplicate ten-fold serial dilution of 1 mL soil suspension was used in aerobic heterotrophic bacterial and fungal population determination using the method of standard spread-plate dilution according to Seeley and VanDemark [23]. A 0.015% (w/v) nutrient agar which contains nystatin (to inhibit fungal growth) was used for bacteria isolation and incubated at 35 °C for a period of five days. Potato dextrose agar containing 0.05% (w/v) chloramphenicol to inhibit bacteria growth was utilized in the fungal isolation, followed by incubation at 25 °C for seven days. Pure isolates of representative communities were maintained on agar slant at 4 °C and further identified based on colonial, cellular, and biochemical characteristics following standards for microbiological investigation [23].

Statistical and data analysis

Data analysis was accomplished with IBM SPSS Statistics Version 20. Correlation analysis was used to establish the connection between soil quality boundaries at a 5% significant level. *t*-test was employed to statistically show that there is a significant difference between soil and water quality of the control site and the actual study area at $p < 0.05$. Principal Component Analysis (PCA) was utilized to determine the exact source of metal contamination as anticipated by the correlation examination using varimax revolution with Kaiser Normalization, adhering to standard strategies [24]. The factor loadings for overwhelming metallic elements in the samples were separated according to eigenvalue >1.

Contamination factor and pollution modeling

Contamination factors (C_f) and pollution load index (PLI)

Contamination factors (C_f) and pollution load index (PLI) were quantitatively estimated according to Eqs. (1) and (2). The contamination factor was computed simply by dividing the measured value by their reference values. The reference values for soil and water were obtained from the Department of Petroleum Resources and the Federal Ministry of Environment as reported by Verla et al. [25]. The values for soil (mg/kg) are: Fe-38,000; Zn-140; Pb-85; Cu-36; Cr-100; Mn-850; Cd-0.80; As-0.80 and water (mg/L): Cu-0.10; Fe-1.00; Mn-0.20; Zn-3.00; Cr-0.05; Cd-0.01; Pb-0.05.

$$C_f = \frac{C_{mean}}{C_R} \tag{1}$$

$$PLI = (C_{f_1} x\, C_{f_2} x\, C_{f_3} \ldots\ldots C_{f_n})^{1/n} \tag{2}$$

Where C_f = contamination factor C_{mean} = concentration of metal in the sample C_R = reference value and n = number of heavy metals used in the computation.

Geo-accumulation index (Igeo)

Igeo was computed according to Eq.3. The 0.67 stated in Eq. (3) is the matrix correction factor that normalizes lithogenic effects [25].

$$\mathrm{Igeo} = \log_2\ (0.67\ \mathrm{x}\ \mathrm{C_f}) \tag{3}$$

Potential ecological risk (RI)

RI was computed according to Eq. (4). Ecological risks caused by heavy metals were evaluated as presented in Eq. (4).

$$RI = \sum^{E_i} = \sum^{T_r} \times C_f \tag{4}$$

Where E_i is the monomial potential ecological risk factor, C_f remains as in Eq. (1), T_r is the metal toxic response factor. T_r gives information about the potential transport avenues of toxic substances to the ecological system. T_r for the soil samples was Cr-2; Cu-5; Pb-5; As-10; Cd-30; Mn-1; Fe-0; Cr-2; Zn-1 [25].

Water quality index (WQI)

The water quality index was computed as described in previous studies presented in Eqs. (5)–(7) [10,22]. The SI is the sub-index of the ith parameter; qi is the rating based on the concentration of ith parameter calculated as the ratio of determined concentration (C_{det}) to the recommended limits (R_L) (Eq. (5)) and Wi is the relative weight of each parameter obtained from the ratio assigned weight (*wi*) to the total assigned weight (Σwi). The weight assigned was based on the importance of each parameter as described in previous report [22], while WQI is the water quality index.

$$qi\ =\ {}^{C_{det}}/_{R_L} * 100 \tag{5}$$

$$\mathrm{SI} = W_i q_i \tag{6}$$

$$WQI = \sum^{S} I \tag{7}$$

The model gives a single value that provides information on the suitability of consuming the water sample. The classification of WQI is related to a qualitative scale classified according to previous report [22].

Results and discussion

Soil physicochemical properties

The results of the physicochemical analysis of the soil samples from the different sites are presented in Table 3. pH measures the acidity (< 7) and alkalinity (> 7–14) of the soils and controls many other parameters of the soil. The pH of the soils from Port Harcourt was weakly acidic (6.75) to weekly alkaline (7.40), while in Owerri soils, the pH was acidic. The overall pH of the soils was considered normal (within 6–8). This observation is similar to the results of other studies reported for tropical soils [24,26].

Cations such as Ca^{2+}, K^+, Na^+ and Mg^{2+} had mean values ranging from 1.61±0.01 to 2.88±0.02 mg/kg; 0.36±0.01 to 0.49±0.01 mg/kg, 0.15±0.01 to 0.38±0.00 mg/kg and 0.74±0.00 to 1.37±0.01 mg/kg respectively in Port Harcourt

Table 3
Physicochemical properties of soil from Port Harcourt and Owerri.

Code	pH	K (mg/kg)	Na (mg/kg)	Ca (mg/kg)	Mg(mg/kg)	P (mg/kg)	EA(cmol/kg)	OC (%)	OM (%)	N%	CEC(cmol/kg)	Sand (%)	Silt (%)	Clay (%)	Textural class
Port Harcourt															
A1	7.40	0.36	0.21	2.44	1.37	6.21	3.26	3.93	5.15	0.16	6.61	85.20	9.40	5.40	Sand
B1	6.80	0.43	0.27	2.11	0.94	4.81	2.28	2.90	5.49	0.10	6.05	92.60	2.00	5.40	Sand
B2	7.00	0.49	0.25	1.75	1.08	4.77	1.94	3.16	4.62	0.12	6.20	85.60	7.00	7.40	Loamy Sand
B3	6.80	0.42	0.23	1.61	0.93	5.41	2.17	3.71	6.34	0.13	5.34	91.20	5.40	3.40	Sand
C1	7.20	0.39	0.19	2.42	1.19	3.84	2.44	3.66	6.25	0.09	6.66	90.60	4.00	5.40	Sand
C2	7.50	0.47	0.27	1.77	0.91	4.78	1.83	3.80	6.58	0.10	7.27	83.20	11.40	5.40	Loamy Sand
C3	7.56	0.41	0.24	2.88	1.24	5.20	1.78	3.34	5.83	0.13	6.51	93.20	3.40	3.40	Sand
C4	6.80	0.42	0.38	1.85	0.85	4.22	2.72	4.44	7.71	0.08	6.41	88.60	6.00	7.40	Sand
C5	6.75	0.46	0.33	1.73	0.91	3.81	2.27	3.73	6.45	0.11	5.69	86.60	6.00	7.40	Loamy Sand
C6	7.00	0.48	0.18	1.34	0.81	4.62	3.17	3.88	6.73	0.10	5.96	92.60	2.40	5.00	Sand
C7	6.75	0.46	0.15	1.6	0.74	5.64	2.82	2.90	5.02	0.08	5.83	86.60	4.60	8.80	Loamy Sand
Mean	7.02a	0.44a	0.25a	1.95a	0.99a	4.85a	2.43a	3.59a	6.02a	0.11a	6.23a	88.73a	5.6a	5.85a	
Ctrl	7.00b	0.24b	0.19b	1.20b	0.85b	7.46b	1.53b	3.18b	5.36b	0.17a	4.69b	73.20b	21.40b	5.40b	Sandy loam
Owerri															
PA1	6.35	0.24	0.17	2.36	1.09	7.85	1.17	1.61	2.79	0.16	5.03	88.60	8.00	3.40	Sand
PA6	6.30	0.22	0.11	3.30	1.20	6.64	1.24	1.74	3.00	0.12	6.08	86.60	8.00	5.42	Loamy Sand
PA4	6.56	0.36	0.18	2.79	2.88	7.39	1.18	1.58	2.73	0.13	7.39	90.60	8.00	1.40	Sand
PL3	6.46	0.35	0.19	2.61	1.14	7.58	1.06	1.71	2.95	0.14	5.35	92.60	5.00	2.40	Sand
PA3	6.60	0.33	0.16	2.44	1.81	7.35	1.21	1.77	3.06	0.10	5.96	88.60	8.20	3.20	Sand
PW1	6.56	0.37	0.18	3.51	2.27	7.78	1.06	1.61	2.77	0.12	7.39	92.40	4.00	3.60	Sand
PL1	6.46	0.34	0.11	2.86	2.60	7.57	1.09	1.73	2.99	0.16	7.04	84.60	10.00	5.40	Loamy Sand
PA2	6.30	0.32	0.18	2.28	1.68	6.69	1.16	1.57	2.72	0.13	5.59	92.60	6.00	1.40	Sand
PW2	6.25	0.35	0.14	2.93	2.02	7.66	1.13	1.63	2.81	0.14	6.58	92.60	4.00	3.40	Sand
PL2	6.40	0.28	0.15	2.59	1.71	7.45	1.08	1.68	2.91	0.15	5.74	86.60	8.00	5.40	Loamy sand
PA5	6.40	0.38	0.19	3.83	1.93	6.88	1.18	1.64	2.85	0.13	7.52	90.60	6.00	3.40	Sand
Mean	6.42c	0.32c	0.16c	2.86c	1.85c	7.35c	1.14c	1.66c	2.87c	0.13c	6.33c	89.67c	6.83c	3.49d	
Ctrl	6.20d	0.47d	0.21d	2.41d	2.85d	12.53d	0.75d	1.46d	2.53d	0.24d	7.40d	88.60d	8.00d	5.42d	Loamy Sand

Values in columns with different alphabet indicates significant differences ($p < 0.05$).

and 2.28±0.04 to 3.83±0.01 mg/kg; 0.22±0.01 to 0.38±0.01 mg/kg, 0.11±0.01 to 0.19±0.00 mg/kg and 1.09±0.00 to 2.88±0.01 mg/kg respectively in Owerri. In Port Harcourt, 100% of the collected soil samples had higher concentrations than the control for K^+, Ca^{2+}, while 91% for Na^+ and Mg^{2+}. In Owerri, 100% of the samples showed lower concentration compared to the control for K^+ and Na^+, while 81% and 91% of soil samples were higher than the control for Ca^{2+} and Mg^{2+} respectively. This indicates that activities of the informal sector may have influenced the soil ionic concentrations. All the cations have low concentrations in the soils, suggesting that the soil could have possible deficiencies. Higher concentrations were reported for soils collected from the flood basin in Owerri [24].

Cation Exchange Capacity (CEC) is the total capacity of a soil to hold exchangeable cations and it indicates the number of sites where positive ions can attach. Therefore, an increase in the value of this parameter increases the tendency of improved soil fertility potential. CEC value less than five (< 5) implies that the soil is not fertile [27]. The recorded CEC values were all higher than 5 except for the control soil in Port Harcourt (4.69±0.01 cmol/kg), indicating increased fertility of the soils. In a related study, Ebong et al. reported a high mean concentration (29.17±3.28 cmol/kg) attributable to abattoir waste [14].

The number of acid cations like Al^{3+} and H^+ attached to the CEC is referred to as the exchangeable acidity (EA). The EA recorded in the soils was higher than their respective controls, indicating that the various activities including livestock, welding/metal works, and auto-repairs in the investigated area may have increased the EA concentrations. Organic matter is a nutrient sink that improves soil structure. The soil organic carbon (OC) is a major energy source for microorganisms in the soil. The straightforwardness and pace with which OC opens up is linked to the soil organic matter (SOM) portion in which it dwells. SOM contains around 58% carbon. The obtained results for OM are shown in Table 3. Port Harcourt soil results ranged from 4.62±0.05 to 7.71±0.02% which exceeded the normal range, while in Owerri, the

Where Ctrl = control,concentrations ranged from 2.72±0.02 to 3.06±0.03% which was within the normal range. Ebong et al. reported high mean SOM concentrations for Southern Nigeria soils [14].

OC values ranged from 2.90±0.06 to 4.44±0.02% in Port Harcourt with only sample C7 showing lower concentration than the control. In Owerri, concentration ranged from 1.57±0.01 to 1.74±0.02%. The mean OM and OC levels obtained in this study could be attributed to the different activities experienced in the study areas.

The result of estimated exchangeable (Ca^{2+}, K^+, Mg^{2+}, Na^+ and EA) and effective CEC is presented in Table SM1. The result indicates that exchangeable bases have mean values of 1.14e-2, 1.07e-2, 0.195, and 0.166 cmol/kg for K^+, Na^+, Ca^{2+}, and Mg^{2+} respectively in Port Harcourt. The mean values of exchangeable catons for Owerri soils were 8.53e-3, 6.96e-3, 0.286, and 0.308 cmol/kg respectively for K^+, Na^+, Ca^{2+}, and Mg^{2+}. It was observed that the control soil samples showed slightly lower levels of exchangeable cations compared to the sites influenced by the activities of the informal sector. The low levels of these cations may be associated with few negatively charged soil surfaces which encourages adsorption of these cations especially in Port Harcourt due to OM levels (Table 3). Table SM1 further revealed that the ECEC ranged from 1.487 – 3.751 cmol/kg with a mean value of 2.810 and 1.750 cmol/kg for Port Harcourt and Owerri respectively. ECEC is an essential soil property which indicates the adsorption capacity of soil surfaces which could be influenced by soil pH. The low ECEC observed in this study may be attributed to absence of soil inorganic surfaces as indicated by the low clay percentage levels (Table 3), which is associated to the influence of informal economic activities [27].

The presence of phosphorus and nitrogen in the soil are indicators of agrochemical usage of the soil [28]. The concentrations of nitrate obtained in Port Harcourt and Owerri soils are similar, and ranged from 0.08±0.00 to 0.24±0.02 mg/kg, while phosphate ranged from 3.81±0.01 to 7.46±0.00 mg/kg in Port Harcourt and 6.64±0.06 to 12.53±0.08 mg/kg in Owerri. The particle size distribution of the soils from Port Harcourt and Owerri are presented in Table 3. The results indicate that the soils were generally of sand and sandy loamy textural class. This is in agreement with the previous reports on soils from the area [24]. The mean values of the soil physicochemical properties compared to the control values suggested a significant difference at $p<0.05$. This indicates that the area may have been influenced by the activities of the informal sector.

Heavy metal distribution in soil

The result of heavy metals such as Fe, Cr, Pb, As, and Cd concentrations in the soils are presented in Table SM2. 100% of the samples in Port Harcourt and Owerri showed higher concentrations for the afore-mentioned metals than the controls. This indicated that the soils are impaired by the various informal sector activities causing an increment in the levels of metallic pollutants in the studied soils. In comparison with the Nigerian Department of Petroleum Resources standard, the studied soils showed higher concentrations only for As and Cd as indicated in Table SM2. These heavy metals are considered toxic contaminants, so their presence in the study area calls for serious concern. Total metal levels in the soils studied fluctuated from one location to the other, and this could be attributed to the discrepancy in the activities, size, and age of these workshops. In Port Harcourt and Owerri, the trend for metals was Fe > Cr > Cd > Pb > As. Ebong et al. reported a higher mean Fe concentration in soil from abattoirs in Southern Nigeria, which was attributed to the wastes generated from abattoirs, as their feeds have a high level of this essential element [14]. All metals showed low ($<$ 20%) to moderate ($>$ 20 to $<$ 50) variations in soils (Table SM2) indicating that the impact of these activities on soil heavy metals is similar. However, there is a significant difference between the mean values of the metallic pollutants recorded in the study area and control sites.

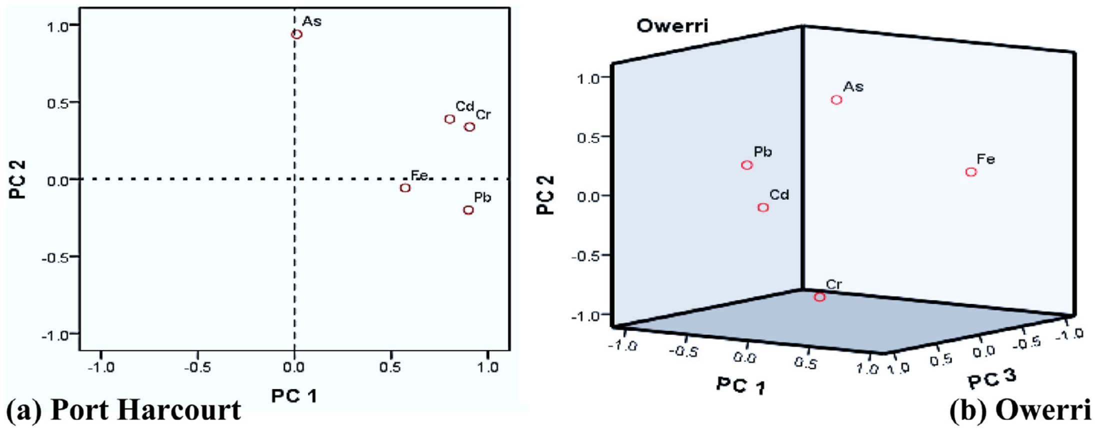

Fig. 2. The principal component plot in rotated space for metals in soils.

Correlation and principal component analysis of metals in soil

Correlation analysis with Pearson's correlation coefficients was used to describe the relationship between the sources of the heavy metals present in the soils at a significant level of 5%. Pearson's correlation coefficients for the studied heavy metals are shown in Table SM3. The metals generally showed weak (Cd-Cr/As) and negative (As/Fe) correlations within the heavy metals in soil samples from Owerri. Furthermore, most metals showed a weak correlation except between Pb, Cd, and Cr for Port Harcourt soil. Weak correlations indicate that the sources of these metals are variable and negative correlation indicates no common source for the metals. The weak and negative correlations obtained in the study could be linked to the fact that the soils were obtained from different sites experiencing different informal sector activities.

The principal component analysis (PCA) was computed to determine the precise pollution sources of the metals in the soil. Two and three principal components were extracted based on eigenvalue > 1 for Port Harcourt and Owerri respectively. The results for the total variations are as indicated in Table SM4. The variances for PC1 and PC2 groups for Port Harcourt soil were 54.223 and 21.507% respectively while PC1, PC2, and PC3 for Owerri were 37.635, 28.244, and 22.489% respectively (Table SM 4).

The PCA plot in rotated space for heavy metals in the soil for Port Harcourt and Owerri is represented in Fig. 2. In Port Harcourt soils, Cd, Cr, Fe, and Pb are grouped in PC1, indicating that the sources were from informal sector activities including auto-repair or artisanal works. In PC2, only As was grouped and indicates that the source could be geogenic or from atmospheric deposition [29]. In Owerri soils, the metals showed that they originated from mixed sources. A similar grouping was reported for soils in Owerri [24].

Contamination and pollution load appraisal of the soil samples

The contamination factors (C_f), degree of contamination (ΣCf), and the pollution load index (PLI) were computed to determine the extent of pollution or contamination due to the presence of heavy metals in the soil resulting from the informal sector activities (Table SM5). The C_f was categorized according to earlier publication [18]. Following the classification for C_f, only Fe, Pb, and Cr showed low contamination, other metals such as Cd showed very high contamination in Port Harcourt and Owerri soils, while As showed moderate to considerable contamination. Similar results have been reported previously [18]. Generally, higher contaminations were shown by metals in Owerri soils than in Port Harcourt soils.

The degree of contamination of metals in soil ranged from 8.524 to 11.244 for Port Harcourt and from 11.716 to 20.430 for Owerri. There are generally four descriptions of the degree of contamination as earlier reported [28]. Following this classification, it could be concluded that soil samples from Port Harcourt were reasonably contaminated, while samples from Owerri showed reasonable to substantial contamination. Substantial contamination of Owerri soils by heavy metals has been reported [28]. However, since the PLI was generally less than 1, the soils are not highly loaded with heavy metals and thus indicate no significant pollution.

Geo-accumulation of metal assessment

The results of geo-accumulation index (Igeo) of heavy metal levels in the analyzed soils are presented in Fig. 3. The Igeo is related to a quantitative scale of pollution level which describes five classes of pollution [30,31]. Only Cd and As showed considerable to strong pollution in the soils which followed the same pattern as the contamination factors.

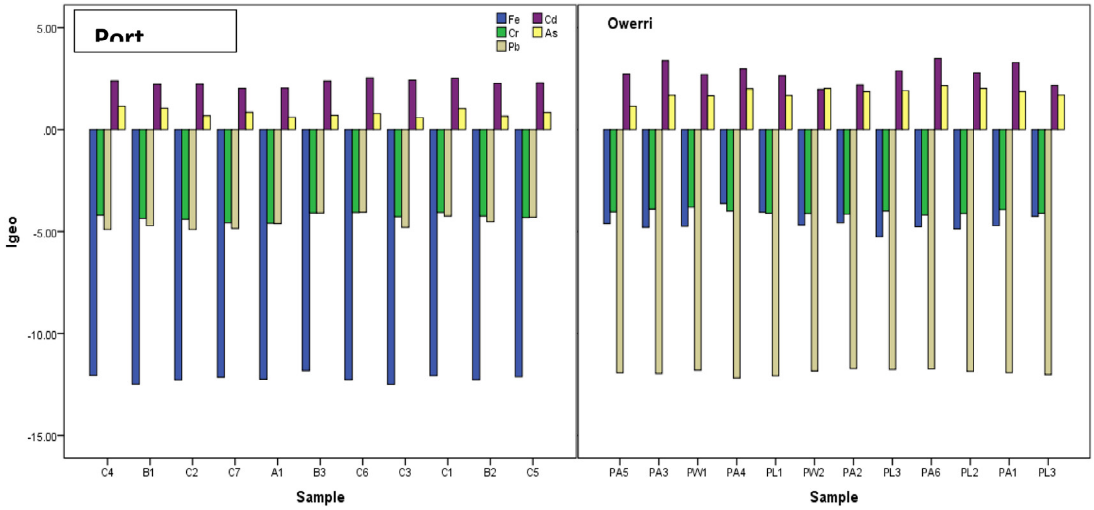

Fig. 3. Geoaccumulation index (Igeo) of heavy metals of in soil.

Risks appraisal of the soil samples

Higher RI values of heavy metals in the environment could result in severe health problems in humans [18,32]. The classification of E_i is based on previous publications [33]. Again, only Cd showed high monomial ecological risk, while other metals showed low risk (Table SM6). Cadmium (Cd) is among the foremost poisonous elements to which humans are predisposed in the environment and workplaces. When assimilated, Cd is productively held in the human body where it bio-accumulates. It is essentially harmful to the kidney, particularly to the proximal rounded cells, the principal site of aggregation. Cd can likewise cause bone demineralization, either through direct bone harm [34]. The order for metal E_i is Cd > As > Pb > Cr > Fe. The potential ecological risks (RI) for all metals in the different sites in Port Harcourt were moderate (RI: 207.199 to 287.963), while posing considerable risks in Owerri (RI > 300) (Table SM6).

Microbial characterization of soil

The mean microbial counts of soil samples and control from Port Harcourt and Owerri are presented in Figure SM 1. The total heterotrophic bacterial counts (THBC) were 3.20×10^8 cfu/g in Port Harcourt and 3.40×10^6 cfu/g in Owerri. The total coliform counts (TCC) were 2.80×10^6 cfu/g in Port Harcourt and 4.97×10^5 cfu/g in Owerri, while total fungal counts (TFC) were 1.70×10^5 cfu/g in Port Harcourt and 2.41×10^4 cfu/g in Owerri. The microbial counts in the sampled soils were higher than control soils except for TFC in Owerri (3.5×10^4 cfu/g). The microbial counts suggest the overall condition of the soil. Total coliforms consist of bacteria whose presence in the soil was possibly affected by wastes emanating from humans or animals. The presence of a high number of total coliform and fecal coliform in the soil samples revealed that various activities in the area may have contributed to the contamination of the surrounding soils.

The biochemical description of bacteria isolated from the soil samples from Port Harcourt and Owerri are shown in Table SM7. The soil samples for Port Harcourt and Owerri were serially diluted; with fourteen and nine well-defined colonies selected and cultured. The isolated bacteria were conditioned to gram reactions and several biochemical characterizations. Nearly all the isolated bacteria (50% in Port Harcourt and 44% in Owerri) were found to be rod-shaped formers, while other shapes of isolates were comma, cocci, and bacilli (Table SM 7). Most of the isolates in Port Harcourt soils were gram-negative (53%), while positive in Owerri soils (56%). For biochemical characterization, the isolates showed variations across all biochemical test parameters. Furthermore, based on the biochemical characterizations, the suspected organisms were *Escherichia coli, Klebsiella* sp., *Pseudomonas* sp., *Vibrio* sp., *Bacillus* sp., *Micrococcus* sp., *Staphylococcus* sp., *Streptococcus* sp., *Lactobacillus* sp., *Shigella* sp., *Salmonella* sp., *Proteus* sp., *Enterobacter* sp., *and Acinetobacter* sp. The fungal isolates for soil samples are presented in Table SM8. Similar organisms including *Aspergillus niger, Aspergillus flavus, Penicillium spp, and Mucor spp* were generally obtained in both areas. The shape, color, and forms of each fungus are presented in Table SM8. Earlier reports have isolated similar organisms for soils in Kano, Nigeria [35]. These fungi may impact soil properties. Many soil fungi, overwhelmingly of the genera *Aspergillus and Penicillium*, possess the capacity to acquire insoluble phosphates in soil and convert them into a dissolvable structure by discharging natural acids [36]. These acids bring down the pH leading to the disintegration of bound phosphates. The activities of the informal sector could influence the biodiversity of microorganisms thereby allowing only those microorganisms that could adapt to the influence to remain in the soil. This may affect the soil quality as well as its usage.

Water physicochemical characteristics

The results for the physicochemical analysis of the water samples from the different sites compared to the World Health Organization (WHO) standards are presented in Table SM9. Water pH is viewed as an important parameter that decides the appropriateness of water for different purposes. The pH range of 6.5–8.5 was set by WHO, pH of all sites was outside this range i.e. < 6.5, except for sample M1 in Owerri which showed neutral pH (7.00). Therefore, all other water samples were acidic with Port Harcourt samples showing higher acidity compared to Owerri. Similar results have been reported for borehole water samples around areas experiencing informal sector activities in Owerri and Port Harcourt [8,11,13,22]. Furthermore, the highest acidity was shown by samples 5A and 6A, which happens to be from surface water and could easily be polluted from runoff, vehicular emission, and atmospheric deposition. In addition, the anthropogenic acidification of allochthonous organic matter such as ammonia from decaying aquatic life forms could cause a drastic change in the water pH [16]. The vulnerability of water sources such as groundwater to acidification is assumed to be linked to the depth of groundwater level which results in increased accessibility to contaminants [37].

Electrical conductivity and total dissolved solids (TDS) generally indicate the presence of solids, which could render water unsuitable for so many uses. High EC and TDS values are indications of excess ionic concentrations in water samples. The recorded EC was generally lower than the permissible limit of 100 μS/cm by WHO, suggesting that the dissolved ions in the water were low (Table SM9). Similarly, the TDS recorded for all water samples was lower than the permissible limit of 500 mg/L. Higher EC values were recorded in Port Harcourt than in Owerri and vice versa for TDS. Increased levels of dissolved organic and inorganic salts in water could impair its taste and render it unwholesome for consumption.

The concentration of cations such as Na, Mg, K, and Ca, in the water ranged from 0.69±0.00 to 10.37±0.00 mg/L, ND to 15.047 mg/L, ND to 12.8 mg/L, and ND to 4.55 mg/L respectively in Port Harcourt. In Owerri, the concentrations ranged from 3.61±0.01 to 6.81±0.01 mg/L, 4.27±0.02 to 6.35±0.02 mg/L, 0.13±0.01 to 0.26±0.01 mg/L, 13.61±0.01 to 32.78±0.02 mg/L respectively for Na, Mg, K, and Ca. Higher concentrations of the cations were observed in Owerri than in Port Harcourt.

The measured total hardness (TH) was generally < 60 mg/L which indicated that the water samples were “soft” and will not produce a noticeable deposit of precipitate when it reacts with soap. The turbidity is related to total suspended solids (TSS). The more total suspended solids in water the murkier it seems and the higher the turbidity. The recorded turbidity for Port Harcourt ranged from 0.04±0.00 to 0.5 ± 0.00 NTU, while in Owerri it ranged from 2.75±0.01 to 3.26±0.02 NTU. The recommended limit for turbidity is 5 NTU as stipulated by WHO. All samples were lower than this limit. However, higher turbidity was recorded for Owerri than Port Harcourt. Similarly, the TSS was below the recommended limit of WHO, and lower concentrations recorded in Owerri than in Port Harcourt.

DO is the oxygen present in dissolved form in a water body, which is generally related to the ability of a water body to hold aquatic life forms, while BOD_5 is DO measured on the fifth day. The standard DO expected in water according to WHO is 5 mg/L. However, all samples except M1 and 5A showed high DO. The observed DO value could be due to low bacterial counts in water. Meanwhile, BOD was higher in Port Harcourt (7.04±0.00 to 1120.0 ± 0.0 mg/L) compared to Owerri (5.67±0.11 to 6.32±0.00 mg/L). The high BOD reported in this study could be attributed to activities of the informal sector.

Total metal concentration in water

The heavy metal levels in water samples are presented in Table SM10. In Port Harcourt water samples, the detected heavy metal concentrations were generally low, Fe ranged from 0.029 to 0.214 mg/L and Zn ranged from 0.007 to 0.235 mg/L, while other metals were not detected. The detected metals showed lower concentrations compared to World Health Organization permissible limits. Some of the metals like Cd, Cu, Cr Mn, and Pb were not detected in the water samples from Port Harcourt. In contrast, the heavy metals were detected in all water samples collected in Owerri. The metals follow the trend: Mn > Fe > Zn > Cr > Cu > Cd > Pb. Hundred percent and eighty percent of samples had a high concentration of Fe and Pb above the permissible limits specified by WHO. Fe is an essential metal at moderate concentrations, while Pb is regarded as one of the potential metallic carcinogens. Consumption of water containing high concentrations of these metals will result in serious health issues. Anthropogenic sources, runoff, and leached iron from waste dumps may have contributed to the elevated iron concentrations in the groundwater sources. Elevated iron levels in water are of great concern especially for children due to their sensitivity to iron toxicity as most baby formulations contain high Fe concentrations. Increased cancer risk and gastro-intestinal problems could result from an overdose of iron intake [38,39]. The results, therefore, suggested that the informal sector events in the study area may have contributed significantly to the observed metal levels in the sampled ground and surface water sources as indicated by t-test at $p<0.05$.

Correlation and principal component analysis of metals in water

Correlation analysis with Pearson’s correlation coefficients was again used to describe the relations between the sources of metallic pollutants in the water samples at 5% significance. Pearson’s correlation coefficients for the studied heavy metals in the water samples are shown in Table SM 11. The correlation matrix was generated for only detected metals. In Port Harcourt water samples, Zn and Fe showed negative correlations. In Owerri water samples, Pb showed a positive and significant correlation with all other metals except for Cd, which showed a negative correlation with all other metals. Positive correlations indicate similar or common sources while negative correlations indicate dissimilar or uncommon sources.

The principal component analysis (PCA) was computed only for Owerri to determine the precise pollution source of metals in the water. Based on eigenvalue > 1, two principal components were extracted and the results for the total variations are shown in Table SM 12. The variances for PC1 and PC2 groups were 58.362 and 19.326% respectively (Table SM 12). The component plot in rotated space using Varimax rotation is presented in Figure SM 2. Only Cd showed dissimilarities from all other metals and happens to be in a different group (PC2). All other metals in PC1showed a common source related to anthropogenic activities.

Contamination and pollution load appraisal of water samples

The contamination factor, degree of contamination, and pollution load index for metallic elements in the water samples are presented in Table SM 13. All metals showed low contamination factor except for Cd and Fe in M4, M5, and M6 which showed moderate contamination. A low degree of contamination was reported for Port Harcourt which ranged from 0.031 to 0.220, while a moderate degree of contamination was recorded for water samples in Owerri. However, in both areas, the water samples showed a very low metal pollution load (< 1). Similar results were obtained in previous studies [10,13,22].

Water quality assessment

The WQI provides information on the suitability of consuming a water samples and its usage for other domestic purposes. Following the WQI classification, only samples 5A (2127.37) and 6A (4142.87) showed very high WQI indicating the unsuitability of the water for consumption (Figure SM3). These could be due to anthropogenic influence on these sources, as they are both surface water located close to auto-repair workshops. All boreholes (1A to 4A) showed excellent quality except for 3A which was very poor. For Owerri, the WQI ranged from 326.64 to 394.08 indicating the borehole water sources to be unsuitable for drinking. Similar results were reported for some borehole water sampled around Orji and Nekede, Owerri, which was attributed to auto-mechanic activities [10,22]. However, good water quality has been reported for some water samples collected in Owerri and environs [13].

Microbial characterization of the water samples

The result of microbiological quality of the water samples is presented in Table SM14. For Port Harcourt, only sample 5A showed a significant concentration of total aerobic count (287 cfu/mL), total coliform count (97 cfu/mL), and E.coli count (19 cfu/mL), all other samples showed no growth. In Owerri, all samples showed a very high contamination with total aerobic count ranging from 27,000 to 57,000 cfu/mL; moderate contamination with a total coliform count ranging from 12 to 16 cfu/mL and low E.coli count ranging from 2 to 4 cfu/mL. These water sources are not safe for consumption except for 6A. A previous report revealed the unsuitability of groundwater sources in the study area due to their vulnerability to microbial contaminants [40]

Conclusion

This research has revealed that the activities of the informal sector could influence the level of contaminants in the surrounding environment. The results of the physicochemical properties of the soils showed that the soil properties are still within the standard limit for fertile soil, but showed alteration from the control soils. The soils from the areas were generally sandy and loamy textural class with high concentrations of As and Cd above the stipulated limit of DPR. The trend for metals was in the increasing order of Fe > Cr > Cd > Pb >As in the soils. The pollution level of the soils studied has approached an alarming status mainly for As and Cd based on the results of contamination factor, geo-accumulation index, and ecological risk assessment. The potential ecological risks (RI) for all metals in the different sites in Port Harcourt were moderate, while posing considerable risks in Owerri.

The metals generally showed a weak (Cd-Cr/As and As/Fe) and negative correlations with other metals in Owerri soil while most metals showed weak correlation except between Pb, Cd, and Cr for Port Harcourt soil. The PCA result identified that factors such as natural soil-forming processes and anthropogenic influence may have contributed to the accumulation of these contaminants in the examined soils. The bacterial load in the soils showed higher concentrations than in the control, indicating that the soils were contaminated. Most of the isolates in Port Harcourt soils were gram-negative (53%), while positive in Owerri soils (56%). For biochemical characterization, the isolates showed variations across all biochemical test parameters. Based on the result of the biochemical characterization, it could be concluded that the identified microorganisms indicate that the samples may have been influenced by the activities of the informal sector in the area. The abundance of bacteria and fungi in the study area is suggestive that these organisms are now adapted to the activities in the area.

The physicochemical properties of the water samples were all within WHO limits except for pH in some samples. Water with low pH levels is not good for human consumption as it could pose health risk. Also, presence of some heavy metals like Cu, Cu, and Zn in water are associated with decreased pH levels. The sampled areas in Port Harcourt showed low heavy metal levels within the stipulated WHO limits. Elevated levels were recorded in Owerri (Mn > Fe > Zn > Cr > Cu > Cd

> Pb) with 100% and 80% of the water samples having a high concentration of Fe and Pb above the permissible values specified by WHO. Port Harcourt and Owerri had a low and moderate degree of water contamination by heavy metals. In the areas studied, water samples showed a very low metal pollution load (< 1). The correlation and principal component analysis for metals in water showed that Cd belongs to a separate group from all other metals. The water quality index (WQI) showed that all the groundwater samples in Port Harcourt were good, while surface water samples were unsuitable for consumption. However, in Owerri, all groundwater samples were unsuitable for drinking due to high WQI. Furthermore, the water samples had high microbial counts, indicating that the groundwater sources in the areas where the informal sector activities are carried out were not safe for consumption. This study has indicated that informal sector activities could affect the environment negatively and significantly. Thus, it is recommended the informal sector activities should be regulated and waste generated from this sector should be properly disposed or managed to forestall the negative effects on environmental quality

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Declaration of Competing Interest

The authors declare that there is no competing interest with respect to the publication of this article.

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Supplementary materials

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