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Assessment, classification and mapping of groundwater quality for agriculture in selected farm settlements of southwestern Nigeria

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ABSTRACT

Good water quality is very vital to the productivity and sustainability of irrigated agriculture. The suitability for irrigation of groundwater samples collected and analyzed during dry and wet seasons from Ajegunle, Akufo and Eruwa farm settlements of southwestern Nigeria were assessed using several irrigation water quality indices (IWQIs). The parameters were analyzed statistically and subjected to correlation. Seasonal spatial distribution maps were generated via GIS. All the water samples from the three farm settlements were found to be mostly soft, fresh, excellent, and suitable for irrigation in both seasons. Meanwhile, soluble sodium percentage (SSP) and Kelley's Ratio (KR) revealed them as unsuitable while other parameters showed different degrees of suitability for different samples from different farm settlements in different seasons. Significant correlations were seen between the selected parameters in both seasons. The distribution maps reveal the spatial distributions of selected parameters within Ajegunle and Akufo farm settlements. Utilizing these findings will enhance systematic groundwater exploitation for irrigation within the settlements. Furthermore, systematic irrigation management practices and crop choices, based on the concentrations and distribution of the parameters viz-a-viz crop requirements should be considered to limit potential dangers that may arise with the use of the water over a long period.

Key words: agricultural productivity, inverse distance weighted, irrigation water quality indices, magnesium adsorption ratio, sodium adsorption ratio, suitability

HIGHLIGHTS

- Groundwater samples were soft, fresh and of good nitrates concentrations, pH, and EC.
- Irrigation parameters revealed the suitability of the water samples for irrigation.
- Seasonal positive and negative significant correlations seen between selected parameters.
- Spatial variation maps showed seasonal spatial distributions of selected parameters.
- Enhancement of systematic groundwater exploitation for irrigation.

1. INTRODUCTION

Water is widely used in the agricultural sector, both for irrigated farming and livestock production (OECD 2006). Groundwater is a dependable source for meeting agricultural water needs. Meanwhile, the discharge of wastewater (e.g. brine) degrades groundwater quality and thus water cannot be directly used for potable water (via desalination) and industrial

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applications (Panagopoulos & Giannika 2022a, 2022b, 2023). Continuous infiltration of greywater also causes reduction in soil absorption and water retention capacity (Asmal *et al.* 2022). These affect agriculture directly or indirectly.

Hence, it is essential to monitor the quality of water to be used for agricultural purposes. When poor quality water is used for irrigation, especially over a long time, salts may accumulate in crop root zones, soil permeability may decrease as a result of excess sodium/calcium percolation or microbial contaminations may occur; which are directly or indirectly toxic to plants as well as consumers (WHO/UNEP 1997), eventually rendering the soil unfit for agriculture (Yakubu *et al.* 2017).

Crop salinity-tolerance, sodium concentration and contaminant concentrations play major roles in determining whether or not water from a source is appropriate for irrigation (WHO/UNEP 1997). Irrigation water quality indices (IWQIs) such as electrical conductivity (EC), acidity and alkalinity, total hardness (TH), magnesium adsorption ratio (MAR), sodium adsorption ratio (SAR), residual sodium bicarbonate (RSBC), soluble sodium percentage (SSP), Kelley's Ratio (KR), potential salinity (PS), permeability index (PI) (Shah & Mistry 2013; Bhat *et al.* 2018) have been developed based on the potential toxic effects of specific contaminants/pollutants/elements. Meanwhile, Integrated-Weight Water Quality Index has also been used for groundwater quality assessment and classification (Nguyen *et al.* 2022).

Water for irrigation is classified with respect to magnesium, sodium and calcium, among other important elements (Todd 1980; Raihan & Alam 2008). Though magnesium is essential for plant growth, excess of it can have severe negative effects on plants. High magnesium hazard (or MAR) in water used for agriculture may lead to excess magnesium in soil, which can inhibit potassium availability, resulting in development of coppery coloration of leaves along the marginal veins, and eventual defoliation (Gupta & Gupta 1987).

High concentration of sodium results in sodium or alkali hazard in irrigation water (Gholami & Srikantaswamy 2009; Ogunfowokan *et al.* 2013), which brings about development of alkaline soils. High sodium ion concentration in water used for irrigation could result in the absorption of the sodium ion by clay particles as well as cause dispersal of magnesium and calcium ions, thereby reducing the permeability of the soil and causing eventual deterioration of soil structure, low aeration as well as poor infiltration and poor internal draining (Raihan & Alam 2008; Bhat *et al.* 2018).

The suitability of water for irrigation does not only depend on the concentration of soluble salts, but also on PS (Doneen 1964; Ogunfowokan *et al.* 2013). It has also been reported that the concentration of highly soluble salts increases the salinity of the soil while low-solubility salts precipitate and accumulate in the soil for successive irrigation (Siamak & Srikantaswamy 2009).

Consecutive use of water containing high salt concentration reduces soil permeability (Singh & Singh 2008). The PI is dependent on total soluble salt, sodium, calcium, magnesium and bicarbonate contents of the water. Water with high RSBC value has high pH; use of such water for irrigation can render the soil infertile, resulting in deposition of sodium carbonate. Sadick *et al.* (2017) noted that the SAR/sodium hazard increases when residual sodium carbonate (RSC) is positive because calcium is lost from the soil solution.

Geographic information system (GIS) has been used for modeling groundwater flow, solute transport, and leaching. It has also been used for site suitability analyses and inventory data management, estimating groundwater vulnerability to contamination, mapping of groundwater quality and creation of spatial decision support systems by integrating groundwater quality assessment models with spatial data (Krishnaraj *et al.* 2015; Pande & Moharir 2018). The inverse distance weighted (IDW) is a GIS-based interpolation technique, in which interpolated estimates are made based on values at nearby locations weighted only by distance from the interpolation location, based on the basic assumption that nearby points ought to be more closely related than distant points to the value at the interpolate location (Naoum & Tsanis 2004). In IDW technique, cell values are determined via a linearly weighted combination of a set of sample points (Naoum & Tsanis 2004).

The Farm Settlement Scheme was introduced in Nigeria in 1959 by the then Western Regional Government in a bid to transform the traditional farming system and educate peasant farmers on food production and exportation of crops through modern agricultural methods (Iwuchukwu & Igbokwe 2012), thereby also enhancing food production, employment, economy of the nation and the standard of living of people. The settlers depend mainly on rainfall, well and surface water but many times these are inadequate, especially in dry seasons and due to climate change; hence the need to explore groundwater.

In this study therefore, seasonal suitability of the groundwater from Ajegunle, Akufo, and Eruwa farm settlements in the southwestern part of Nigeria for irrigation was assessed using different irrigation water quality indices. The groundwater samples, which were collected during the wet season of 2016 and dry season of 2016/2017, were also classified using pH, EC, TDS, TH, Nitrates, Chloride (with effects on plants) and the computed irrigation water quality indices. Selected

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hydrochemical and irrigation parameters were correlated to reveal their relationships. Spatial characterization was done, and spatial distribution maps were generated using the GIS-based Inverse Density Weighted (IDW) interpolation method, to depict the spatial distributions of selected parameters in both wet and dry seasons, to enhance selective/systematic exploitation of the water within the farm settlements, for improved agricultural productivity.

Though the settlements have been in operation for decades, the information in this paper was not available before this research was conducted, to the best of the authors' knowledge. With proper utilization, this information will greatly enhance irrigated agriculture as well as general all-year-round agricultural productivity within the three farm settlements.

2. MATERIALS AND METHODS

2.1. Study area

This study was conducted within three selected farm settlements of southwestern Nigeria; namely, the Ajegunle farm settlement, Mile 6, Ajebo road, Obafemi Owode Local Government Area of Ogun State; the Akufo farm settlement, along Ibadan-Eruwa road, Ido Local Government Area of Oyo State and the Eruwa farm settlement, near Eruwa town, Ibarapa-East Local Government Area, Oyo State.

The predominant crops grown within the Ajegunle farm settlement are cassava and maize. The Akufo farm settlers grow cassava, yam, oil palm, kola nut, timber and cocoa among others while the Eruwa farm settlers grow cassava, vegetables and fruits such as watermelon and cashew.

The settlements are all within the Ogun river basin (Figure 1(a)), with latitudes between 6° 26′ N and 9° 10′ N and longitudes between 2° 28′ E and 4° 8′ E (Oke *et al.* 2013). Two tropical climatic seasons are distinguishable in the basin; a dry season between November and March and a wet season between April and October. The three farm settlements lie within the basement complex terrain of the southwestern part of Nigeria. The Ajegunle farm settlement is underlain mainly with the Abeokuta formation and migmatite, Akufo with quartzite and Eruwa with undifferentiated gneiss according to NGSA (2010).

2.2. Methodology

Water samples were collected from hand-dug wells within the selected farm settlements; in conformity with standard procedures (APHA *et al.* 1998). Three sets of samples were collected from each sampling point; one in colored 1.0-L polypropylene bottles (preserved with about 10 ml of 0.1 N HCl acid for cations determination), another in white 1.0-L polypropylene bottles (for anions) and the last set in universal sterilized bottles (for microbial analyses). All the samples were stored below 4 °C, transported to the laboratory within 24 h and analyzed using standard methods. Samples were collected from 15, 12 and 5 hand-dug wells and the main earth dams/rivers/dams within the Ajegunle, Akufo, and Eruwa farm settlements, respectively. They were collected during both the wet and dry seasons for assessment of seasonal variability. Figure 1(b)–1(d) shows the sampling points with the land-use features. All the readings were taken in duplicates and the averages computed and recorded.

Irrigation water quality indices (IWQI) such as SAR, MAR, PI, KR, SSP, RSBC, and PS were computed from the laboratory analyses results.

All ionic concentrations are expressed in mEq/l (Al-Ruwaih & Shafiullah 2017):

$$\text{Concentration (mEq/l)} = \frac{\text{Concentration (mg/l)} * \text{Valence}}{\text{Formular weight of the ion}} \quad (1)$$

2.2.1. Magnesium adsorption ratio

In this study, MAR was calculated using Equation (2) (Raghunath 1987):

$$\text{MAR} = \frac{Mg^{2+}}{Mg^{2+} + Ca^{2+}} * 100 \quad (2)$$

MAR values <50 values of groundwater are considered to be suitable for irrigation while those >50 are unsuitable (Rawat *et al.* 2018).

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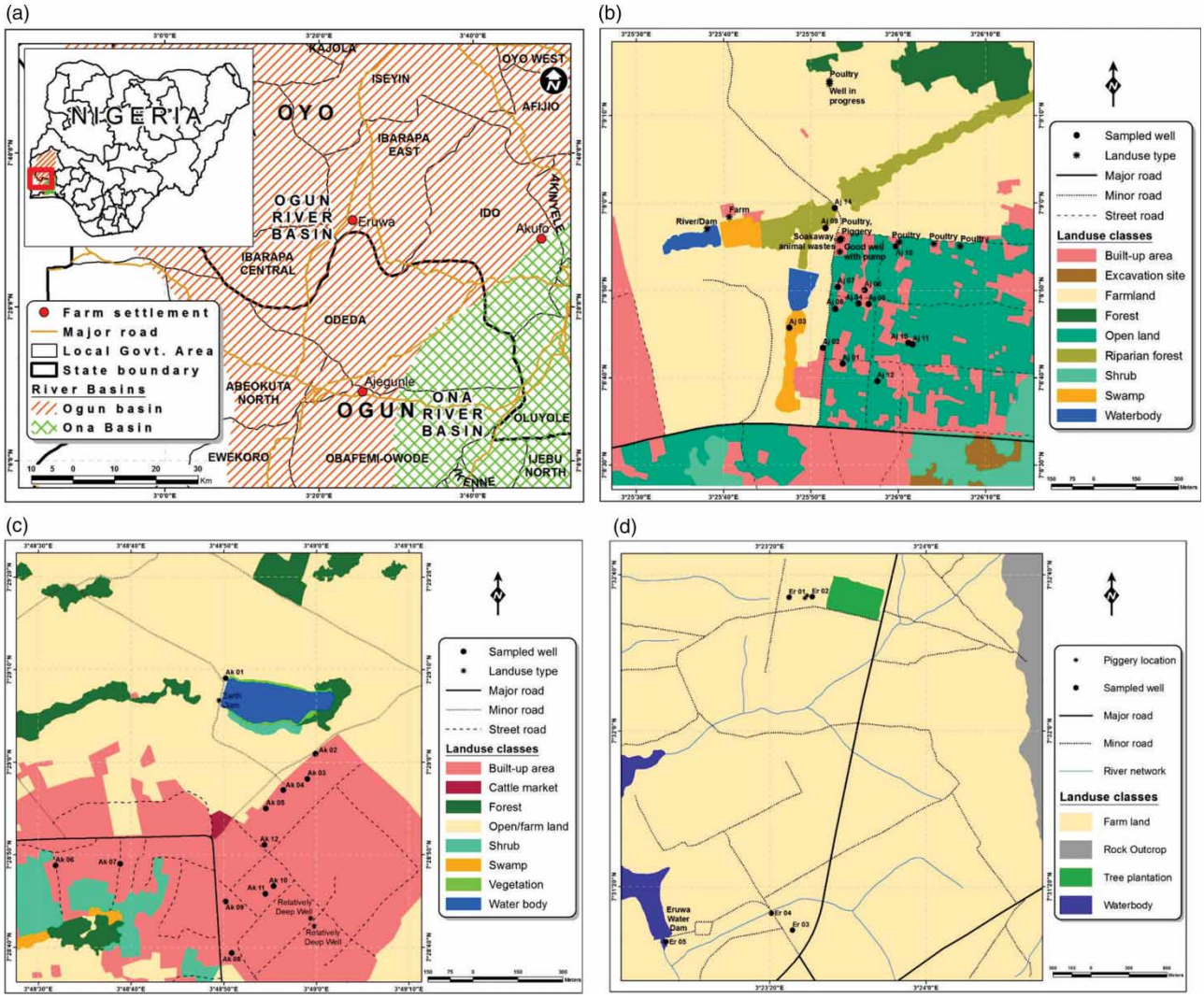


Figure 1 | Map showing (a) the three farm settlements and the river basins that are covering parts of Ogun and Oyo States of Nigeria, as well as water sampling points at (b) Ajegunle farm settlement, (c) Akufo farm settlement, and (d) Eruwa farm settlement with land-use features.

2.2.2. Sodium adsorption ratio

SAR was calculated using the Equation (3) (Karanth 1987):

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{(\mathrm{Mg}^{2+} + \mathrm{Ca}^{2+})/2}} \tag{3}$$

The water samples having SAR values less than 10 were classified as excellent, 10–18 as good, 18–26 as fair (doubtful), and greater than 26 as unsuitable for irrigation purpose (USDA 1954).

2.2.3. Soluble sodium percentage

SSP was calculated as defined by Todd (1980, 1995):

$$\mathrm{SSP} = \frac{\mathrm{Na}^{+} + \mathrm{K}^{+}}{\mathrm{Mg}^{2+} + \mathrm{Ca}^{2+} + \mathrm{Na}^{+} + \mathrm{K}^{+}} * 100 \tag{4}$$

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As it has been classified, SSP values <50 indicate that the water is good for irrigation while >50 indicate that it is bad/unsafe (USDA 1954).

2.2.4. Potential salinity

PS was calculated as (Ogunfowokan *et al.* 2013):

$$PS = Cl^{-} + \frac{1}{2}SO_4^{2-} \tag{5}$$

PS of water between 1 and 3 mEq/l is suitable to be used in fine, medium and coarse textured soils; between 3 and 15 mEq/l in medium and coarse textured soils and between 15 and 20 mEq/l only in coarse textured soils (Mohamed 2017).

2.2.5. Permeability index

PI was evaluated as defined by Doneen (1962, 1964):

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Mg^{2+} + Ca^{2+} + Na^{+}} * 100 \tag{6}$$

PI values >75 indicate excellent quality of water for irrigation purposes. Water with PI values <25 are unsuitable for irrigation (Doneen 1964).

2.2.6. The residual sodium bicarbonate

The RSBC was determined using the formula (Gupta & Gupta 1987):

$$RSBC = HCO_3^{-} - Ca^{2+} \tag{7}$$

Water for irrigation has been classified based on RSBC as satisfactory (<5 mEq/l), marginal (5–10 mEq/l), and unsatisfactory (>10 mEq/l) (Gupta & Gupta 1987).

2.2.7. Kelley's ratio

KR was calculated using the formula (Kelley 1963):

$$KR = \frac{Na^{+}}{Mg^{2+} + Ca^{2+}} \tag{8}$$

KR of ≤1 indicates good quality water for irrigation purpose, whereas >1 suggests that the water is unsuitable for agricultural purpose due to alkali hazards (Karanth 1987).

The results from the laboratory analyses of water samples and calculated IWQI were subjected to data analysis using SPSS, version 20. Descriptive statistics, Analysis of Variance (ANOVA) and Duncan Multiple Range Test were carried out. The groundwater samples were subsequently classified based on pH, EC, TDS, TH, nitrates, and chloride (with effects on plants); which were estimated using standard methods (APHA 2000) as well as the computed IWQI.

The percentages of the water samples that were within different categories for each farm settlement were also determined. EC was classified based on USDA (1954); TDS on Freeze & Cherry (1979) categorization; TH on Sawyer & McCarty (1967); pH, Nitrates and Chloride on the categorizations after Bhat *et al.* (2016). Classification of Chloride with effects on plants was based on Ogunfowokan *et al.* (2013).

Pearson's correlation matrix was used to determine the relationship between selected hydrochemical and irrigation parameters. The classification was based on Guildford's rule of thumb for interpreting the Pearson product moment correlation; with *r* values of 0.0–0.29 depicting negligible or little correlation, 0.3–0.49 depicting low correlation, 0.5–0.69 depicting moderate or marked correlation, 0.7–0.89 depicting high correlation, and 0.9–1.00 depicting very high correlation (Guildford 1973).

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The base maps were geo-referenced and digitized via Arc GIS. Inverse distance weighted (IDW), a GIS-based spatial interpolation technique was used in this study (Teli *et al.* 2014). IDW uses the measured values surrounding an unmeasured location to predict a value for such location, based on the assumption that the value of an attribute z at any unsampled point is a distance-weighted average of sampled points lying within a defined neighborhood around that unsampled point. Spatial variation maps were generated by integrating the spatial and attribute databases, for water quality parameters such as pH, EC, TH, dissolved oxygen (DO), SAR, and MAR for Ajegunle and Akufo farm settlements. These were done for both wet and dry seasons to show seasonal variabilities. The available sampling points within Eruwa farm settlement were very few and sparsely located, hence spatial variation maps are not presented for the settlement.

3. RESULTS

3.1. Means and standard deviations of irrigation water quality indices

Table 1 shows the mean values and standard deviations of the physico-chemical parameters, zinc and microbial populations of the water samples from the three farm settlements.

The mean values and standard deviations of the IWQI for the water samples collected within each of the farm settlements are shown in Table 2. It was observed in Ajegunle that for SAR, the value obtained for the dry season was significantly higher than that for the wet season at $p < 0.05$ level. In Akufo, it was observed that for SSP, KR, and MAR, the values obtained for the dry season were significantly higher than those for the wet season at $p < 0.05$ level. It was observed in Eruwa that for SSP, KR and MAR, the values obtained for the dry season were significantly higher than those for the wet season while for RSBC, the value obtained for the dry season was significantly lower than that for the wet season; all at $p < 0.05$ level.

3.2. Groundwater classifications

The classification of the groundwater from the farm settlements based on pH revealed that all the water samples from the three farm settlements were within the 'No problem' category in the wet season. In the dry season, 30.77and 50% and 69.23 and 50% were within the 'No problem' and 'Moderate' categories for Ajegunle and Akufo, respectively. For Eruwa, however, all were within the 'Moderate' category in the dry season.

Based on EC, for Ajegunle farm settlement, 92.86 and 7.14% of the water samples taken were 'Excellent' and 'Good', respectively, in the wet season while all were 'Excellent' in the dry season. For Akufo and Eruwa, all were 'Excellent' in both seasons. Assessment of the nature of the groundwater samples based on the total dissolved solids (TDS) revealed that all from all the farm settlements belonged to the 'Fresh' category in both seasons.

The classification based on chloride concentration for irrigation purposes of the groundwater samples collected from the three farm settlements showed that for Ajegunle, 35.71 and 64.29% belonged to the 'No problem' and 'Moderate' categories, respectively, in the wet season while all the samples were 'Moderate' in the dry season. For Akufo, 25% of the samples were of 'No problem' quality, 66.67% were 'Moderate' and 8.33% of 'Severe' quality in the wet season while all the samples were 'Moderate' in the dry season. For Eruwa, 50% of the samples were within each of 'Moderate' and 'Severe' categories in the wet season while all the samples were of 'Moderate' quality in the dry season.

Based on the effects of chloride however, for Ajegunle, 71.43% of the samples would adversely affect sensitive plants and 28.57% would negatively affect moderately tolerant plants in the wet season. For all plants, 7.69% of the samples were generally good, 15.39% would make sensitive plants show injury and 76.92% would cause problem for moderately tolerant plants in the dry season. For Akufo, 25% of the samples were generally safe for all plants, 66.67% would harm moderately tolerant plants and 8.33% could cause severe problems for plants in the wet season while all the samples could have adverse effects on moderately tolerant plants in the dry season. For Eruwa farm settlement, 50% of the samples would harm moderately tolerant plants and 50% could cause severe problems for plants in the wet season while all the samples could make moderately tolerant plants show injury in the dry season.

From the classifications of groundwater using nitrates and TH $CaCO_3$, all the samples were within the 'No problem' and 'Soft' categories, respectively, in both the wet and dry seasons.

According to the classification based on SSP, all the samples from all the farm settlements were found to be 'Unsuitable' in both the wet and dry seasons. Using MAR, for Ajegunle, 42.86% of the samples were found 'Suitable' while 57.14% were 'Unsuitable' in the wet season, and 15.38% of the samples were 'Suitable' while 84.62 were 'Unsuitable' in the dry season. For Akufo, all the samples were 'Suitable' in the wet season but in the dry season, 87.5% were 'Suitable' while 12.5% were 'Unsuitable'. However, for Eruwa, all the samples were 'Suitable' in the wet season while all were 'Unsuitable' in the

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Table 1 | Mean values and standard deviations of hydrochemical parameters and microbial populations of the water samples from the three selected farm settlements

	Ajegunle farm settlement		Akufo farm settlement		Eruwa farm settlement	
Parameter	**Dry season**	**Wet season**	**Dry season**	**Wet season**	**Dry season**	**Wet season**
pH	6.208 ± 0.352^{a}	6.933 ± 0.167^{a}	6.379 ± 0.515^{a}	7.340 ± 0.539^{ab}	5.825 ± 0.180^{a}	7.550 ± 0.178^{a}
Electrical conductivity (μScm^{-1})	127.969 ± 4.279^{a}	130.343 ± 36.127^{a}	130.038 ± 5.350^{a}	127.088 ± 7.400^{a}	119.015 ± 2.533^{a}	120.625 ± 5.218^{a}
Total dissolved solids (mg/l)	6.700 ± 0.655^{a}	2.643 ± 2.613^{a}	7.115 ± 0.812^{a}	5.560 ± 0.847^{a}	5.080 ± 0.520^{a}	4.708 ± 0.360^{b}
Calcium (mg/l)	1.319 ± 0.064^{a}	1.141 ± 0.262^{a}	1.305 ± 0.087^{a}	2.993 ± 0.465^{b}	0.823 ± 0.196^{a}	3.015 ± 0.474^{a}
Magnesium (mg/l)	0.847 ± 0.074^{a}	0.710 ± 0.225^{b}	0.738 ± 0.091^{a}	1.410 ± 0.967^{a}	0.633 ± 0.377^{a}	1.325 ± 0.079^{b}
Nitrates (mg/l)	0.045 ± 0.013^{a}	0.004 ± 0.038^{a}	0.084 ± 0.035^{a}	0.123 ± 0.030^{a}	0.025 ± 0.006^{a}	0.105 ± 0.006^{a}
Sulphates (mg/l)	7.872 ± 0.465^{a}	10.433 ± 0.902^{a}	7.776 ± 0.497^{a}	11.498 ± 1.182^{a}	6.253 ± 0.458^{a}	10.500 ± 0.483^{a}
Chloride (mg/l)	214.938 ± 103.819^{a}	149.471 ± 55.540^{a}	202.138 ± 97.359^{a}	235.433 ± 119.220^{a}	289.013 ± 74.668^{a}	345.938 ± 127.245^{a}
Dissolved oxygen (mg/l)	7.960 ± 0.588^{a}	7.632 ± 0.527^{a}	7.890 ± 0.360^{a}	7.757 ± 0.473^{a}	7.500 ± 0.253^{a}	7.763 ± 0.225^{a}
Biological oxygen demand (mg/l)	26.158 ± 2.412^{a}	22.160 ± 5.118^{a}	24.811 ± 2.565^{a}	32.900 ± 2.757^{a}	26.525 ± 0.573^{a}	29.100 ± 3.235^{b}
Chemical oxygen demand (mg/l)	38.829 ± 3.600^{a}	32.184 ± 4.584^{a}	38.905 ± 1.930^{a}	41.322 ± 2.399^{a}	35.718 ± 2.281^{a}	37.850 ± 0.867^{b}
Potasium (mg/l)	25.157 ± 5.432^{a}	24.205 ± 10.936^{a}	28.168 ± 3.421^{a}	38.597 ± 10.784^{b}	28.240 ± 1.044^{a}	28.234 ± 3.052^{a}
Sodium (mg/l)	28.311 ± 7.188^{a}	20.348 ± 4.076^{a}	30.780 ± 3.149^{a}	38.736 ± 9.538^{b}	20.513 ± 1.479^{a}	35.800 ± 6.965^{a}
Total hardness (mg/l)	6.350 ± 0.417^{a}	2.491 ± 0.826^{b}	5.768 ± 0.338^{a}	7.591 ± 0.805^{b}	3.105 ± 0.194^{a}	4.340 ± 0.503^{a}
Alkalinity (mg/l)	220.535 ± 67.099^{a}	167.439 ± 71.590^{a}	230.806 ± 74.774^{a}	339.813 ± 336.130^{b}	187.238 ± 52.036^{a}	495.550 ± 175.248^{b}
Zinc (mg/l)	0.530 ± 0.106^{a}	0.352 ± 0.077^{b}	0.3563 ± 0.0867^{a}	1.2808 ± 0.1569^{b}	$0.2575 \pm 0.1725a$	1.1525 ± 0.0822^{b}
Microbial population ($\times 10^{5}$ CFU ml^{-1})						
Coliform count	0.185 ± 0.069^{a}	0.143 ± 0.096^{a}	0.25 ± 0.53^{a}	0.91 ± 0.25^{a}	0.33 ± 0.1^{a}	0.90 ± 0.30^{a}
Total bacteria count	1.069 ± 0.253^{a}	0.896 ± 0.304^{a}	0.85 ± 0.26^{a}	1.26 ± 0.23^{a}	1.20 ± 0.37^{a}	0.79 ± 0.25^{a}
E. coli count	0.177 ± 0.060^{a}	0.129 ± 0.080^{b}	0.10 ± 0.05^{ab}	0.33 ± 0.17^{b}	0.15 ± 0.06^{a}	0.08 ± 0.10^{b}

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

Table 2 | Mean values and standard deviations of irrigation water quality indices

Location	**Season**	**SSP**	**KR**	**MAR**	**RSBC**	**PI**	**PS**	**SAR**
Ajegunle	Dry	92.94 ± 1.57^{a}	9.08 ± 2.34^{a}	51.31 ± 2.32^{a}	3.55 ± 1.10^{a}	236.41 ± 45.67^{a}	6.15 ± 2.93^{a}	4.73 ± 1.20^{a}
	Wet	92.41 ± 2.80^{a}	8.14 ± 2.79^{a}	49.93 ± 11.28^{a}	2.69 ± 1.17^{a}	254.84 ± 39.76^{a}	4.69 ± 1.56^{a}	3.77 ± 0.93^{b}
Akufo	Dry	94.20 ± 0.70^{a}	10.67 ± 1.26^{a}	48.07 ± 2.92^{a}	3.72 ± 1.22^{a}	224.90 ± 31.77^{a}	5.79 ± 2.75^{a}	5.34 ± 0.55^{a}
	Wet	90.58 ± 1.97^{b}	6.39 ± 1.71^{b}	43.92 ± 3.52^{b}	6.40 ± 5.52^{a}	218.12 ± 65.08^{a}	6.77 ± 3.36^{a}	4.63 ± 1.17^{a}
Eruwa	Dry	94.54 ± 0.84^{a}	9.74 ± 1.71^{a}	56.28 ± 4.10^{a}	3.03 ± 0.86^{a}	266.64 ± 18.92^{a}	8.23 ± 2.11^{a}	4.16 ± 0.51^{a}
	Wet	89.52 ± 2.52^{b}	6.11 ± 1.70^{b}	42.21 ± 3.70^{b}	7.97 ± 2.87^{b}	246.72 ± 54.08^{a}	9.88 ± 3.60^{a}	4.36 ± 1.02^{a}

Values represent mean ± standard deviation (SD). Values along the same column with different superscripts are significantly different at $p < 0.05$.

dry season. The SAR classification showed that all the samples from the three farm settlements were 'Excellent' for irrigation in both seasons.

All the groundwater samples were 'Unsuitable' for irrigation in both the wet and dry seasons based on the classification by KR while all belonged to 'Class I/Excellent' category in both seasons based on the classification using PI. PS indicated

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suitability for irrigation on different soil textures. For Ajegunle farm settlement, all the samples were better suited for medium and coarse soils in the wet season while 7.69% were good for all soil textures and 92.31% were suited for medium and coarse soils in the dry season. For Akufo and Eruwa, however, all the samples were better suited for medium and coarse soils in both the wet and dry seasons.

Based on RSBC, for Ajegunle, 92.86% of the samples were 'Satisfactory' and 7.14% were 'Marginal' in the wet season while all the samples were 'Satisfactory' in the dry season. For Akufo, 66.67% of the samples were 'Satisfactory', 16.67% were 'Marginal' and 16.66% were 'Unsatisfactory' in the wet season while 87.5% were 'Satisfactory' and 12.5% were 'Marginal' in the dry season. Meanwhile for Eruwa farm settlement, 75% of the samples were 'Marginal' and 25% were 'Unsatisfactory' in the wet season while all the samples were 'Satisfactory' in the dry season. Corresponding tables are available in the supplementary file.

3.3. Seasonal correlation of selected hydrochemical and irrigation parameters of the water samples from the selected farm settlements

3.3.1. Ajegunle farm settlement

The result of the correlation of selected hydrochemical and irrigation parameters of the water samples collected within Ajegunle farm settlement for wet season revealed high positive correlation between chemical oxygen demand (COD) and MAR ($r = 0.736$) and TDS had high negative correlation with Zn ($r = -0.832$), both at $p < 0.01$. pH and TDS had moderate positive correlations with Cl ($r = 0.572$) and MAR ($r = 0.615$), respectively, at $p < 0.05$ while EC had moderate negative correlation with SAR ($r = -0.630$) at $p < 0.05$. Also, biochemical oxygen demand (BOD) and COD had moderate negative correlations with Zn ($r = -0.651$ and $r = -0.661$, respectively) at $p < 0.05$. TH had moderate negative correlation with SAR ($r = -0.688$) at $p < 0.01$ and Zn ($r = -0.560$) at $p < 0.05$ while Zn had moderate negative correlation with MAR ($r = -0.682$) at $p < 0.01$, SAR had moderate negative correlation with MAR ($r = -0.563$) at $p < 0.05$ and COD had moderate negative correlation with SAR ($r = -0.530$). Other correlations were low or negligible.

For dry season, TDS had very high positive correlation with SAR ($r = 0.934$) at $p < 0.01$. It had high positive correlation with TBC ($r = 0.853$) at $p < 0.01$ and TBC had high positive correlation with SAR ($r = 0.827$) at $p < 0.01$. TDS had high negative correlation with BOD ($r = -0.786$) at $p < 0.01$ while BOD had high negative correlation with SAR ($r = -0.824$) at $p < 0.01$. TDS, BOD and COD had moderate positive correlations with COD ($r = 0.602$) at $p < 0.05$, Alkalinity ($r = 0.569$) at $p < 0.05$ and TBC ($r = 0.686$) at $p < 0.01$, respectively. EC and COD also had moderate positive correlations with Cl ($r = 0.503$) and SAR ($r = 0.510$), respectively. EC had moderate negative correlation with *Escherichia coli* count ($r = -0.580$) at $p < 0.05$ while BOD had moderate negative correlations with Coliform count ($r = -0.587$) and TBC ($r = -0.652$), both at $p < 0.05$. Zn also had moderate negative correlation with Coliform count ($r = -0.605$) at $p < 0.05$. Other correlations were low or negligible. The corresponding table is available in the supplementary file.

3.3.2. Akufo farm settlement

The result of the correlation of selected hydrochemical and irrigation parameters of the water samples collected within Akufo farm settlement for wet season revealed that BOD and COD had high positive correlations with COD ($r = 0.699$) at $p < 0.05$ and TH ($r = 0.808$) at $p < 0.01$, respectively. EC and COD had high negative correlations with *E. coli* count ($r = -0.739$) and MAR ($r = -0.716$), respectively, at $p < 0.01$ level. TH had high negative correlations with TBC ($r = -0.745$) and MAR ($r = -0.822$), both at $p < 0.01$. Cl, BOD and COD had moderate positive correlations with *E. coli* count ($r = 0.606$, 0.617 and 0.606, respectively) at $p < 0.05$. TBC had moderate positive correlation with MAR ($r = 0.682$) at $p < 0.05$. Also, EC, BOD and Zn had moderate positive correlations with TDS ($r = 0.499$), TH ($r = 0.510$) and Coliform count ($r = 0.531$), respectively. pH had moderate negative correlation with Cl ($r = -0.648$) while EC had moderate negative correlations with BOD ($r = -0.686$) and COD ($r = -0.596$), all at $p < 0.05$. BOD had moderate negative correlation with Alkalinity ($r = -0.670$) at $p < 0.05$ and Alkalinity had moderate negative correlation with Coliform count ($r = -0.601$) at $p < 0.05$. Also, moderate negative correlations were observed of pH with BOD ($r = -0.538$), COD ($r = -0.519$) and SAR ($r = -0.510$); BOD with Alkalinity ($r = -0.519$) and Zn ($r = -0.504$) and EC with TH ($r = -0.568$). Other correlations were low or negligible.

For dry season, BOD had very high positive correlation with SAR ($r = 0.917$) at $p < 0.01$. pH and TH had high positive correlations with MAR ($r = 0.717$ and $r = 0.783$, respectively) at $p < 0.05$. BOD had high negative correlation with Zn ($r = -0.738$) at $p < 0.05$ while Zn had high negative correlation with SAR ($r = -0.883$) at $p < 0.01$ and Alkalinity had high negative correlation with SAR ($r = -0.704$). Moderate positive correlations were observed of pH with EC ($r = 0.562$) and

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TH ($r = 0.662$), EC with BOD ($r = 0.530$) and SAR ($r = 0.584$), BOD with *E. coli* count ($r = 0.596$) and MAR ($r = 0.506$), COD with *E. coli* count ($r = 0.688$) and SAR ($r = 0.603$), TH with *E. coli* count ($r = 0.525$), Alkalinity with Zn ($r = 0.503$), Coliform count with *E. coli* count ($r = 0.500$) as well as *E. coli* count with SAR ($r = 0.508$) and MAR ($r = 0.545$). Also, moderate negative correlations were observed of pH with TDS ($r = -0.562$) and Cl ($r = -0.686$), EC with TDS ($r = -0.690$) and Zn ($r = -0.591$), TDS with BOD ($r = -0.650$), MAR ($r = -0.543$), Cl with *E. coli* count ($r = -0.586$) and MAR ($r = -0.671$), BOD with Alkalinity ($r = -0.677$), COD with Zn ($r = -0.614$) and Alkalinity with Coliform count ($r = -0.578$). Other correlations were low or negligible. The corresponding table is available in the supplementary file.

3.3.3. Eruwa farm settlement

The result of the correlation of selected hydrochemical and irrigation parameters of the water samples from Eruwa farm settlement for wet season revealed that Cl and TH had very high positive correlations with BOD ($r = 0.957$) and Zn ($r = 0.967$), respectively, both at $p < 0.05$. pH and Zn also had very high positive correlations with BOD ($r = 0.938$) and *E. coli* count ($r = 0.942$), respectively. *E. coli* count had very high negative correlation with SAR ($r = -0.960$) at $p < 0.05$ and Zn had very high negative correlations with SAR ($r = -0.931$) and MAR ($r = -0.912$). High positive correlations of pH with EC ($r = 0.817$) and Cl ($r = 0.832$), TDS with TBC ($r = 0.836$) and MAR ($r = 0.795$), Cl with SAR ($r = 0.865$), BOD with SAR ($r = 0.696$), COD with Alkalinity ($r = 0.705$), Zn ($r = 0.762$) and *E. coli* count ($r = 0.867$), TH with *E. coli* count ($r = 0.830$), Alkalinity with TBC ($r = 0.826$) and SAR with MAR ($r = 0.709$) were obtained. High negative correlations were observed of Cl with *E. coli* count ($r = -0.705$), COD with MAR ($r = -0.813$), TH with SAR ($r = -0.862$) and MAR ($r = -0.885$), Alkalinity with Coliform count ($r = -0.839$), Coliform count with TBC ($r = -0.860$) and *E. coli* count with MAR ($r = -0.812$). Moderate positive correlations were revealed of EC with Cl ($r = 0.533$), BOD ($r = 0.611$) and COD ($r = 0.615$), COD with TH ($r = 0.591$) and Alkalinity with *E. coli* count ($r = 0.697$) while moderate negative correlations were observed of EC with Coliform count ($r = -0.670$), TDS with TH ($r = -0.680$), Zn ($r = -0.572$) and Coliform count ($r = -0.526$), Cl with TH ($r = -0.625$), Alkalinity ($r = -0.542$) and Zn ($r = -0.654$), BOD with Alkalinity ($r = -0.532$) and *E. coli* count ($r = -0.506$), COD with Coliform count ($r = -0.542$) and SAR ($r = -0.692$) and Alkalinity with SAR ($r = -0.623$). Other correlations were low or negligible.

For dry season, Cl, BOD, Alkalinity and SAR had very high positive correlations with MAR ($r = 0.978$), TBC ($r = 0.977$), *E. coli* count ($r = 0.977$) and MAR ($r = 0.956$), respectively, at $p < 0.05$. TDS had very high positive correlation with Total hardness (TH) ($r = 0.949$). TDS also had very high negative correlations with Cl ($r = -0.968$), SAR ($r = 0.966$) and MAR ($r = -0.985$) at $p < 0.05$ and Cl had very high negative correlation with TH ($r = -0.998$) at $p < 0.01$. BOD and TH had very high negative correlations with Alkalinity ($r = -0.952$) and MAR ($r = -0.967$), respectively, at $p < 0.05$; and COD had very high negative correlation with *E. coli* count ($r = -0.927$). High positive correlations were obtained of pH with Cl ($r = 0.871$), TH ($r = 0.890$) and MAR ($r = 0.748$), TDS with COD ($r = 0.764$), Cl with SAR ($r = 0.886$), COD with Zn ($r = 0.786$), Alkalinity with SAR ($r = 0.820$) and *E. coli* count with SAR ($r = 0.848$). High negative correlations were observed of pH with TDS ($r = -0.747$) and Coliform count ($r = -0.801$), EC with MAR ($r = -0.730$), BOD with *E. coli* count ($r = -0.887$), COD with Alkalinity ($r = -0.831$) and SAR ($r = -0.860$), TH with SAR ($r = -0.857$), Alkalinity with TBC ($r = -0.875$) and TBC with *E. coli* count ($r = -0.772$). Moderate positive correlations of pH with SAR ($r = 0.554$), EC with TDS ($r = 0.604$), BOD ($r = 0.575$), TH ($r = 0.680$), Coliform count ($r = 0.576$) and TBC ($r = 0.619$), Cl with *E. coli* count ($r = 0.505$), BOD with COD ($r = 0.655$), COD with TH ($r = 0.522$), TH with Coliform count ($r = 0.653$), Alkalinity with MAR ($r = 0.657$) and *E. coli* count with MAR ($r = 0.663$) were obtained. Moderate negative correlations were revealed of EC with Cl ($r = -0.660$), Alkalinity ($r = -0.604$) and SAR ($r = -0.642$), TDS with Alkalinity ($r = -0.646$) and *E. coli* count ($r = -0.689$), Cl with COD ($r = -0.579$) and Coliform count ($r = -0.599$), BOD with SAR ($r = -0.615$), COD with MAR ($r = -0.684$) and Zn with *E. coli* count ($r = -0.519$). Other correlations were low or negligible. The corresponding table is available in the supplementary file.

3.4. Seasonal spatial distribution maps of selected parameters

Spatial distribution maps of selected parameters were generated using a geospatial method; the inverse density weighted (IDW) interpolation method of the GIS. They were generated for both dry and wet seasons. IDW maps are not presented for Eruwa farm settlement because the sampling points within the settlement were very few and very wide apart.

3.4.1. Seasonal spatial distribution of pH

The seasonal spatial distributions of pH are presented in Figure 2. The seasonal spatial distribution of pH for Ajegunle farm settlement revealed that during the dry season (Figure 2(a)(i)), the groundwater from sampling point Aj 01 was in the region

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with pH range of 6.6–6.8; Aj 06–08 and 10–15 of 6.1–6.5, and Aj 02–05 as well as 09 of 5.7–6.0. During the wet season (Figure 2(a)(ii)), Aj 01, 05, and 13 were in the region where pH ranged from 7.00 to 7.25 while Aj 02–04, 06–12, and 14–15 from 6.75 to 7.00.

For Akufo farm settlement, during the dry season (Figure 2(b)(i)), the groundwater from sampling points Ak 01, 04, 05, and 09 were within the region with pH in the range of 6.50–7.01; Ak 03, 06–08, and 12 of 6.00–6.50; and Ak 02, 10, and 11 of 5.83–6.00. During the wet season (Figure 2(b)(ii)), Ak 02–03 were within the region with pH range of 8.0–8.3; Ak 11 of 7.5–8.0; Ak 01, 04, 08–10, and 12 of 7.0–7.5; and Ak 05, 06 as well as 07 of 6.8–7.0.

3.4.2. Seasonal spatial distribution of EC

The seasonal spatial distributions of EC are shown in Figure 3. The seasonal spatial distribution of EC for Ajegunle farm settlement showed that during the dry season (Figure 3(a)(i)), the groundwater from sampling points Aj 09 and 10 were in the region where EC ranged from 131.1 to 134.5 μScm^{-1}; Aj 02, 04, 06, 12, and 13 from 127.6 to 131.1 μScm^{-1}; Aj 03, 05, 08, 11, 14, and 15 from 124.2 to 127.6 μScm^{-1}; and Aj 01 and 07 from 120.7 to 124.2 μScm^{-1}. During the wet season (Figure 3(a)(ii)), Aj 03 was in the region with EC in the range of 182.5–254.2 μScm^{-1}; Aj 04, 07–08, 10–12, and 15 in the range of 122.3–130.5 μScm^{-1}; Aj 01, 09, 13, and 14 in the range of 118.2–122.3 μScm^{-1}; and Aj 02, 05, and 06 in the range of 110.0–118.2 μScm^{-1}.

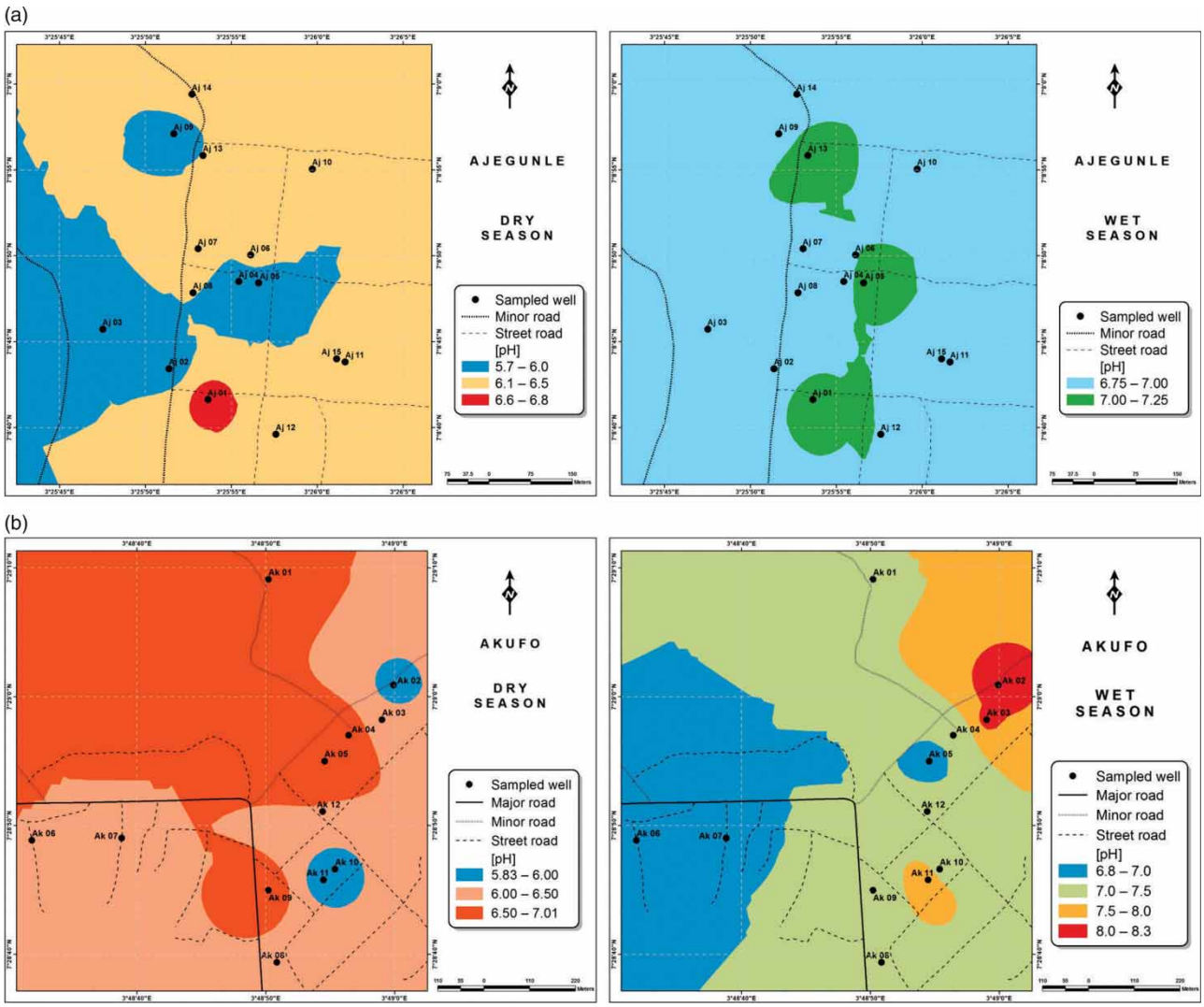


Figure 2 | Spatial distribution maps of pH in dry and wet seasons for (a) Ajegunle and (b) Akufo farm settlements.

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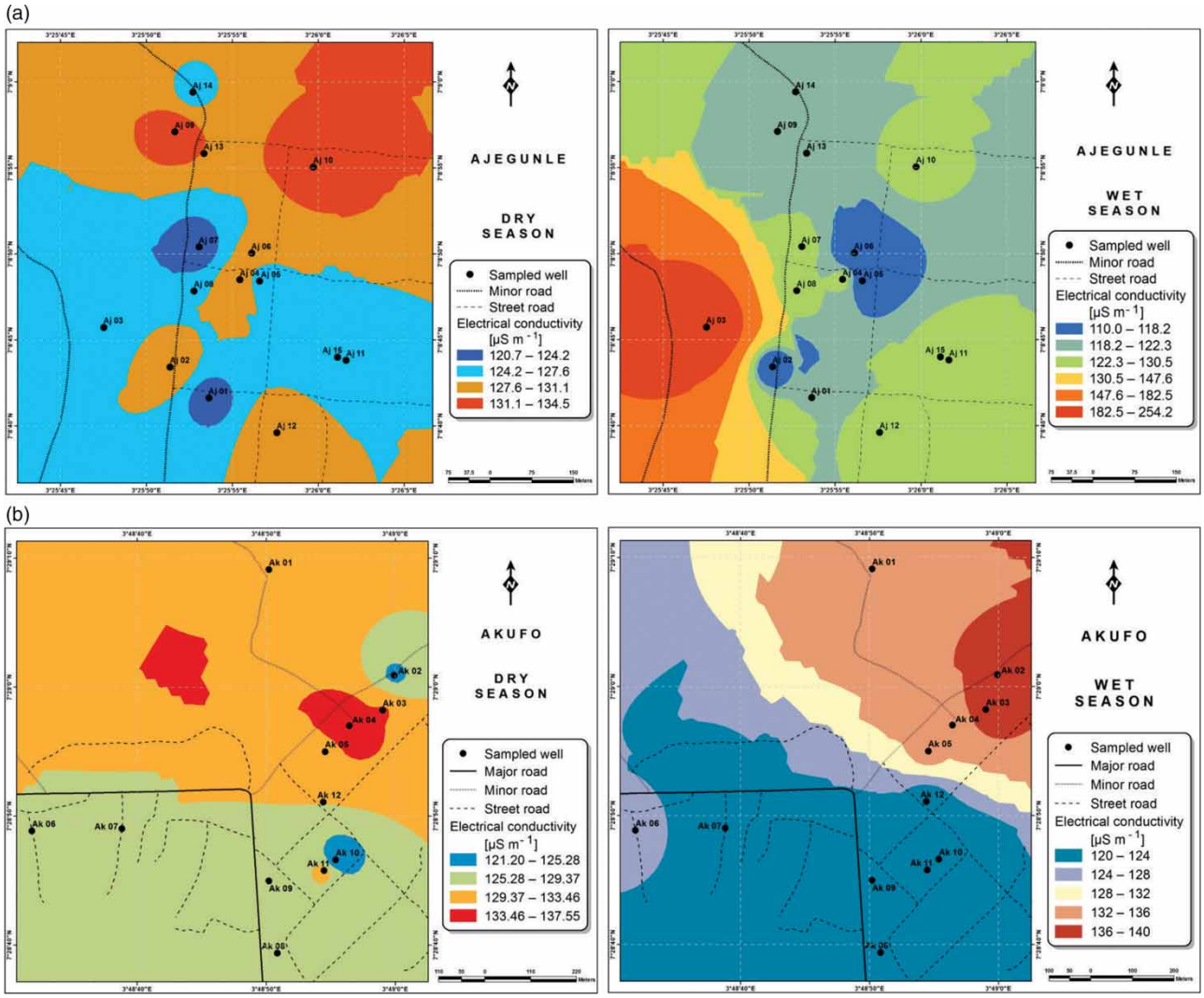


Figure 3 | Spatial distribution maps of EC in dry and wet seasons for (a) Ajegunle and (b) Akufo farm settlements.

For Akufo farm settlement, during the dry season (Figure 3(b)(i)), the groundwater from sampling points Ak 03 and 04 were within the region with EC ranging from 133.46 to 137.55 μScm^{-1}; Ak 01, 05, 11 and 12 from 129.37 to 133.46 μScm^{-1}; Ak 06–09 from 125.28 to 129.37 μScm^{-1}; and Ak 02 and 10 from 121.20 to 125.28 μScm^{-1}. During the wet season (Figure 3(b)(ii)), Ak 02 and 03 were in the regions where EC ranged from 136.00 to 140.00 μScm^{-1}; Ak 01, 04 and 05 from 132.00 to 136.00 μScm^{-1}; Ak 06 from 124.00 to 128.00 μScm^{-1}; and Ak 07–12 from 120.00 to 124.00 μScm^{-1}.

3.4.3. Seasonal spatial distribution of DO

Figure 4 shows the seasonal spatial distributions of DO. The seasonal spatial distributions of DO for Ajegunle farm settlement revealed that during the dry season (Figure 4(a)(i)), the groundwater from sampling points Aj 02 and 03 were within the region where DO was in the range of 8.43–8.80 mg/l; Aj 05, 07, 08 and 12 of 8.06–8.43 mg/l; Aj 01, 04, 06 and 15 of 7.69–8.06 mg/l; Aj 09, 13 and 14 of 7.32–7.69 mg/l; and Aj 10–11 of 6.95–7.32 mg/l. During the wet season (Figure 4(a)(ii)), Aj 09 and 14 were in the region with DO ranging from 8.25 to 8.70 mg/l; Aj 07 from 7.80 to 8.25 mg/l; Aj 02–04, 06–08, 11, 13 and 15 from 7.35 to 7.80 mg/l; and Aj 01, 05, 10 and 12 from 6.91 to 7.35 mg/l.

For Akufo farm settlement, during the dry season (Figure 4(b)(i)), the groundwater from sampling point Ak 01 was within the region where DO range from 8.25 to 8.50 mg/l; Ak 03 from 8.05 to 8.25 mg/l; Ak 02, 08, 09 and 11 from 7.85 to 8.05 mg/l; Ak 06, 07, 10 and 12 from 7.55 to 7.85 mg/l; and Ak 04–05 from 7.37 to 7.55 mg/l. During the wet season (Figure 4(b)(ii)), Ak

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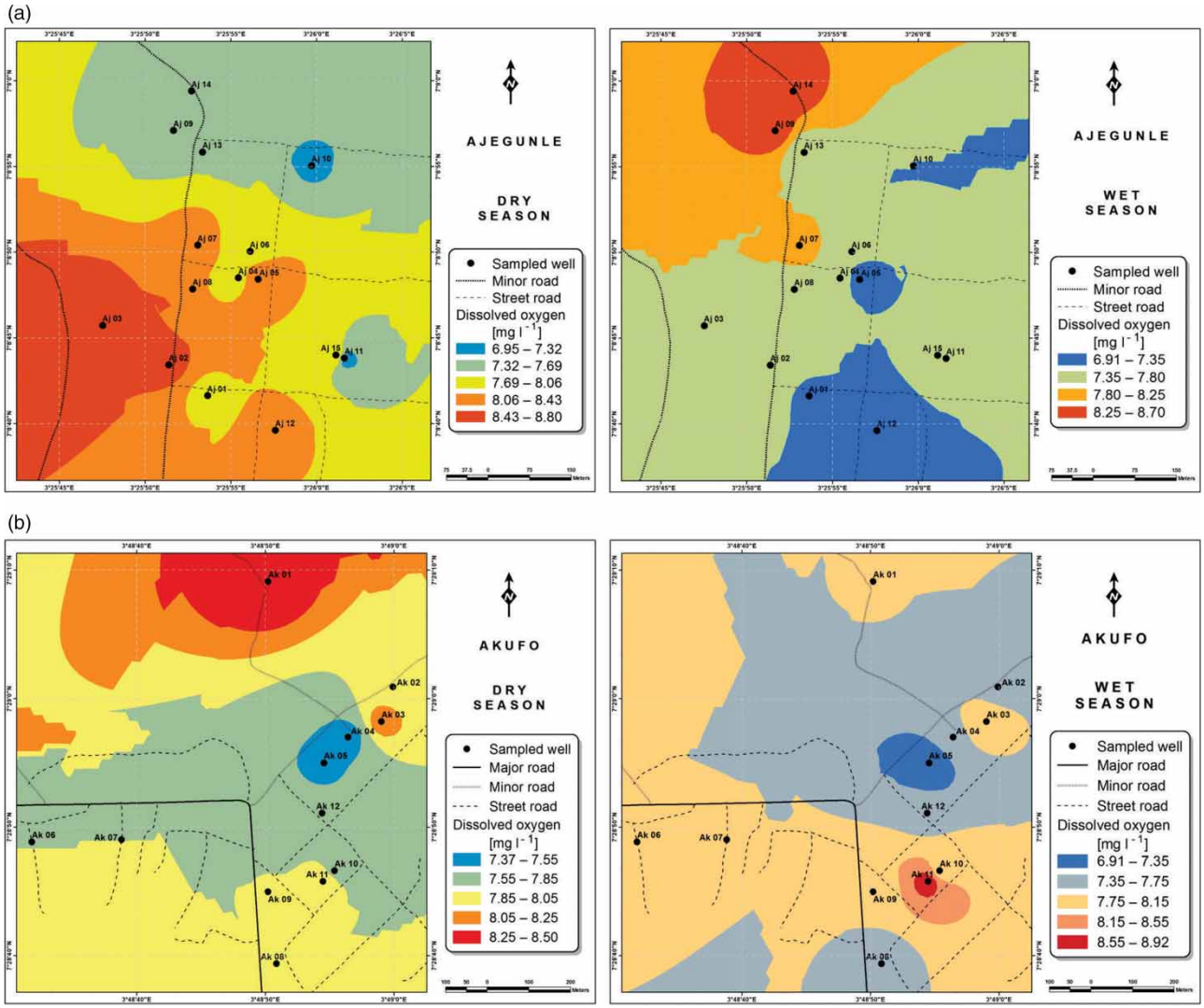


Figure 4 | Spatial distribution maps of DO in dry and wet seasons for (a) Ajegunle and (b) Akufo farm settlements.

11 was in the region where DO ranged from 8.55 to 8.92 mg/l; Ak 01, 03, 06, 07, 09 and 10 from 7.75 to 8.15 mg/l; Ak 02, 04, 08 and 12 from 7.35 to 7.75 mg/l; and Ak 05 from 6.91 to 7.35 mg/l.

3.4.4. Seasonal spatial distribution of TH

The seasonal spatial distributions of TH are presented in Figure 5. The seasonal spatial distributions of TH for Ajegunle farm settlement showed that during the dry season (Figure 5(a)(i)), the groundwater from sampling points Aj 12 and 14 were in the region with TH in the range of 2.14–2.34 mg/l; Aj 06, 09, 11, 13 and 15 of 2.03–2.14 mg/l; Aj 01–02, 04–05, 07–08 and 10 of 1.96–2.03 mg/l; and Aj 03 of 1.93–1.96 mg/l. During the wet season (Figure 5(a)(ii)), Aj 03 was in the region with TH range of 2.04–2.35 mg/l; Aj 01, 06–08 and 13 of 1.73–2.04 mg/l; Aj 04–05, 10–12 and 15 of 1.42–1.73 mg/l; and Aj 02, 09 and 14 of 1.11–1.42 mg/l.

For Akufo farm settlement, during the dry season (Figure 5(b)(i)), the groundwater from sampling points Ak 01, 02 and 09 were within the region where TH ranged from 1.925 to 1.990 mg/l; Ak 03–05 from 1.865 to 1.925 mg/l; Ak 06–08 and 12 from 1.805 to 1.865 mg/l; Ak 10 from 1.745 to 1.805 mg/l; and Ak 11 from 1.680 to 1.745 mg/l. During the wet season (Figure 5(b)(ii)), Ak 09–10 and 12 were in the region where TH ranged from 4.85 to 5.26 mg/l; Ak 04 and 08 from 4.45 to 4.85 mg/l; Ak 02–03, 05–07 and 11 from 4.00 to 4.45 mg/l and Ak 01 from 3.64 to 4.00 mg/l.

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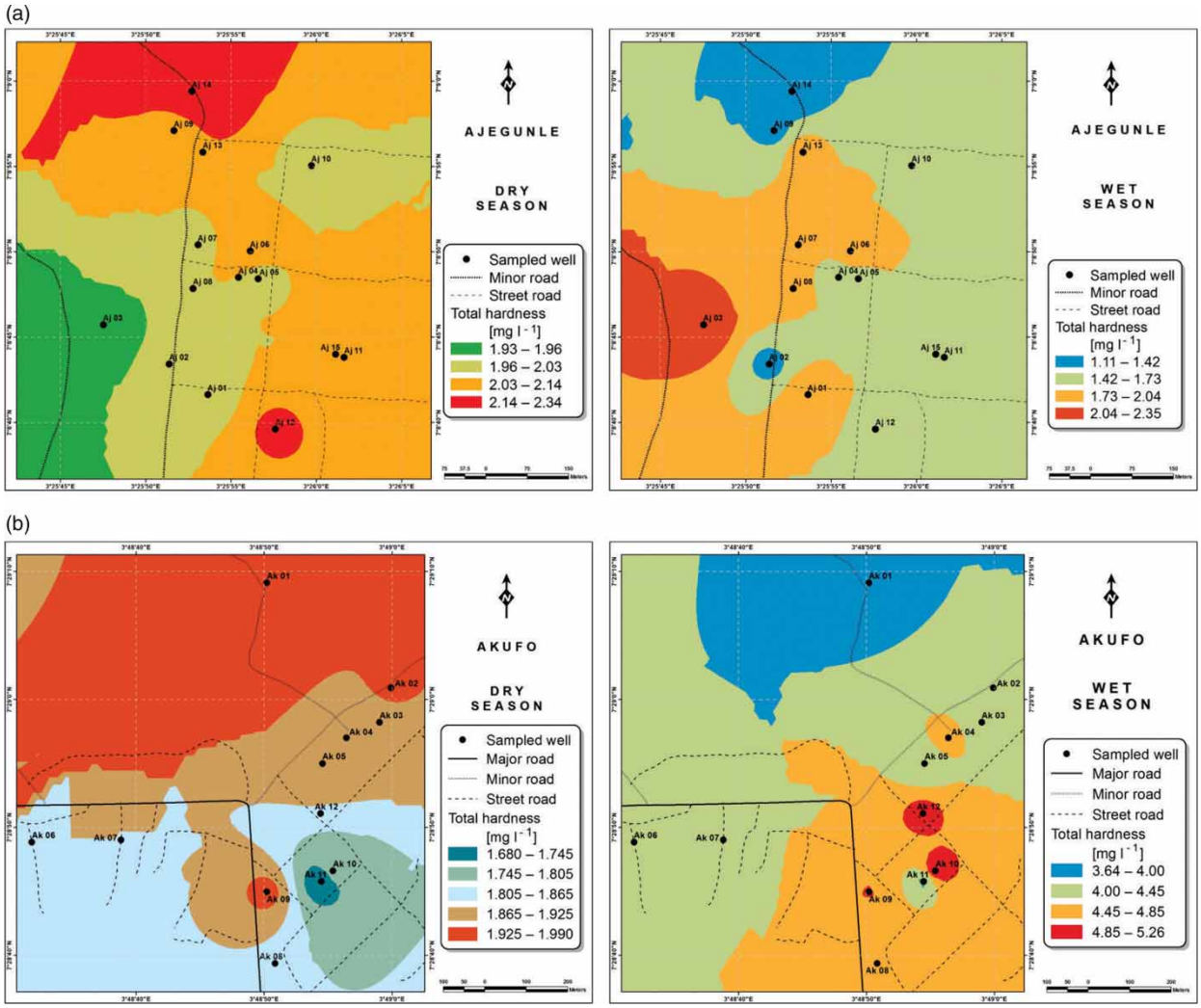


Figure 5 | Spatial distribution maps of TH in dry and wet seasons for (a) Ajegunle and (b) Akufo farm settlements.

3.4.5. Seasonal spatial distribution of SAR

The seasonal spatial distributions of SAR are shown in Figure 6. The seasonal spatial distributions of SAR for Ajegunle farm settlement revealed that during the dry season (Figure 6(a)(i)), the groundwater from sampling point Aj 01 was in the region where SAR ranged from 6.0 to 6.5; Aj 02–04 and 06–08 from 5.5 to 6.0; Aj 05 from 5.0 to 5.5; Aj 13 from 4.0 to 4.5; Aj 09, 11, 14 and 15 from 3.5 to 4.0; and Aj 10 and 12 from 3.2 to 3.5. During the wet season (Figure 6(a)(ii)), Aj 02, 04, 09, 13 and 14 were in the region where SAR was in the range of 4.0–5.1; Aj 05–08, 10–12 and 15 of 3.0–4.0; Aj 01 and 03 of 2.0–3.0 and 1.6–2.0, respectively.

For Akufo farm settlement, during the dry season (Figure 6(b)(i)), the groundwater from sampling points Ak 02–04 were within the region where SAR ranged from 5.75 to 6.16; Ak 05 from 5.25 to 5.50; Ak 01, 11 and 12 from 5.00 to 5.25; Ak 06–09 from 4.75 to 5.00 and Ak 10 from 4.54 to 4.75. During the wet season (Figure 6(b)(ii)), Ak 05 was in the region where SAR ranged from 6.5 to 7.3; Ak 04 and 06 from 5.5 and 6.5; Ak 08 and 09 from 4.5 to 5.5; and Ak 01–03, 07 and 10–12 from 3.2 to 4.5.

3.4.6. Seasonal spatial distribution of MAR

The seasonal spatial distributions of MAR are presented in Figure 7. The seasonal spatial distributions of Magnesium Adsorption Ratio (MAR) for Ajegunle farm settlement showed that during the dry season (Figure 7(a)(i)), the groundwater from sampling point Aj 04 was in the region where MAR ranged from 53.5 to 54.7; Aj 05, 07, 08, 11, 14 and 15 from 52.0 to

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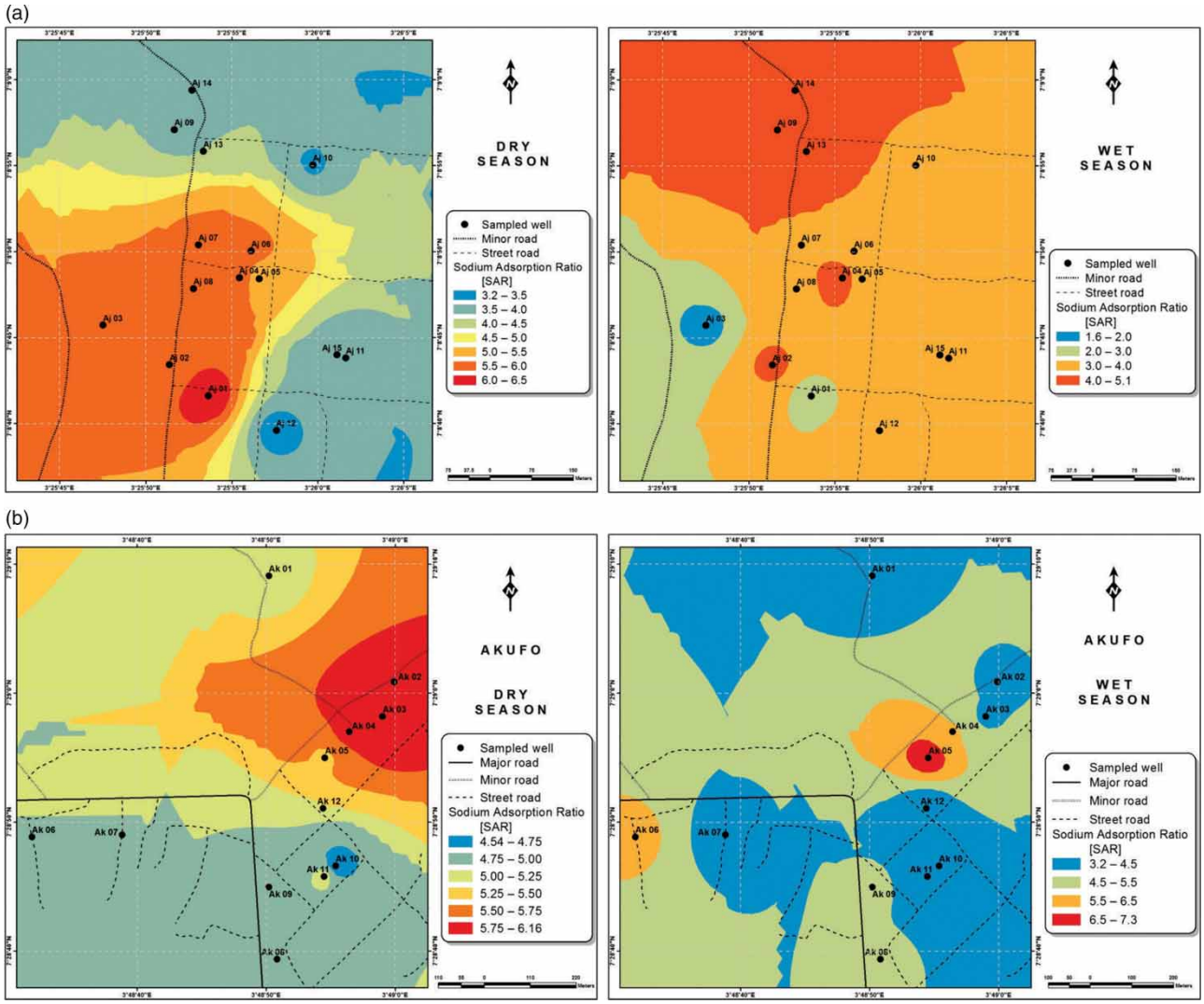


Figure 6 | Spatial distribution maps of SAR in dry and wet seasons for (a) Ajegunle and (b) Akufo farm settlements.

53.5; Aj 03, 06, 09, 10, 12 and 13 from 50.5 to 52.0; Aj 02 from 47.5 to 49.0 and Aj 01 from 45.5 to 47.5. During the wet season (Figure 7(a)(ii)), Aj 03 and 05 were in the region where MAR was in the range of 60.0–66.1; Aj 01, 02, 04, 06 and 07 of 50.0–60.0; Aj 10, 11 and 15 of 40.0–0.0; Aj 13 and 14 of 30.0–40.0 and Aj 09 of 20.9–30.0.

For Akufo farm settlement, during the dry season (Figure 7(b)(i)), the groundwater from sampling point Ak 05 was within the region where MAR ranged from 50.5 to 52.7; Ak 01–04, 09 and 12 from 48.0 to 50.5; Ak 02 and 06–08 from 45.5 to 48.0; and Ak 10 and 11 from 42.9 to 45.5. During the wet season (Figure 7(b)(ii)), Ak 01 and 11 were in the region where MAR was in the range of 47.5–49.9; Ak 05 of 45.5–47.5; Ak 03, 06 and 07 of 43.5–45.5; Ak 04, 08, 10, and 12 of 41.5–43.5; and Ak 02 and 09 of 39.8–41.5.

4. DISCUSSION

In assessing water for irrigation, it is important to consider the long-term effect of the use of the water on soil and plant health as the use of inferior quality water for irrigation could result in reduced crop yield (Ramesh & Elango 2012). Meanwhile, for proper assessment of the suitability of a particular irrigation water supply, the apparent salt tolerance of specific crop(s) of interest should be taken into consideration (Shah & Mistry 2013).

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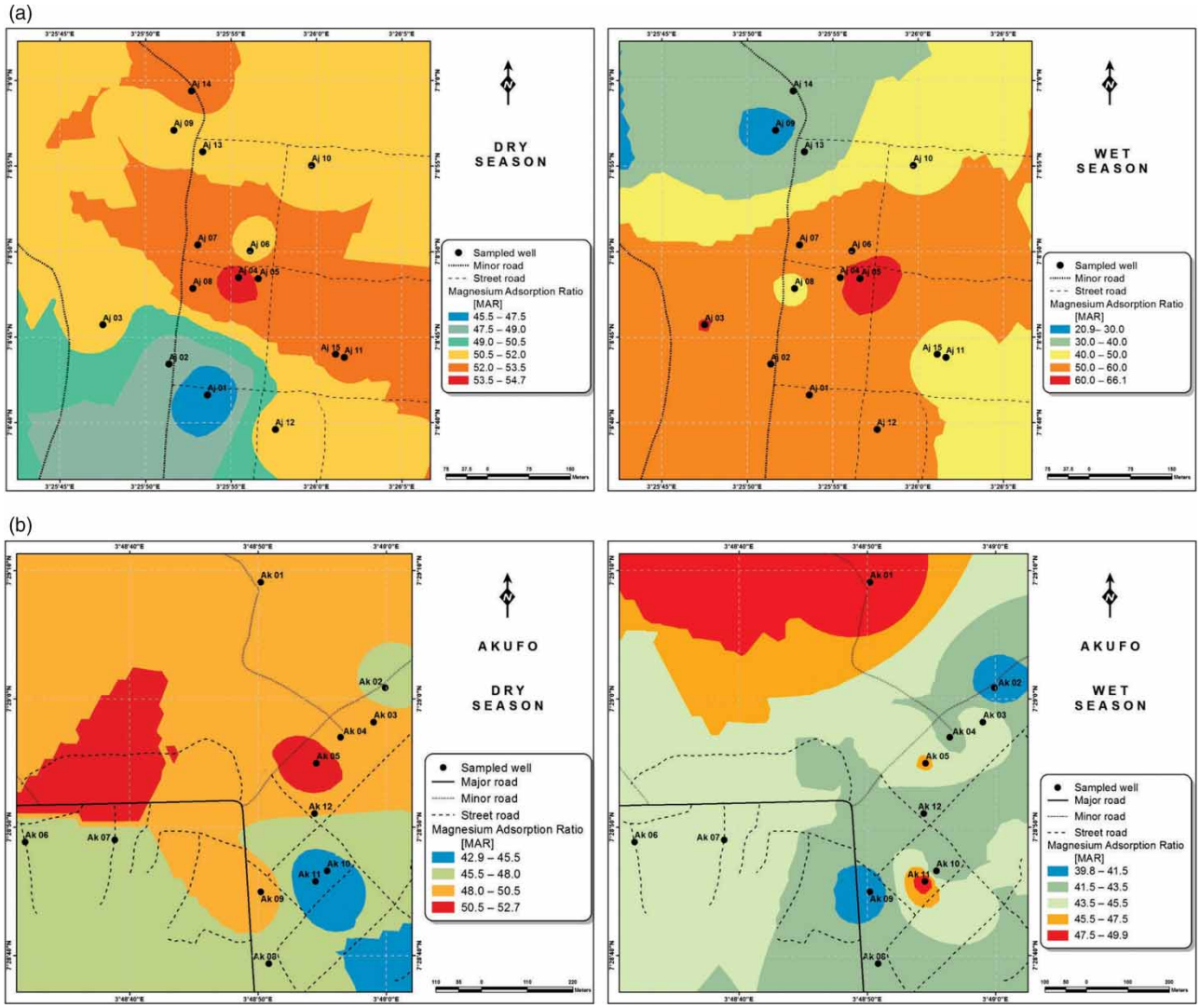


Figure 7 | Spatial distribution maps of MAR in dry and wet seasons for (a) Ajegunle and (b) Akufo farm settlements.

Based on SAR, all the samples were found to be 'Excellent' for irrigation, with proposed careful use on sodium-sensitive crops (Singh *et al.* 2020), in both the wet and dry seasons; indicating that the capacity of the water samples to induce sodicity to the soil is low. Meanwhile the SAR obtained for the dry season was significantly higher than that for the wet, for all the settlements, which could be attributed to the fact that since there was more water in the soil during the wet season, there was also more dilutions. Therefore, the capacity for sodicity was even lower during the wet season. This is in line with the submission of Nolakana (2016).

High SSP in the water from the farm settlements, as reported in this paper, making the samples unsuitable for irrigation, was an indication that they had greater Na^+ levels relative to other cations. This could result in reduced soil permeability and plant growth inhibition (Nolakana 2016). KR of more than 1 also indicated an excess level of Na^+ in the water samples, making them unsuitable for irrigation (Nolakana 2016). High PI values have been correlated with high amount of sodium and bicarbonate ions in groundwater (Xu *et al.* 2019), and with subsurface structural features that enhance groundwater contamination (Singh *et al.* 2020).

In this study, many of the samples from the farm settlements were found to be unsuitable in either wet or dry season (Singh *et al.* 2020); hence may require appropriate treatment to be suitable. High magnesium content in irrigation water (or magnesium hazard greater than 50%) can make the soil more alkaline, which could also affect its infiltration capacity and

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affect crop production adversely (Nolakana 2016; Singh *et al.* 2020). Calcium-supplying interventions and effective drainage system to get rid of excess magnesium salts from irrigated soils can be used to fix effects of high magnesium (Qadir *et al.* 2018). Such water samples may however be suitable for magnesium-tolerant crops or crops that require high magnesium concentrations.

Only water from wells AJ 02, 09 and 10; AK 02 and 11 in the dry season as well as AK 01, 06, 07, and 08; ER 03 and 04 in the wet season were suspected to have tendencies to harm crops. Hopkins *et al.* (2007) had reported that Chloride ion can cause severe problems in crops at concentrations greater than 350 mg/l. RSBC of irrigation water or soil water is used to indicate the alkalinity hazard for soil and the suitability of the water for irrigation in clay soils which have high cation exchange capacity (Bouderbala 2017).

All the samples were found to be suitable for irrigation based on pH during the wet season. Water suitable for irrigation should have pH ranging from 6.5 to 8.4 and most biological life require pH ranging from 6 to 9 for survival (Metcalf & Eddie 2003). The pH (acidity or alkalinity) has significant influence on reactions in soil and water (SAI 2010), thereby affecting crop performance.

The classification of EC indicated low salt enrichment and based on TDS, nitrates, and TH, the water samples were revealed to be suitable for agriculture in both the dry and wet seasons in line with the reports of Islam *et al.* (2004) and Tanjima *et al.* (2017). When salinity is in excess, the osmotic activity of plants reduces and the absorption of water and nutrients from the soil is adversely affected (Al-Tabbal & Al-Zboon 2012). Evaluating the TDS in water is very essential in assessing suitability for irrigation as many toxic solid materials may be dissolved in the water, which may be harmful to plants and eventually consumers. Since nitrates (NO_3^-) are very soluble in water, they readily percolate into the groundwater from where they ultimately can enter wells. In the soil, bacteria convert some of the nitrates into nitrites (NO_2^-) and when they accumulate in crops, they can be risky to the health of consumers (Laborde & Pecchia 2012). The TH is an important parameter to consider in determining the suitability of water for domestic, irrigation and industrial purposes (Singh *et al.* 2020).

In this study, significant positive and negative correlations were revealed between the selected hydrochemical and microbial parameters in both seasons as shown in the results. Significant positive correlation between a parameter and another indicates that increase in such parameter would produce increase in the other. Significant negative correlation on the other hand indicates the converse. Several researchers from diverse locations had reported seasonal significant correlations between several water quality parameters (such as Bhandari & Nayal 2008; Obiefuna & Orazulike 2010; Khatoon *et al.* 2013; Muthulakshmi *et al.* 2013; Nolakana 2016).

Spatial distribution maps generated for selected parameters: pH, EC, DO, TH, SAR, and MAR, for both dry and wet seasons show the spatial distributions of the parameters within Ajegunle and Akufo farm settlements in the seasons. These maps will enhance systematic positioning of well/borehole, cropping and livestock agricultural activities according to the water quality needs/requirement. The GIS-based IDW maps are excellent tools for summarizing overall water quality conditions over space and time (Al Maliki *et al.* 2020); which can enhance sustainable management of the groundwater resources within the farm settlements. Similar spatial distribution maps have been generated by other researchers, such as Gidey (2018), Jacintha *et al.* (2015), Sahoo *et al.* (2014) and Zaharaddeen (2015).

5. CONCLUSION

All the groundwater samples from the three farm settlements were classified as 'soft' based on TH; 'fresh' and 'excellent' based on TDS; and 'no problem' based on nitrates in both dry and wet seasons. All the samples from the settlements were 'excellent' based on EC in both seasons, except very few which were 'good' from Ajegunle farm settlement during wet season. Based on pH, some were of the 'no problem' category while others were of the 'moderate' category for each of the farm settlements in different seasons.

Irrigation parameters such as PI and SAR showed the groundwater samples from all the farm settlements to be excellent and suitable for irrigation in both the dry and wet seasons while others such as SSP and KR revealed them as unsuitable. Other parameters showed different degrees of suitability for different samples from different farm settlements.

Selected parameters such as pH, SAR, MAR, BOD, COD, TDS, TBC, Cl, alkalinity, EC, TH, zinc, coliform count and *E. coli* were correlated for each of the farm settlements. Positive and negative significant correlations were seen between the parameters in the dry and wet seasons.

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The spatial distribution maps of pH, EC, DO, TH, SAR and MAR generated using the IDW interpolation method for both dry and wet seasons show the spatial distributions of the parameters within Ajegunle and Akufo farm settlements in the seasons.

Utilizing the findings and maps generated from this research will enhance systematic exploitation of groundwater as well as appropriate positioning of farming/agricultural practices within the settlements. Appropriate systematic irrigation management practices as well as crop choices are recommended; based on the concentrations and distribution of the parameters viz-a-viz the crop requirements. This will limit potential dangers that may arise with the use of the water within the settlements over a long period. Furthermore, periodic assessment should be conducted to monitor the water quality within the farm settlements.

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AUTHORS' CONTRIBUTIONS

G.M.F. acquired, analyzed, and interpreted the data under the supervision of B.S.B., O.D.A., O.A.I., and A.O.O., as well as wrote the first draft of this manuscript. T.O. did the GIS analyses using IDW and produced the maps. All the authors, including G.O.B., contributed to the content, as well as read, edited, and fine-tuned the manuscript. All authors approve the final manuscript.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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