

environmentally sustainable all-season farming could be practised. In spite of the abundance of these ecosystems in southwest Nigeria, however, their potential for crop production has not been fully exploited due to their heterogeneity in terms of morphology, soil types, vegetation, hydrology, and agro-economy (Ogban and Babalola, 2003; Ogunremi *et al.*, 2000; WARDA, 1996). According to Thenkabail and Nolte (1996), only 8 to 20% of inland valley bottoms and 15 to 22% of inland valley fringes are being exploited for agriculture in West Africa. Inland valleys, due to annual flooding, could be rich in soil fertility, have potential for rice cultivation during the main cropping season, and be moist enough to sustain upland crops during the dry season (Ogunremi *et al.*, 2000).

A major challenge to utilisation of the valleys for cropping is the dearth of information on the detailed specific characteristics of these valleys that could enable their identification for specific agricultural utilisation (Fagbami and Ajayi, 1990; Ogban and Babalola, 2009). One of the characteristics that need to be understood is the quality of their groundwater with regards to applicability for supplementary irrigation during the dry season. The groundwater, the quality of which depends on the source of recharge and the geological environment through which it flows, has to meet standards for safe use (Mukherjee *et al.*, 2005).

There have been a number of studies on the quality of surface and groundwater for domestic and irrigation purposes in the study area (Adebisi, 1981; Ige *et al.*, 2008; Jaji *et al.*, 2007; Ogunfowokan *et al.*, 2009; Ogunkoya and Adejuwon, 1990; Talabi and Tijani, 2013). Little is, however, known about the

quality of groundwater of inland valley eco-systems of the study area, particularly in relation to agricultural utilisation. This study evaluates the quality of groundwater of 3 typologies of inland valleys and assesses the suitability of the waters for irrigation.

2 Materials and methods

2.1 Description of the study area

The 6 inland valleys investigated belong to 3 typologies commonly found in the study area – amphitheatre-like valley-heads (sites Am1 and Am2), valley-side inland valleys (sites VS1 and VS2), and low depression inland valleys (sites LD1 and LD2). These sites are located west of the main trunk of the River Niger in portions of Osun and Kwara states of Nigeria. The entire area falls within latitudes 7° 57' to 8° 14' north and longitudes 4° 41' to 4° 58' east, around the southern foothills of the topographic zone referred to as the Yoruba Hills (see Figure 1). The terrain is underlain by Basement Complex rocks, comprising granites, granite-gneisses, and schist, and consists of plains studded with granite and granite-gneiss inselbergs, and hill ranges. The highland features constitute the watersheds, while rivers tributary to the River Niger flow northwards or westwards on the plains. The soils are the ferruginous tropical type that derived from Basement Complex rocks. The character of the soils is a function of the underlying parent materials, the marked rainfall seasonality of the climate, and the woodland vegetation type.

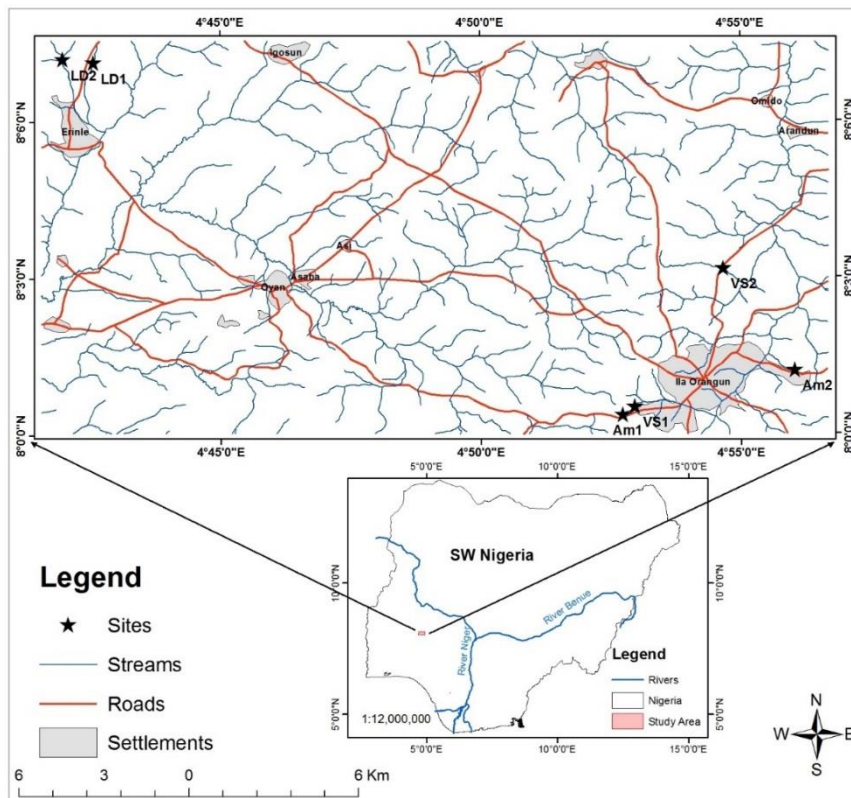


Figure 1. The study area with the sampling sites indicated by the star symbol.

The climate of the study area is the Koppen's A_{w1} Tropical Wet and Dry type characterised by the dry season extending from November to February/March and the wet season extending from March/April to October (Aboyeji and Ogunkoya, 2014). The temperature is generally high throughout the year with an annual mean of about 26 °C. The mean minimum and maximum temperatures are 20 °C and 33 °C, respectively. The mean annual rainfall is about 1300 mm, with a bimodal distribution characterised by a rainfall minimum between July and August.

2.2 Water sample collection and analysis

Sampling was carried out during the rainy and dry seasons of 2012. Five sets of groundwater samples were collected from piezometers installed at pre-selected locations. The samples were collected mid-May 2011, mid-August 2011, mid-November 2011, mid-January 2012, and mid-March 2012. These months were selected to cover the period when rain begins to be well established (May) through to the peak dry season of March. The number of the samples collected at each site varied according to the valley size and availability of water in the piezometers, as some dried up during the dry season (Figures 2 and 3).

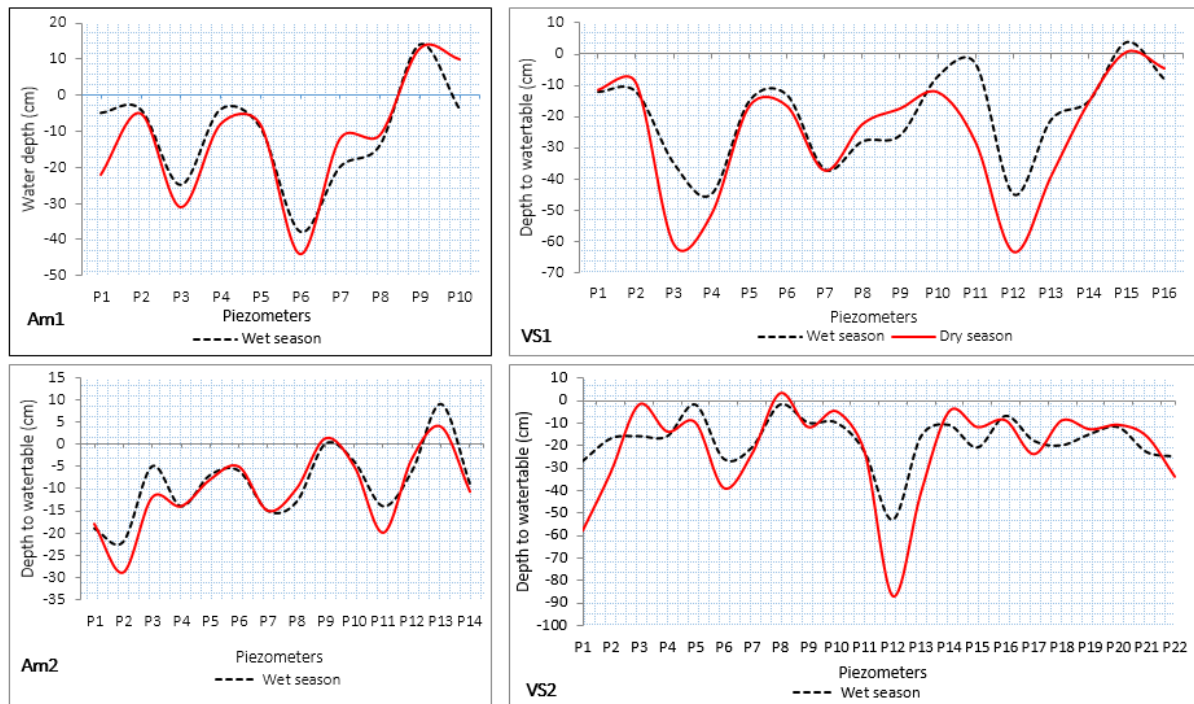


Figure 2. Seasonal pattern of groundwater level fluctuation in Amphitheatre-like (Am) and Valley-side (VS) inland valleys.

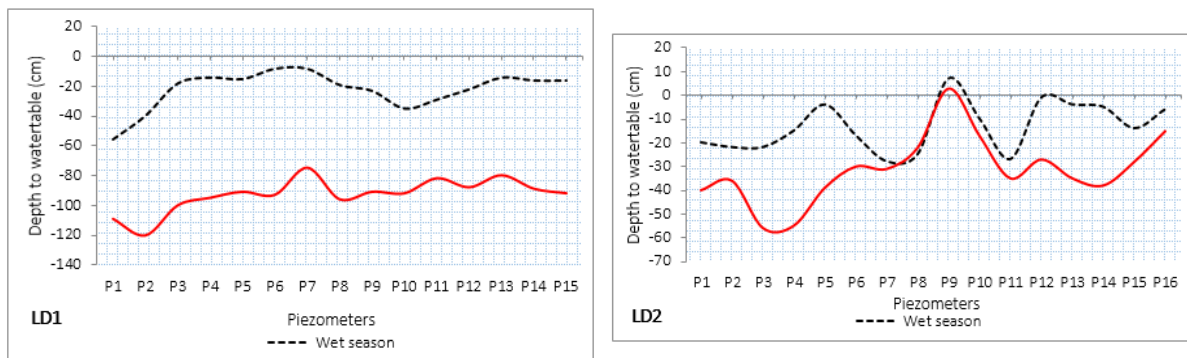


Figure 3. Seasonal pattern of groundwater level fluctuation in low depression (LD) inland valleys.

A total of 25, 24, 19, 20, and 26 water samples were collected in May 2011, August 2011, November 2011, January 2012, and March 2012, respectively. The samples were collected in pre-rinsed plastic bottles using a suction sampler. Prior to sampling at each location, the Buckner flask attached to the sampler and the sample bottle used to store the water were rinsed with the water collected at the location.

The bottles were kept in a chilled box while being transported to the laboratory for analysis. The pH and electrical conductivity (EC) were measured *in situ*. Chemical analyses of the water samples were carried out at the laboratory of the Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria. Each sample was analysed for calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and

sodium (Na⁺), using a flame photometer, while the anions (CO₃²⁻, HCO₃⁻, Cl⁻, and SO₄²⁻) were analysed using titration, as described in Page *et al.* (1982). The heavy metals (iron, copper, zinc, lead and nickel) were analysed using atomic absorption spectrometry (AAS).

The results were used to assess the water quality of the sites for agricultural utilisation using the following water quality indices (all the ions are expressed in milligram equivalents per litre, meq/L):

- Sodium Adsorption ratio (SAR) was calculated using the following equation (Raghunath, 1987; Wallender and Tanji, 2012):

$$SAR = \frac{Na^+}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}} \quad (1)$$

- Soluble sodium percentage (%Na) was calculated using the equation below (Todd and Mays, 2005):

$$\%Na = \frac{Na^+ + K^+}{Na^+ + Ca^{2+} + Mg^{2+} + K^+} \times 100 \quad (2)$$

- Total dissolved solids (TDS) were estimated from specific conductance values by multiplying with a factor of 0.64 (i.e. TDS (mg/L) = EC (µS/cm) × 0.64), which is taken as the conversion factor for most natural waters (Richards *et al.*, 1954; Wallender and Tanji, 2012).
- Permeability index (PI) was calculated according to Doneen (1964) (Raghunath, 1987) by the following equation:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \quad (3)$$

- Magnesium adsorption ratio (MAR) was calculated using the following equation (Prasanth *et al.*, 2014; Raghunath, 1987):

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (4)$$

- Kelly's ratio (KR) was calculated based on Kelly (1963) and the following equation:

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (5)$$

- Residual sodium bicarbonate (RSBC) was calculated following Gupta and Gupta (1987):

$$RSBC = HCO_3^- - Ca^{2+} \quad (6)$$

The results of these indices were compared with known or stipulated standards. Non-parametric tests (Mann-Whitney *U* test and Kruskal-Wallis test) were used to determine if any difference existed between the hydro-geochemistry of the inland valleys.

3 Results and discussion

3.1 Physicochemical characteristics. Concentration of heavy metals in groundwater

Table 1 presents the summary statistics of the physicochemical characteristics and concentration of heavy metals of the groundwater samples. The groundwater samples were generally acidic to alkaline with pH ranging from 5.03 (Am1) to 8.80 (Am2) and having an average of 7.01. This result is similar to those reported by Ogunkoya and Adejuwon (1990) and Jaji *et al.* (2007) in studies conducted in parts of southwest Nigeria.

Table 1. Summary statistics of physicochemical and heavy metals in groundwater of inland valleys in the study area.

IV	Statistic	Na ⁺	K ⁺	Ca	Mg	HCO	CO ₃	Cl ⁻	SO ₄	Fe	Ni	Pb	Zn
Am1	Min	1.9	0.3	0.0	0.4	0.4	0.01	2268.8	3.9	0.10	0.083	0.008	0.02
	Max	10	12.3	22.0	25.0	50.0	0.1	5814	26.9	2.01	0.039	0.027	0.18
	Mean	4.2	5.2	8.7	8.3	15.2	0.1	3732	13.4	0.45	0.022	0.024	0.08
	SD	2.3	4.2	8.4	8.1	16.1	0.02	1493	7.6	0.69	0.012	0.003	0.07
	CV	0.5	0.8	1.0	1.0	1.1	0.4	0.4	0.6	1.53	0.561	0.144	0.88
Am2	Min	2.2	2.0	2.0	3.9	0.2	0.02	3013	6.0	0.09	0.002	0.002	0.05
	Max	6.0	96	34.0	30.2	35	0.1	13825	47.5	0.28	0.086	0.096	0.14
	Mean	3.8	12.5	18.0	11.1	15.3	0.1	9140	20.2	0.13	0.043	0.047	0.09
	SD	0.9	23	8.5	7.9	15.5	0.02	4144	15.4	0.07	0.034	0.047	0.03
	CV	0.2	1.8	0.5	0.7	1.01	0.3	0.5	0.76	0.52	0.794	1.010	0.36
VS1	Min	1.5	2.3	0.0	0.1	0.20	0.01	1631	2.48	0.09	0.008	0.006	0.03
	Max	23.5	15.8	26.0	24.1	40.0	0.1	11415	39.4	0.24	0.083	0.065	0.18
	Mean	4.9	5.8	14.1	7.8	14.1	0.0	5106	9.84	0.14	0.045	0.036	0.09
	SD	5.0	4.1	8.9	7.0	14.4	0.0	3252	12.3	0.05	0.028	0.025	0.05
	CV	1.0	0.7	0.6	0.9	1.02	0.8	0.6	1.25	0.37	0.612	0.700	0.60
VS2	Min	3.3	0.5	0	0.4	0.20	0.01	2552	3.51	0.09	0.005	0.041	0.02
	Max	37.5	22	24.0	35.4	40	0.1	12620	22.7	116.3	0.105	0.118	0.30
	Mean	12.2	8.2	12.6	10.8	12.7	0.1	6681	14.3	11.93	0.040	0.087	0.10
	SD	10.5	5.3	8.5	8.4	13.3	0.0	3465	5.78	35.71	0.035	0.036	0.08
	CV	0.9	0.6	0.7	0.8	1.05	0.5	0.5	0.40	2.99	0.888	0.418	0.80

IV	Statistic	Na ⁺	K ⁺	Ca	Mg	HCO	CO ₃	Cl ⁻	SO ₄	Fe	Ni	Pb	Zn
LD1	Min	1.8	0.3	0.0	0.3	0.20	0.01	3439	8.51	0.08	0.005	0.018	0.01
	Max	39.5	97.3	14.0	20.6	40	0.1	16165	511.7	0.34	0.131	0.110	0.13
	Mean	9.3	15	5.8	4.9	26.9	0.04	8973	66.1	0.12	0.064	0.064	0.05
	SD	12.1	23.3	4.9	5.5	14.9	0.04	4819	147.3	0.10	0.053	0.039	0.04
	CV	1.3	1.5	0.8	1.1	0.55	0.9	0.5	2.23	0.83	0.827	0.611	0.82
LD2	Min	2.4	0.5	0	0.2	0.20	0.01	778	5.32	0.08	0.001	0.001	0.01
	Max	38.5	28	22	26.5	255	0.1	13117	98.9	55.04	0.061	0.113	0.12
	Mean	16.7	8.3	9.6	5.7	30.1	0.03	6902	25.3	7.43	0.024	0.060	0.07
	SD	12.4	7.3	8.6	6.7	55	0.03	3412	25.1	18.61	0.026	0.048	0.03
	CV	0.7	0.9	0.9	1.2	1.8	0.8	0.5	1.0	2.50	1.084	0.798	0.48

All the values are in mg/L. Min = minimum; Max = maximum; SD = standard deviation; IV = inland valley; Am = Amphitheatre - head inland valley; VS = Valley-side inland valley; LD = Low-slope depression inland valley.

The cationic content of the waters is generally low (Table 1) with an average dominance structure of the order Na⁺ > Ca²⁺ > K⁺ > Mg²⁺. The dominance structure across the sites is of the order Ca²⁺ > Mg²⁺ > K⁺ > Na⁺ for Am1, Am2, and VS1 valleys, and Ca²⁺ > Na⁺ > Mg²⁺ > K⁺; K⁺ > Na⁺ > Ca²⁺ > Mg²⁺; and Na⁺ > Ca²⁺ > K⁺ > Mg²⁺ for VS2, LD1, and LD2, respectively. The overall dominance pattern for anions is of the order Cl⁻ > SO₄²⁻ > HCO₃⁻ > CO₃. For the individual inland valleys, the anionic dominance structure is of the order Cl⁻ > HCO₃⁻ > SO₄²⁻ > CO₃ in Am1, VS1, and LD2, and Cl⁻ > SO₄²⁻ > HCO₃⁻ > CO₃ in Am2, VS2, and LD1. The cationic and anionic concentrations in water samples indicate that they are generally suitable for irrigated agriculture. The values obtained are also comparable with those reported by earlier studies in the region (e.g. Ige *et al.* (2008), Nwankwoala and Nwagbogwu (2012), and Olorunfemi *et al.* (2011)). For example, Nwankwoala and Nwagbogwu (2012) reported that in groundwater samples around Akure and environment of southwest Nigeria, Ca²⁺, Mg²⁺, Na⁺ and HCO₃ ranged between 12.3 and 92.2, 0.9 and 32.6, 1.07 and 8.7, and 28 and 88 mg/L, respectively.

The groundwater mean concentrations of Fe were 0.45, 0.13, 0.14, 11.93, 0.12, and 7.43 mg/L in Am1, Am2, VS1, VS2, LD1, and LD2, respectively, with outlier values of 116.3 mg/L in VS2 and 55.04 in LD2. According to Ayers and Westcot (1994), iron concentrations > 5.0 mg/L may cause nutritional imbalances in some crops. The Ni content was generally low, with the mean concentration of 0.022, 0.043, 0.045, 0.040, 0.064, and 0.061(mg/L) at Am1, Am2, VS1, VS2, LD1, and LD2, respectively. These values were lower than the limit of 0.5 mg/L to

1.0 mg/L suggested by (Ayers and Westcot, 1994). Concentrations greater than this level may be toxic to a number of plants. The concentration of lead (Pb) in the waters was generally lower than the recommended value of 5.0 mg/L for plants. Very high concentrations in irrigation water can inhibit plant cell growth. For all the sites, the concentrations ranged from 0.001 mg/L to 0.118 mg/L. Zn is an essential nutrient for most plants, though its high concentration is toxic. The values obtained from the inland valleys ranging between 0.01 and 0.18 mg/L were lower than the recommended maximum concentration of 2.0 mg/L. At all the sites, the concentration of Cu was below the detection level of the equipment used. It can be concluded that the concentrations of heavy metals in the waters of the inland valleys of the study area were generally within the recommended limits.

3.2 Characteristics of major water quality indices in groundwater of the study area

Table 2 shows the groundwater quality indices of the inland valleys. The mean electrical conductivity (dS/m) values were 0.19, 0.52, 0.32, 0.30, 0.22, and 0.21 in Am1, Am2, VS1, VS2, LD1, and LD2, respectively. The seasonal average values ranged from 0.24 to 0.3 dS/m. An outlier value of 1.1 dS/m was recorded at a location (P7) in Am2 during the dry season. The majority of the water samples fall within low saline to moderately saline water types as measured using the suitability rating scale provided by Richards *et al.* (1954). These water types are rated to be generally safe for the irrigation purpose.

Table 2. Summary statistics of major water quality indices in groundwater of the study area.

IV	Statistic	EC	SAR	% Na	TDS	PI	MAR	KR	RSBC
Am1	Min	0.03	0.12	10.21	16	17.2	27.92	0.07	-0.99
	Max	0.41	0.81	79.87	261.76	454.9	100	3.26	0.49
	Mean	0.19	0.36	35.08	123.63	143.9	73.70	0.60	-0.13
	SD	0.11	0.22	22.78	69.81	135.5	26.56	0.79	0.47
	CV	0.56	0.6	0.65	0.56	0.9	0.36	1.33	-3.63
Am2	Min	0.18	0.12	8.72	113.92	11.2	31.44	0.06	-1.69
	Max	3.06	13.02	49.56	1957.12	137.1	76.54	4.48	0.31
	Mean	0.52	0.99	19.74	329.60	44.9	50.08	0.39	-0.70
	SD	0.72	3.21	10.66	457.95	33.4	13.75	1.09	0.60
	CV	1.39	3.23	0.54	1.3894	0.7	0.275	2.78	-0.86

IV	Statistic	EC	SAR	% Na	TDS	PI	MAR	KR	RSBC
VS1	Min	0.08	0.07	9.21	49.92	11.1	22.39	0.04	-1.20
	Max	0.56	1.30	96.09	360.96	908.3	100	13.05	0.66
	Mean	0.32	0.57	34.87	202.67	128.5	50.22	1.41	-0.46
	SD	0.14	0.32	21.81	89.23	220.7	23.94	2.88	0.59
	CV	0.44	0.55	0.625	0.4403	1.7	0.477	2.05	-1.29
VS2	Min	0.08	0.13	8.02	49.28	11.8	17.42	0.05	-1.19
	Max	0.59	3.65	91.16	376.32	325.7	100	5.79	0.33
	Mean	0.30	0.82	37.98	192.37	77.7	60.35	0.94	-0.42
	SD	0.13	0.86	22.72	81.75	72.1	21.52	1.63	0.54
	CV	0.42	1.04	0.598	0.4249	0.9	0.357	1.73	-1.29
LD1	Min	0.04	0.12	11.77	27.52	22.8	4.61	0.07	-0.69
	Max	0.55	3.08	86.26	352.64	283.9	100	2.83	0.47
	Mean	0.22	0.77	55.73	142.16	120.0	60.43	0.81	0.04
	SD	0.14	0.81	21.01	91.76	78.3	27.35	0.73	0.34
	CV	0.65	1.05	0.377	0.66	0.7	0.45	0.9	8.85
LD2	Min	0.05	0.16	13.01	31.36	23.6	7.23	0.09	-1.09
	Max	0.58	4.38	91.83	370.56	284.1	100	7.86	3.78
	Mean	0.21	1.56	56.96	134.91	112.8	52.03	2.19	-0.06
	SD	0.12	1.14	24.81	74.36	82.9	32.44	2.17	1.02
	CV	0.55	0.73	0.44	0.55	0.7	0.62	0.99	-17.8

Note: All the values are in meq/L except pH, TD (mg/L) and EC (dS/m). Min = minimum; Max = maximum; SD = standard deviation; IV = inland valley; Am = amphitheatre - head inland valley; VS = Valley-side inland valley; LD = low-slope depression inland valley.

The electrical conductivity of the groundwater is comparable with those reported by Nwankwoala and Nwagbogwu (2012), who found that the concentration of EC in the groundwater of Akure environ in southwest Nigeria was in the range of 0.12 – 1.0 dS/m, and the mean was 0.36 dS/m. According to Wilcox (1955), conductivities of less than 0.2 dS/m are permissible for irrigation. Average values of SAR (meq/L) of 0.35, 1.05, 0.35, 0.80, 0.78, and 1.42 were obtained for Am1, Am2, VS1, VS2, LD1, and LD2 inland valley sites, respectively. The values were generally lower during the wet months than during the dry months. According to the classification based on Richards *et al.* (1954), 95.7 % of the water samples were found within the range of excellent to good category.

Figures 4 and 5 show the plots of SAR (alkali hazard) and specific conductance (salinity hazard) following Richards *et al.* (1954) for water samples collected in the wet and dry seasons. The wet season plot indicates that all the samples fall within C1S1 (low salinity–low sodium) and C2S1 (medium salinity–low sodium) water type, except the sample (AIV2) in Am2 that had a higher value, which falls within very high salinity–low sodium (C3S3) class. The plot of the dry season samples (Figure 5) indicates that the majority of the samples are within the low sodium (S1) and low to medium salinity (C1–C2) category.

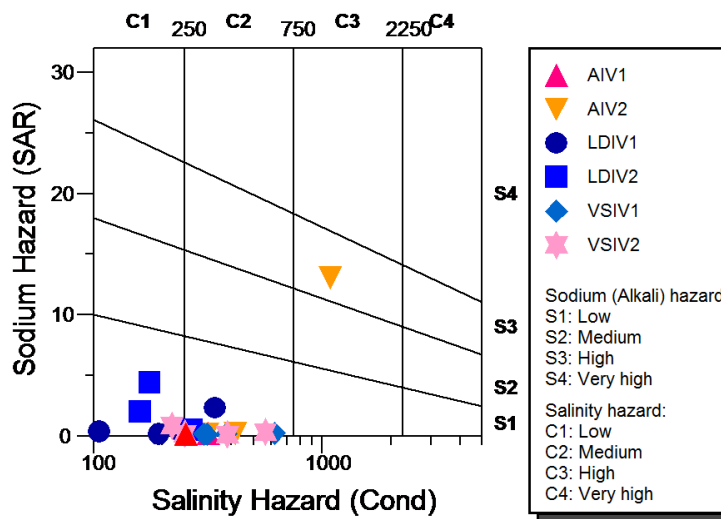


Figure 4. Classification of groundwater samples collected in the wet season with respect to salinity and sodium hazards. AIV1/AIV2, LDIV1/LDIV2, and VSIV1/VIV2 are samples collected from amphitheatre - head inland valley (Am), valley-side inland valley (VS) and low-slope depression inland valley sites, respectively.

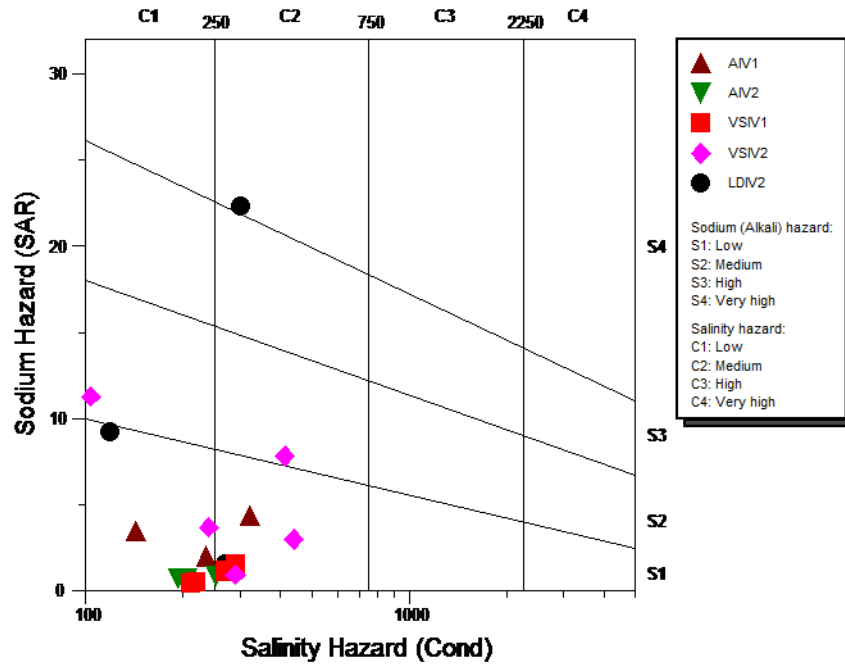


Figure 5. Classification of groundwater samples collected in the dry season with respect to salinity and sodium hazards. AIV1/AIV2, LDIV1/LDIV2, and VSV1/VSV2 are samples collected from amphitheatre - head inland valley (Am), valley-side inland valley (VS) and low-slope depression inland valley sites, respectively.

The soluble sodium percentage (%Na) of the groundwater ranged from 6.06 to 69.71%, 5.49 to 73.91%, 3.28 to 51.03%, 4.24 to 83.68%, 5.78 to 73.69% and 6.77 to 87.09% in Am1, Am2, VS1, VS2, LD1, and LD2, respectively. Based on the classification given by Wilcox (1955), 55.55%, 93.75%, 85%, 79.84%, 18.30%, and 30% of the groundwater samples fall within excellent and good with respect to usefulness for cropping in Am1, Am2, VS1, VS2, LD1, and LD2, respectively (Table 2).

The total dissolved solids (TDS) of the groundwater ranged from 16 to 261.76, 113.92 to 1957.12, 49.92 to 360.96, 49.28 to 376.32, 27.52 to

352.64 and 31.36 to 370.56 mg/L in sites Am1, Am2, VS1, VS2, LD1, and LD2, respectively. Higher values were recorded in the rainy season months than in the dry season months; and in the inland valleys located in the southern part of the study area (Am1, Am2, VS1, and VS2) than in those of the northern part (LD1 and LD2). According to the classification given by Robinove *et al.* (1958), the groundwater of the study area is mostly non-saline (99.1%) and is excellent for cropping (Table 3). This result is similar to those obtained by other research works around the study area.

Table 3. Classification of soluble sodium percentage (Na%) and total dissolved solids (TDS) in groundwater (extended from Fipps (2003) and Richards *et al.* (1954)).

Index	Classification	Range	% of Sample					
			Am1	Am2	VS1	VS2	LD1	LD2
EC (dS/m)	Low saline	Below 0.25 (Totally save)	66.7	43.8	35.0	50	62.2	60.0
	Moderately saline	0.25 - 0.75 (Save for all conditions)	33.3	43.8	65.0	50	37.5	40.0
	Medium to high salinity	0.75 - 2.25 (Save only with permeable soils and moderately leaching)	0	12.5	0	0	0	0
	High salinity	2.25 - 4.0 (Unsafe)	0	0	0	0	0	0
	Very high salinity	4.0 - 6.0 (Unsafe)	0	0	0	0	0	0
	Excessive salinity	Above 6.0 (Unsafe)	0	0	0	0	0	0
Total Dissolved Solids (mg/L)	Non saline	< 1000	100	100	100	100	100	100
	Slightly Saline	1000 - 3000	0	0	0	0	0	0
	Moderately saline	3000-10000	0	0	0	0	0	0
	Very saline	> 10000	0	0	0	0	0	0
SSP (%)	Excellent	< 20	44.4	75	40	16.7	6.25	10
	Good	20-40	11.1	18.8	45	54.2	12.5	20
	Permissible	40-60	33.3	6.25	15	12.5	37.5	25
	Doubtful	60-80	11.1	0	10	4.17	31.25	30
	Unsuitable	> 80	0	0	5	12.5	12.5	15

The permeability index (PI) is an important factor which influences quality of irrigation water in relation to soil. It is affected by the amount of sodium, calcium, magnesium, and bicarbonate content of irrigation water (Nagaraju *et al.*, 2006). Doneen (1964) developed a scheme for assessing the suitability of water for irrigation based on the permeability index. Waters classified as Class I and Class II are categorised as good for irrigation with 75% or more maximum permeability, while those classified as Class III are unsuitable with 25% of maximum permeability. For this study, sites Am1, Am2, VS1, VS2, LD1, and LD2 had 92.86%, 66.67%, 82.25%, 95%, 93.75%, and 90% of the groundwater samples falling within Class I and Class II PI index, suggesting that the groundwater of the study area is generally suitable for irrigation. This result is similar to those obtained by Talabi *et al.* (2014) in their studies in parts of southwest Nigeria; they found that the majority of the groundwater had PI Class II, with only a small percentage unsuitable for irrigation.

The mean values of Kelly's ratio (KR) obtained were 0.60, 0.39, 1.41, 0.94, 0.81, and 2.19 meq/L for Am1, Am2, VS1, VS2, LD1, and LD2, respectively. The lowest values were recorded in September and the highest in January. Following Kelly's (1963) classification, 77.78%, 93.75%, 85%, 79.17%, 68.75%, and 45% of the groundwater samples in sites Am1, Am2, VS1, VS2, LD1, and LD2 had Kelley's ratio below < 1. This suggests that the groundwater of the inland valleys is generally suitable for irrigation. The mean values of magnesium adsorption ratio (MAR) in the groundwater were 73.70, 50.08, 50.22, 60.35, 60.43, and 52.03 meq/L in Am1, Am2, VS1, VS2, LD1, and LD2, respectively. According to Raghunath (1987), MAR values > 50% are considered harmful and unsuitable for irrigation purposes. Based on this, 22.22%, 50%, 65%, 20.83%, 31.25%, and 60% of the groundwater samples in Am1, Am2, VS1, VS2, LD1, and LD2 inland valleys, respectively, fall above the acceptable limit. This suggests that the groundwater of some inland valleys may not be suitable for irrigation. This result is close to Odukoya *et al.* (2013) results, who found that 33% of groundwater samples had MAR less than 50%. However, the result differs from those of Talabi *et al.* (2014), who found that water samples were generally below the MAR value of 50%.

Suitability of water for the irrigation purpose is also influenced by the amount of carbonate and bicarbonate in water. Irrigating with water with high residual sodium bicarbonate (RSBC) can result in soil infertility due to deposition of sodium carbonate. Concentration of RSBC in the groundwater of the site ranged from -0.99 to 0.49, -1.69 to 0.31, -1.20 to 0.66, -1.19 to 0.33, -0.69 to 0.47, and -1.09 to 3.78 meq/L in Am1, Am2, VS1, VS2, LD1, and LD2, respectively. The lowest values occurred in September and the highest in January. The negative values of RSBC obtained for some of the water samples indicate that in these waters Na^+ build-up is unlikely due to sufficient available Ca^{2+} and Mg^{2+} in

excess of what can be precipitated as CO_3^{2-} and HCO_3^- (Talabi *et al.*, 2014). According to the classification given by Gupta and Gupta (1987), all the groundwater samples had RSBC below < 1.5, suggesting that the groundwater of the inland valleys can be considered safe for cropping purposes.

A comparative evaluation of the hydro-geochemistry for equality of distributions of water quality parameters/indices between the valley types using Mann-Whitney *U* tests (2-tailed) revealed that amphitheatre valley types Am1 and Am2 were not different significantly (Mann-Whitney *U* = 214, $n_1 = n_2 = 21$, $P < 0.88$). The same results of Mann-Whitney *U* = 180, $n_1 = n_2 = 21$, $P < 0.31$ and Mann-Whitney *U* = 218, $n_1 = n_2 = 21$, $P < 0.96$, were obtained for sites VS1 and VS2, and LD1 and LD2, respectively. Kruskal-Wallis H test (2-tailed) showed that there was no statistically significant difference in the distributions of hydro-geochemistry in all the sites, $P = 0.935$, with the mean rank hydrochemistry score of 59.62 for site Am1, 60.43 for site VS1, 61.81 for site Am2, 63.57 for site LD1, 64.76 for site LD2, and 70.81 for site VS2.

4 Conclusions

The study revealed that the cationic content of the groundwater of the inland valleys was generally low compared with the anionic content. The dominance structures of the major cations and anions were in the order of $\text{Na}^+ > \text{Ca}^{2+} > \text{K}^+ > \text{Mg}^{2+}$ and $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{CO}_3$, respectively. The pH indicates an acidic to alkaline water type. The concentration of heavy metals in the waters of the inland valleys of the study area were generally within the recommended limits and suitable for irrigated agriculture. The seasonal average values of EC ranged from 0.24 to 0.3 dS/m. The majority of the water samples fall within low saline to moderately saline water types and are rated to be generally safe for irrigational purpose. The results are comparable with those reported in the literature for areas around the study area.

The results also showed that the values of major water quality indices, i.e. sodium adsorption ratio, soluble sodium percentage, total dissolved solids, permeability index, magnesium adsorption ratio, Kelly's ratio, and residual sodium bicarbonate in the groundwater of the study area were generally within the levels suitable for agricultural utilisation. The evaluation of hydro-geochemistry for equality of distributions of water quality parameters/indices between the valley types revealed that amphitheatre, valley-side and low depression valley types were not significantly different (Mann-Whitney *U* = 214, $n_1 = n_2 = 21$, $P < 0.88$; Mann-Whitney *U* = 180, $n_1 = n_2 = 21$, $P < 0.31$ and Mann-Whitney *U* = 218, $n_1 = n_2 = 21$, $P < 0.96$, respectfully). In addition, Kruskal-Wallis H test (2-tailed) showed that there was no statistically significant difference in the distributions of hydro-geochemistry between the inland valley sites, $P = 0.935$, with the mean rank hydrochemistry

score of 59.62 for site Am1, 60.43 for site VS1, 61.81 for site Am2, 63.57 for site LD1, 64.76 for site LD2, and 70.81 for site VS2.

The study concluded that the groundwater of the inland valley agro-ecosystems of the study area was generally suitable for agricultural utilisation. The assessment of the dynamics of surface and the groundwater of the ecosystems as well as their morphological characterisation in relation to sustainable use for agriculture is recommended for further studies.

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Drėkinimui skirto gruntinio vandens kokybės įvertinimas pasirinktose toli nuo jūros esančio pietvakarių Nigerijos slėnio žemės ūkio ekosistemose

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Tyrimė buvo įvertinta gruntinio vandens kokybė šešiose toli nuo jūros esančiose (IV) žemės ūkio ekosistemose, siekiant nustatyti jo tinkamumą laukų apsodinimui pietvakarių Nigerijos savanoje. Vandens bandiniai buvo matuojami pjezometrais lietinguoju ir sausuoju sezonais, buvo analizuotos jų fiziocheminės savybės ir sunkiųjų metalų kiekiai. Vandens panaudojimo drėkinimo tikslams tinkamumui nustatyti buvo naudojami pagrindiniai vandens kokybės rodikliai ir jie buvo palyginti su priimtais standartais. Tyrimas parodė, kad vandens bandiniai įprastai buvo neutralūs arba lengvai šarminiai, o dominuojanti katijonų ir anijonų struktūra buvo tokios sekos $\text{Na}^+ > \text{Ca}^{2+} > \text{K}^+ > \text{Mg}^{2+}$ ir $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{CO}_3$. Sunkiųjų metalų koncentracijos reikšmės įprastai buvo tarp rekomenduojamų ribų daugumai pasėlių rūšių, auginamų tiriamojoje teritorijoje. Pagrindiniai vandens kokybės rodikliai (natrio adsorbcijos santykis, tirpaus natrio procentas, bendras ištirpusių dalelių rodiklis, dirvožemio pralaidumo rodiklis, magnio adsorbcijos santykis, Kelly's santykis ir likutinio natrio bikarbonato kiekis) įprastai buvo tarp pasėliams tinkamų ribų. Kruskal-Wallis H testas (dvikryptis) parodė, kad jokio statistiškai žymaus vandens kokybės parametru (rodikliu) skirtumo tarp toli nuo jūros esančių slėnių vietų nebuvo, kai $P = 0.935$. Nustatyta, kad gruntinis toli nuo jūros esančių slėnių žemės ūkio ekosistemų vanduo tiriamojoje teritorijoje buvo tinkamas žemės ūkio naudojimui.

Raktiniai žodžiai: *pietvakarių Nigerija, gruntinis vanduo, pelkė, žemės ūkis, vandens kokybės rodikliai.*