Research Article

An integrated indexical investigation of selected heavy metals in drinking water resources from a coastal plain aquifer in Nigeria

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Abstract
With respect to the rapid changes in climatic conditions, commerce, industrialization, and urbanization, the water quality of many shallow coastal aquifers in different parts of the world is under serious heavy metals pollution threats. In the current study, three water quality indexical models and hierarchical cluster analysis (HCA) were integrated to investigate the heavy metals contamination and drinking quality of groundwater from the coastal plain aquifer in Oshodi-Isolo area (Nigeria). Several groundwater samples were analyzed for pH and selected heavy metals such as Fe, Zn, Pb, Cu, Ni, Cr, Mn, and Cd. The pH values ranged from 5.1 to 6.9, with about 71.43% of the total groundwater samples indicating slightly acidic nature. Among the analyzed heavy metals, Cu contamination was predominant in over 80% of the samples. However, the water quality evaluation models revealed that the majority of the water samples are suitable for drinking. Based on pollution index of groundwater, 80.95% of the samples have insignificant pollution. Nonetheless, both synthetic pollution index and overall index of pollution classified 85.7% of the samples as excellent water suitable for drinking. The HCA was used to resolve the disparity between the results of the models. Two major water quality classes (excellent water and polluted water) were identified in this study based on the HCA. It is, therefore, recommended that the polluted water be treated before human consumption.

Keywords Groundwater quality · Hierarchical cluster analysis (HCA) · Overall index of pollution (OIP) · Pollution index of groundwater (PIG) · Synthetic pollution index (SPI)

1 Introduction

In order to sustain the quality of life, health, food, economy and the environment, it is very fundamental to first sustain the quality of water resources, as they play significant roles in many sectors of human existence. Factually, one of the most important objectives of Sustainable Development Goals (SDGs) is to ensure that all people have access to safe and affordable drinking water [1], regardless of their race, wealth, age, gender and creed. Groundwater has been reported to be the most important and desirable natural source of drinking water due to the ease of contamination of surface water resources [2, 3]. However, it has been reported that only about 33% of the world's teeming population have access to and utilizes groundwater for drinking purposes [1, 4]. It has also been reported that the availability of the groundwater resource in many parts of the world faces rapid shrinkages due to increasing pollution and over-exploitation rates [2, 5]. Not only is groundwater resource useful for drinking purposes, it also plays a major role in many segments of a nation's economy, such as commerce, industry, agriculture, and hydropower generation.

Researches have shown that the scarcity of quality drinking water is more persistent in most developing countries [2, 3, 6–9]. Moreover, in many areas where drinking water is available in the developing countries, anthropogenic and/or geogenic processes predispose

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the water systems and sources to different levels of contamination. The anthropogenic factors which usually influence the quality and availability of safe drinking water in most developing countries include rapid and unsystematic growth of human population, urbanization, industrialization, poor waste disposal and management, groundwater mismanagement, and inadequate water management policies [1, 2, 6, 9]. Investigations have shown that about 884 million people around the world make use of contaminated water resources for drinking purposes [10, 11]. The use of contaminated drinking water sources exposes both the consumers and the environment to a wide range of adverse health effects [1, 7, 9]. Similarly, in cases where contaminated water is used in agriculture and industry, a nation's food security and economy become adversely threatened. In order to avert such adverse results, it is important to regularly examine the quality and suitability of available water supplies in both rural and urban areas.

Groundwater quality evaluation is a crucial aspect of environmental quality management and sustainability. Such research niche is important toward the enhancement of human existence and the entire ecosystem. In order to achieve this feat, investigations are usually carried out to understand the level of contaminants in water. Currently, water quality assessment is a major research focus of many researchers round the globe. Because of this development and trend, several numerical and statistical models have been developed and employed for the assessment of the quality of both surface water and groundwater in different regions of the world. Such methods which are currently being adopted in water quality assessments include pollution index of groundwater (PIG), synthetic pollution index (SPI), integrated water quality index (IWQI), overall index of pollution (OIP), and hierarchical cluster analysis (HCA). Over time, these quality indexing tools have proven to be very useful in categorizing the water quality of different areas in a simple manner [1, 2, 6, 7, 12–17]. These tools reflect the pollution statuses of different sources of drinking water, thereby providing insights for sustainable water management.

This study is focused on Ajao (Oshodi-Isolo) area of Lagos State, Nigeria. Following the rapid increase in industrialization, urbanization, commercial activities, and inadequate waste disposal policy in this coastal area, it is thought that the shallow coastal plain groundwater system could be under serious threats of heavy metals pollution by these anthropogenic stresses [1, 3, 18]. Therefore, it became necessary to assess the quality of the groundwater (which serves as the major source of drinking water for homes, industries, and markets) for human consumption using three water quality evaluation models (i.e., PIG, SPI, and OIP) and HCA. This study is based on pH and selected heavy metals such as Fe, Zn, Pb, Cu, Ni, Cr, Mn, and Cd. The models were integrated in this study to minimize the subjectivity in the use of a single water quality evaluation model and to also establish the correlation between the three models utilized. This paper could help both local and international water quality experts to have a simplified overview of the efficacy of these models and the status of groundwater in this industrialized and urbanized area. Moreover, the local non-governmental organizations, researchers, industrialists, policymakers, and residents could also benefit from the information provided in this paper, for better planning and decision-making toward the sustainability of groundwater resources.

2 Materials and methods

2.1 Study site description

The study area is a small district located between latitudes 6° 30′ to 6° 33′ N and longitudes 3° 18′ to 3° 22′ E (Fig. 1). The area is within the highly populated area of Oshodi-Isolo Local Government Area, Lagos State, Nigeria. The inhabitants of this area are estimated to be more than 500,000. The common anthropogenic activities thought to predispose the water resources in this area include commerce, industrial food/wine production processes, automobile workshops and factories, inadequate industrial waste disposal, lack of strict environmental protection policies, etc. The predominant surface drainage systems that recharge the aquifers are coastal lagoons which also empty into the Atlantic Ocean located southward of the study area (not shown in Fig. 1). Specifically, the Ogun, Adiyan, and Osse rivers are the major rivers draining the area. Due to the abundance of surface water networks in the study area, high rainfall intensity is experienced annually.

Geologically, the Ajao area of Oshodi-Isolo is underlain by coastal plain sands and alluvial river sands (Fig. 1), both of which are within the Dahomey basin [19, 20]. Lithologically, the study area is characterized by medium to poorly sorted coarse-grained sands commonly associated with mudrock intercalations. In this area, the coastal plain sands constitute the major aquifer systems [21]. According to Longe et al. [21], three aquiferous sand bodies, extending from the outcrop area in the north of the study area to the coast in the south, supply groundwater to the residents via boreholes and hand-dug wells. The first aquifer system is encountered at an average depth of 35 m, with an average thickness of 6 m. It was reported that this aquifer is more prone to surface contamination [21]. On the other hand, the second and third aquifers are the most preferred sources of water, possibly due to the fact that they are situated at deeper depths. The second aquifer is situated between the depths of 40–55 m (and about 8 m

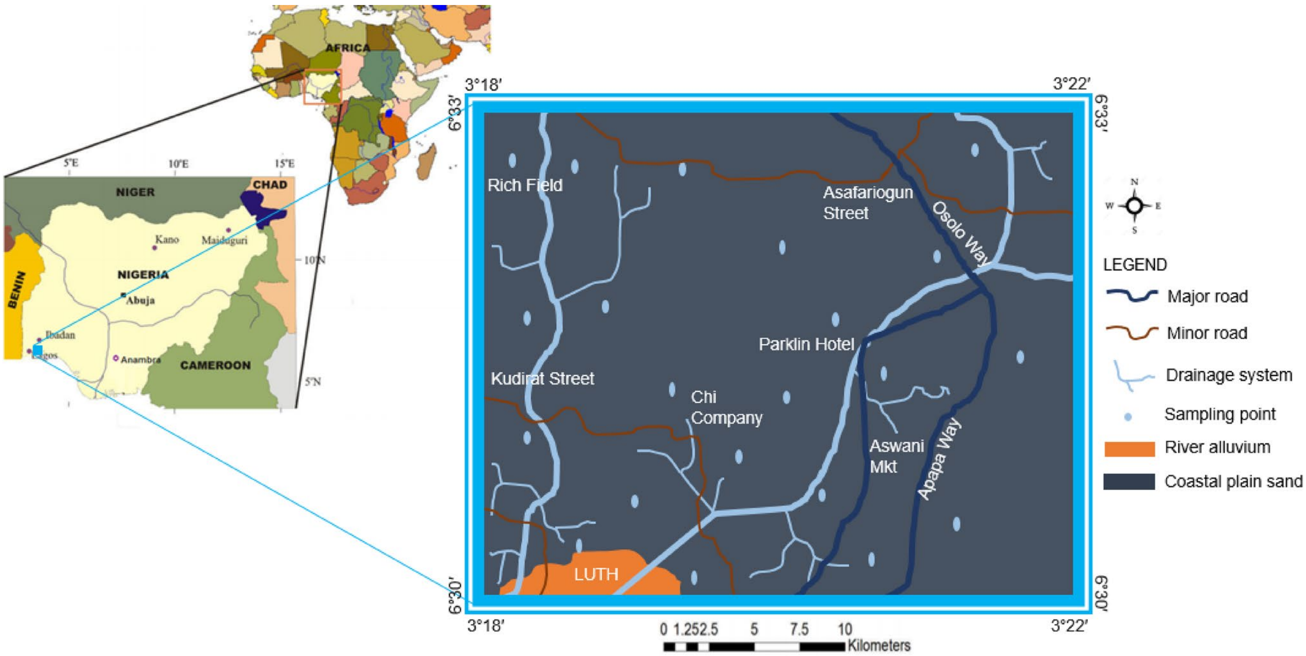

Fig. 1 Location, drainage, and geological map of the study area

thick), whereas the third is between the depths of 30–90 m (and about 32 m thick) [21].

2.2 Groundwater sampling and analysis

A total of 21 available borehole locations (Fig. 1) were randomly sampled with sterilized 1-liter plastic bottles. Groundwater samples were collected and analyzed for pH, Fe, Zn, Pb, Cu, Ni, Cr, Mn, and Cd. The determination of pH was done in situ using a Testr-2 pH meter, whereas the analysis of heavy metals was conducted in the laboratory using specific hollow cathode lamp at a specific wavelength, which was then aspirated into the flame of AAS (atomic absorption spectrophotometer) PerkinElmer Analyst 200. Prior to the laboratory analysis, the groundwater samples were acidified with concentrated HNO_3 (to prevent precipitation) and later filtered through a cellulose acetate (0.45-micron millipore) filter. All the analysis was done following the recommendations of the American Public Health Association (APHA) [22].

2.3 Drinking water quality evaluation

2.3.1 Pollution index of groundwater (PIG)

The pollution index of groundwater (PIG) was developed by Subba Rao [12] and has been successfully used in researches for the monitoring and assessment of drinking water quality [14–16]. The final PIG values express the contributions of all analyzed quality variables of groundwater samples. For the evaluation of PIG, five steps were taken. The first step involved the estimation (on a scale of 1–5) of relative weight (R_w) of the analyzed parameters (Table 1). The weight assignment was based on the significances and impact on human health of the parameters [12]. The second, third, fourth, and fifth steps are described in Eqs. 1–4, respectively.

$$W_p = \frac{R_w}{\Sigma R_w} \tag{1}$$

$$S_c = \frac{C}{D_s} \tag{2}$$

$$O_w = W_p \times S_c \tag{3}$$

$$\mathrm{PIG} = \Sigma O_w \tag{4}$$

where W_p is the weight parameter for each of the water quality variables; R_w, relative weight of a parameter; S_c, the status of concentration; C, analyzed water quality variables' content in each water sample; D_s, the respective water quality standard limit of parameter, as described by NIS [23] and WHO [24]; O_w, overall quality of the groundwater sample [12, 14–16].

Table 1 Parameters considered in the PIG evaluation

Parameter	Unit	Relative weight (R_w)	Weight parameter (W_p)	NIS [23] and WHO [24] standard limits
pH	–	3	0.0769	6.5
Fe	mg/L	4	0.1026	0.3
Zn	mg/L	4	0.1026	3
Pb	mg/L	5	0.1282	0.01
Cu	mg/L	4	0.1026	0.1
Ni	mg/L	5	0.1282	0.02
Cr	mg/L	5	0.1282	0.05
Mn	mg/L	4	0.1026	0.2
Cd	mg/L	5	0.1282	0.003
		$\Sigma R_w = 39$	$\Sigma W_p = 1.0001$	

2.3.2 Synthetic pollution index (SPI)

The synthetic pollution index (SPI) has also been successfully used by different researchers to depict the level of pollution in water resources [1, 13] and their drinking suitability. For evaluating SPI, the following equations were used:

$$\sum_{i=1}^{n} \frac{V_o}{V_s} \times W_i \tag{5}$$

$$W_i = \frac{K}{V_s} \tag{6}$$

$$K = 1 \bigg/ \sum_{i=1}^{n} \frac{1}{V_s} \tag{7}$$

where K is the constant of proportionality; V_s, each parameter's standard NIS level; n, total number of observed parameters; V_o, each parameter's concentration; and W_i, weight coefficient for each parameter [1, 13].

2.3.3 Overall index of pollution (OIP)

The overall index of pollution (OIP) was proposed by Sargaonkar and Deshpande [25] for the assessment of the level of pollution in drinking water resources. It is another evaluation model that provides insights into the suitability of water for drinking purpose. In this study, the OIP was computed for the analyzed eight heavy metals, using the functions described in Eqs. 8 and 9.

$$\text{OIP} = \frac{1}{n} \times \sum_{i=1}^{n} \text{PI} \tag{8}$$

$$\text{PI} = \frac{V_n \text{ (observed value of parameter)}}{V_s \text{ (NIS standard value of parameter)}} \tag{9}$$

where PI is the pollution index for the ith parameters; n, number of analyzed heavy metals.

2.3.4 Hierarchical cluster analysis (HCA)

Multivariate statistical analysis, such as the hierarchical cluster analysis (HCA), has proven very useful in many water quality researches [1–3, 6, 7, 9, 15–17]. Precisely, the HCA is a powerful multivariate tool for classifying water quality parameters and water samples based on their genetics [6, 7, 15]. In the current study, the HCA was performed using SPSS software (v. 22). The analysis involved the utilization of Ward's linkage method (with squared Euclidean distance and z-score standardization). A dendrogram grouping of the groundwater samples based on the integration of PIG, SPI, and OIP was produced to show the quality demarcations of the groundwater samples.

3 Results and discussion

3.1 General characteristics of the groundwater

This study was based on the measurements of pH and selected heavy metals. The results obtained from the water quality analysis are summarized in Table 2, with the descriptive measures (such as minimum, maximum, mean, and standard deviation) of the analyzed water quality parameters. Groundwater pH values below 6.5 are classified as acidic, indicating the depletion of hydroxide ions compared to the abundant hydrogen ions present [26]. The pH values obtained in this study ranged from 5.1 to 6.9, with about 71.43% of the total groundwater samples indicating slightly acidic nature. Acidity is known to affect the fresh taste of water and the water supply systems. According to Ebong et al. [26], "areas where the groundwater is acidic could be attributed to anthropogenic activities

Table 2 Univariate statistics of analyzed parameters and water quality standard limits

Parameter	Number of samples	Minimum	Maximum	Average	SD	Standard limits		% Samples exceeding limits
						NIS [23]	WHO [24]	
pH	21	5.1	6.9	5.9133	0.5946	6.5–8.5	6.5–8.5	71.43
Fe (mg/L)	21	0.039	1.742	0.3468	0.5785	0.3	0.3	23.81
Zn (mg/L)	21	0.051	1.732	0.7185	0.4814	3	4	0.00
Pb (mg/L)	21	0.00	0.021	0.0017	0.0053	0.01	0.01	9.52
Cu (mg/L)	21	0.00	3.142	0.5464	0.7842	0.1	0.05	85.71
Ni (mg/L)	21	0.00	0.73	0.0389	0.1589	0.02	0.07	14.29
Cr (mg/L)	21	0.00	0.32	0.0321	0.0854	0.05	0.05	14.29
Mn (mg/L)	21	0.00	0.13	0.0082	0.0285	0.2	0.4	0.00
Cd (mg/L)	21	0.00	0.005	0.0005	0.0014	0.003	0.003	4.76

and indiscriminate sewage disposal." For the study area, the acidic nature of the water samples is attributed to industrial gases released into the atmosphere, leading to the formation of acid rain.

The heavy metals, Fe, Zn, Pb, Cu, Ni, Cr, Mn, and Cd, concentrations were found to range from 0.039 to 1.742 mg/L, 0.051 to 1.732 mg/L, 0 to 0.021 mg/L, 0 to 3.142 mg/L, 0 to 0.73 mg/L, 0 to 0.32 mg/L, 0 to 0.13 mg/L, and 0 to 0.005 mg/L, respectively. Based on their geometric mean (average) values, the heavy metals distribution in the groundwater follows the trend Zn > Cu > Fe > Ni > Cr > Mn > Cd > Pb. In the groundwater quality evaluation for drinking purposes, the water quality data were compared to the specific standards set by the NIS [23] and WHO [24] for drinking water quality. By making reference to these quality standards and as presented in Table 2, it was observed that the majority (85.71%) of the groundwater samples were contaminated with Cu. About 14.29% of the samples had Ni and Cr in excess, whereas 23.81%, 9.52%, and 4.76% of the samples had excess Fe, Pb, and Cd, respectively. Therefore, the consumers of the contaminated water resources are exposed to adverse health risks due to excess concentrations of these heavy metals. However, none of the samples recorded excess Mn and Zn (Table 2). Hence, the consumers face no adverse health risks due to Mn and Zn enrichment in water.

Several factors (e.g., rock–mineral weathering, climatic conditions, drainage density, geological and hydro-geological settings, and several anthropogenic activities) influence the enrichment of heavy metals in groundwater. In this study, the origins of the heavy metals are attributed to human activities, owing to the described features of the study area. The geological makeup of the area has been described to be dominantly alluvial sands. Such deposits are not naturally rich in heavy metals but are coarse, porous and permeable enough to facilitate the contamination of shallow groundwater. Moreover, because the aquifers are generally situated at shallow depths, it seems that the contamination of the groundwater by surface processes will be much easier. Furthermore, the abundance of surface water networks provides an easy pathway for the heavy metals to be leached and transported down to the aquifer systems.

The HCA was performed with *z*-score standardization (to remove bias) on the analyzed water quality parameters in order to establish the linkages (relationships) between them. Three major clusters were identified (Fig. 2). Cluster 1 comprises Ni, Mn, and Zn. These parameters represent heavy metals typically from anthropogenic sources such

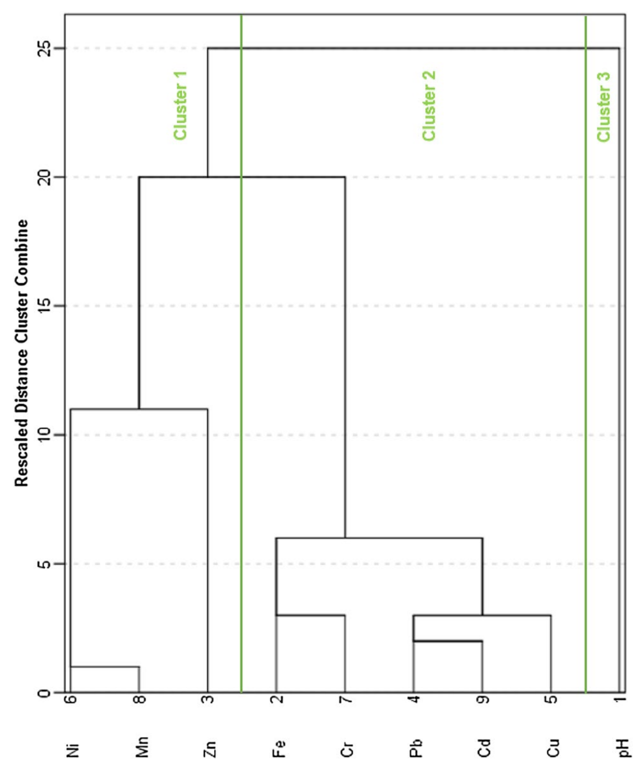

Fig. 2 A dendrogram showing the association of the analyzed parameters

as dumpsites and heavy chemicals from industrial activities [6, 9]. Cluster 2 is also made up of parameters (Fe, Cr, Pb, Cd, and Cu) peculiar to anthropogenic inputs. In this class, the possible sources of the heavy metal contaminants include automobile batteries, tires, petrochemicals, and electronic wastes [6, 24]. However, Cluster 3 comprises only pH, indicating that the release of the heavy metals into the groundwater is not controlled by the pH.

3.2 Evaluation of drinking water quality

3.2.1 Pollution index of groundwater (PIG)

In PIG evaluation, an overall chemical quality of groundwater (Ow) greater than 0.1 indicates a contribution of about 10% value of 1.0 of the final PIG, thereby depicting the actual influence of different parameters in the pollution of the groundwater [12, 14–16]. In this current study, the Ow of pH and all the heavy metals were below 0.1, except for Cu and Ni in sample 6 (Table 3). This indicates that the majority of the analyzed parameters have low impact (of less than 10% contribution) in the pollution of the groundwater system. However, the higher enrichment of Cu and Ni in sample 6, more than other samples, suggests that the borehole in this location could be tapping a shallower aquifer, which is more vulnerable to surface contamination.

Overall, the pollution index of groundwater (PIG) values in this study ranged from 0.158 to 7.416 with a mean value of 1.154 (Table 3). According to Subba Rao [12], the degree of pollution of drinking water on the basis of PIG is classified into five: PIG < 1.0 (insignificant pollution); 1.0–1.5 (low pollution); 1.5–2.0 (moderate pollution); 2.0–2.5 (high pollution); and PIG > 2.5 (very high pollution). With respect to this classification scheme, 80.95% of the total samples have insignificant pollution, indicating that the majority of the groundwater samples are suitable for human consumption. It further indicates that industrial activities and urbanization have not significantly impacted on the groundwater system, with respect to heavy metals pollution. However, sample 8 has low pollution, whereas samples 6, 12, and 15 were observed to have very high pollution level and thus adjudged as unsuitable for drinking purposes (Table 3). It is believed that these samples possibly were exposed to high loads of anthropogenic inputs or are from shallower aquifers.

3.2.2 Synthetic pollution index (SPI)

The synthetic pollution index (SPI) model was also used in this study to validate the PIG results. Similar to the PIG, the SPI is used to classify drinking water based on five categories: SPI < 0.2 (suitable for drinking), 0.2–0.5 (slightly polluted water), 0.5–1.0 (moderately polluted), 1.0–3.0

Table 3 Pollution index of the groundwater (PIG) of the groundwater samples

Sample number	O_w (pH)	O_w (Fe)	O_w (Zn)	O_w (Pb)	O_w (Cu)	O_w (Ni)	O_w (Cr)	O_w (Mn)	O_w (Cd)	ΣO_w
01	0.079	0.015	0.015	0	0.527	0	0	0	0	0.636
02	0.063	0.015	0.002	0	0.371	0	0	0	0	0.451
03	0.078	0.018	0.007	0	0.064	0	0	0	0	0.167
04	0.065	0.022	0.007	0	0.061	0	0	0	0	0.155
05	0.070	0.015	0.011	0	0.045	0	0	0	0	0.141
06	0.076	0.514	0.057	0.026	1.050	4.679	0.820	0.067	0.128	7.416
07	0.069	0.019	0.012	0	0.423	0	0	0	0	0.523
08	0.065	0.257	0.033	0	0.668	0	0	0.002	0	1.025
09	0.079	0.018	0.017	0	0.044	0	0	0	0	0.158
10	0.062	0.017	0.053	0	0.166	0	0	0	0	0.298
11	0.060	0.017	0.031	0	0.068	0	0	0	0	0.176
12	0.068	0.596	0.030	0.269	2.320	0.340	0.564	0.008	0.214	4.408
13	0.067	0.025	0.034	0	0.323	0	0	0	0	0.449
14	0.082	0.018	0.013	0	0.064	0	0	0	0	0.177
15	0.065	0.557	0.059	0.167	3.224	0.212	0.333	0.012	0.128	4.756
16	0.064	0.278	0.011	0	0	0.006	0.005	0	0	0.365
17	0.065	0.021	0.031	0	0.215	0	0	0	0	0.333
18	0.078	0.015	0.026	0	0.732	0	0	0	0	0.851
19	0.065	0.013	0.020	0	0.681	0	0.008	0	0	0.787
20	0.068	0.023	0.015	0	0.654	0	0	0	0	0.759
21	0.082	0.019	0.030	0	0.074	0	0	0	0	0.205

(highly polluted), and > 3.0 (unfit for drinking) [1, 13]. In the current study, the SPI values of the groundwater samples ranged from 0.010 to 4.651, with a mean value of 0.468. Contrary to the PIG report, the SPI results classified 85.71% of the total samples (with values < 0.2) as water suitable for drinking purposes (Table 4). However, two samples (9.53%) are highly polluted with heavy metals, whereas only one sample (4.76%) is extremely polluted and thus unsuitable for human consumption.

3.2.3 Overall index of pollution (OIP)

Prior to the OIP evaluation, the pollution index (PI) of all the samples was determined. The PI and OIP values of all the samples are presented in Table 5. According to a PI classification presented in Adimalla et al. [27], PI values < 1 signify low pollution, 1–2 signify low–moderate pollution, 2–3 signify moderate pollution, 3–4 signify moderate–high pollution, 4–5 signify high pollution, and PI values > 5 indicate very high pollution. In the current study, the pollution indices of the eight heavy metals are summarized as follow: PI (Fe) ranged from 0.13 to 5.807 with a mean value of 1.156; PI (Zn) ranged from 0.017 to 0.577 with an average value of 0.240; PI (Pb) ranged from 0 to 2.1 with a mean value of 0.171; PI (Cu) ranged from 0 to 31.42 with an average value of 5.463; PI (Ni) has a range of 0–36.5 and an average of 1.945; PI (Cr) ranged from 0 to 6.4 with a mean value of 0.643; PI (Mn) ranged from 0 to 0.65 with an average value of 0.041; and PI (Cd) ranged from 0 to 1.667 with an average value of 0.175. Based on the PI classification presented in Table 6, the majority of the samples had low pollution of all the heavy metals, except for Cu. About 57.14% of the water samples were identified as moderately to very highly polluted. This result indicates that anthropogenic pollution is prevalent than geogenic pollution, as the alluvial sands that underlie the area are not known to be geological deposits rich in these heavy metals.

However, according to Sargaonkar and Deshpande [25], the OIP model classifies water quality into five categories: OIP score < 1.9 indicates an excellent water quality (Class C_1); OIP < 3.9 signifies acceptable water quality (Class C_2); OIP scores < 7.9, < 15.9, and > 16 indicate slightly polluted (Class C_3), polluted (Class C_4), and heavily polluted (Class C_5) water, respectively. In the current study, the OIP values ranged from 0.086 to 7.568 and an average value of 1.229. With respect to the OIP scores obtained in this study, the majority (about 85.71%) of the total groundwater samples were identified to be in excellent condition (as their OIP scores were < 1), whereas the remaining 14.29% of the samples were identified as slightly polluted water and hence unsuitable for drinking purposes. This confirms that

Table 4 Synthetic pollution index (SPI) of the groundwater samples

Sample number	SPI (pH)	SPI (Fe)	SPI (Zn)	SPI (Pb)	SPI (Cu)	SPI (Ni)	SPI (Cr)	SPI (Mn)	SPI (Cd)	Sum
01	0.0003032	0.0009149	9.42113E−05	0	0.098	0	0	0	0	0.100
02	0.0002405	0.0009575	0.000010846	0	0.069	0	0	0	0	0.071
03	0.0002995	0.0011064	4.55107E−05	0	0.012	0	0	0	0	0.013
04	0.0002496	0.0013404	4.61487E−05	0	0.011	0	0	0	0	0.013
05	0.0002678	0.0009149	6.78407E−05	0	0.008	0	0	0	0	0.010
06	0.0002905	0.0319576	0.000353027	0.038	0.196	3.495	0.245	0.006	0.638	4.651
07	0.000266	0.0012128	7.29447E−05	0	0.079	0	0	0	0	0.080
08	0.0002505	0.0160001	0.000204798	0	0.125	0	0	0.0001436	0	0.141
09	0.0003027	0.0011489	0.000104845	0	0.008	0	0	0	0	0.010
10	0.0002369	0.0010426	0.000332398	0	0.031	0	0	0	0	0.033
11	0.0002315	0.0010426	0.000193952	0	0.013	0	0	0	0	0.014
12	0.0002596	0.037064	0.000187785	0.402	0.433	0.254	0.169	0.0008	1.064	2.360
13	0.0002573	0.0015319	0.000213305	0	0.060	0	0	0	0	0.062
14	0.0003132	0.0011064	8.37907E−05	0	0.012	0	0	0	0	0.013
15	0.0002478	0.034681	0.000368339	0.249	0.602	0.158	0.100	0.001	0.638	1.783
16	0.0002451	0.0172979	6.86913E−05	0	0	0.005	0.002	0	0	0.024
17	0.000251	0.0012979	0.000193952	0	0.040	0	0	0	0	0.042
18	0.0003004	0.0009149	0.000162265	0	0.137	0	0	0	0	0.138
19	0.0002505	0.0008298	0.000121858	0	0.127	0	0.002	0	0	0.131
20	0.0002591	0.0014043	9.46367E−05	0	0.122	0	0	0	0	0.124
21	0.0003132	0.0011915	0.000187785	0	0.014	0	0	0	0	0.015

Table 5 Overall index of pollution (OIP) of the groundwater samples

Sample number	PI (Fe)	PI (Zn)	PI (Pb)	PI (Cu)	PI (Ni)	PI (Cr)	PI (Mn)	PI (Cd)	ΣPI	OIP
01	0.143	0.148	0	5.14	0	0	0	0	5.431	0.679
02	0.150	0.017	0	3.62	0	0	0	0	3.787	0.473
03	0.173	0.071	0	0.62	0	0	0	0	0.865	0.108
04	0.210	0.072	0	0.59	0	0	0	0	0.872	0.109
05	0.143	0.106	0	0.44	0	0	0	0	0.690	0.086
06	5.007	0.553	0.2	10.23	36.50	6.40	0.65	1.0	60.540	7.568
07	0.190	0.114	0	4.12	0	0	0	0	4.424	0.553
08	2.507	0.321	0	6.51	0	0	0.02	0	9.353	1.169
09	0.180	0.164	0	0.43	0	0	0	0	0.774	0.097
10	0.163	0.521	0	1.62	0	0	0	0	2.304	0.288
11	0.163	0.304	0	0.66	0	0	0	0	1.127	0.141
12	5.807	0.294	2.1	22.61	2.65	4.40	0.08	1.7	39.608	4.951
13	0.240	0.334	0	3.15	0	0	0	0	3.724	0.466
14	0.173	0.131	0	0.62	0	0	0	0	0.925	0.116
15	5.433	0.577	1.3	31.42	1.65	2.60	0.12	1.0	44.096	5.512
16	2.710	0.108	0	0	0.05	0.04	0	0	2.908	0.363
17	0.203	0.304	0	2.10	0	0	0	0	2.607	0.326
18	0.143	0.254	0	7.13	0	0	0	0	7.528	0.941
19	0.130	0.191	0	6.64	0	0.06	0	0	7.021	0.878
20	0.220	0.148	0	6.37	0	0	0	0	6.738	0.842
21	0.187	0.294	0	0.72	0	0	0	0	1.201	0.150

Table 6 Pollution index classes and percentages of groundwater samples in category

Heavy metals	Low pollution (%)	Low–moderate pollution (%)	Moderate pollution (%)	Moderate–high pollution (%)	High pollution (%)	Very high pollution (%)
Fe	76.19	–	9.52	–	–	14.29
Zn	100	–	–	–	–	–
Pb	90.48	4.76	4.76	–	–	–
Cu	38.1	4.76	4.76	9.52	4.76	38.1
Ni	85.71	4.76	4.76	–	–	4.76
Cr	85.71	–	4.76	–	4.76	4.76
Mn	100	–	–	–	–	–
Cd	85.71	14.29	–	–	–	–

only few water sources received relatively higher heavy metals enrichment.

3.2.4 Classification of groundwater quality using HCA

A dendrogram integrating the PIG, SPI, and OIP results was produced using the Ward's linkage method (and *z*-score standardization to remove bias in the parameter values). In Fig. 3, two major clusters based on the quality of the drinking water are identified. The first cluster consists of 85.71% of the samples (3, 4, 5, 9, 14, 11, 21, 10, 17, 16, 2, 7, 13, 19, 20, 1, and 8), which were identified by the numerical models to have insignificant to low pollution, and as such suitable for drinking. However, the second cluster comprises three samples (12, 15, and 6) which are well loaded with heavy metals and thus adjudged to be unsuitable for drinking purposes.

3.2.5 Relationship between the indexical models

With respect to the PIG, SPI, and OIP results presented in this study, samples 6, 12, and 15 (constituting about 14.29% of the total samples) were identified by the three models as water unsuitable for drinking. This indicated that the three models have similar degree of efficacy in water quality evaluation. However, in an attempt to further

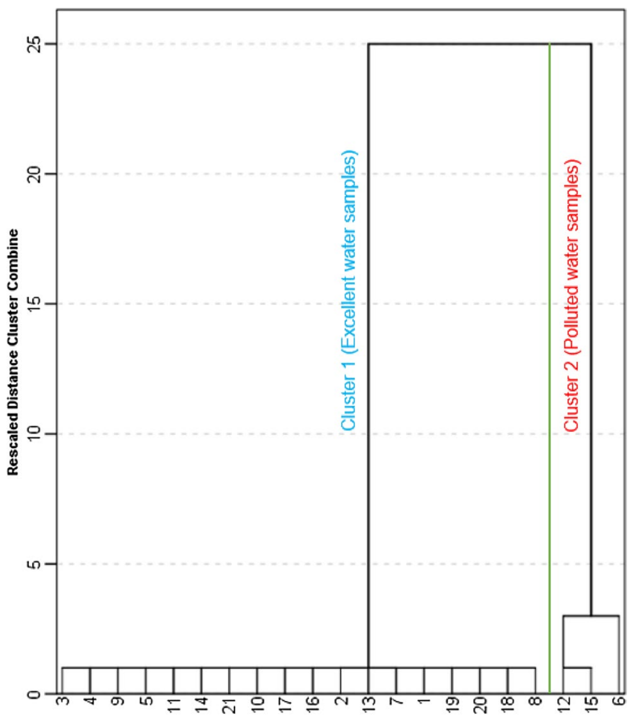

Fig. 3 A dendrogram grouping of the groundwater samples based on the integration of PIG, SPI, and OIP results

Table 7 Correlation of the numerical (indexical) models

	PIG	SPI	OIP
PIG	1		
SPI	0.978**	1	
OIP	0.998**	0.963**	1

**Correlation is significant at the 0.01 level (2-tailed)

establish the correlation between the three numerical models, a Pearson's correlation matrix was produced in the SPSS (v. 22) software environment. The result of the correlation analysis is presented in Table 7. Traditionally, correlation coefficients > 0.7, 0.5 < *r* < 0.7, and < 0.5 are considered as strong, moderate, and weak, respectively [9]. Based on the coefficients obtained, the three models were confirmed to have very strong relations. This proves that they are efficient in identifying the variations in the groundwater quality of the study area.

4 Conclusions

Groundwater pollution and quality evaluation (based on pH and selected heavy metals) of Ajao, Oshodi-Isolo coastal plain aquifer, has been carried out using the integration of PIG, SPI, OIP, and HCA models. The PIG, SPI, and OIP proved to be very efficient models in the drinking water quality evaluation of the study area. From the findings of this paper, it concluded that:

- Most of the groundwater samples are slightly acidic nature.
- Of all the heavy metals (Fe, Zn, Pb, Cu, Ni, Cr, Mn, and Cd) analyzed, Cu was identified as the predominant contaminant in the study area.
- Based on the PIG, 80.95% of the samples have insignificant pollution, and thus, the majority are suitable for drinking. About 4.76% and 14.29% of the samples have low pollution and very high pollution levels, respectively.
- Both the synthetic pollution index (SPI) and overall index of pollution (OIP) classified 85.7% of the samples as excellent water suitable for drinking, whereas 14.3% are unsuitable for drinking.
- The HCA successfully grouped the groundwater samples into two distinct classes: 14.29% which are unsuitable water for drinking formed the first cluster and 85.71% which are potable for human consumption formed the second cluster.
- Based on these findings, it is indicated that the wide ranging anthropogenic activities in this area have not extremely impacted on the groundwater quality. However, contaminated water should be treated before drinking, and regular monitoring and adequate environmental management practices should be adopted to protect the shallow aquifers from further pollution. This will ensure that both humans and the entire ecosystem are not exposed to adverse health effects.
- This study was based on only the pH and eight heavy metals for 21 water samples. It could be expanded in the future by analyzing more heavy metals and taking more samples.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest regarding this paper.

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