Multivariate analysis of groundwater around Solous III dumpsite, Lagos, South-West Nigeria

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Abstract

The study of changes in groundwater quality across different areas is necessary so as to track the sources of the contamination in the water sources. Assessment of the physiochemical parameters of groundwater samples obtained from both borehole and hand-dug wells were conducted around the Solous III dumpsite, Lagos, South-western, Nigeria. Multivariate statistics such as correlation coefficient analysis, Hierarchical cluster analysis (HCA) and principal component analyses (PCA) were utilised to assess the mode of association of parameters and their interrelationships to establish possible sources of groundwater contamination. Eight groundwater samples were obtained around the dumpsite during the wet and dry seasons for analysis of their physicochemical properties. The results of the analyses of water samples indicated seasonal changes for the various elemental constituents analysed. There was generally an increase in mean concentration of total dissolved solid (TDS), pH, temperature and hardness in the dry season study, and a corresponding increase in the mean concentration of Ca^{2+}, Mg^{2+}, Na^{+}, SO_4^{2-}, NO_3^{2-}, Pb, and Cr, when compared with the wet season. On the other hand, there was reduction in the mean concentration of electrical conductivity (EC), K^{+}, Cl^{-}, PO_4^{3-}, Fe, Zn, Mn, Cu, and Ni in the dry season when compared with the wet season. Some of the water sample parameters exhibited high concentration when compared with WHO/SON standard, which may be due to the impact of leachate migration from the dumpsite. Five varimax rotated factor loadings and communalities were responsible for 30 % and 35 % of the total variance in the data set during wet and dry seasons respectively. The PCA parameters identified to be influencing the quality of water are perhaps related to anthropogenic activities from the dumpsite, soluble mineral dissolution, rock–groundwater interaction and weathering activities while PCA performed on samples of groundwater during wet and dry seasons indicated 2 and 3 important clusters, respectively. The clusters of parameters as observed in the parameters dendrograms clearly validates the results earlier obtained in the correlation analysis component of this research. The dendrogram was also able to reflect variation in the quality of water with season as indicated in the difference in the number of clusters during both wet and dry seasons.

Introduction

The importance of water to man cannot be overemphasized because it is a very important natural resource that life is highly dependent on. Humans need water from surface and underground sources for many purposes, including manufacturing, agricultural and, household (cooking, washing and drinking) uses. Each one of the aforementioned purposes however, has its own peculiar water quality requirement that qualifies it to be fit. Groundwater is the only viable and safe means of water in many geologic environments where the development of surface water is characterised with a myriad of problems. Groundwater is readily available in many countries and serves as a principal source of water resources (Amadi et al., 2013; Prasad and Kumar 2008; Selvakumar et al., 2017). The chief source of water in most under developed countries of the world is subsurface water (Lutterodt et al., 2018). Over 20% of the world population use groundwater for drinking purposes (Kim and Park, 2016). Surface water which is the alternative to groundwater is not available everywhere and, relative to groundwater sources, it is more easily contaminated (Ameloko et al., 2022; Ameloko et al., 2018; Sorensen et al. 2015; Mbaka et al., 2017; Mazhar et al., 2019). As a result of the high rate of the drop in the groundwater levels in recent times, water obtained from groundwater sources such as hand dug wells and boreholes tend to be exposed to contamination due to rock-water interaction. Water contamination and pollution is one of the most serious global environmental issues at the moment. Surface waters are most vulnerable to contaminants from anthropogenic and natural sources. These include but not limited to agricultural practices, leachate from municipal waste disposal, industrial activities, mining of ore, and weathering, domestic, urban runoff etc. (Ameloko and Ayolabi, 2020; Zarazua et al., 2006; Gupta et al., 2009; Sekabira et al., 2010). The physiochemical characteristics of water bodies are also affected by many factors including interaction with topography, vegetation cover, and geology (Han and Liu, 2004). Water contaminants can be classified into different categories namely; inorganic, organic, sediments and suspended solids, and potentially toxic elements such as radioactive materials and heavy metals (Botikin and Keller, 1995). Heavy metals are category of metalloids and metals whose atomic densities are larger than 4 g/ cm^3 and specific gravities are greater than 5 (Barzegar et al. 2015; Ganiyu *et al.* 2017; Enuneku et al. 2018). Metals are naturally occurring constituent of the earth's crust, but their levels in porous media such as sediment and soil and in water bodies are a major source of concern due to their inability to decompose, long-lasting properties, and dangerous (Chen et al. 2017; Giri and Singh, 2019). Heavy Metals can be detected in water from manmade activities or geological environment (Nawab et al. 2017; Paul et al. 2019). Toxicity of heavy metals can be passed into the human body via dermal contact, ingestion and inhalation (Olujimi et al. 2014; Ayedun et al. 2015; Ogundele et al. 2019). It is worthy of note that only a small fraction of heavy metals is considered vital for the various biochemical activities in the human body (Singh et al. 2011; Selvam et al. 2017; Shankar, 2019). Many heavy metals including, Fe, Cr, As, Mn, Pb, Hg and Cr pose a serious danger as they can interfere with the human body systems because of the length of their half-lives (biological), thereby giving rise to different diseases (Barzegar et al. 2019; Suvarapu and Baek, 2017). For example, it has been noted that after As, Pb is the second most toxic metal and constitutes 0.002% of earth's crust (Arias et al. 2010; Kumar et al. 2020). Contamination of groundwater by As in a particular location can take place either through anthropogenic or geogenic inputs (Kumar et al. 2021; Pal et al. 2020). Many people living in different countries are reported to be vulnerable or at a risk of increased consumption of groundwater rich in As (Kumar et al. 2021; Ravindra and Mor 2019). The occurrence of dissolved metals in drinking water above standard limits may pose danger to the health of the residents, particularly where enormous farming takes place and also human activities leading to disposal of metallic waste (Kumar et al. 2021; Wu et al. 2019). From many recent work, researchers have also studied soil's geochemical constituents and its physicochemical properties using the PCA, analysis of heavy metals presence in dust and evaluation of influence of seasons on air pollution and identification of heavy metal pollutants in soil (Ma et al. 2016; Satyanarayanan et al. 2016; Adhikari et al. 2003). Heavy metal index (HMI), water quality index (WQI) and multivariate statistics have been utilized and were established to be very important techniques for revealing valuable information that can assist in sustainable policy formulation for the management of water. Examples abound in literature including; Kondom *et al.*, (2021), Sharma et al., (2020), and Rana et al. (2018), who have proven in their research works that these techniques are useful for assessing surface water, groundwater and rivers contamination status in various parts of the world. This present work was conducted during the rainy and dry season periods on groundwater samples from boreholes and hand-dug wells obtained around the Solous III solid waste dumpsite for better appreciation of the seasonal and spatial variability of the physicochemical properties of groundwater and discerning sources of pollution that may influence the qualities of groundwater utilizing multivariate statistical techniques. The relationship that exists among the contaminants and the contaminant sources were studied and inferred through the instrumentality of the HCA and PCA.

The Study Area

The study dumpsite, Solous III, is an open waste disposal system where dumping commenced so many years ago. It is located within latitude $6^{o}33^{1}42^{11}\mathrm{N} - 6^{o}33^{1}58^{11}\mathrm{N};$ longitude $3^{o}15^{1}02^{11}\mathrm{E} - 3^{o}15^{1}15^{11}\mathrm{E}$ (Fig. 1). Waste materials are usually unsorted and are being dumped indiscriminately by residents around the area. The types of wastes materials dumped on the site are mostly household waste, and non-hazardous industrial wastes. Some components of these wastes including electronic, food, papers etc., which most often are oxidized thereby changing the redox potential of the water in the dump. Percolating groundwater provides a platform through which the organic component of the waste material can undergo decomposition into simpler substances via biochemical processes involving hydrolysis, dissolution, reduction, and oxidation reactions. The percolating liquid dissolves different components of the waste to form a complex and concentrated mixture referred to as leachate. The leachate composed mainly of organic carbon solely in the form of fulvic acids which at the end of the day moves into the subsurface environment and contaminate the groundwater. The implication of this therefore is that shallow sources of water (hand-dug wells and groundwater), which constitute about 85% of sources for irrigation water systems and domestic use are at high risk of contamination from the dumpsite.

Materials And Methods

Water sampling and analyses

Eight sampling locations (BH33–BH40) were chosen randomly based on accessibility to water source. Geographic coordinates of sampling points were obtained using a portable handheld Geographic Positioning System (GPS) equipment (Garmin GPS Channel 76 model). The detailed description of each sampling location is presented in Fig. 1. At each sampling location, 500 mL of water sample from hand dug wells and boreholes were obtained by lowering already cleaned container down the upper surface (18–25 m) of the hand dug well or in the case of a borehole, water was pumped out for about 5 minutes in order to maintain quality standard before samples of fresh water were collected in plastic bottles. The bottles were washed three times with the samples of water obtained before taking the final water samples. Sampling took place in August 2020 and December 2021. The reason for examining variations comparing two periods (wet and dry seasons) was the considerable differences in weather and hydrological conditions respectively, of the periods leading to water quality changes. The pH, TDS, EC, and temperature values of groundwater samples were obtained using a portable pocket size TDS/Conductivity/Temperature tester (HANNA Combo HI98130 Model) that was immersed in the water container. Using the flame photometric method, $\mathrm{k^{+} and Na^{+}}$concentrations were obtained while $\mathrm{Cl^{-}}$was analysed in the laboratory through titration of silver-nitrate with potassium chromate as an indicator. The absorption mode of Atomic Absorption Spectrophotometric (AAS) technique was utilised to determine the concentrations of $\mathrm{Mg^{2+} and Ca^{2+}. N0_{3}^{-}}$and $\mathrm{P0_{4}^{3-}}$values were obtained by ultraviolet spectrophotometric approach while the turbidimetric technique was utilized to determine the amount. Potentially toxic metals such as Pb, Fe, Mn, Ni, Cu, Fe, Cr and Zn were obtained by acid digestion with the aid of nitric acid and further analysed with Perkin Elmer Analyst 200 Flame Atomic Absorption Spectrometer (APHA, 1998). From both data sets obtained in the dry and wet seasons, all examined variables were compared with each other to examine the degree of temporal variation with respect to time. Concentrations of the measured data were recorded in a tabular form accordingly to observe the spatial variation in the concentration of physicochemical values in the selected boreholes and hand dug wells around the dumpsite. The results from the analysed data samples were subsequently compared with WHO, (2007) and SON, (2007) standard limit.

Statistical analysis

Two types of multivariate statistical analyses were utilized to analyse the physiochemical parameters of groundwater obtained around the study site. These are the PCA and HCA. The PCA is a multivariate statistical technique used to reduce the dimension of the original data set made up of a great number of similar variables (Jianqin et al., 2010). This is achieved while still keeping the inherent dependencies existing in a data set. The HCA was utilized for categorizing data into groups according to features, sources, and characteristics that are dissimilar or similar (Hajigholizadeh and Melesse, 2017; Hamid et al., 2016). In PCA analysis, the loading matrix gives the weight (importance) of initial variables on the PCs while the location of samples in the new coordinate system is showed by the score matrix. In this study, the Euclidian distance as the criterion, with the agglomerative hierarchical cluster analysis according to Ward's method were implemented on the data set to detect multivariate with common denominator in the contamination levels. Pictorial depiction of the HCA results on the basis of either the analysed sampling locations or parameters were produced in form of dendrograms.

Results And Discussion

Analysis of physiochemical properties of the water samples

The results of physiochemical parameter of water samples obtained are shown in Tables 1, 2 and 3. The Tables show the change in the level of concentration of analysed data sets during dry and wet season periods.

The TDS parameters obtained from boreholes and wells ranged between 13–295 mg/L in 2020 and 15-780 mg/L in 2021, while the mean concentration increased from 133.25 mg/L in 2020 to 134.50 mg/L in 2021, with difference of 1.25 mg/L (0.94 %). The TDS concentration was remarkably low in all locations and were below the prescribed limit of 500 ppm/mg/L for both the dry and wet season study, except at W 35 (from dry season result). The measured EC ranged from 27–788 μS/cm in the rainy season and 31-1556 μS/cm in dry season with reduced mean concentration from 292.63 μS/cm in 2020 to 268.25 μS/cm in 2021. Results of the seasonal changes in the EC concentration against the WHO, (2007) bench mark for quality of drinking water from all the sampled points showed a strong positive linear relationship with the TDS content, and EC did not also exceed the prescribed standard of 1000 μS/cm for quality of drinking water in all the sampled points for both wet and dry seasons except at W 35. Hardness values ranged from 15-115 mg/L in the wet to 25-250 mg/L in the dry season. All the measured hardness values around the site were less than the acceptable standard (150 mg/L) for drinking water in rainy season but exceeded the standard value at BH 34 and W 36 from the dry season result (i.e. about 25 % of the sampled locations). Mean concentration of hardness surged from 80 mg/L in 2020 to 148.13 mg/L in 2021, with difference of 68.13 mg/L (85.2 %). All the measured pH values in 2020 were below the permissible limit stipulated by WHO (6.5-8.5), while only about 12.5 % of the measured pH values (at W 35) fell within the standard limit in the dry season. The mean value of pH increased from 5.58 in 2020 to 5.78 in 2021, with interval difference of 0.2 (3.6 %), and values ranging between 4.74-6.48 in August 2020 and 5.07-7.04 in December 2021.

Table 1: Seasonal Paired Samples Statistics of groundwater physical parameters around Solous III landfill

August 2020 results (Wet Season) December 2021 results (Dry Season)

Sample	Coordinate	pH	Temp (°C)	EC (µS/cm)	TDS (ppm/mg/L)	Hardness (mg/L)
BH 33	06^0 33′ 54.24″N	4.87	28.5	27	13	15.0
	003^0 15′ 15.52″E	5.59	30.7	31	15	60.0
BH 34	06^0 33′ 57.01″N	4.74	27.4	38	20	110.0
	003^0 15′ 15.71″E	5.07	30.7	45	25	550.0
W 35	06^0 33′ 50.10″N	6.07	28.3	600	248	100.0
	003^0 15′ 16.71″E	7.04	30.6	1556	780	90.0
W 36	06^0 33′ 45.11″N	6.23	26.9	788	295	115.0
	003^0 15′ 07.32″E	5.62	30.4	60	30	230
W 37	06^0 33′ 41.67″N	6.01	28.2	415	210	70.0
	003^0 15′ 16.96″E	6.33	30.7	217	108	80.0
BH 38	06^0 33′ 41.78″N	5.28	34.0	83	57	100.0
	003^0 15′ 20.26″E	5.15	30.7	74	37	90.0
BH 39	06^0 33′ 56.80″N	6.48	28.6	360	208	55.0
	003^0 14′ 58.92″E	6.17	30.7	117	58	25.0
BH 40	06^0 33′ 56.97″N	4.96	26	30	15	75.0
	003^0 14′ 52.86″E	5.24	30.5	46	23	60.0
Mean		5.58		292.63	133.25	80
		5.78		268.25	134.50	148.13
Range		4.74-6.48		27-788	13-295	15-115
		5.07-7.04		31-1556	15-780	25-550
St. Dev.		0.69		294.64	118.26	33.59
		0.69		523.78	262.50	173.33
Coef. Of Variation (%)		12.36		100.68	88.75	41.98
		11.94		195.26	195.17	117.01
	WHO/SON Standard	6.5-8.5	-	1000	500	150

The concentrations of Ca^{2+} and Mg^{2+} in the water samples across the sampling locations have mean values of 32.06 mg/L and 34.57 mg/L and 11.64 mg/L and 12.47 mg/L in 2020 and 2021 respectively (Table 2). Seasonal variation results of Ca^{2+} and Mg^{2+} concentration versus WHO, (2007) prescribed standard for drinking water quality from all the sampling points showed that, Ca^{2+} did not exceed the bench mark (50 mg/L) for drinking water quality at all locations for both wet and dry season investigations except at BH 36. The measured Mg^{2+} concentration exceeded the standard limit for both the dry and wet period. The concentration of K^+ exceeded the WHO, (2007) prescribed limit of 1.0-2.0 at points BH 38, BH 39 and BH 40 in the wet season (about 37.5 % of the locations) and at BH 39 and BH 40 during the dry season (about 25 %). The measured K^+ values showed reduction in mean concentration from 1.78-1.66 mg/L. The concentration of Na^+ in all sampled points during the dry and wet seasons were less than the WHO bench mark of 200 mg/L, and measured values ranged from 5.01-9.11 mg/L in the rainy season and 9.32-19.06 mg/L in the dry season. All the measured Cl^- values less than the minimum bench mark (250 mg/L) in both dry and wet season results. The mean concentration of Cl^-decreased from 144.01 mg/L to 70.91 mg/L with difference of 73.1 (103.08 %). The measured SO_4^{2-} concentration were less than the prescribed limits of (200 mg/L) from the wet and dry season results, while NO_3^{2-} values in the wet season were all less than the minimum bench mark (10 mg/L) set by WHO, while about 37.5 % of sampled locations (At W 35, BH 36 and W 37) in the dry season exceeded the prescribed standard.

Table 2: Seasonal Paired Samples Statistics of Macroelements and anions content of water samples obtained around the Solous III dumpsite

August 2020 results (Wet Season) — December 2021 results (Dry Season)

Samples	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Cl^- (mg/L)	SO_4 (mg/L)	PO_4 (mg/L)	NO_3 (mg/L)
BH 33	6.01	2.18	1.32	7.33	230.43	52.0	9.3	0.8
	24.05	8.74	1.09	14.62	35.45	48.0	0.26	4.7
BH 34	44.09	16.02	1.41	9.11	106.35	13.0	18.5	2.9
	22.04	8.01	1.24	10.66	70.90	28.0	3.06	4.1
W 35	40.08	14.56	0.92	7.81	141.80	30.0	5.8	0.0
	36.07	13.11	1.31	9.32	177.3	146.0	0.52	24
W 36	46.09	16.75	1.21	6.30	177.25	24.0	6.0	3.4
	92.18	33.49	1.09	10.89	35.45	46.0	7.65	10.8
W 37	28.06	10.19	1.98	5.11	70.9	40.0	19.5	3.9
	32.06	11.65	1.91	14.89	53.18	48.0	0.72	15.9
BH 38	40.08	14.56	2.33	5.01	141.80	34.0	18.6	0.0
	36.07	13.11	1.53	15.77	70.90	46.0	8.56	9.4
BH 39	22.04	8.01	2.11	8.22	141.80	8.0	16.9	0.9
	10.02	2.91	2.98	19.06	70.90	50.0	0.30	9.3
BH 40	30.06	10.92	3.01	6.77	141.80	27.0	35.9	3.9
	24.05	8.74	2.09	12.74	53.18	80.0	0.64	6.3
Mean	32.06	11.64	1.78	6.96	144.01	28.5	16.31	1.97
	34.57	12.47	1.66	13.49	70.91	61.5	2.71	10.56
Range	6.01-46.09	2.18-16.75	0.92-3.01	5.01-9.11	70.9-230.4	8-52	5.8-35.9	0-3.9
	10.02-92.2	2.91-33.49	1.09-2.98	9.32-19.06	35.45-177	28-146	.26-8.56	4.1-24
St. Dev.	13.46	4.89	0.69	1.45	46.83	14.14	9.78	1.72
	24.82	9.12	0.65	3.21	45.45	36.99	3.46	6.62
Coef. Of Variation	42	42	39	21	33	50	60	87
	71.79	73.13	39.15	23.79	64.95	60.14	127.67	62.68
WHO/SON Standard	50	2.0	1.0-2.0	200	250	200/100	5.0	10

The seasonal paired sample statistics of the heavy metal content of water samples obtained around the dumpsite presented in Table 3. Among the examined variables, Fe had the highest mean in 2020 (4.96 mg/L) followed by Zn (1.70 mg/ L), while Ni remained the least (0.003 mg/L). Fe also displayed the highest standard deviation of 0.54 mg/L from the 2020 study. This was followed by Zn (0.41 mg/L from 2021 result) while Ni recorded the least value (0.001 mg/L from 2021 result). Furthermore, among the examined water quality parameters within the study area, Mn and Cr remained the most absolutely varied parameters. The WHO prescribed limit of Chromium (0.05 mg/L) was not exceeded in all the sampled boreholes in the study area in the dry and wet seasons. The mean concentration of Cr around the site in 2020 increased from 0.02 mg/L to 0.064 mg/L in 2021, with difference of 0.044 (2.2 %). The concentration of Lead was not detectable in the sampled water from all the locations except at BH 33, BH 39 and BH 40 in the wet season, where value only exceeded the WHO bench mark of 0.01 mg/L at BH 39. The water samples collected in the dry season did not show presence of Pb at locations BH 33, BH 38 and BH 40. The mean concentration of Cu in 2020 reduced from 0.35 mg/L to 0.34 mg/L in 2021, with difference of 0.01 (2.94 %). Values obtained varied from 0.14-0.57 mg/L in 2020 and 0.09-0.43 mg/L in 2021. The WHO standard limit of Cu (0.5 mg/L) was not exceeded in all water samples collected in the dry season, but was surpassed at sampling points W 37, BH 38 and BH 39 (37.5 % of the locations) in the wet season. The WHO standard limit of Iron (0.3 mg/L) in all the sampled borehole water around the study area in 2020 was surpassed but were all below the permissible limit in 2021. The mean concentration reduced from 4.96 mg/L in the wet season to 0.1 mg/L in the wet season. The mean concentration of Zn reduced from 1.70 mg/L to 1.31 mg/L with difference of 0.39 (29.8 %). The measured values ranged from 1.42-2.12 mg/L in the wet season and 1.0-2.21 mg/L in the dry season. In all the sampled locations during the dry and wet seasons, the WHO bench mark for Zinc (5.0 mg/L) in the groundwater was not exceeded. About 12.5 % of the measured Mn values (W 37) was within the standard requirement (0.5 mg/L) for drinking water quality in wet season, while the dry season results all showed values below the standard limit. The measured values of Mn concentration ranged from 0.5-1.2 mg/L in 2020 to 0.02-0.29 mg/L in 2021, with mean values reducing from 0.84 to 0.07 mg/L.

Table 3: Seasonal Paired Samples Statistics of Heavy metal contents of water sample obtained around Solous III dumpsite

August 2020 results (Wet Season) December 2021 results (Dry Season)

Samples	Fe (mg/L)	Zn (mg/L)	Mn (mg/L)	Cu (mg/L)	Pb (mg/L)	Ni (mg/L)	Cr (mg/L)
BH 33	5.33	2.12	1.20	0.19	0.01	0.02	0.02
	0.06	1.57	0.29	0.33	ND	0.004	0.04
BH 34	5.41	1.71	1.04	0.18	ND	0.02	0.02
	0.10	1.09	0.03	0.43	0.007	0.002	0.03
W 35	5.11	1.55	0.81	0.14	ND	0.02	0.01
	0.12	1.22	0.06	0.41	0.002	ND	0.25
W 36	5.21	1.67	0.51	0.31	ND	0.03	0.02
	0.08	1.09	0.08	0.32	0.004	ND	0.03
W 37	5.00	1.48	0.50	0.51	ND	0.02	0.01
	0.12	1.00	0.08	0.33	0.009	ND	0.04
BH 38	5.31	1.51	0.91	0.51	ND	0.03	0.02
	0.06	2.21	0.02	0.42	ND	ND	0.04
BH 39	4.50	1.42	0.82	0.57	0.02	0.03	0.04
	0.16	1.04	0.03	0.41	0.02	ND	0.04
BH 40	3.82	2.11	0.91	0.41	0.01	0.03	0.01
	0.10	1.27	0.03	0.09	ND	ND	0.04
Mean	4.96	1.70	0.84	0.35	0.005	0.025	0.02
	0.1	1.31	0.07	0.34	0.008	0.003	0.064
Range	3.82-5.41	1.42-2.12	0.5-1.2	0.14-0.57	0-0.02	0.02-0.03	0.01-0.04
	0.06-0.16	1-2.21	0.02-0.29	0.09-0.43	.002-0.02	.002-.004	0.03-0.25
St. Dev.	0.54	0.28	0.24	0.17	0.008	0.005	0.01
	0.034	0.41	0.089	0.11	0.007	0.001	0.075
Coef. Of	11	16	29	49	160	20	50
Variation	34	31.29	127.14	32.35	87.5	33.3	117.18
WHO/SON Standard	0.3	5.0	0.5	0.5	0.01	0.02	0.05

Note: ND = Not Detected

Tables 4 and 5 shows the degree of linear relationship between the analysed variables measured by Pearson's correlation coefficients for wet and dry seasons. Identifying pairs of variables that are strongly correlated is important for the purpose of detecting and avoiding potential multicolinearity in case regression analysis is to be performed on this data. Also, pairs identified to be correlated here would be expected to also have similar influence (loading) on principal components. Strongly positively correlated variables during the wet season include; pH, EC and TDS; Hardness, Ca^{2+} and Mg^{2+} (perfect correlation, rho = 1); K^+ and PO_4^{3-}; K^+ and Cu. In spite of PO_4^{3-} and Cu being individually strongly correlated to K^+, they are weakly correlated to one another. On the other hand, the strongly negatively correlated variables were TDS and Mn; and EC and Mn. The parameters that were strongly positively correlated during the dry season are; pH, EC, TDS, Cl^-, SO_4^{2-}, NO_3^- and Cr; K, Fe, and Pb; Ca^{2+} and Mg^{2+}; and Ni and Mn. While the weakly correlated variable during the dry season are; temperature and Ca^{2+}; and temperature and Mg^{2+}.

Table 4: Degree of linearity of water samples data obtained during wet season

	pH	Temp	EC	TDS	Hard.	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}	PO_4^{3-}	NO_3^-	Fe	Zn	Mn	Cu	Pb
pH	1																	
Temp	-0.03	1																
EC	0.85	-0.22	1															
TDS	0.94	-0.15	0.97	1														
Hard.	0.15	0.05	0.39	0.32	1													
Ca^{2+}	0.15	0.05	0.39	0.32	1	1												
Mg^{2+}	0.15	0.05	0.39	0.32	1	1	1											
K^+	-0.21	0.12	-0.50	-0.42	-0.15	-0.15	-0.15	1										
Na^+	-0.15	-0.45	-0.13	-0.14	-0.05	-0.05	-0.05	-0.37	1									
Cl^-	-0.18	0.01	-0.06	-0.16	-0.44	-0.44	-0.44	-0.27	0.14	1								
SO_4^{2-}	-0.29	0.22	-0.16	-0.22	-0.48	-0.48	-0.48	-0.10	-0.54	0.36	1							
PO_4^{2+}	-0.42	-0.13	-0.61	-0.55	-0.06	-0.06	-0.06	0.91	-0.13	-0.40	-0.17	1						
NO_3^-	-0.09	-0.67	0.07	0.02	0.18	0.18	0.18	0.29	-0.14	-0.39	-0.12	0.47	1					
Fe	-0.08	0.42	0.14	0.08	0.19	0.19	0.19	-0.74	-0.01	0.13	0.27	-0.74	-0.35	1				
Zn	-0.71	-0.42	-0.51	-0.64	-0.43	-0.43	-0.43	0.16	0.15	0.57	0.41	0.30	0.24	-0.27	1			
Mn	-0.76	0.15	-0.79	-0.82	-0.43	-0.43	-0.43	0.02	0.49	0.47	0.15	0.12	-0.44	0.08	0.57	1		
Cu	0.38	0.35	-0.04	0.12	-0.11	-0.11	-0.11	0.73	-0.53	-0.38	-0.19	0.48	0.13	-0.44	-0.42	-0.40	1	
Pb	0.13	-0.18	-0.25	-0.14	-0.68	-0.68	-0.67	0.38	0.35	0.32	-0.25	0.27	-0.15	-0.59	0.19	0.31	0.37	1
Ni	0.24	0.17	0.08	0.09	0.19	0.19	0.19	0.58	-0.28	0.15	-0.39	0.33	0.04	-0.49	-0.07	-0.22	0.61	0.3
Cr	0.31	0.19	-0.02	0.09	-0.24	-0.24	-0.24	0.02	0.37	0.23	-0.54	-0.16	-0.34	0.01	-0.32	0.15	0.37	0.6

Table 5: Degree of linearity of water samples data obtained during dry season

	pH	Temp	EC	TDS	Hard.	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Cl^{-}	SO_4^{2-}	PO_4^{3-}	NO_3^{-}	Fe	Zn	Mn	Cu	Pb
pH	1																	
Temp	0.05	1																
EC	0.80	-0.05	1															
TDS	0.79	-0.05	1	1														
Hard.	-0.43	-0.01	-0.17	-0.17	1													
Ca^{2+}	-0.02	-0.76	0.01	0.01	0.15	1												
Mg^{2+}	-0.03	-0.76	0.02	0.02	0.16	0.99	1											
K^{+}	0.18	0.22	-0.16	-0.16	-0.45	-0.53	-0.55	1										
Na^{+}	-0.07	0.52	-0.48	-0.48	-0.53	-0.47	-0.48	0.72	1									
Cl^{-}	0.67	0.09	0.95	0.95	-0.06	-0.16	-0.16	-0.04	-0.39	1								
SO_4^{2-}	0.69	-0.25	0.91	0.91	-0.38	-0.02	-0.01	-0.04	-0.43	0.84	1							
PO_4^{3-}	-0.48	-0.30	-0.28	-0.28	0.28	0.67	0.66	-0.39	-0.11	-0.23	-0.35	1						
NO_3^{-}	0.88	-0.10	0.87	0.87	-0.32	0.21	0.21	-0.03	-0.29	0.76	0.76	-0.14	1					
Fe	0.59	0.15	0.29	0.29	-0.14	-0.39	-0.40	0.76	0.26	0.36	0.25	-0.57	0.37	1				
Zn	-0.41	0.25	-0.13	-0.13	-0.24	-0.05	-0.04	-0.25	0.22	-0.04	-0.07	0.51	-0.19	-0.69	1			
Mn	0.04	0.14	-0.10	-0.11	-0.22	0.003	0.01	-0.42	0.04	-0.31	-0.09	-0.29	-0.20	-0.45	0.11	1		
Cu	0.25	0.55	0.26	0.26	0.30	-0.05	-0.06	-0.14	0.09	0.37	-0.11	0.24	0.24	0.11	0.13	-0.05	1	
Pb	0.29	0.31	-0.13	-0.13	-0.01	-0.31	-0.33	0.74	0.55	-0.04	-0.27	-0.29	0.02	0.83	-0.56	-0.30	0.35	1
Ni	-0.30	0.37	-0.26	-0.25	0.25	-0.26	-0.25	-0.46	-0.03	-0.29	-0.31	-0.25	-0.53	-0.45	0.14	0.81	0.10	-0.
Cr	0.76	-0.06	0.99	0.99	-0.19	-0.01	-0.01	-0.18	-0.49	0.95	0.93	-0.29	0.83	0.25	-0.07	-0.07	0.22	-0.

Principal component analysis (PCA)

From the descriptive statistics above, it was observed that the water quality parameters have vastly different means and standard deviation. In order to avoid disproportionate influence of some variables, the data is standardized (centred and scaled) before performing PCA; i.e. all variables were transformed to have zero mean and unit variance. The number of principal components to be retained was determined on the basis of proportion of variance explained (PVE) by the principal components. As many principal components as explained a significant proportion of variance would be retained. It is observed from results above that the first five (5) principal components (PC) account for over 90% of variance, in both the wet season and dry season data (Figs.2 and 3). Therefore, these 5 PCs are retained.

Analysis of the Principal Components Loadings

Here, the influence (loading) of each original variable on each principal component was examined. The set of loading values of all p variables in a given principal component is the coordinates of the PC vector (direction) in the p-dimensional space. For example, in a 2D x-y space, if a principal component lies in the 45-degree direction, then the loading vector is (1,1). Such set of loading values is known as the loading vector. A matrix containing the loading vectors for all PCs is part of the output of the prcomp call. In simple terms, the loadings are measures of the contributions of each variable to that particular PC. The sign (positive or negative) of a loading is an indication of the type of proportionality between the variable and the PC. A positive loading indicates a direct proportionality between the variable and the PC; i.e. an increase in the variable caused an increase in the PC score and vice-versa for a negative loading. The magnitude of a loading (either positive or negative) is an indication of the magnitude of the proportionality between the variable and the PC. For example, the larger a positive loading is, the more increase in the PC score is caused by a unit increase in that variable. Also, the larger a negative loading is, the more decrease in the PC score is caused by a unit increase in that variable. Actually, a PC is a linear combination of the variables (x_1, x_2, x_3) such that the loading values are the coefficients in that linear combination;

$$PC_K = w_{1,k}x_1 + w_{2,k}x_2 + w_{3,k}x_3 + \ldots$$

1

In this case, the loading vector is;

$$w_{1,k}w_{2,k}w_{3,k}\ldots$$

2

From the loading vectors obtained in this analysis, the following interpretations are made. Note that any loading value of magnitude greater than $\sqrt{\frac{1}{n}}$ = 0.2236 is deemed strong (either positively or negatively); where n is the number of variables involved.

Wet Season Data

Factor loadings for the wet and dry season parameters are presented in Tables 6 and 7. From Table 6, it was observed that five PCs were revealed alongside the communality level during the rainy season. The pH, EC, TDS, Hardness, Ca^{2+} and Mg^{2+} with 30 % of the total variance were all strongly positively loaded into PC1 and could be said to be accountable for the pollution loads of the studied area during the rainy season. This implies that PC1 is a measure of the extent of abundance of these variables; i.e. PC1 score would be high when these variables have high values, and vice-versa. This agrees with the conclusions made in the correlation analysis above where these variables were observed to be positively correlated. The parameters in PC1 probably indicated rock–water geochemical reaction, dilution of groundwater, dissolution of carbonate minerals, mineral components of groundwater, anthropogenic and weathering activities from the dumpsite (Ganiyu *et al.*, 2018). Zn and Mn were both strongly negatively loaded into PC1. The implication is that PC1 is a measure of the extent of lack of these variables; i.e. PC1 score would be high when the Zn and Mn variables have low values, and vice-versa. Interpreting the positive and negative loadings together, it can be stated that high PC1 scores occur in the case of high values of pH, EC, TDS, Hardness, Ca^{2+}, Mg^{2+} and low values of Zn and Mn. The Negative loading of Zn and Mn in PC 1 could be a reflection of their reduction in concentration due to dilution process during wet season (Ganiyu et al., 2018)

Table 6: Varimax rotated factor loadings and communalities for the wet season dataset

	PC1	PC2	PC3	PC4	PC5
pH	0.2757	-0.0999	0.3587	0.0062	0.1572
Temp	0.0135	0.0200	0.0789	-0.5104	-0.3850
EC	0.3359	0.0554	0.1964	0.0742	0.2466
TDS	0.3313	0.0023	0.2570	0.0415	0.2240
Hardness	0.3228	-0.0220	-0.2562	0.0792	-0.2198
Ca^{2+}	0.3228	-0.0220	-0.2563	0.0792	-0.2198
Mg^{2+}	0.3228	-0.0220	-0.2561	0.0794	-0.2198
K^{+}	-0.1490	-0.4290	-0.1138	-0.1312	-0.0364
Na^{+}	-0.0789	0.1395	0.0719	0.5390	-0.2144
Cl^{-}	-0.1886	0.2074	0.2072	0.0244	0.0216
SO_4^{2-}	-0.1512	0.2064	-0.0603	-0.4148	0.3263
PO_4^{3-}	-0.1654	-0.3743	-0.2607	0.0250	-0.0137
NO_3^{-}	0.0491	-0.1963	-0.2705	0.1992	0.3538
Fe	0.1143	0.3811	0.0038	-0.1949	-0.1723
Zn	-0.3053	0.0738	-0.1881	0.1460	0.1965
Mn	-0.3296	0.1644	-0.0451	0.0756	-0.3037
Cu	0.0250	-0.4119	0.1552	-0.2604	-0.0265
Pb	-0.2318	-0.2046	0.3463	0.2017	-0.0167
Ni	0.0391	-0.3432	0.1111	-0.0244	-0.1610
Cr	-0.0366	-0.1021	0.4049	0.1365	-0.3227
Variance (%)	30	21	17	12	11

Fe was the only variable strongly positively loaded into PC2. Notably, in the correlations values reported above, Fe was not observed to be positively correlated with any of the variables in PC1; expectedly, it is loaded into a separate PC. K^{+}, PO_4^{3-}, Cu and Ni are all strongly negatively loaded into PC2 hence, PC2 is a measure of extent of abundance of Fe and lack of K, PO_4^{3-}, Cu and Ni; i.e. high PC2 scores occur in the case of high Fe values and low values of K, PO_4^{3-}, Cu and Ni. pH, TDS, Pb and Cr were all strongly positively loaded into PC3 while hardness, Ca^{2+}, Mg^{2+}, PO_4^{3-} and NO_3^{-} were strongly negatively loaded into PC3. Comparing PC1 and PC3, the following observations are made. In PC1, all five variables (pH, TDS, Hardness, Ca^{2+}, Mg^{2+}) have positive loadings. However, in PC3, the duo of pH and TDS are having positive loadings while the trio of Hardness, Ca^{2+} and Mg^{2+} have negative loadings. The situation in PC1 is not contradictory to the situation in PC3 as it seems to appear. Results from the correlation analysis indicate that Hardness, Ca^{2+} and Mg^{2+} were all perfectly correlated (rho = 1). It is only such perfectly correlated variables that must necessarily have similar effects (magnitude and direction) on any PC. Other variables correlated (not perfectly) may have different effects. In summary, pH and TDS were positively (but not perfectly) correlated with Hardness, Ca^{2+} and Mg^{2+}; and this association is captured by PC1. PC3 only captures the correlation of pH and TDS with some other variables.

Only Na is strongly positively loaded into PC4. Temperature, SO4 and Cu were all strongly negatively loaded into PC4. EC, TDS, SO_4^{2-} and NO_3^- were strongly positively loaded into PC5 while Temperature, Mn and Cr were strongly negatively loaded into PC5.

Dry Season Data

EC, TDS, pH, Cl^-, SO_4^{2-}, NO_3^- and Cr were all strongly positively loaded into PC1 (Table 7). This confirms the correlation analysis results where all these 7 variables have been reported to be strongly positively correlated with each other. Hence, PC1 captures the joint behaviour of these 7 variables. Influence from the leachate generated around the dumpsite cannot be overlooked since these sampling locations are in the vicinity of an unengineered dumpsite. No variable was strongly negatively loaded into PC1. While Ca^{2+}, Mg^{2+} and PO_4^{3-} were all strongly positively loaded into PC2, K^+, Na^+, Fe and Pb were strongly negatively loaded into PC2. These loadings are in agreement with the correlation analysis results reported earlier.

Table 7: Varimax rotated factor loadings and communalities for the dry season dataset

	PC1	PC2	PC3	PC4	PC5
pH	0.3322	-0.0869	-0.0128	-0.0632	0.0518
Temp	-0.0261	-0.2834	0.3440	0.2997	-0.1198
EC	0.3678	0.0738	0.0996	0.0410	-0.0081
TDS	0.3676	0.0742	0.0999	0.0427	-0.0068
Hardness	-0.0961	0.1298	-0.0187	0.4707	0.4148
Ca^{2+}	-0.0130	0.3659	-0.2785	-0.0009	0.0219
Mg^{2+}	-0.0133	0.3717	-0.2704	-0.0027	0.0230
K^+	0.0198	-0.3927	-0.2420	-0.1243	-0.1482
Na^+	-0.1374	-0.3398	-0.0205	-0.0577	-0.3349
Cl^-	0.3485	0.0138	0.0986	0.1768	-0.0755
SO_4^{2-}	0.3435	0.0749	0.0661	-0.2072	-0.0689
PO_4^{3-}	-0.1387	0.2765	-0.1901	0.3003	-0.3386
NO_3^-	0.3449	0.0577	-0.0770	0.0198	-0.1101
Fe	0.1887	-0.3270	-0.2432	0.0453	0.1829
Zn	-0.1022	0.1170	0.2585	0.0544	-0.5974
Mn	-0.0820	0.0637	0.3942	-0.2718	0.1780
Cu	0.0745	-0.0446	0.1288	0.6114	-0.0745
Pb	0.0191	-0.3508	-0.2457	0.2111	0.1509
Ni	-0.1539	0.0187	0.4684	-0.0119	0.2959
Cr	0.3601	0.0832	0.1327	0.0150	-0.0255
Variance (%)	35	24	14	10	9

Temperature, Zn, Mn and Ni were all strongly positively loaded into PC3, while Ca^{2+}, Mg^{2+}, K^+, Fe and Pb were strongly negatively loaded into PC3. This indicates that during the dry season, Zn, Mn and Ni appeared to be the dominant heavy metals accountable for the contamination of water. Temperature, Hardness, PO_4^{3-} and Cu were strongly positively loaded into PC4. Curiously, this set of variables were not observed to be strongly positively correlated in the correlation analysis section of this report. Their assumed joint behaviour in PC4 might as well be of little significance, considering that PC4 only accounts for 10% of the total variation in the dry-season data. Only Mn is strongly negatively loaded into PC4. Hardness and Ni were both strongly positively loaded into PC5 while Na, PO_4^{3-} and Zn were strongly negatively loaded into PC5.

Biplot: PC1 versus PC2

The biplot shows the location of each observation (sample) in the principal components coordinate space (i.e. PC1-PC2). Essentially, it is a scatter plots of the PC scores. PC scores are the projection of the original data to each PC axis. With all samples plotted on the biplot, the spatial relationship between samples (clusters of samples) can be examined. Viewing such clusters would not be possible in the original data space of 20 variables (that's 20 dimensional plot).

PCA offers a low-dimensional view of the data (with most of the variance in the data still retained). Detecting such clusters is one of the key objectives of performing PCA. The PC score for the nth sample on the kth PC is calculated thus:

$$PC_{n,K} = w_{1,k}x_{n,1} + w_{2,k}x_{n,2} + w_{3,k}x_{n,3} + \cdots + w_{p,k}x_{n,p}$$

3

In addition to plotting each sample in the PC coordinate space, a biplot also plots each of the original variables in the same space. In the space, pth variable is represented by an arrow (vector) starting from the axis origin and ending at a point whose coordinates are the variable's loading values to each PC making up the axis. In a biplot with PC1 as x-axis and P C2 at y-axis, the arrow for the pth variable ends at point $(w_{p,1} w_{p,2})$. This way, clusters of variables (group of variables with similar behaviour) can also be detected and analysed. The display of variables' vectors on the biplot also provides a way to visualize the results of the PCA loadings analysis. The longer a variable's arrow along a PC axis, the more that variable is loaded into that PC; the direction of the arrow shows the sign of the loading (positive or negative).

Patterns observed in variables

While there is no obvious clustering pattern among the 8 samples in the wet season dataset (Fig. 4), sample 1 stands out from the other samples in the sense that it has a low value on PC1 but a high value on PC2. This implies sample 1 has low values of pH, EC, TDS, Hardness, Ca^{2+}, and Mg^{2+}, and has high value of Fe, considering the loading vectors. Clearly, pH, EC, TDS, Hardness, Ca^{2+}, Mg^{2+} all clustered together towards the right side of the plot. Other clusters of variables observed include Zn, Mn, Cl^-, SO_4^{2-}, towards the top left corner, made up of Zn, Mn, Cl^-, SO_4^{2-} and Na^+ (top left), and PO_4^{3-}, K^+, Ni, Cu (bottom). Each of these clusters shows a group of correlated variables having a joint behaviour, as earlier explained. In fact, these clusters are the visual form of the results explained in the analysis of the principal components loadings. For the dry season data, Samples 1, 2, 6, and 8 appeared to be clustered together (Fig. 5). Clusters observed include pH, EC, TDS, Cl^-, SO_4^{2-}, NO_3^- and Cr (right), Na^+, Temp, Pb, K^+ and Fe (bottom), and Ca^{2+}, Mg^{2+} and PO_4^{3-} (top left).

Hierarchical Cluster Analysis

Here, the hierarchical clustering algorithm was used to obtain both clusters of variables and clusters of sampling points. Euclidean distance was adopted as the measure of dissimilarity between sampling points while correlation-based distance is adopted as the measure of dissimilarity between variables. Ward's linkage method was used for agglomeration for both sampling points and variable cluster analyses.

Wet Season

Establishing a cut at height 8 for the wet season data, two clusters of sampling points were obtained: sampling points 2, 3, 4, 5 and 6, and sampling points 1, 7 and 8 (Fig. 6a). Somewhat, these clusters agree with those observed on the P C1 versus P C2 biplot where each of these groups of variables takes different sides of the plot. Suffice it to state that the clustering observations made here supersede those made in the biplot; since the biplot only consider two principal components. The clusters of parameters as observed in the parameters dendrograms above clearly validates the results earlier obtained in the correlation analysis segment of this report. Depending on the point of cut, each cluster presents a group of variables that are positively correlated with one another. The lower the cut-point, the stronger the correlation between parameters in the resultant clusters. For example, cutting at height 1.0 yields the following six clusters of parameters (Fig 7a):

Cluster 1 (pH, EC and TDS- recognized in correlation analysis as a strongly positively correlated group), Cluster 2 (Hardness, Ca^{2+} and Mg^{2+}- recognized in correlation analysis as a strongly positively correlated group), Cluster 3 (K^+, PO_4^{3-}, Cu, NO_3^- and Ni), Cluster 4 (SO_4^{2-}, Mn, Cl^- and Zn), Cluster 5 (Temp and Fe), and Cluster 6 (Na^+, Pb and Cr).

Dry Season

For the Dry season dendogram, three clusters were obvious (Fig. 6b), so, the cut is made at height 7. The three clusters are: sampling point 3 (stand-alone), sampling points 5, 7 and 8, and sampling points 1, 2, 4 and 6. Again, these observations align with the biplot where sampling point 3 is indeed stand-alone. Sampling points 1, 2, 4 and 6 are towards the top and sampling points 5, 7 and 8 are towards the bottom. Fig. 7b shows the results of five separated clusters of parameters during the dry season. Cluster 1 (pH, EC, TDS, Cl^-, SO_4^{2-}, NO_3^- and Cr) recognized in correlation analysis as a strongly positively correlated group, Cluster 2 (Ni and Mn) also recognized in correlation analysis as a strongly positively correlated group, while Clusters 3, 4 and 5 are Zn, Temp and Cu; Na^+, K^+, Fe and Pb; and Hardness, PO_4^{3-}, Ca^{2+} and Mg^{2+} respectively.

Note that some clusters here contain more parameters than listed in the correlated parameters earlier reported. This is because only strongly correlated parameters were identified there; the cluster here identified all positively correlated groups of parameters.

Conclusion

The research provides information about the groundwater quality of samples obtained from boreholes and hand-dug wells at different locations around the Solous III dumpsite. Seasonal variation in the content levels of physiochemical properties of groundwater was studied using descriptive and multivariate statistical techniques. Comparing the mean concentration values of the physiochemical properties of groundwater around the study area, it can be concluded that the variables: total dissolved solid (TDS) pH, temperature and hardness were higher during the dry season study, and a corresponding increase in the mean concentration of Ca, Mg^{2+}, Na^+, SO_4^{2-}, NO_3^-, Pb, and Cr, when compared with the wet season. On the other hand, there was reduction in the mean concentration of Electrical Conductivity (EC) K^+, Cl^-, PO_4^{3-}-, Fe, Zn, Mn, Cu, and Ni in the dry season when compared with the wet season. Seasonal changes of the groundwater quality caused by dissolution mechanism, ion exchange, and anthropogenic impacts from leached pesticides, and other industrial wastes must be taken into consideration by the groundwater managers particularly during the dry season in which higher concentrations were observed. It is recommended that a well-designed monitoring schemes be put in place to constantly obtain real time data about the interactions, behaviour and movement of the contaminants within the subsurface environment, especially the groundwater reservoirs where many inhabitants living around these site draw their water from.

Declarations

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References

1. Adhikari P., Shukla M. K., Mexal J. G., Sharma P., (2003). Assessment of soil physical and chemical properties of desert soils irrigated with treated wastewater using principal component analysis. *Soil Sci* 176(7):1–11. https ://doi.org/10.1097/ss0b0 13e31 821f4 a721.
2. Amadi A. N., Dan-Hassan M. A., Okoye N. O., Ejiofor I. C., Tukur A., (2013). Studies on pollution hazards of shallow hand-dug wells in Erena and environs, North-central Nigeria. Environ Nat Resour Res 3(2):69–77.
3. Ameloko A. A., Obihan I., Onugba A., Ajayi G., Rotimi O. J., Okezie U., (2022). Geophysical investigation of aquifer vulnerability and protective capacity of overburden rocks in part of Ajaokuta, Kogi State, North Central, Nigeria. Sustainable Water Resources Management, 8:102.
4. Ameloko A. A., Ayolabi, E. A., (2020). Geophysical and hydrophysical evaluation of groundwater around the Igbenre-Ekotedo dumpsite Ota, South West Nigeria, using correlation and regression analysis. Arabian Journal of Geosciences.
5. Ameloko A. A., Ayolabi A. E., Akinmosin A., (2018). Time dependent Electrical Resistivity Tomography and Seasonal Variation Assessment of Groundwater around the Olushosun Dumpsite Lagos, South-West, Nigeria. Journal of African Earth Sciences 147: 243–253
6. APHA, (1998). American Public Health Association, Standard Methods for the Examination of Water and Wastewater. 18th Edition, American Public Health Association, Washington, DC., USA.
7. Arias J. A., Peralta-Videa J. R., Ellzey J. T., Ren M., (2010). Effects of Glomus deserticola inoculation on Prosopis: enhancing the chromium and lead uptake and translocation as confirmed by X-ray mapping, ICP-OES and TEM techniques. Environ Exp Bot 68:139–148.
8. Ayedun H., Gbadebo A. M., Idowu O. A., Arowolo T. A., (2015). Toxic elements in groundwater of Lagos and Ogun States southwest Nigeria and their human health risk assessment. Environ Monit Assess 187(6):1–17.
9. Barzegar R., Moghaddam A. A, Kazemian N., (2015). Assessment of heavy metal concentrations with emphasis on arsenic in the Tabriz plain aquifers, Iran. Environ Earth Sci 74:297–313. https:// doi. org/ 10. 1007/ s12665- 015- 4123-2.
10. Barzegar R., Moghaddam A. A., Soltani S., Baomid N., Tziriti S. E., Adamowski J., Inam A., (2019). Natural and anthropogenic origins of selected trace elements in the surface water of Tabriz area, Iran. Environ Earth Sci 78:254. https:// doi. org/ 10. 1007/ s12665- 019- 8250-z.
11. Botikin D., and Keller E., (1995). Environmental Science. Earth as a living planet. John Wiley and Son Inc. New York, USA. 7th Edition. pp 410-476.
12. Chen J., Wu H., Qian H., Gao Y., (2017). Assessing nitrate and fluoride contaminants in drinking water and their health risk of rural residents livings in a semiarid region of Northwest China. Expo Health 9(3):183–195.
13. Enuneku A., Omoruyi O., Tongo I., Ogbomida E., Ogbeide O., Ezemonye L., (2018). Evaluating the potential health risks of heavy metal pollution in sediment and selected benthic fauna of Benin River, Southern Nigeria. Appl Water Sci 8:224. https:// doi. org/ 10. 1007/ s13201- 018- 0873-9.
14. Ganiyu S. A., Olurin O. T., Awaye K. T., Adeleke O. O., (2018). Heavy metals content and physico-chemical status of groundwater around lead smelting area in southwestern Nigeria Urban settlement. Afr Rev Phys 12:14–22.
15. Giri S., Singh A. K., (2019). Assessment of metal pollution in groundwater using a novel multivariate metal pollution index in the mining areas of the Singh hum copper belt. Environ Earth Sci 78:192. https:// doi. org/ 10. 1007/ s12665- 019- 8200-9.
16. Gupta C., Rai R., Pandey S., Sharma B., (2009). Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad. Environ Monit Assess 157:449–458.
17. Hajigholizadeh M., Melesse A. M., (2017). Assortment and spatio temporal analysis of surface water quality using cluster and discriminant analyses. CATENA 151:247–2.
18. Hamid A., Bhat S. A., Bhat S. U., Jehangir A., (2016). Environmetric techniques in water quality assessment and monitoring: a case study. Environ Earth Sci 75:321. https://doi.org/10.1007/s12665-015-5139-3.
19. Han G, and Liu C (2004). Water geochemistry controlled by carbonate dissolution: a study of the river waters draining karst-dominated terrain, Guizhou province, China. Chem Geol 204: 1-21.
20. Jianqin M., Jingjing G., Xiaojie L., (2010). Water quality evaluation model based on PCA and information entropy. Application in Jinshui River. J Resour Ecol 1(3):249–252.
21. Kim H., Park S., (2016). Hydrogeochemical characteristics of Groundwater highly polluted with nitrate in an agricultural area of Hongseong, Korea. *Water* 8:345. https:// doi. org/ 10. 3390/ w808a 0345.
22. Kondum F. A., Iwar R. T., Kon E. T., (2021). A Comparison of water quality indexes for an inland river. J Eng Res Reports 20(4):1–14.

23. Kumar A., Kumar A., Cabral-Pinto M. M. S., (2020). Lead toxicity: health hazards, influence on food chain, and sustainable remediation approaches. Int J Environ Res Public Health 17:2179. https:// doi. org/ 10. 3390/ ijerp h1707 2179.

24. Kumar A., Ali M., Kumar R., Kumar M., (2021). Arsenic exposure in Indo Gangetic plains of Bihar causing increased cancer risk. Sci Rep 11:2376. https:// doi. org/ 10. 1038/ s41598- 021- 81579-9.

25. Lutterodt G., Vossenberg J., Hoiting Y., Kamara A. K., Oduro-Kwarteng S., Foppen J. W. A., (2018). Microbial groundwater quality status of hand-dug wells and boreholes in the Dodowa Area of Ghana. *Int J Environ Res Public Health* 15:730. https:// doi. org/ 10. 3390/ ijerp h1504 0730.

26. Ma L., Yang Z., Li L., Wang L., (2016). Source Identification and risk assessment of heavy metal contaminations in urban soils of Changsha, a mine impacted city in southern China. Environ Sci Pollut. Res 23:17058–17066. https ://doi.org/10.1007/s1135 6-0616-6890-z.

27. Mazhar I., Hamid A., Afzal S., (2019). Groundwater quality assessment and human health risks in Gujranwala District, Pakistan. Environ Earth Sci 78:634. https:// doi. org/ 10. 1007/ s12665- 019- 8644-y.

28. Mbaka P. K., Mwangi J. K., Kiptum C. K., (2017). Assessment of water quality in selected shallow wells of Keiyo Highlands, Kenya. Afr J Sci Technol Innov Dev. https:// doi.org/ 10. 1080/ 20421 338. 2017. 13274 76.

29. Nawab J., Khan S., Khan M. A., Sher H., Rehamn U. U., Ali S., Shah S. M., (2017). Potentially toxic metals and biological contamination in drinking water sources in Chromite mining-impacted areas of Pakistan: a comparative study. Expo Health 9:275–287.

30. Ogundele L. T., Adejooro I. A., Ayeku P. O., (2019). Health risk assessment of heavy metals in soil from an abandoned industrial waste dumpsite in Ibadan, Nigeria. Environ Monit Assess 191:290. https:// doi. org/ 10. 1007/ s10661- 019- 7454-8.

31. Olujimi O., Steiner O., Goessler W., (2014). Pollution indexing and health risk assessment of trace elements in indoor dust from classrooms, living rooms and offices in Ogun State, Nigeria. J Afr Earth Sci 101:396–404.

32. Oziegbe O., Oluduro A. O., Oziegbe E. J., Ahuekwe E. F., Olorunsola S. J., (2021). Assessment of heavy metal bioremediation potential of bacterial isolates from landfill soils. Saudi Journal of Biological Sciences. 28:3948-3956.

33. Pal D. K., Agrawal A., Ghosh S., Gosh A., (2020). Association of arsenic with recurrence of urinary bladder cancer. Trop Doct 0(0):1–5. https:// doi. org/ 10. 1177/ 00494 75529 30155.

34. Paul R., Brindha K., Gowrisankar G., Tan M. L., Singh M. K., (2019). Identification of hydrogeochemical processes controlling groundwater quality in Tripura, Northeast India using evaluation indices, GIS and multivariate statistical methods. Environ Earth Sci 78:470. https:// doi. org/ 10. 1007/ s12665- 019- 8479-6.

35. Prasad B, Kumari P., Bano S., Kumari S., (2008). Groundwater quality evaluation near a mining area and development of heavy metal pollution index. *Appl. Water Sci* 4:59. https:// doi. org/ 10. 1007/ s13201- 013- 0126-x.

36. Rana R., Ganguly R., Gupta A. K., (2018). Indexing method for assessment of pollution potential of leachate from non-engineered landfill sites and its effect on ground water quality. Environ Monit Assess 190:46. https:// doi. org/ 10. 1007/ s10661- 017- 6417-1.

37. Ravindra K., Mor S., (2019). Distribution and health risk assessment of arsenic and selected heavy metals in groundwater of Chandigarh, India. Environ Pollut 250:820–830.

38. Satyanarayanan M., Eswaramoorthi S., Subramanian S., Periakali P., (2016). Factor analysis of rock, soil and water geochemical data from salem magnesite mines and surrounding area, Salem, southern India. Water Sci Appl. https ://doi.org/10.1007/s13201-016-0411-6.

39. Sekabira K., Oryem O., Basamba T., Mutumba G., Kudidi E., (2010). Assessment of heavy metal pollution in the urban stream sediments and its tributaries. Int J Environ Sci Technol 7:435–446.

40. Selvakumar S., Chandrasekar N., Kumar G., (2017). Hydrogeochemical characteristics and groundwater contamination in the rapid urban development areas of Coimbatore, India. *Water Resour Ind* 17:26–33.

41. Selvam S., Anthony R. A, Venkatramanan S., Singaraja C., (2017). Assessment of heavy metal and bacterial pollution in coastal aquifers from SIPCOT Industrial zones, Gulf of Mannar, South coast of Tamil Nadu, India. Appl Water Sci 7:897–913. https:// doi. org/ 10. 1007/ s13201- 015- 0301-3.

42. Shankar B. S., (2019). A critical assay of heavy metal pollution index for the groundwater of Peenya Industrial Area, Bangalore, India. Environ Monit Assess 191:289. https:// doi. org/ 10. 1007/ s10661- 019- 7453-9.

43. Sharma A., Ganguly R., Gupta A.K., (2020). Impact assessment of leachate pollution potential on groundwater: An Indexing method. J Environ Eng 146(3):05019007. https:// doi. org/ 10. 1061/ (ASCE) EE. 1943- 7870. 00016 47.

44. Singh S., Lal S., Harjit L., Amlathe S., Kataria H. C., (2011). Potential of metal extractions in determination of trace metals in water samples. Adv. Stud Biol. 3(5):239–246.

45. SON-Standard Organization of Nigeria, (2007). “Standard for Drinking Water Quality,” Nigerian Industrial Standard, Abuja.

46. Sorensen J. P. R., Lapworth D. J., Read D. S., Nkuwa D. C. W., Bell R. A., Chibesa M., Chirwa M., Kabika J., Liemisa M., Pedly S., (2015). Tracing enteric pathogen contamination in Sub-saharan Africa groundwater. *Sci Total Environ* 538:888–895.

47. Suvarapu L. N., Baek S. D., (2017). Determination of heavy metals in the ambient atmosphere: a review. Toxicol Ind Health 33(1):79–96.

48. WHO, (2007). Water for pharmaceutical use in quality assurance of pharmaceuticals. A compendium of guidelines and related materials, 2nd updated edn. World Health Organization, Geneva, pp 170–187.

49. Wu J., Zhou H., He S., Zhang Y., (2019). Comprehensive understanding of groundwater quality for domestic and agricultural purposes in terms of health risks in a coal mine area of the Ordos basin, north of the Chinese Loess plateau. Environ Earth Sci 78:446. https:// doi. org/ 10. 1007/ s12665- 019- 8471-1.

50. Zarazua G., Avila P., Tejeda S., Barcelo I., Martinez T., (2006). Analysis of total and dissolved heavy metals in surface water of a Mexican polluted river by total reflection X-ray fluorescence spectrometry. Spectrochim Acta Part B Atom Spectrosc 61: 1180-1184.

Figures

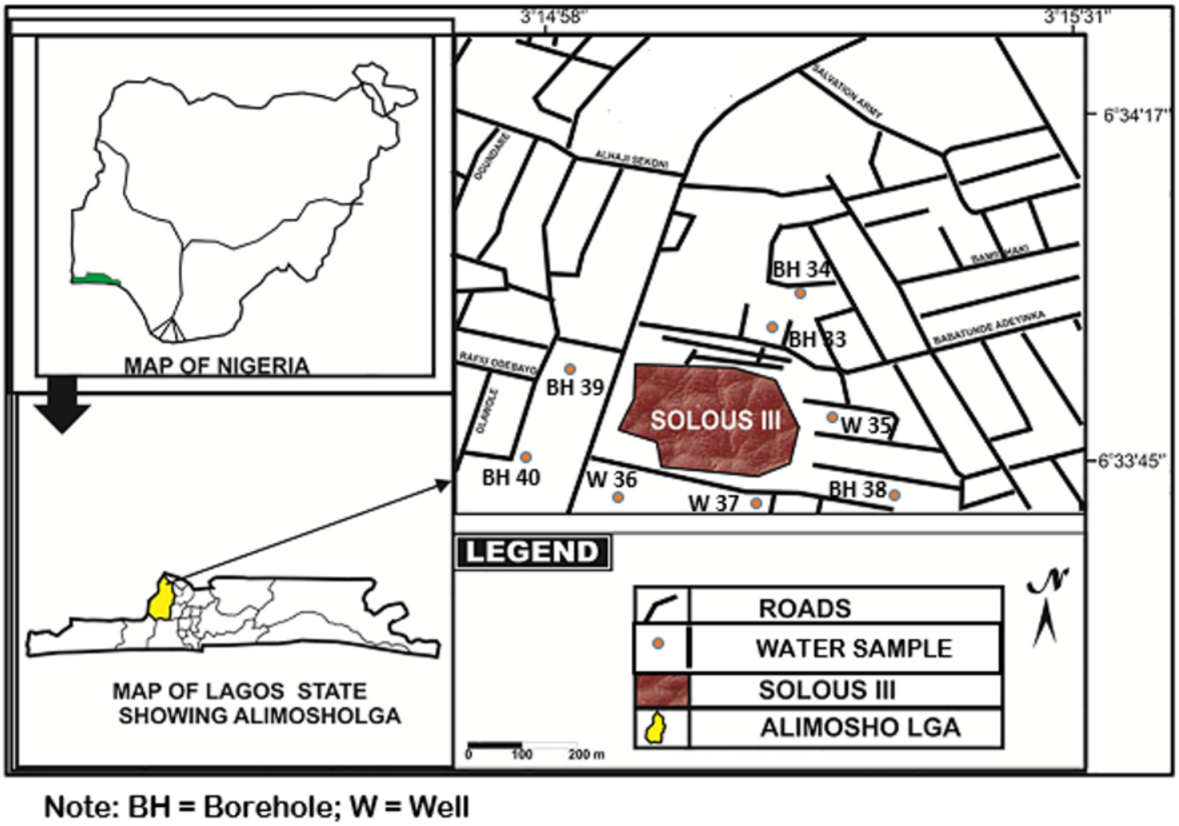

Figure 1

Map showing Solous III dumpsite (modified after Oziegbe *et al.,* 2021)

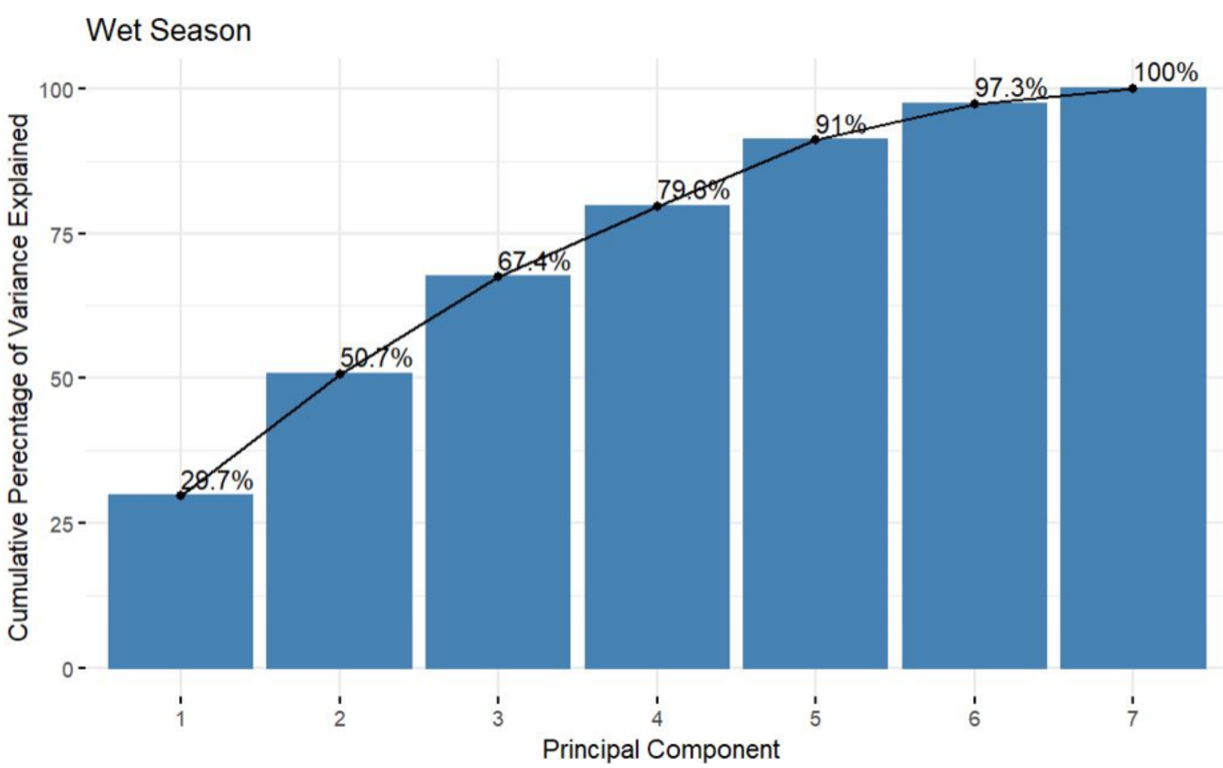

Figure 2

Number of principal components to retain from the wet season data

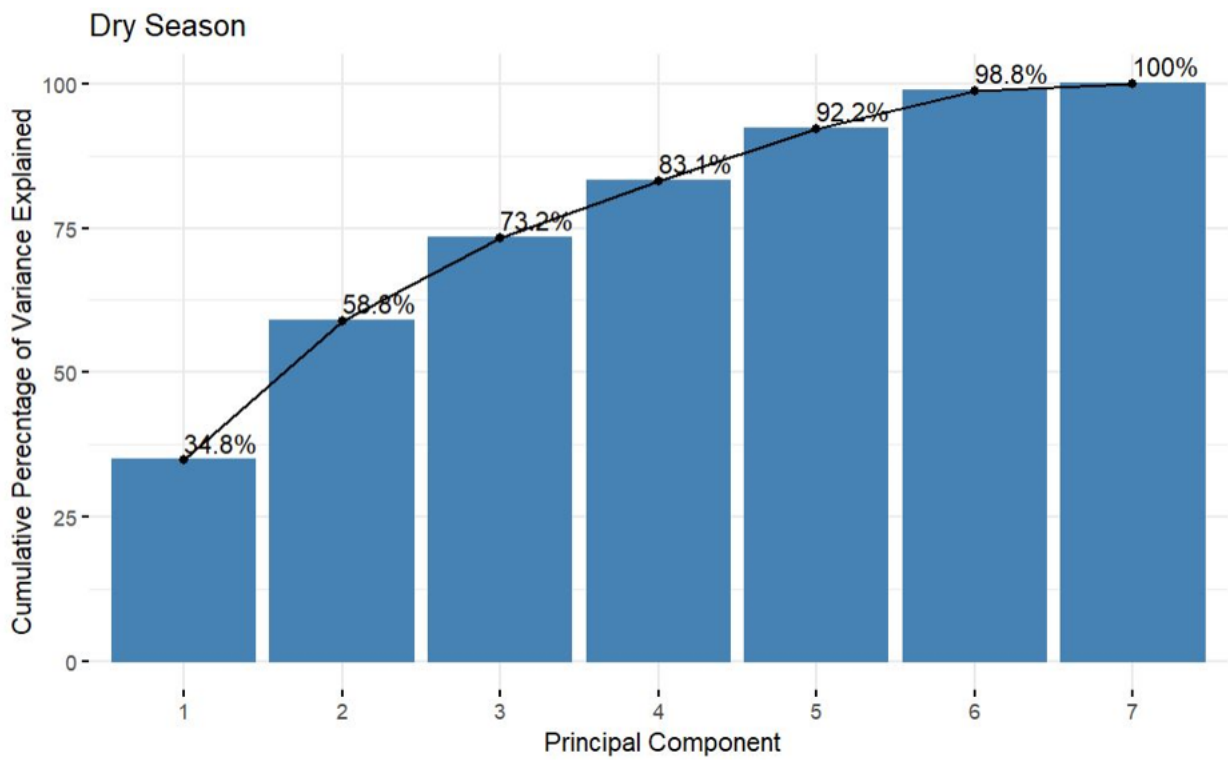

Figure 3

Number of principal components to retain from the dry season data

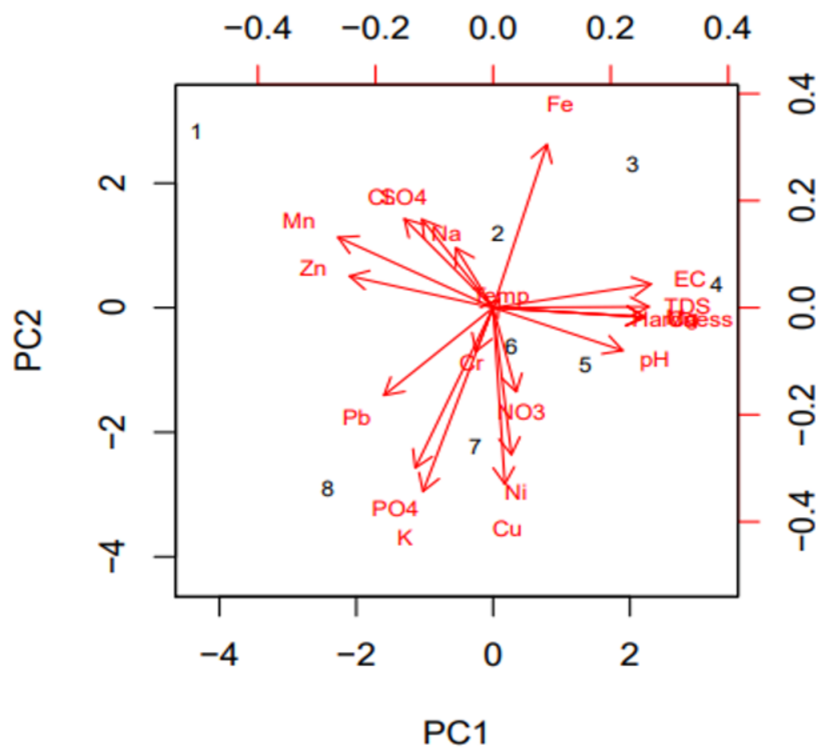

Figure 4

Biplot of PC1 and PC2 of the wet season data

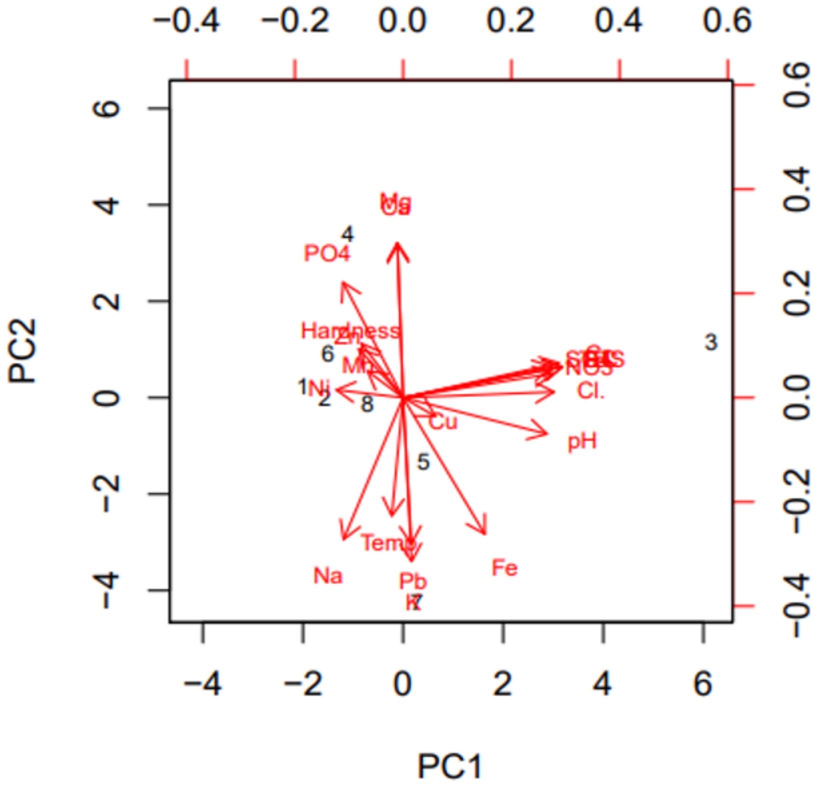

Figure 5

Biplot of PC1 and PC2 of the dry season data

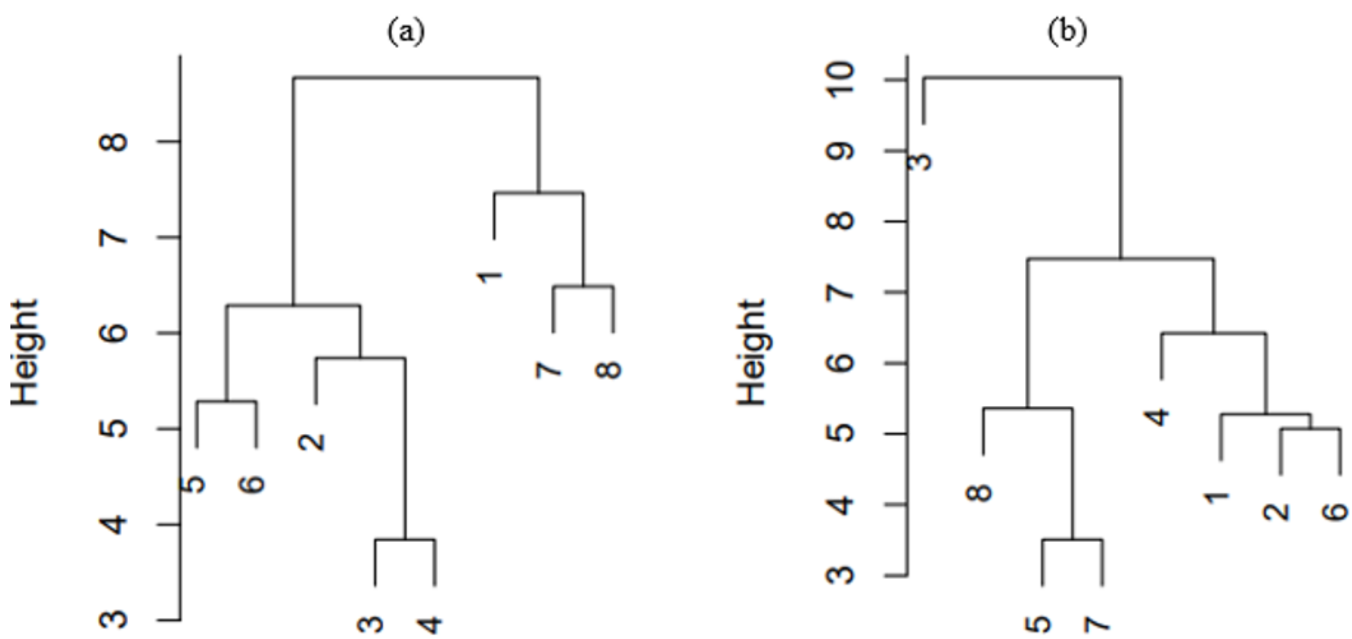

Figure 6

Cluster analysis of sampling locations for wet (a) and dry (b) seasons

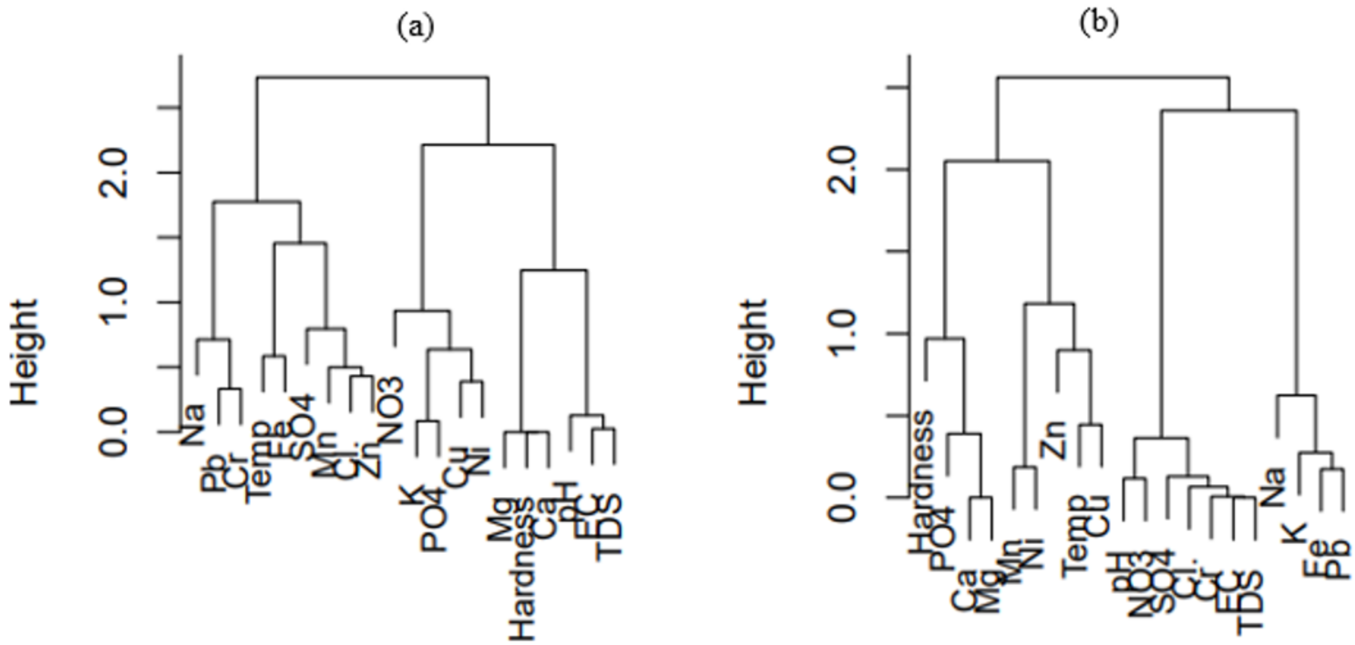

Figure 7

Dendrogram from the cluster analysis for wet (a) and dry (b) seasons