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Metal and Microbial Contamination in the Water Available for Agriculture in Selected Farm Settlements in Nigeria

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ABSTRACT

Background and Objective: Several diseases have been reportedly linked to the consumption of water with metal and/or microbial contamination, or agricultural produce watered by such method. This study assessed the water available for agriculture in three selected farm settlements in Southwestern Nigeria. **Materials and Methods:** As 15, 12 and 5 water samples from the Ajegunle, Akufo and Eruwa farm settlements, respectively were analyzed for 11 heavy and trace metals and 7 microbial populations, using standard laboratory procedures, for dry and wet seasons. Analysis of Variance (ANOVA) and Duncan's Multiple Range Tests were done using SPSS, version 20. Pollution sources were apportioned using Principal Component Analysis while seasonal spatial variation maps were generated via the Inverse Density Weighted method. **Results:** Water from the three farm settlements showed possibilities of cadmium, iron, manganese, *E. coli* and streptococcal contaminations. The pollution sources identified were bedrock weathering, fertilizer/agricultural waste/run-off leachates, agricultural activities, fecal contamination, livestock agricultural wastes, sewage effluents and organic decomposition. Spatial maps showing the existing distributions of selected metals and microbial populations within Ajegunle and Akufo farm settlements were produced. **Conclusion:** This research has generated information for the eradication or substantial reduction of the potential harm of metal and microbial contamination to the farm settlers and consumers of their agricultural produce.

KEYWORDS

Pollution, health, inverse density weighted, microbial populations, spatial variation maps, total bacteria count, principal component analysis, water quality assessment

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INTRODUCTION

Over time, there have been reports of pollution from high levels of heavy and trace metals in different media as well as negative health effects on humans resulting from consumption via the food chain[1]. The use of contaminated water for irrigation and livestock farming has been considered to be responsible for several disease outbreaks after consumption of such produce[2,3]. Hence the need to assess and monitor their concentrations in plant tissues and animal meat to curb their excessive build-up in the human food chain[1,4,5].

Researchers have used multivariate statistical analyses such as principal component analysis (PCA) and cluster analysis (CA) to analyze water quality and apportion pollution sources[6-9]. Also, geographic information system (GIS), using different techniques, such as inverse distance weighted (IDW) interpolation, etc. has been used for site suitability analyses and inventory data management, solute transport and leaching studies, assessment of groundwater contamination vulnerability and modeling of groundwater flow as well as spatial mapping by integrating water quality data with spatial data[10,11]. Spatial groundwater variation maps have been generated by Sahoo *et al.*[12] and Gidey[13] among others.

This study assessed the contamination, apportioned pollution sources using principal component analysis (PCA) and mapped the spatial variabilities of heavy and trace metals as well as microbial populations in the water samples collected from the Ajegunle, Akufo and Eruwa farm settlements.

Despite many years of cultivation and use of fertilizers in these predominantly agricultural farm settlements, information on heavy and trace metal concentrations as well as microbial populations and their potential dangers were not available till the time this research was conducted. The findings from this research will enhance good and systematic utilization of the water within the settlements in such a way as to eradicate, or at least minimize the potentially harmful effects of metal and microbial contamination in plants, animals and eventual human consumers.

MATERIALS AND METHODS

Study area: This study was conducted in three selected farm settlements within the Southwestern part of Nigeria, Ajegunle, Akufo and Eruwa farm settlements (Fig. 1a). Akufo and Eruwa are in Ido and Ibarapa East Local Government of Oyo State, respectively while Ajegunle farm settlement is in the Obafemi Owode Local Government of Ogun State.

The three farm settlements are located within the Ogun River Basin, within Latitudes 6°26'N and 9°10'N and Longitudes 2°28'E and 4°8'E. The basin is of generally low relief with a North-South direction gradient and experiences two seasons: Dry from November to March and wet from April to October[14,15]. The three farm settlements fall within the basement complex terrain (Fig. 1b and c). The Abeokuta formation and migmatite underlie the Ajegunle farm settlement while Akufo and Eruwa are underlain with quartzite and undifferentiated gneiss, respectively[9,16].

The Ajegunle farm settlers are majorly livestock farmers in poultry, fish farming and piggery, but they also grow maize and cassava. The Akufo farm settlers grow cassava, yam, oil palm, kola nut, cocoa and timber as well as do poultry farming and cattle rearing. In the Eruwa farm settlement, the prevalent crops are cassava, vegetables, cashew and fruits such as watermelon while they also engage in livestock farming such as piggery. These farm settlements have a long history of over 60 years of cultivation of staple crops and use of pesticides and fertilizers as well as other veterinary drugs and agrochemicals.

Water sampling: Water samples were collected in conformity with standard procedures[17] from the Ajegunle, Akufo and Eruwa farm settlements, 15, 12 and 5 from hand-dug wells and the main earth dams/rivers/dams, respectively (Fig. 2a-c). The samples were collected for analysis during both the wet and dry seasons between August, 2016 and April, 2017. The latitudes, longitudes and elevations of the sampling points were measured with an eTrex 10 Garmin handheld GPS device.

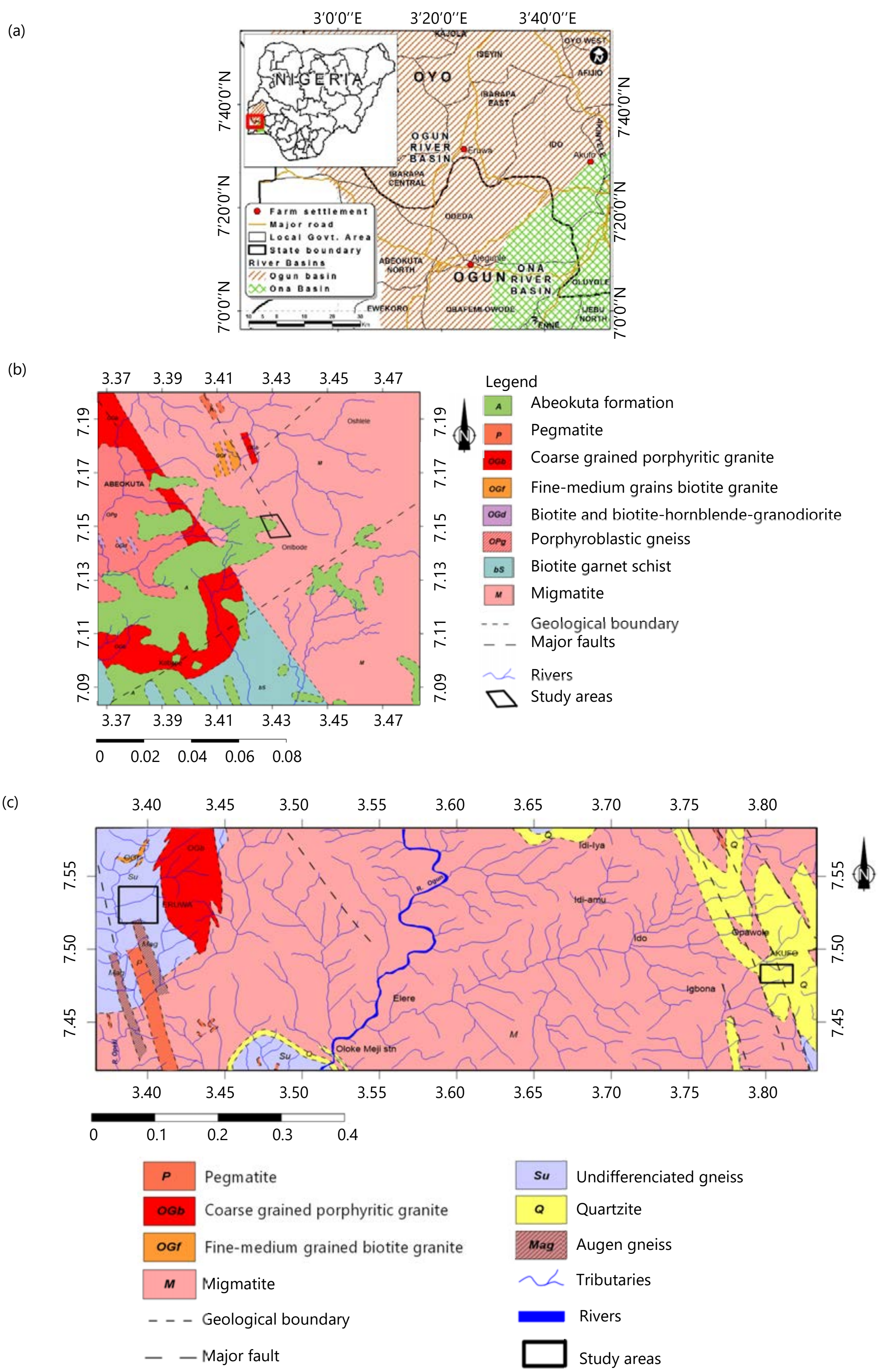

Fig. 1(a-c): Location map showing the three farm settlements within the Ogun River Basin, (a) Geological maps showing the rock types underlying (b) Akufo and (c) Eruwa farm settlements (modified after Nigeria Geological Survey Agency)

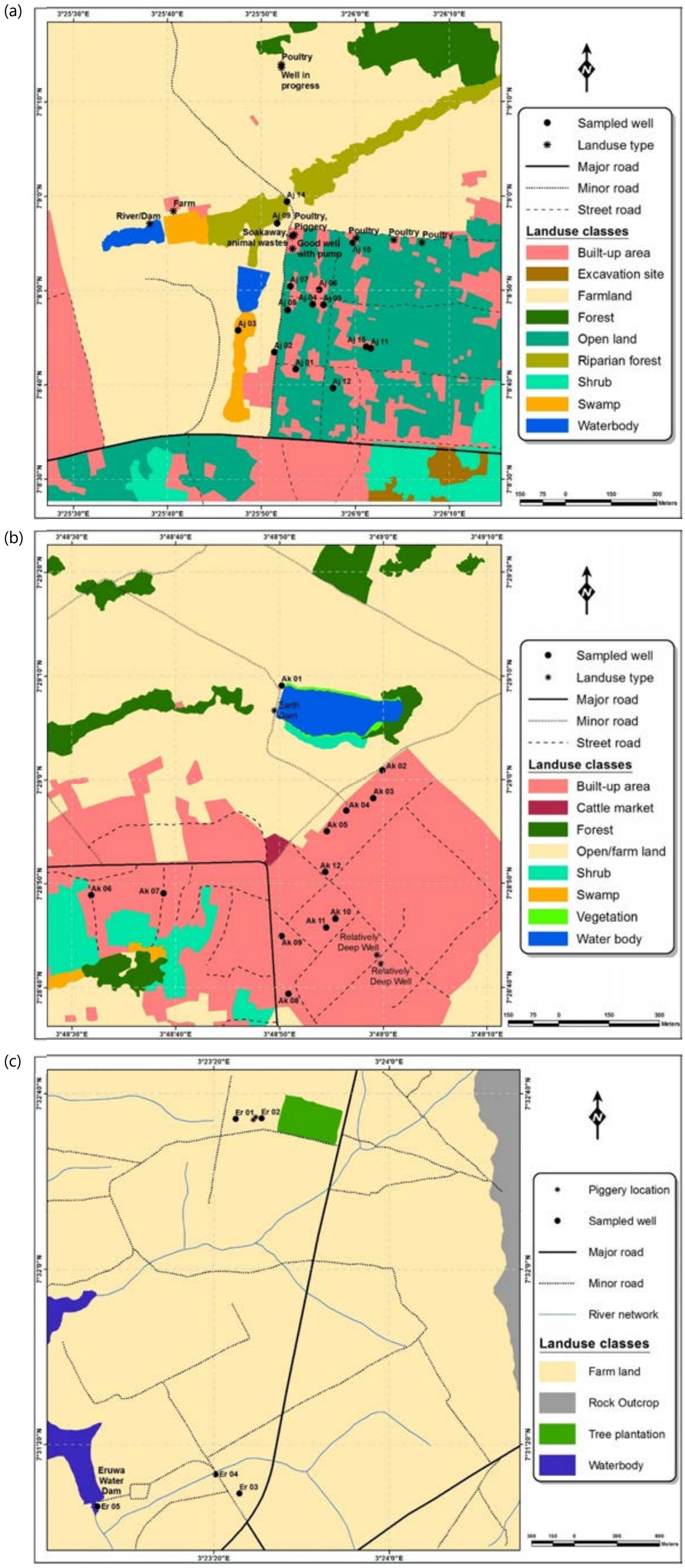

Fig. 2(a-c): Water sampling locations, with land-use characteristics, at the (a) Ajegunle, (b) Akufo and (c) Eruwa farm settlements

Laboratory analyses: The water samples were analyzed for Lead, Cadmium, Zinc, Manganese, Copper, Chromium, Aluminium, Arsenic, Mercury, Boron and Iron, as well as for Coliform count, Total Bacteria Count, *E. Coli* count, *Salmonella* count, V*ibrio cholera*, *S. aureus* and *Streptococcal* feacal, using standard laboratory procedures. The concentrations of the metals were determined using an Atomic Absorption Spectrophotometer (AAS), model BUCK 200 while the Multiple Fermentation Tube/Most Probable Number (MPN) method was used for the microbial analyses[17-21]. The measurements were done in duplicates and the averages computed and recorded.

Statistical analysis: The heavy and trace metal concentrations as well as the microbial population counts from the laboratory analyses of the water samples were subjected to descriptive statistics and the results compared with the World Health Organization[22] and the Nigerian Standard for Drinking Water Quality[23] standards. Analysis of Variance (ANOVA) and Duncan's Multiple Range Test were done using SPSS, version 20. The results are presented as means±standard error (S.E.) at a 5% level of significance.

PCA pollution source apportionment: Heavy and trace metal pollution, as well as microbial contamination sources, were apportioned via principal component analysis (PCA), using SPSS, version 20. The PCA was carried out after the necessary standardization and application of the Kaiser-Mayer-Olkin (KMO) measure of sampling adequacy. Only components with eigenvalues greater than 1.00 were retained as the extracted components[24-28].

IDW spatial variation mapping: This was achieved by geo-referencing and digitizing the base maps via the Arc GIS software, version 10 (2015). The inverse distance weighted (IDW) interpolation technique was used to generate and integrate spatial and attribute databases. Spatial variation maps of the heavy and trace metals, as well as the microbial populations, were then generated for the wet and dry seasons to show the patterns and seasonal variabilities within Ajegunle and Akufo farm settlements[29,30]. The sampling points within the Eruwa farm settlement were very few and very wide apart, hence spatial variation maps were not generated for the settlement using IDW.

RESULTS

Means and standard deviations: The means and standard deviations, minimum and maximum values for heavy and trace metal concentrations (mg L^{-1}) and microbial populations ($\times 10^5$ CFU mL^{-1}) in the water samples collected within Ajegunle farm settlement are presented in Table 1.

The means and standard deviations, minimum and maximum values for heavy and trace metal concentrations (mg L^{-1}) and microbial populations ($\times 10^5$ CFU mL^{-1}) in the water samples collected within the Akufo farm settlement are presented in Table 2.

The means and standard deviations, minimum and maximum values for heavy and trace metal concentrations (mg L^{-1}) and microbial populations (x10^5 CFU mL^{-1}) in the water samples collected in the Eruwa farm settlement are presented in Table 3.

Principal component analysis

Factor loadings: The result of the principal component analysis of heavy and trace metals in the water samples collected from the Ajegunle farm settlement revealed 4 extracted components while that of microbial populations showed only 2 extracted components (Table 4).

The result of the principal component analysis of heavy and trace metals in the water samples collected from the Akufo farm settlement showed 2 extracted components while that of microbial populations showed only 1 extracted component (Table 5).

The result of the principal component analysis of heavy and trace metals in the water samples collected from the Eruwa farm settlement revealed only 1 extracted component while that of microbial populations showed 2 extracted components (Table 6).

Table 1: Metal concentrations and microbial populations in the water samples from Ajegunle Farm Settlement

Heavy and trace metal ($mg\ L^{-1}$)	Dry season	Wet season	WHO (2011)	NSDWQ (2007)	Dry season Min	Dry season Max	Wet season Min	Wet season Max
Lead	0.005 ± 0.005^{a}	0.004 ± 0.005^{a}	0.010±0.000	0.010±0.000	0.010	0.010	0.010	0.010
Cadmium	0.002 ± 0.004^{a}	0.004 ± 0.005^{a}	0.003±0.000	0.003±0.000	0.001	0.010	0.001	0.010
Zinc	0.530 ± 0.106^{a}	0.352 ± 0.077^{b}	-	3.000±0.000	0.340	0.660	0.130	1.130
Manganese	0.017 ± 0.005^{a}	0.048 ± 0.028^{a}	0.400±0.000	0.200±0.000	0.010	0.020	0.010	0.100
Copper	0.010 ± 0.004^{a}	0.050 ± 0.054^{a}	2.000±0.000	1.000±0.000	0.010	0.020	0.010	0.140
Chromium	Not detected	Negligible	0.0500±0.0000	0.0500±0.0000	-	-	-	-
Aluminium	Not detected	Negligible	0.1000±0.0000	0.2000±0.0000	-	-	-	-
Arsenic	Not detected	Negligible	0.0100±0.0000	0.0100±0.0000	-	-	-	-
Mercury	Not detected	Negligible	0.0060±0.0000	0.0010±0.0000	-	-	-	-
Boron	Not detected	Negligible	2.4000±0.0000	-	-	-	-	-
Iron	0.268 ± 0.121^{a}	0.617 ± 0.290^{a}	0.100±0.000	0.200±0.000	0.270	0.360	0.130	1.150
Microbial population ($\times10^{5}$ CFU mL^{-1})								
Coliform count	0.185 ± 0.069^{a}	0.143 ± 0.096^{a}	-	10.000±0.000	0.100	0.300	0.100	0.300
Total bacteria count	1.069 ± 0.253^{a}	0.896 ± 0.304^{a}	-	-	0.600	1.400	0.400	1.300
E. coli count	0.177 ± 0.060^{a}	0.129 ± 0.080^{b}	-	0.000±0.000	0.100	0.300	0.100	0.300
S. aureus count	0.308 ± 0.104^{a}	0.293 ± 0.149^{b}	-	-	0.200	0.500	0.100	0.600
Streptococcal count	0.262 ± 0.051^{a}	0.061 ± 0.056^{a}	-	0.000±0.000	0.200	0.300	0.100	0.150

Values represent mean±standard deviation (SD), values along the same row with different superscripts are significantly different at $p<0.05$ level

Table 2: Metal concentrations and microbial populations in the water samples from Akufo farm settlement

Heavy and trace metal ($mg\ L^{-1}$)	Dry season	Wet season	WHO (2011)	NSDWQ (2007)	Dry season Min	Dry season Max	Wet season Min	Wet season Max
Lead	0.0050 ± 0.0054^{a}	0.0093 ± 0.0099^{a}	0.0100±0.0000	0.0100±0.0000	0.010	0.010	0.001	0.030
Cadmium	0.0015 ± 0.0035^{a}	0.0075 ± 0.0062^{a}	0.0030±0.0000	0.0030±0.0000	0.001	0.010	0.010	0.020
Zinc	0.3563 ± 0.0867^{a}	1.2808 ± 0.1569^{b}	-	3.0000±0.0000	0.250	0.510	1.120	1.610
Manganese	0.0350 ± 0.0120^{a}	1.3558 ± 0.2413^{b}	0.4000±0.0000	0.2000±0.0000	0.020	0.050	0.750	1.600
Copper	0.0075 ± 0.0046^{a}	0.4133 ± 0.1028^{b}	2.0000±0.0000	1.0000±0.0000	0.010	0.010	0.230	0.620
Chromium	0.0003 ± 0.0005^{a}	0.0002 ± 0.0004^{a}	0.0500±0.0000	0.0500±0.0000	-	-	-	-
Aluminium	0.0001 ± 0.0003^{a}	0.0000 ± 0.0000^{a}	0.1000±0.0000	0.2000±0.0000	-	-	-	-
Arsenic	0.0001 ± 0.0003^{a}	0.0000 ± 0.0000^{a}	0.0100±0.0000	0.0100±0.0000	-	-	-	-
Mercury	0.0002 ± 0.0004^{a}	0.0000 ± 0.0000^{a}	0.0060±0.0000	0.0010±0.0000	-	-	-	-
Boron	0.0002 ± 0.0004^{a}	0.0000 ± 0.0000^{a}	2.4000±0.0000	-	-	-	-	-
Iron	0.2988 ± 0.0412^{a}	1.5675 ± 0.1764^{b}	0.1000±0.0000	0.2000±0.0000	0.240	0.360	1.270	1.800
Microbial population ($\times10^{5}$ CFU mL^{-1})								
Coliform count	0.25 ± 0.53^{a}	0.91 ± 0.25^{a}	-	10.0000±0.0000	0.200	0.300	0.450	1.250
Total bacteria count	0.85 ± 0.26^{a}	1.26 ± 0.23^{a}	-	-	0.600	1.300	0.800	1.500
E. coli count	0.10 ± 0.05^{ab}	0.33 ± 0.17^{b}	-	0.0000±0.0000	0.100	0.200	0.100	0.700
Salmonella count	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	-	-	-	-	-	-
Vibrio cholera count	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	-	-	-	-	-	-
S. aureus count	0.16 ± 0.07^{a}	0.32 ± 0.12^{a}	-	-	0.100	0.300	0.200	0.550
Streptococcal count	0.18 ± 0.13^{a}	0.25 ± 0.67^{a}	-	0.0000±0.0000	0.100	0.400	0.200	0.400

Values represent mean±standard deviation (SD), values along the same row with different superscripts are significantly different at $p<0.05$ level

Table 3: Metal concentrations and microbial populations in the water samples from Eruwa farm settlement

Heavy and trace metal (mg L^{-1})	Dry season	Wet season	WHO (2011)	NSDWQ (2007)	Dry season Min	Dry season Max	Wet season Min	Wet season Max
Lead	0.0025±0.0050[a]	0.0150±0.0058[b]	0.0100±0.0000	0.0100±0.0000	0.001	0.001	0.01	0.02
Cadmium	0.0003±0.0050[a]	0.0175±0.0150[a]	0.0030±0.0000	0.0030±0.0000	0.001	0.001	0.01	0.04
Zinc	0.2575±0.1725[a]	1.1525±0.0822[b]	-	3.0000±0.0000	0.32	0.36	1.06	1.24
Manganese	0.6500±0.0904[a]	0.9900±0.4044[b]	0.4000±0.0000	0.2000±0.0000	0.01	0.20	0.59	1.40
Copper	0.0050±0.0058[a]	0.9875±0.1443[b]	2.0000±0.0000	1.0000±0.0000	0.01	0.01	0.81	1.11
Chromium	0.0002±0.0004[a]	0.0000±0.0000[a]	0.0500±0.0000	0.0500±0.0000	-	-	-	-
Aluminium	Not detected	Not detected	0.1000±0.0000	0.2000±0.0000	-	-	-	-
Arsenic	Not detected	Not detected	0.0100±0.0000	0.0100±0.0000	-	-	-	-
Mercury	Not detected	Not detected	0.0060±0.0000	0.0010±0.0000	-	-	-	-
Boron	Not detected	Not detected	2.4000±0.0000	-	-	-	-	-
Iron	0.1750±0.0420[a]	1.2900±0.1388[b]	0.1000±0.0000	0.2000±0.0000	0.13	0.23	1.11	1.43
Microbial population (x10^5 CFU mL^{-1})								
Coliform count	0.33±0.10[a]	0.90±0.30[a]	10.00±0.00	10.0000±0.0000	0.20	0.40	0.60	1.25
Total bacteria count	1.20±0.37[a]	0.79±0.25[a]	-	-	0.70	1.60	0.50	1.00
E. coli count	0.15±0.06[a]	0.08±0.10[b]	0.00±0.00	0.0000±0.0000	0.10	0.20	0.10	0.20
Salmonella count	0.00±0.00[a]	0.00±0.00[a]	-	-	-	-	-	-
Vibrio cholera count	0.00±0.00[a]	0.00±0.00[a]	-	-	-	-	-	-
S. aureus count	0.33±0.05[a]	0.20±0.08[a]	-	-	0.30	0.40	0.10	0.30
Streptococcal count	0.30±0.08[a]	0.15±0.06[a]	0.00±0.00	0.0000±0.0000	0.20	0.40	0.10	0.20

Values represent mean±standard deviation (SD) and values along the same row with different superscripts are significantly different at $p<0.05$ level

Table 4: Factor loadings for heavy and trace metals as well as microbial populations in the water samples from Ajegunle farm settlement

Variable	Principal component 1	2	3	4
Lead	-0.415	0.094	0.777	0.100
Cadmium	-0.147	0.035	0.852	0.026
Zinc	0.862	-0.189	-0.154	-0.276
Manganese	0.896	-0.132	-0.115	-0.241
Copper	0.917	-0.205	-0.213	-0.156
Iron	0.890	0.071	-0.152	0.191
Chromium	-0.390	0.168	-0.312	0.821
Aluminum	-0.008	-0.157	0.404	0.864
Arsenic	0.042	0.800	0.443	-0.172
Mercury	-0.172	0.968	-0.052	0.059
Boron	-0.172	0.968	-0.052	0.059
Initial eigenvalues	4.608	2.311	1.616	1.287
Variance (%)	41.893	21.012	14.687	11.701
Cumulative (%)	41.893	62.905	77.592	89.293
Coliform count	0.110	0.833		
Total bacteria count	0.819	0.092		
Escherichia coli count	0.750	-0.361		
Staphylococcus aureus count	0.057	-0.649		
Streptococcal count	0.796	0.150		
Initial eigenvalues	1.883	1.276		
Variance (%)	37.663	25.522		
Cumulative (%)	37.663	63.185		

Extraction method: Principal component analysis[a], Rotation method: Varimax with Kaiser normalization and [a]2 components extracted

Table 5: Factor loadings for heavy and trace metals as well as microbial populations in the water samples from Akufo farm settlement

	Principal component	
Variable	1	2
Lead	0.037	0.891
Cadmium	0.347	0.782
Zinc	0.940	0.276
Manganese	0.960	0.238
Copper	0.966	0.045
Iron	0.952	0.213
Initial eigenvalues	4.182	1.171
Variance (%)	69.696	19.512
Cumulative (%)	69.696	89.208
Coliform count	0.827	
Total bacteria count	0.833	
Escherichia coli count	0.690	
Staphylococcus aureus count	0.730	
Streptococcal count	0.540	
Initial eigenvalues	2.677	
Variance (%)	53.541	
Cumulative (%)	53.541	

Extraction method: principal component analysis[a] and [a]1 component extracted

Table 6: Factor loadings for heavy and trace metals as well as microbial populations in the water samples from Eruwa farm settlement

	Principal component	
Variable	1	2
Lead	0.932	
Cadmium	0.734	
Zinc	0.971	
Manganese	0.835	
Copper	0.981	
Iron	0.986	
Initial eigenvalue	4.981	
Variance (%)	83.011	
Cumulative (%)	83.011	
Coliform count	-0.824	-0.470
Total bacteria count	0.814	0.055
Escherichia coli count	0.020	0.993
Staphylococcus aureus count	0.948	-0.120
Streptococcal count	0.714	0.487
Initial eigenvalues	3.048	1.166
Variance (%)	60.966	23.318
Cumulative (%)	60.966	84.284

Extraction method: principal component analysis[a], Rotation method: Varimax with Kaiser normalization and [a]2 components extracted

Spatial variabilities: The spatial distributions of selected metals for Ajegunle and Akufo farm settlements during the dry and wet seasons respectively are presented as follows: Cadmium in Fig. 3a-b while Copper in Fig. 3c-d, Iron in Fig. 4a-b while Zinc in Fig. 4c-d and Manganese in Fig. 5a-b.

Also, the spatial distributions of selected microbial populations for Ajegunle and Akufo farm settlements during the dry and wet seasons, respectively are presented as follows: Coliform counts in Fig. 6a-b while total bacteria counts in Fig. 6c-d, *E. coli* counts in Fig. 7a-b while *S. aureus* counts in Fig. 7c-d and Streptococcal counts in Fig. 8a-b.

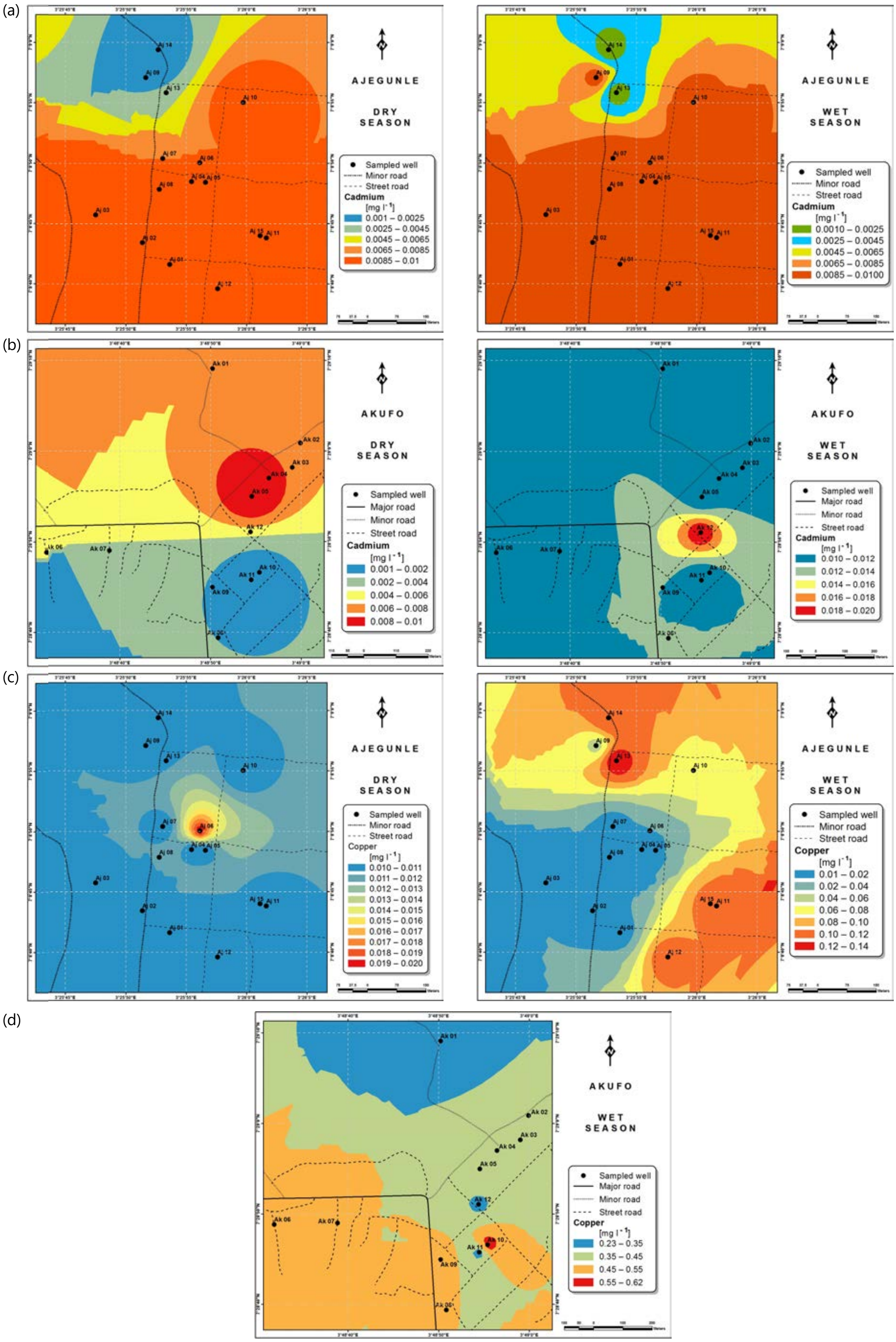

Fig. 3(a-d): Spatial variability map of cadmium for (a) Ajegunle, (b) Akufo and of copper, (c) Ajegunle and (d) Akufo farm settlements

(a)
(b)
(c)
(d)

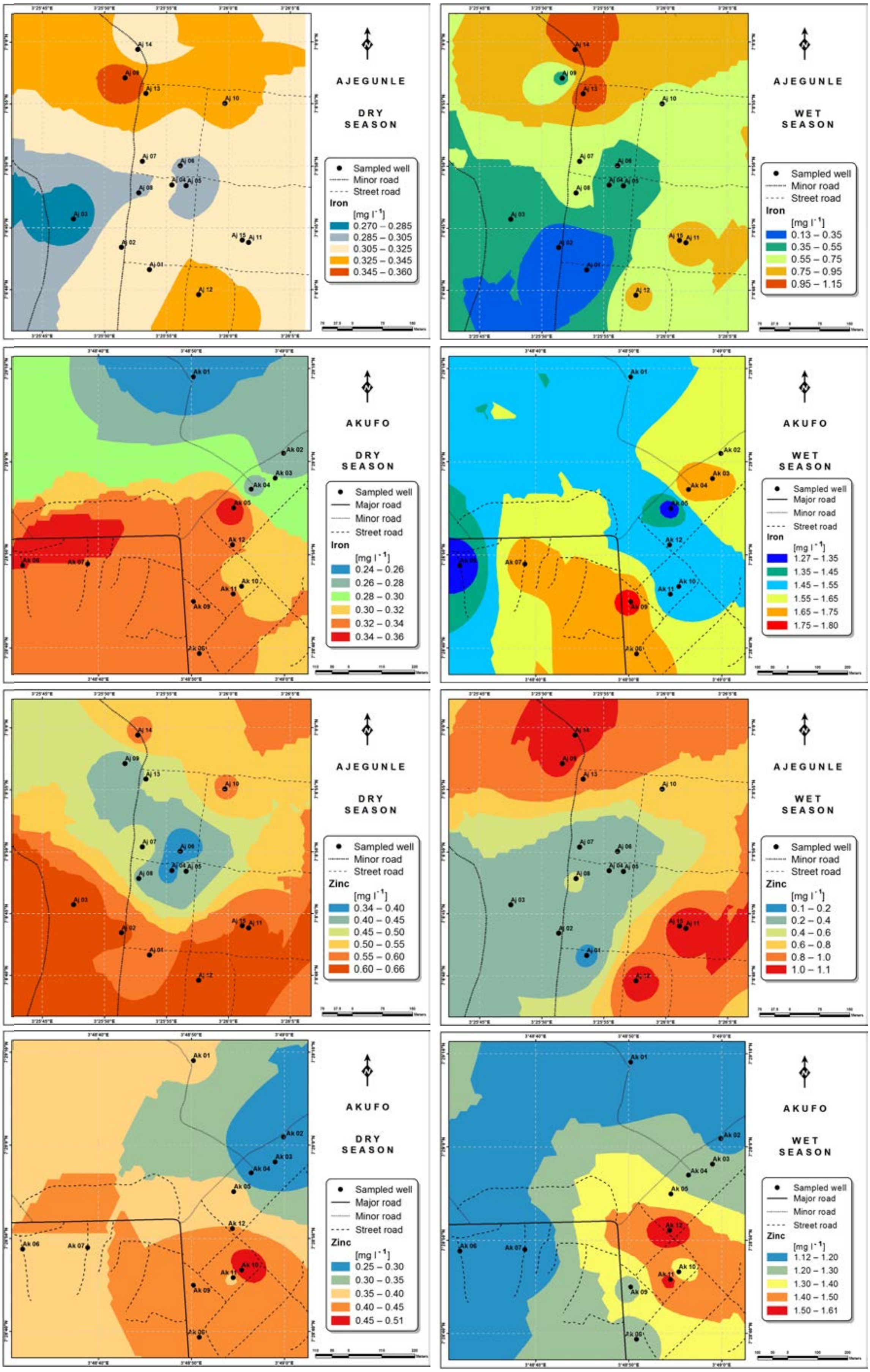

Fig. 4(a-d): Spatial variability map of iron for (a) Ajegunle, (b) Akufo and of Zinc, (c) Ajegunle and (d) Akufo farm settlements

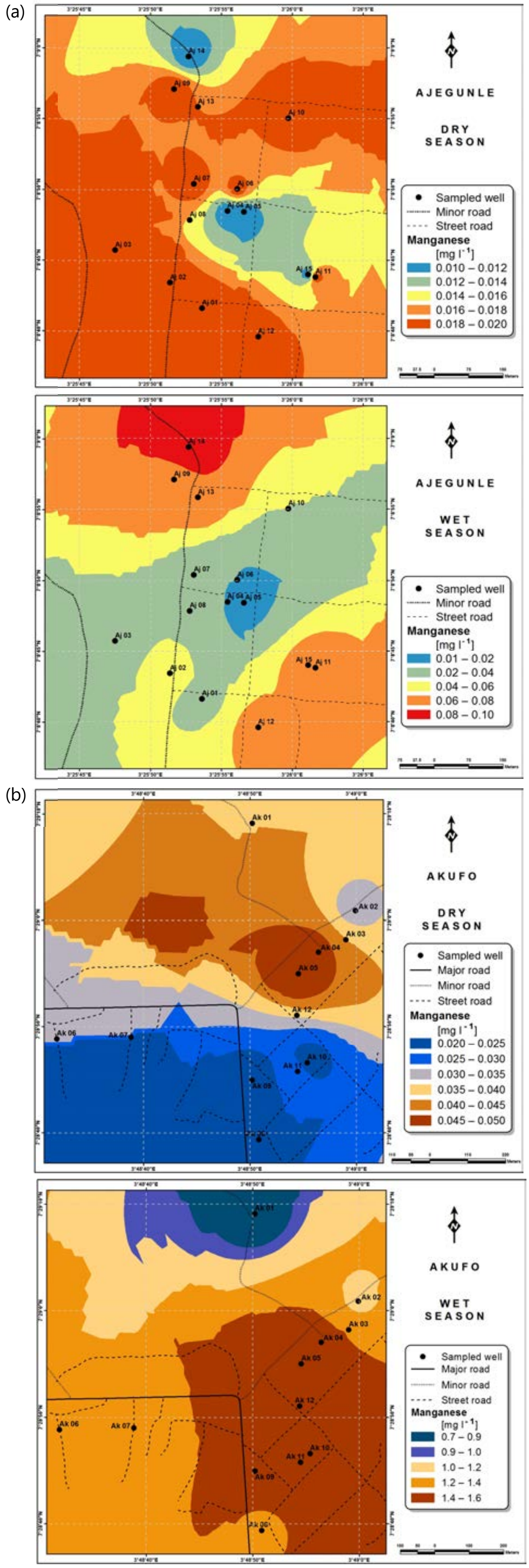

Fig. 5(a-b): Spatial variability map of manganese for (a) Ajegunle and (b) Akufo farm settlement

(a)

(b)

(c)

(d)

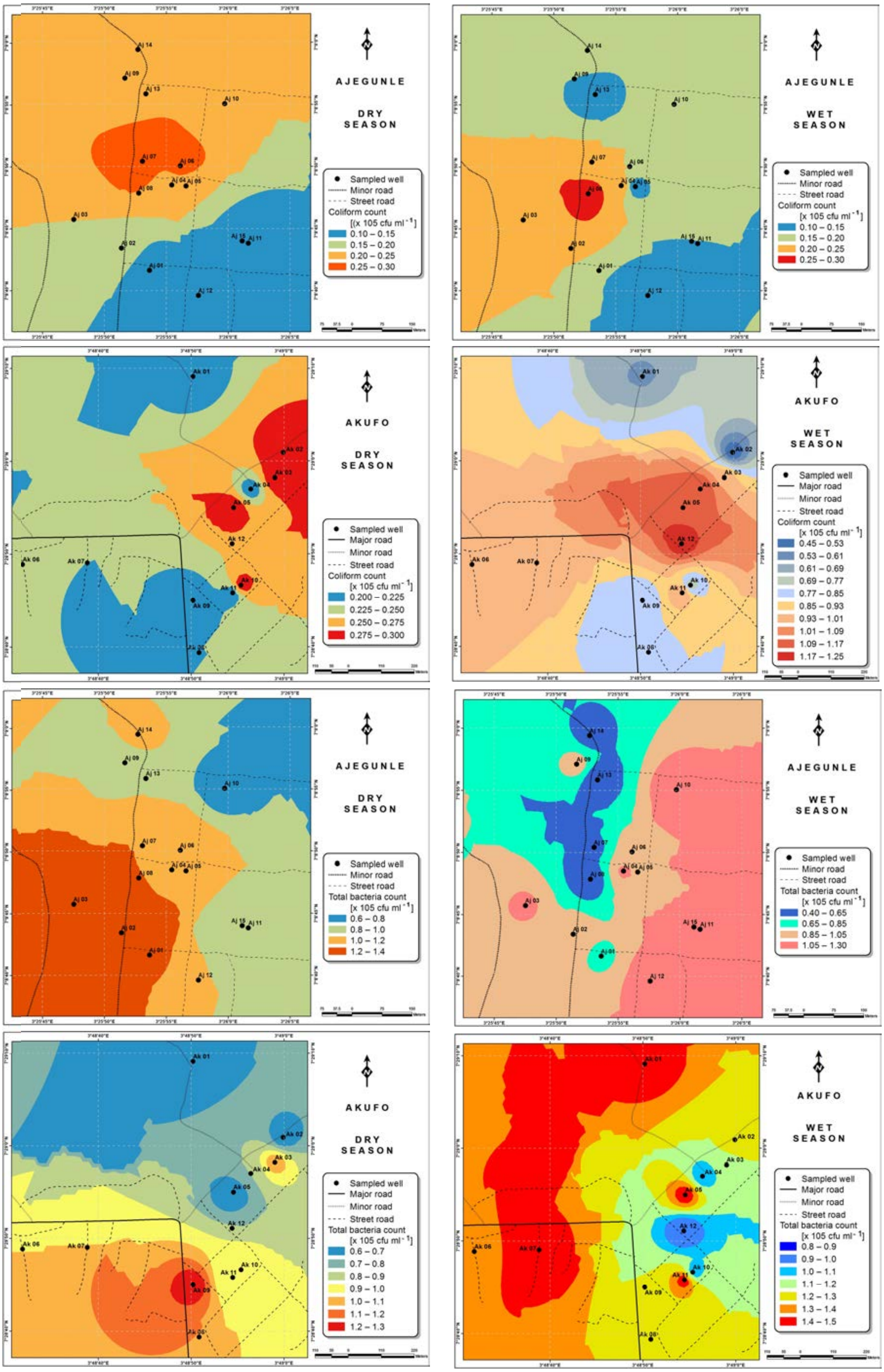

Fig. 6(a-d): Spatial variability map of coliform count for (a) Ajegunle, (b) Akufo and of total bacteria count, (c) Ajegunle and (d) Akufo farm settlements

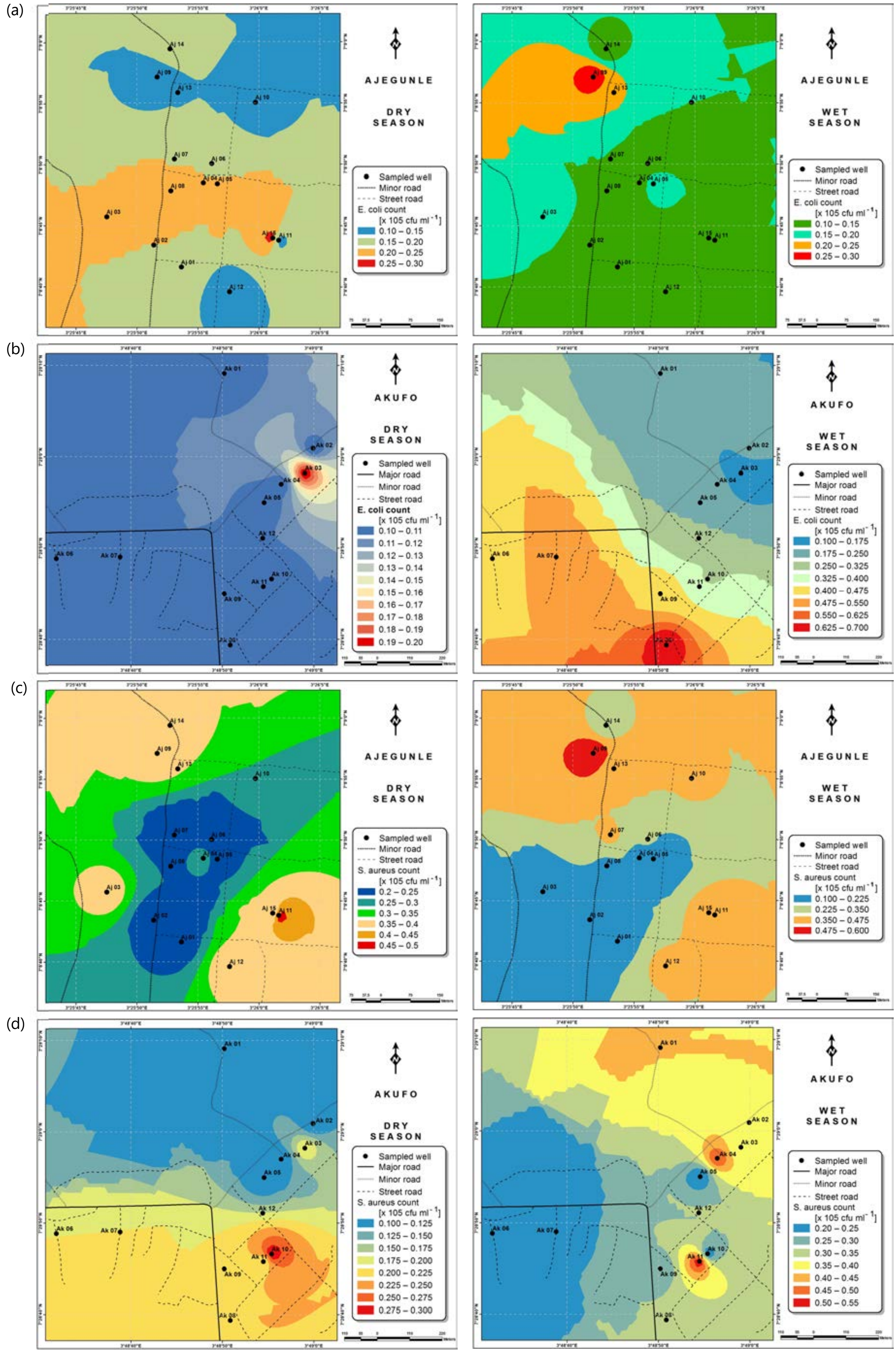

Fig. 7(a-d): Spatial variability map of *E. coli* count for (a) Ajegunle, (b) Akufo and of *S. aureus* count (c) Ajegunle and (d) Akufo farm settlements

(a)

(b)

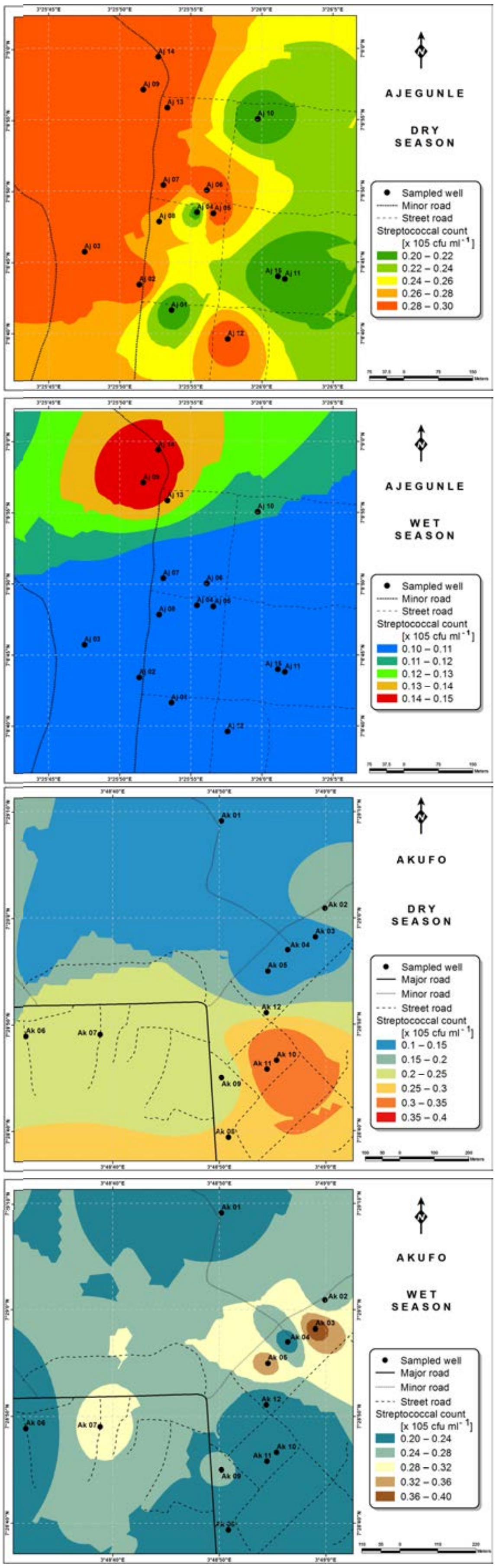

Fig. 8(a-b): Spatial variability map of streptococcal count for (a) Ajegunle and (b) Akufo farm settlement

DISCUSSION

For the water samples collected from the Eruwa farm settlement, the high levels of Copper in the wet season were likely due to agricultural activities. As shown via this study, the groundwater from the three farm settlements should be monitored and treated for cadmium, iron and manganese contaminations. Heavy metals are usually either dissolved in water or occur as colloids and/or particles[31]. They occur in water bodies naturally as eroded minerals within sediments, leached ore deposits, etc., or originate from anthropogenic sources such as solid waste disposal, as well as industrial, agricultural and domestic effluents[32]. Dissociations from bedrocks through which groundwater flows also contribute to metal concentrations in it[33]. Levels of Copper above 1 mg L^{-1} in water have been noted to tend to cause astringent tastes[34].

As revealed via this study, Arsenic poses no threat to the water within the three farm settlements. Kayode *et al.*[35] discovered high concentrations of Arsenic and Cadmium in some parts of Ogun State, Nigeria. High concentrations of Cadmium can negatively affect seed germination and plant development as well as generate oxidative damages[36,37]. Elevated Cadmium concentrations in humans can contribute to high blood pressure and kidney damage as well as the destruction of red blood cells and testicular tissues. Cadmium, due to their chemical similarity, may replace Zinc in some enzymes and thus alter the stereo-structure of the enzymes, impairing their catalytic activities[35,38].

The major sources of Manganese are ores, rocks, fertilizers, steel production, pesticides and battery charging[34]. Studies have associated cognitive behavioral problems in children with Manganese concentration in drinking water[39,40].

Iron is common in rural groundwater supplies with concentration levels between 0 and 50 mg L^{-1}. According to Al Maliki *et al.*[37], it is not toxic to plants where the soil is aerated but can enhance processes that lead to soil acidification and loss of phosphorus, which is an important element for plant well-being. Iron can accumulate on plant leaves and/or fruits as a result of long-term irrigation with water containing Iron in high concentrations, which in turn can reduce the quality of crop production[37,41]. No serious health implications have been reported in humans[42]. It has however been noted that in high concentrations, Iron may produce adverse neurological effects[43]. Iron-mediated oxidative damage to the mitochondrial genome may result from long-term iron contamination, eventually adversely affecting functionality[40,44].

The concentrations of Iron and Manganese in this study follow a similar trend to what Emenike *et al.*[45] observed, Iron and Manganese usually exist together in water, the concentration of Iron being always higher than that of Manganese because it is more abundant in the earth crust.

As excess heavy and trace metal intake by humans through the food chain (or agriculture) has been reported to be potentially dangerous in many countries[1], it is recommended that the water from the three farm settlements be monitored and treated for cadmium, iron and manganese contaminations. This is to protect the consumers of agricultural produce from the potential dangers of consuming the metals in higher quantities than permissible. Also, crops that are resistant to, or require high concentrations of these metals are recommended for cultivation within the farm settlements.

Several studies have shown that microbial pathogens, such as *Salmonella*, *E. coli*, *S. faecalis* and enteroviruses are relatively stable in underground water[46-49], which is a major source of water for agriculture within the farm settlements.

High coliform counts appear to be characteristic of rural groundwater quality in Nigeria[50]. Meanwhile for the three farm settlements, coliform counts for both dry and wet seasons considered were revealed to be safe. However, *E. coli* and *Streptococcal* counts for the two seasons suggest the need for appropriate treatment before use. This likely resulted mostly from livestock wastes in the farm settlements, since livestock agriculture is a major occupation of the settlers. It could as well be suspected that these contaminants infiltrated from human and animal wastes into the hand-dug wells[51]. *Escherichia coli* is regarded as the most sensitive indicator of faecal pollution and its presence in a water sample is a major health concern which calls for remedial attention[51]. Its presence also indicates that other enteric pathogens may be present[52]. *Streptococcus faecalis*, *Staphylococcus aureus* and *Bacillus* sp., have been implicated to be possibly responsible for gastro-intestinal disorders[53]. *Salmonella* and *vibrio cholera* were not found in any of the samples examined from the farm settlements.

Consumption of contaminated water has been known to result in diseases such as diarrhea, meningitis, acute renal failure, urinary tract infections and haemolytic anaemia, or indirectly from contaminated agricultural produce. Meanwhile, Terzieva and McFeters[54] as well as Pandey *et al.*[49] noted that controlling pathogen contamination from livestock/wildlife can be challenging.

The principal component analysis (PCA) is a multivariate statistical technique that can use mutual correlation coefficients to relate variables to principal components or factors. When used in hydrochemistry, these may be interpreted based on specific or multiple hydrochemical processes like mineralization, lithology and environmental processes[8,55].

The PCA extracted 4 components for Ajegunle farm settlement. The PC 1 resulted very likely from the weathering of bedrock materials, in line with Kwami *et al.*[56]. The PC 2 was likely from the leaching of agricultural wastes and/or chemicals. The PC 3 was likely due to leachate from fertilizers/agricultural wastes or run-off while PC 4 resulted from agricultural activities. Fertilizers used for agriculture are well-known sources of cadmium and copper[57]. For the Akufo farm settlement, PCA produced 2 components. The PC 1 resulted very likely from weathering of bedrock materials, similar to apportionment made by Shrestha *et al.*[58], while PC 2 was likely due to leachate from fertilizers/agricultural wastes or run-off[57,59]. Meanwhile, for the Eruwa farm settlement, the only PC extracted was proposed to have been from weathering of bedrock materials and leachate from fertilizers/agricultural wastes or run-off, in line with the findings of Elumalai *et al.*[57] The farm settlements have a long history of over 60 years of cultivation of staple crops, use of pesticides, fertilizers, other veterinary drugs and agrochemicals.

Heavy and trace metal concentrations/distributions have been reported to vary seasonally[60,61]. This study revealed higher concentrations of most of the metals during the wet season than during the dry. Agricultural activities form a major source of metal and microbial contamination in the water within the three farm settlements, as apportioned earlier via PCA. It is also the predominant occupation of the settlers and due to water availability challenges during the dry season, they depend largely on rainfall and availability of more water during the wet season. Hence, the higher concentrations of the metals during the wet season were very likely because, within the farm settlements, agricultural activities increased during the wet season.

For microbial populations, 2 components were extracted via PCA for the Ajegunle farm settlement. The PC 1 was a result of fecal contamination[59] through livestock and human wastes. Faecal pollution is a major contaminant in both surface and groundwater resources in Nigeria[59,62]. The PC 2 was indicated to have resulted from the use of manures and livestock agricultural wastes[55]. For the Akufo farm settlement, the only principal component was probably a result of livestock agricultural wastes, sewage effluents and organic decomposition. From the Eruwa farm settlement, however, 2 PCs were extracted. The PC 1 was mostly due to livestock agricultural wastes. The negative loading of the coliform count indicated that it was not necessarily dependent on the others with positive loading[59]. *Escherichia coli* count had strong positive loading on PC 2 indicating faecal contamination[59].

The spatial variation maps generated for the heavy and trace metals, as well as for the microbial populations showed the seasonal distributions of the metals and microbial populations within the farm settlements. The maps show the quality zones within the settlements during the dry and wet seasons, thereby providing a guide for identifying places with the best quality/suitability of the water for different purposes, such as fish farming, piggery, vegetable farming, etc.[63,64]. They are useful for locating less polluted areas for wells or borehole drilling. Agricultural activities can then be systematically positioned according to water needs and safety. The GIS-based IDW maps are capable of enhancing sustainable management of water resources within the farm settlements[65], they are excellent tools for summarizing overall water quality conditions over space and time[37]. Similar variation maps have been generated by Sahoo *et al.*[12], Gidey[13] and Zaharaddeen[66] among others.

Effective and sustainable agricultural (especially livestock) waste management strategies as well as pollution control against agricultural run-off and chemicals are necessary within the farm settlements to curb contamination and ensure good health for the settlers.

The water samples from the three farm settlements showed possibilities of cadmium, iron, manganese *E. coli* and streptococcal contaminations. Bedrock weathering, fertilizer/agricultural waste/run-off leachates, agricultural activities, fecal contamination, livestock agricultural wastes, sewage effluents and organic decomposition were identified as pollution sources for the metal and microbial contaminations in the settlements. The spatial maps revealed the existing distributions of selected metals and microbial populations within Ajegunle and Akufo farm settlements, which would enhance the systematic utilization of the water for agriculture.

It is hereby recommended that routine groundwater quality assessment be carried out to follow the dynamics and be able to manage and control pollution within the farm settlements. Also, appropriate treatments should be administered to the groundwater, especially, to take care of magnesium, iron, cadmium, manganese, *E. coli* and Streptococcal contaminations. Since, this study identified high magnesium concentrations in the study areas, magnesium-tolerant crops will thrive better. Finally, effective and sustainable agricultural (especially livestock) waste management strategies as well as pollution control against agricultural run-off and chemicals are necessary within the farm settlements to curb contamination and ensure good health for the settlers.

A limitation of this study is that the water sources within the Eruwa farm settlement were very few and wide apart and hence spatial maps could not be generated for the settlement.

CONCLUSION

The water samples from the three farm settlements showed possibilities of cadmium, iron, manganese *Escherichia coli* and streptococcal contaminations and therefore should be monitored and treated accordingly before use for agricultural or other purposes. Also, crops that are resistant to, or require high concentrations of cadmium, iron and manganese are recommended for cultivation within the farm settlements. The information from this research will help safeguard the lives of the farm settlers as well as the consumers of agricultural produce from the settlements against metal and microbial contamination.

SIGNIFICANCE STATEMENT

This study assessed the contamination, apportioned pollution sources using principal component analysis (PCA) and mapped the spatial variabilities of heavy and trace metals as well as microbial populations in the water available for agriculture at the Ajegunle, Akufo and Eruwa farm settlements in southwestern Nigeria. The information from this research will help safeguard the lives of the farm settlers as well as the consumers of agricultural produce from the settlements against metal and microbial contamination. The water samples from the three farm settlements showed possibilities of cadmium, iron, manganese, *Escherichia coli* and streptococcal contaminations and therefore should be monitored and treated accordingly before use for agricultural or other purposes.

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