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Source identification and apportionment of pollution sources to groundwater quality in major cities in Southwest, Nigeria

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Groundwater in form of hand-dug wells and boreholes serves as the main source of drinking water to the people of south-western Nigeria. Contamination of this resource has been linked to many ambiguous pollution sources. The aim of this paper is to identify and apportion sources of pollution to groundwater in five major cities in south-western Nigeria using Principal Components Analysis (PCA). Studies on physico-chemical parameters of groundwater from Abeokuta, Ifo, Sango, Ibadan and Lagos were adopted from published literatures, and evaluated using a SPSS statistical package. PCA revealed factor ranges between four and eight. Sources identified were bedrock weathering/sea water, nutrient, solids, urban/traffic runoff, industry, hardness, faecal pollution, soil leaching, nutrient, salt-water intrusion and leachate.

Keywords: groundwater, factor, PCA, pollution, loading, southwest Nigeria

1. Introduction

Distribution of drinking through pipes by State Water Corporations is below demands in Nigerian cities and in many parts of the world. Large numbers of people depended absolutely on groundwater resource from hand-dug wells and boreholes. Recent epileptic supply of electricity had caused a further shortage in daily water production by water authorities. Therefore, the pressure on groundwater exploitation had increased (Gbadebo and Taiwo, 2011). The high cost of construction and maintenance of boreholes (which is believed to be potable) had left their affordability to the rich only (Ojo, 2002) leaving the majority of poor masses at the mercy of shallow hand-dug wells. These wells are often managed in an un-hygienic manner (Orebiyi et al., 2010, Taiwo et al., 2011). Access to potable water is still a major concern in all the developing nation of the world (Taiwo, 2011) as millions of people died of water-borne diseases annually (Lefort, 2006). Groundwater contaminations from southwestern Nigeria have been reported by many researchers with details on their physical, chemical and microbiological characteristics (Yusuf et al., 2007; Orebiyi et al., 2010; Eni et al., 2011; Gbadebo and Taiwo, 2011). High concentrations of metals and nitrates have been observed in these groundwater samples (Gbadebo et al., 2010; Ayedun et al., 2011; Taiwo et al., 2011). Presence of elevated amounts of metals in drinking water is detrimental to human health (Florea and Busselberg, 2006) while nitrate toxicity is dangerous to infants below six months with the risk of methemoglobinemia (McCasland et al., 2007). Potential sources to groundwater pollution in these study areas had been identified to include septic tank, pit latrine, cess pits (Eni et al.,

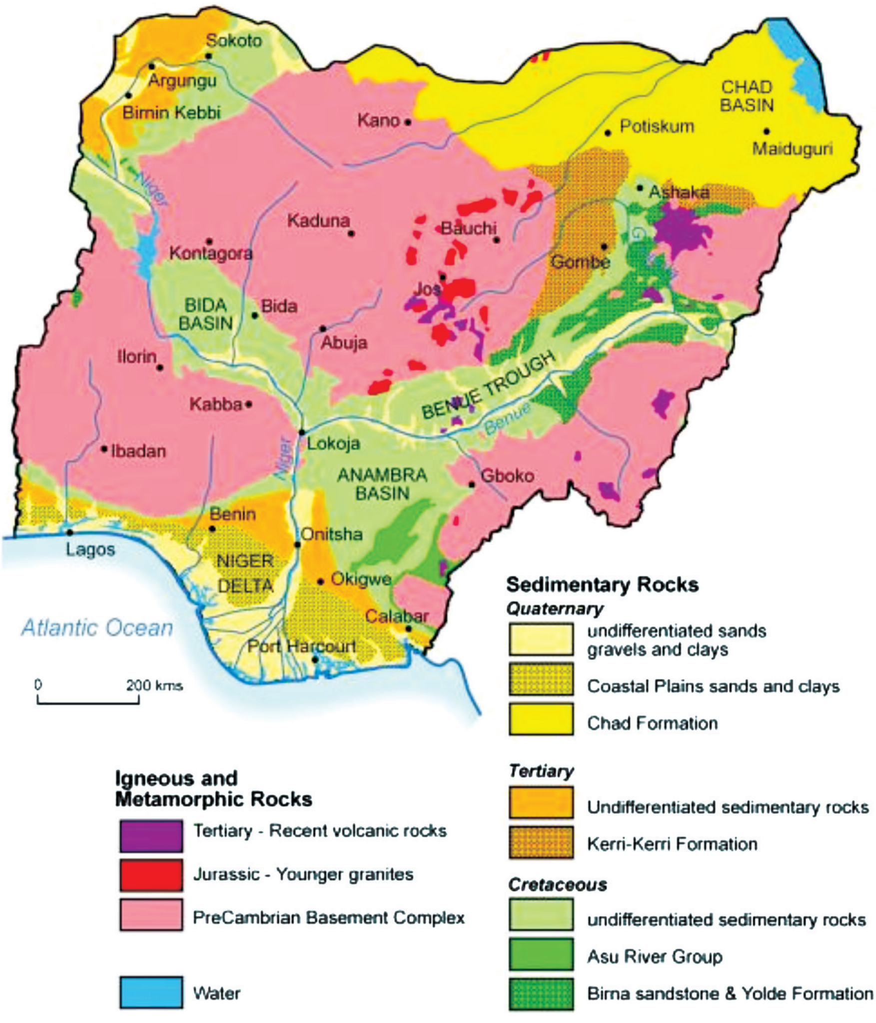

Figure 1. Geological map of Nigeria (Adelana et al., 2008).

2011), dumpsite (Longe and Balogun, 2010), run-off (Taiwo et al., 2011), industrial (Gbadebo and Taiwo, 2011) and agriculture (Taiwo, 2010) among others. However, none of these researchers has applied multivariate analysis such as principal component analysis (PCA) for source apportionment of groundwater pollutants.

The knowledge of source identification and apportionment using a multivariate statistical tool like PCA is not peculiar to air pollution only (Watson et al., 2002; Harrison et al., 2003; Yin et al., 2010). It has also been applied to surface and groundwater studies (Simeonov et al., 2003; Singh et al., 2005; Zhang et al., 2009; Huang et al., 2010; Zhang et al., 2011). The essence of applying source apportionment to water pollution is to develop optimal pollution-control strategies by relevant authorities (Pekey et al., 2004). The main objective of this paper is to apportion pollution sources to groundwater in major cities in south-western Nigeria using PCA.

1.1. Geological setting of the study areas

Geological map of Nigeria is presented in Fig. 1. Details of the geological setting of southern Nigeria had been discussed extensively by Jones and Hockey (1964). Briefly, south-western Nigeria fell under two main geological Formations, which include Basement Complex and Dahomey Basins. These two geological settings are subdivided into many components (Abeokuta Formation, Alluvium, Ewekoro Formation, Ilaro Formation and Coastal Plain Sands). The south-western Nigeria's geology is made up of rocks, which include older granite (consisting pegmatite, granite-gneiss, grandiorite, migmatite and quartz diorite), charnockitic intrusive (made up of pyroxene-diorite and metagabbro) and gneiss complex (consisting quartzitite, biotite and biotite hornblende-gneiss mica-schist, amphibolite schist and granulitic gneiss) (Oyedele et al., 2011). The hydrological characteristics of the study areas have been discussed elsewhere in Akoteyon et al. (2010). The major aquifer unit that exists in the Coastal Plain Sands is a water table aquifer made of dirty, white to grayish colored unconsolidated sands with an average thickness of 10 m (Longe, 2011).

2. Methodology

Secondary data sets published on groundwater quality in five cities in south-western Nigeria have been used for the source apportionment. The published materials include collection of studies from Abeokuta 1 (urban sites) (Orebiyi et al., 2010), Abeokuta 2 (peri-urban locations) (Taiwo et al., 2011), Ifo (Ayedun et al., 2011), Sango (Gbadebo and Taiwo, 2011), Ibadan (Nkolika and Onianwa, 2011) and Lagos (Yusuf, 2007). Three capital cities were included in this data, and this made it more important. Data set was evaluated for descriptive statistics (mean and standard deviation) and factor analysis (PCA) using SPSS for windows version 19.0.

3. Results and discussion

3.1. Physico-chemical parameters of the groundwater

Groundwater characteristics from six locations in five cities from southwestern Nigeria are shown in Tab. 1. Abeokuta 1 data set is the richest and comprehensive in terms of the number of samples as well as water quality parameters analyzed (Orebiyi et al., 2010). Groundwater parameters like total suspended solids (TSS), nitrate (NO_3^-), phosphate (PO_4^{3-}), iron (Fe), lead (Pb), bacteria count (BC) and *Escherichia coli* (E. Coli) were higher than World Health Organization (WHO) standards in drinking water. Although, there are no health-based guidelines established for TSS and PO_4^{3-}. High TSS is drinking water could harbor microbiological pollutants and could pose health risk to the public. PO_4^{3-} is associated with nutrient enrichment of a water body (Taiwo, 2010). Pb is a toxic metal affecting central nervous system and reproductive system (Taiwo et al., 2010a; 2010b).

Fe with no health-based guideline may affect the acceptability of drinking water in terms of taste, odor and corrosion (WHO, 2011). For Abeokuta 2, TSS and NO_3^- average values were high like Abeokuta 1 groundwater values. Ifo groundwater mean values showed higher concentrations of Fe, cadmium (Cd) and Pb slightly higher than WHO (2011) permissible limits. Mean value of Pb from Sango study was also higher than WHO standards in drinking water. In Ibadan groundwater, only TSS mean value was relatively high like the values recorded in Abeokuta 1 and 2. Other observed parameters were within the limit of WHO standard.

Mn is an essential element, but at higher concentration could result into adverse neurological disorders (WHO, 2011). WHO health-based guideline for Mn is 0.4 mg L^{-1} while for non-health based guideline, it should be less than 0.1 mg L^{-1} (WHO, 2011). Mn concentrations in all the groundwater samples may, however, not be harmful to the public. Average values of temperature in all the groundwater quality are higher than the CEC (1988) limit given as 25 °C. Temperature is non-health based guideline in drinking water, and therefore, may not pose any problem. Besides, the annual mean (ambient) temperature in southwestern Nigeria is 28 °C (Bello, 2009). Nitrate and Pb values were high in these reported groundwater samples and thus suggested severe contaminations from percolated leachates from sewages, landfills as well as urban and agricultural runoff.

Many authors have reported landfill leachate infiltration as major groundwater contamination in southwestern Nigeria (Longe and Kehinde, 2005; Longe and Enekwechi, 2007). Geological nature of the underlining soil and rock in these study areas could also abet groundwater contamination by leachates. Drinking water from these wells and borehole without a prior treatment will continue to expose the public to the danger of metals, nitrate and solids.

Table 1. The mean values of groundwater quality in major cities in South-western Nigeria reported by different authors.

Parameters	Abeokuta 1 (N=54) Orebiyi et al. (2010)		Abeokuta 2 (N=25) Taiwo et al. (2011)		Ifo (N=22) Ayedun et al. (2011)		Sango (N=14) Gbadebo and Taiwo (2011)		Ibadan (N=20) Nkolika and Onianwa (2011)		Lagos (N=18) Yusuf (2007)		WHO (2011)
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation	
Color (TCU)	6.39	2.98	-	-	-	-	-	-	-	-	-	-	15.0
Turbidity (NTU)	4.16	2.20	-	-	-	-	-	-	-	-	-	-	5.0
Temperature (°C)	25.19	0.68	27.97	0.20	28.68	0.45	-	-	28.45	1.66	25.81	0.63	
EC (µS cm^{-1})	865.37	242.19	332.92	127.02	677.82	350.65	19.68	10.58	-	-	761.11	497.08	
pH	6.73	0.30	8.60	0.61	5.70	0.98	7.32	0.70	5.79	0.44	6.38	0.47	6.5-8.5
TS (mg L^{-1})	604.52	198.13	464.09	125.61	-	-	-	-	550.10	383.97	-	-	
TDS (mg L^{-1})	402.72	117.44	162.80	63.35			10.04	5.45	433.63	396.33	513.78	333.35	<600
TSS (mg L^{-1})	201.80	112.17	296.82	98.05	4.67	0.60	-	-	115.50	71.87	-	-	
Ca (mg L^{-1})	23.17	9.77	-	-	-	-	5.24	0.80	72.20	51.97	-	-	
Fe (mg L^{-1})	0.37	.65	-	-	0.31	0.15	0.14	0.05	-	-	-	-	0.3
Mg (mg L^{-1})	7.09	3.57	-	-	-	-	0.64	0.16	14.66	15.04	-	-	
K (mg L^{-1})	29.50	23.73	-	-	-	-	53.61	15.69	-	-	21.22	25.49	
Na (mg L^{-1})	64.32	41.68	-	-	-	-	7.50	6.72	-	-	78.45	80.13	200

Table 1. Continued.

Hardness (mg L^{-1})	30.26	11.90	106.86	46.90	–	–	–	–	85.95	54.92	110.28	75.95	
Alkalinity (mg L^{-1})	–	–	84.21	35.01	76.82	22.34	30.64	11.45	120.50	95.01	75.33	69.57	
Cl^- (mg L^{-1})	128.51	83.68	55.47	33.02	–	–	51.78	13.57	134.00	143.51	64.21	60.62	200–300
NO_3^- (mg L^{-1})	12.02	7.52	17.67	10.48	–	–	25.77	14.40	–	–	0.42	0.41	11.0
SO_4^{2-} (mg L^{-1})	26.21	18.19	145.32	84.52	–	–	1.61	0.66	–	–	1.54	1.25	<250
PO_4^{3-} (mg L^{-1})	0.21	0.36	0.05	16.68	–	–	–	–	–	–	0.09	0.26	
NH_4^+ (mg L^{-1})	–	–	0.11	0.18	–	–	–	–	–	–	–	–	1.5/35
DO (mg L^{-1})	–	–	–	–	–	–	–	–	4.68	1.25	–	–	
Pb (mg L^{-1})	0.25	0.162	–	–	0.07	0.07	0.04	0.02	–	–	0.62	1.27	0.01
Cd (mg L^{-1})	–	–	–	–	0.004	0.003	0.01	0.01	–	–	–	–	0.003
Mn (mg L^{-1})	0.02	0.07	–	–	–	–	0.17	0.19	–	–	0.30	0.98	<0.1
Zn (mg L^{-1})	0.12	0.25	–	–	0.04	0.03	0.29	0.10	–	–	–	–	3.0–5.0
Cr (mg L^{-1})	–	–	–	–	–	–	0.01	0.01	–	–	–	–	0.05
Cu (mg L^{-1})	0.06	0.13	–	–	–	–	0.09	0.03	–	–	–	–	2.0
Co (mg L^{-1})	–	–	–	–	–	–	0.001	0.001	–	–	–	–	
BC (cfu 100 mL^{-1})	88.52	68.77	–	–	–	–	–	–	–	–	–	–	0
E. Coli (cfu mL^{-1})	105.56	27.06	–	–	–	–	–	–	–	–	–	–	0

3.2. Principal component analysis

The varimax rotated analysis results are presented in Tabs. 2–7. Tab. 2 is the PCA for groundwater samples from Abeokuta 1 reported by Orebiyi et al. (2010). The varimax rotated analysis revealed eight factors/components. The percentage of variability of data set ranges between 4.62 and 24.11%; while 87.2% of the total variance of the data set is explained by the eight factors leaving less than 13% unidentified. Factor 1 which represents the higher percentage of variability has high significant loadings for sodium (Na), potassium (K), chloride (Cl^-) and Mn. This factor could be best described as a bedrock source. The weathering of crystalline basement rock hosting the groundwater aquifer might be responsible for the high concentration of these ionic species (Olmez et al., 1994). Factor 2 has strong significant positive loadings for total solids (TS), electrical conductivity (EC), total dissolved solid (TDS) and TSS. This factor is a solids source. For factor 3, hardness, calcium (Ca) and magnesium (Mg) has strong positive loadings for this factor, and it's suspected to be a hardness source. Factor 4 has been positive loading for E. Coli and Bacteria Counts, with negative loading for Fe. This factor represents a feacal pollution source. Ayedun et al. (2011) had reported that confined aquifer of a sedimentary basin are vulnerable to the building up of dissolved iron. Negative loading for Fe may suggest the presence of Fe in the groundwater may be natural rather than anthropogenic via faecal pollution. Feacal pollution is a major contaminant to be reckoned with in both surface and groundwater resources in Nigeria (Chieng et al., 2011). Reason for this cannot be over-emphasized due to poor sanitation, indiscriminate waste disposal, proliferation of septic tanks and latrine pits by each house. Factor 5 is highly loaded for color, turbidity, sulphate (SO_4^{2-}), which is probably due to pollution by run-off. This source could be designated urban run-off. This is a prominent factor in groundwater in Abeokuta during the rainfall (due to the poor drainage system. During and after rainfall, groundwater in Abeokuta becomes turbid and laden with suspended solids (Taiwo et al., 2011). SO_4^{2-} could as well be carried along from sewage and domestic refuse or wastes by run-off into the wells through available entrance. Poor management of the groundwater resources in most cities in Nigeria reflects the water-quality parameters depicted in Tab. 1. Factor 6 is positively loaded for NO_3^- and negatively correlated with pH. This factor may be described as a nutrient source. Leaching of septic tanks, sewage and wastes into the groundwater resource may lead to nitrate pollution. One of the major threats to groundwater contamination in Nigeria is lack of central sewerage system. Every house has its own sewage system with the use of septic tanks, cesspools and pits for storing excretal and sewages (Chieng et al., 2011). Negative correlation of pH with NO_3^- shows independent relationships between the two parameters. Factor 7 has a high loading for Mn and negative loading for PO_4^{3-}. Assuming PO_4^{3-} is positive in the loading, it would have been best termed nutrient source. Mn is a marker for industrial source, but unfortunately, Abeokuta is a civil-servant state with a scanty number of industries. Therefore, this

Table 2. Abeokuta 1 rotated component matrix from dataset of Orebiyi et al. (2010).

	Component								
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Communali-ties
Na	**0.933**	–0.174	0.190	0.031	0.033	–0.055	–0.037	0.034	0.854
K	**0.887**	–0.090	0.148	–0.122	–0.018	–0.103	–0.033	–0.060	0.901
Cl^-	**0.726**	–0.209	0.234	–0.373	0.142	–0.010	–0.203	0.197	0.881
Mn	**0.665**	–0.118	0.050	0.028	0.235	–0.135	**0.560**	–0.093	0.968
TS	–0.071	**0.975**	–0.044	0.066	0.051	0.060	0.026	0.105	0.910
EC	–0.203	**0.927**	–0.036	0.014	–0.138	–0.061	0.201	–0.048	0.979
TDS	–0.183	**0.896**	0.014	0.104	–0.228	–0.061	0.239	–0.028	0.960
TSS	0.085	**0.752**	–0.098	0.000	0.366	0.184	–0.234	0.230	0.859
Zn	0.319	–0.529	–0.098	0.428	0.202	–0.235	0.082	0.362	0.918
Hardness	0.145	–0.015	**0.976**	–0.065	0.003	–0.023	0.016	0.065	0.894
Ca	0.141	0.021	**0.943**	–0.027	0.010	0.039	0.061	0.055	0.790
Mg	0.121	–0.114	**0.827**	–0.154	–0.020	–0.191	–0.113	0.077	0.847
Fe	–0.043	–0.307	0.145	–0.875	–0.022	0.025	–0.007	0.102	0.944
E. coli	–0.413	–0.171	–0.154	**0.682**	0.368	0.295	–0.143	0.023	0.983
BC	–0.413	–0.171	–0.154	**0.682**	0.368	0.295	–0.143	0.023	0.865
Pb	–0.153	0.001	0.408	0.533	–0.165	0.462	0.034	0.084	0.808
Color	0.226	0.022	–0.048	0.091	**0.861**	0.008	–0.117	0.191	0.738

Table 2. Continued.

Turbidity	–0.526	–0.171	–0.095	0.031	**0.749**	–0.124	0.097	0.010	0.768
SO_4^{2-}	0.265	–0.009	0.380	0.251	**0.597**	0.288	0.143	–0.015	0.722
pH	0.093	0.001	0.264	–0.131	–0.065	–0.898	0.001	–0.063	0.855
NO_3^-	–0.550	0.270	0.208	0.077	0.060	**0.583**	0.187	–0.065	0.809
PO_4^{3-}	–0.220	–0.220	0.046	0.094	0.054	–0.078	**–0.820**	0.038	0.818
Cu	–0.067	–0.067	–0.100	0.140	–0.240	0.071	0.260	**–0.800**	0.931
Temp	0.125	0.125	0.231	0.137	–0.080	0.317	0.405	**0.695**	0.931
% of Variance	16.311	16.311	13.668	10.077	7.814	5.589	5.396	4.263	
Cumulative %	40.417	40.417	54.085	64.162	71.976	77.565	82.961	87.224	

source would be named refuse run-off source. The last factor 8 has loadings for Cu (negative) and temperature (positive). It will be unfair to categorize this source as run-off source from traffic/road even though, Cu is a marker for traffic pollutant; however the inclusion of temperature in the source will make the factor to stand as unknown.

In the varimax rotated PCA done on the groundwater quality from Abeokuta 2 (Tab. 3), five major factors were revealed with variability percentage varying from 10.95 to 26.92%. The identified sources are less than the Abeokuta 1 probably due to the data size. The factor 1, which has been positive loaded for TDS, EC, SO_4^{2-} and hardness could be simply described as urban runoff from non-point anthropogenic sources. For factor 2 with positive high loading for TSS and TS, this could be named as a solid source. Both factor 1 and 2 could have been best designated as solid sources assuming SO_4^{2-} and hardness had not come between them. SO_4^{2-} pollution is usually anthropogenic from domestic and agricultural wastes. Factor 3 is having positive loading for NO_3^- and negative loading for alkalinity, and the factor is put as a nutrient source 1 similar to Abeokuta 1. Suthar et al. (2009) had strongly suggested intensive agriculture and heavy use of N-fertilizer to be major enrichment of groundwater with NO_3^-. The same source is witnessed in Factor 4 with loadings for PO_4^{3-} and ammonium (NH_4^+). Factor 4 is a nutrient 2 source. The last factor 5 is having positive loading for Cl^- and negative loading for temperature. This factor may be

Table 3. PCA for Abeokuta 2 dataset from Taiwo et al. (2011).

	Component					
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communalities
pH	–0.134	0.383	**0.762**	0.029	0.268	0.818
Temperature	0.381	–0.230	–0.033	0.060	**–0.760**	0.781
TDS	**0.909**	0.351	0.032	0.162	–0.071	0.982
TSS	0.093	**0.889**	0.116	–0.033	0.163	0.841
TS	0.476	**0.830**	0.118	0.010	0.055	0.932
EC	**0.911**	0.342	0.082	0.156	–0.079	0.985
PO_4^{3-}	0.012	0.269	–0.131	**0.841**	–0.196	0.834
NH_4^+	0.290	–0.286	0.052	**0.829**	0.082	0.862
SO_4^{2-}	**0.583**	0.468	–0.153	0.281	–0.238	0.718
NO_3^-	0.204	0.135	**0.849**	–0.301	–0.113	0.883
Cl^-	0.425	–0.009	0.048	–0.068	**0.762**	0.768
Hardness	**0.897**	–0.112	0.035	–0.008	0.195	0.857
Alkalinity	–0.002	0.135	–0.928	–0.099	–0.015	0.890
% of Variance	26.972	18.017	17.269	12.566	10.951	
Cumulative %	26.972	44.988	62.257	74.823	85.775	

a bedrock weathering/anthropogenic pollution source. It will be difficult to ascertain the authentic source of chloride in the groundwater since parameters such as Na, K, and Mg that could have consolidated the suggested bedrock source are missing in the study conducted by the author (Taiwo et al., 2011). There is a possibility of groundwater Cl^- pollution occurring from contaminations from sewage percolation, runoff containing chloride salts, landfill leachates, septic tank, animal feed and industrial effluents (Taiwo et al., 2011).

Table 4. Rotated PCA for Ifo groundwater water quality reported by Ayedun et al. (2011).

	Component				
	Factor 1	Factor 2	Factor 3	Factor 4	Communalities
pH	**0.923**	–0.123	–0.090	0.188	0.911
Temperature	0.064	0.244	–0.804	–0.121	0.724
Alkalinity	**0.928**	–0.005	–0.084	–0.043	0.870
DO	–0.285	0.486	0.330	–0.407	0.592
Salinity	**0.691**	–0.168	0.600	–0.173	0.896
Redox Potential	–0.195	**0.712**	0.061	0.078	0.555
Cd	0.007	–0.054	0.153	**0.854**	0.756
Fe	–0.183	**0.690**	–0.205	0.084	0.558
Pb	–0.042	0.185	0.**790**	0.111	0.673
Zn	–0.215	–0.682	0.008	–0.055	0.514
EC	0.014	0.292	0.053	**0.832**	0.781
% of Variance	21.782	17.349	16.598	15.444	
Cumulative %	21.782	39.131	55.729	71.173	

Ifo groundwater having undergone a varimax rotation by PCA, four major components were identified (Tab. 4). Only 71.17% of the total data set was identified leaving up to 28.93% unidentified as four major factors allotted. Factor 1 is having high loadings for pH, alkalinity and salinity. This source is probably a salt/saline source as it dominates the whole data set with 21.78% of the 71.17% variability. Ifo is geologically located on the Coastal Plain Sands within Dahomey Basin, which are characterized by soft, very poorly sorted, clayey sands, pebbly sands, sandy clays and rare thin lignite (Akoteyon et al., 2010). Salinity might be sourced from salt-water bearing aquifers. Factor 2 has been loaded for

Table 5. Sango varimax rotated PCA for groundwater parameters from Gbadebo and Taiwo (2011).

	Component						
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communalities
pH	**–0.917**	–0.212	0.013	0.014	0.003	0.214	0.932
TDS	0.456	**0.615**	–0.119	–0.496	–0.120	0.213	0.905
EC	0.469	**0.593**	–0.101	–0.514	–0.109	0.205	0.900
SO_4	0.112	0.123	**0.602**	–0.270	–0.026	0.013	0.463
Cl–	–0.429	–0.172	0.276	–0.407	**0.619**	0.043	0.841
Alkalinity	0.255	**0.822**	0.121	0.034	–0.232	–0.160	0.835
NO_3^-	0.400	0.520	**0.604**	0.157	–0.181	0.002	0.853
Na	0.070	–0.174	–0.072	0.347	**0.807**	–0.045	0.813
K	0.243	–0.077	0.482	0.148	**0.724**	0.155	0.868
Ca	0.028	–0.010	–0.143	–0.090	–0.027	**–0.922**	0.881
Mg	–0.006	–0.463	0.479	0.221	–0.513	0.109	0.768
Co	–0.018	**0.966**	–0.040	–0.049	0.020	0.105	0.950
Zn	0.208	–0.048	–0.054	**0.900**	–0.051	0.148	0.883
Fe	**0.724**	0.267	0.042	0.034	0.020	0.477	0.826
Cr	**0.897**	–0.165	0.197	–0.052	–0.085	0.100	0.890
Cu	–0.134	–0.034	0.044	**0.907**	0.215	0.028	0.891
Pb	–0.318	–0.259	**0.817**	–0.157	0.320	0.068	0.967
Cd	0.136	–0.004	**0.839**	0.282	0.092	0.118	0.824
Mn	–0.898	–0.294	–0.057	–0.066	–0.221	0.070	0.955
% of Variance	21.429	16.87	14.484	14.324	11.329	7.069	
Cumulative %	21.429	38.299	52.783	67.106	78.435	85.504	

Fe and redox potential with negative loading for Zn. This factor is designated soil source. For factor 3, the loadings were Pb (positive) and temperature (negative). This factor might be designated runoff from the traffic/road. Pb is a marker for traffic pollution (Qu and Kelderman, 2001). The final factor 4 has strong positive loadings for Cd and EC. The factor could be best put as an industrial source.

Groundwater parameters from Sango have been separated into six components by PCA with % variability of data set varying from 7.07 to 21.42 (Tab. 5). Factor 1 has a high loading for Fe, Cr, and Mn with negative loading for pH. This factor represents crustal matter/soil source. The loadings for factor 2 are TDS, EC, alkalinity and cobalt (Co); this source might be likely originated from urban runoff source (from diverse non-point sources) similar to Abeokuta 2 groundwater. Factor 3 loadings are SO_4^{2-}, NO_3^-, Pb and Cd. This factor could be designated leachate source. Leachate from septic tanks and open dumps could have infiltrated into the groundwater resource thereby polluting it. Factor 4 has been loading for Zn and Cu. Copper and zinc are markers for industrial pollution. Therefore, this source could be seen as an industrial source. Sango is one of the industrial bases in Ogun State. Effluents or discharges from the industries could have raised the concentrations of these elements. Factor 5 has been loaded for Cl^-, Na and K, which represented salt water source. Factor 6 is negatively loaded for Ca, which probably suggests run-off from traffic/road and construction sites. Since negative loading also suggests negative correlation, it means that wells or borehole located close to road are exposed to danger of traffic pollution during precipitation.

Tab. 6 shows the PCA of groundwater quality from Ibadan. Five factors were identified with % variability ranging from 9.53–33.70. Factor 1 shows high significant positive loading for Cl^-, hardness and Ca. This could be termed bedrock weathering source. Chemical weathering of the basement bedrock might have led to increase ionic strength of the groundwater, and subsequent increase in water hardness. Unfortunately, Mg does not fall into this group. Notwithstanding, groundwater hardness could have been resulted from high concentration of Ca ion. Factor 2 shows high loading for TS and TDS signifying a solid source. Factor 3 has been loading for Mg, alkalinity and negative loading for dissolved oxygen (DO). Low DO in water body is an indication of organic pollution. Hence this factor could be best described as an organic pollution source. The alkaline nature of the groundwater coupled with the presence of macro-element, magnesium could provide a conducive environment for microbiological pollutant to thrive in the aquifer with subsequent reduction in DO (Taiwo, 2010). Factor 4 has been negative loading for TSS, which suggests soil leaching source. Simeonov et al. (2003) has identified TSS as soil leaching source in PCA carried out on water quality parameters from Northern Greece. Factor 5 has a strong loading for temperature only. This could probably be identified as an industrial source. Leaching of industrial discharges into the groundwater could have resulted into

Table 6. Rotated component matrix for Ibadan groundwater dataset from Nkolika and Onianwa (2011).

	Component					
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communalities
Temperature	0.038	0.079	0.026	0.071	**0.928**	0.874
pH	0.172	–0.817	0.321	0.197	0.025	0.840
Cl^-	**0.752**	0.400	–0.059	0.130	0.260	0.813
Hardness	**0.909**	0.061	0.278	0.071	–0.106	0.923
Mg	0.130	0.059	**0.733**	0.311	–0.394	0.809
Ca	**0.953**	0.102	0.084	–0.015	–0.007	0.926
TS	0.324	**0.890**	0.130	0.059	0.079	0.924
TDS	0.327	**0.872**	0.125	0.226	0.086	0.942
TSS	–0.066	–0.047	0.005	**–0.939**	–0.065	0.892
Alkalinity	0.444	–0.400	**0.657**	0.227	0.095	0.849
DO	–0.033	–0.070	–0.827	0.311	–0.191	0.824
% of Variance	33.704	23.039	10.945	10.205	9.532	
Cumulative %	33.704	56.742	67.687	77.893	87.424	

this source. High groundwater temperature, which was greater than the CEC (1998) standard had been identified by PCA as a thermal pollution source from the industries. Five factors have been identified by PCA in groundwater from Lagos (Tab. 7). Factor 1 has a positive loading for EC, TDS, hardness, alkalinity, SO_4^{2-}, Cl^- and Na representing 36.71% of the total variability in the data set. This factor could be best described as leachate source from sewage and other organic wastes. Factor 2 is having a positive loading for $Cl^{-,}$ Na, K and moderate loading for EC with 15.5% variability. This factor could be best described as salt water intrusion. Intrusion of salt water from the ocean into the groundwater aquifer could have been responsible for the high loading of these ionic species rather than weathering of bedrock bearing the groundwater described in Olmez et al. (1994) and Zhou et al. (2007). Additionally, Lagos falls under Coastal Plain Sands geological formation where salt water bearing-sands overlie fresh water aquifers, which are exploited by boreholes (Oteri and Atolagbe, 2003). Saline water intrusions in confined and unconfined aquifers have been reported by Oteri (1990), Oteri and Atolagbe (2003), Adelana et al. (2008) and Akoteyon et al. (2010). Factor 3 has a high positive loading for temperature and negative loading for Pb. This factor could be termed industrial source like Ibadan's PCA previously described. Leachates of lead-containing materials from industries could have resulted into the groundwater contamination by Pb. Negative loading of

Table 7. Rotated component matrix in Lagos groundwater dataset reported by Yusuf (2007).

	Component					
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communalities
pH	0.057	0.143	–0.137	**0.896**	0.233	0.899
Temperature	–0.226	–0.001	**0.909**	–0.058	–0.085	0.888
EC	**0.561**	**0.552**	0.153	0.419	–0.127	0.835
TDS	**0.904**	0.252	0.109	–0.070	–0.077	0.903
Hardness	**0.864**	0.151	–0.228	0.160	0.105	0.859
Alkalinity	**0.654**	0.227	–0.279	**0.560**	–0.071	0.876
SO_4^{2-}	**0.799**	–0.096	–0.069	–0.110	0.338	0.780
NO_3^-	0.262	0.347	–0.116	**–0.624**	0.422	0.770
PO_4^{3-}	0.167	–0.449	0.461	0.357	0.459	0.780
Cl^-	**0.605**	**0.739**	0.030	–0.011	0.028	0.914
Na	**0.558**	**0.708**	–0.097	–0.123	0.155	0.861
K	–0.023	**0.880**	0.255	0.143	0.195	0.899
Pb	–0.038	–0.209	**–0.797**	0.074	0.129	0.702
Zn	–0.064	–0.175	0.177	–0.052	**–0.796**	0.702
% of Variance	36.711	15.507	13.051	9.635	8.446	
Cumulative %	36.711	52.218	65.269	74.904	83.35	

Pb, and positive loading for temperature suggests that Pb concentration in the groundwater is not temperature dependent. Temperature influences water chemistry. The fourth factor with positive loading for pH and alkalinity and negative loading for NO_3^- may not be fitted in any factor, and hence termed unknown. The last factor 5 has a negative loading for Zn and moderate positive correlation for nitrate, and phosphate could be assigned nutrient source. Leaching of nutrients from septic tanks, pit latrines and dumping sites could have been responsible for the factor.

4. Conclusion

It was observed from this review study that physico-chemical parameters reported by various authors in the groundwater from south-western Nigeria showed high concentrations of Fe, Mn, Pb and NO_3^-. Elevated microbial populations were observed in some of the groundwater samples, signifying faecal pollution. Using PCA as an apportionment tool, major sources identified were bedrock weathering/sea water, nutrient, solids, urban/traffic runoff and industry. Urgent attention is required for protection of groundwater resource in this region for its importance as the major source of drinking water.

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SAŽETAK

Identifikacija izvora onečišćenja podzemnih voda u većim gradovima jugozapadne Nigerije

Adewale Matthew Taiwo

Kao glavni izvor pitke vode stanovnicima jugozapadne Nigerije služi voda iz kopanih ili bušenih bunara. Njihovo onečišćenje potječe iz mnogih nepoznatih izvora. Cilj ovog rada je odrediti izvore onečišćenja podzemnih voda u pet većih gradova u jugozapadnoj Nigeriji metodom (analizom) glavnih komponenti (PCA). Fizikalno-kemijski parametri podzemnih voda u gradovima: Abekuta, Ifo, Sango, Ibadan i Lagos preuzeti su iz literature, a evoluirani pomoću statističkog paketa SPSS. Vrijednost faktora dobivenih analizom glavnih komponenti kreće se u rasponu od četiri do osam. Identificirani izvori onečišćenja su: dekompozicija stijena (pod utjecajem morske vode ili u kombinaciji s morskom vodom), nutrienti, krute tvari, urbano-prometna odvodnja, industrija, tvrdoća (otopljeni minerali), fekalno onečišćenje, ispiranje tla, prodor slane vode i procjedna voda.

Ključne riječi: podzemna voda, faktor, analiza glavnih komponenti, onečišćenje, opterećenje, jugozapadna Nigerija

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