Ajayi Crowther Journal of Pure and Applied Sciences
https://acjpas.acu.edu.ng

Ajayi Crowther J. Pure Appl. Sci. 2023, 2(2), pp. 26-50.
https://doi.org/10.56534/acjpas.2023.02.02.26

Article

Hydrochemical and Health Risk Assessment of Groundwater of Ladigbolu and Ojongbodu in Oyo Town, Southwestern Nigeria

***Roland Anthony Isibor, Joseph Ayofe Aderogbin, Oyenike Olubola Ojo**

Department of Earth Sciences, Ajayi Crowther University, Oyo, Oyo State, Nigeria.
ra.isibor@acu.edu.ng (R.A.I.); ja.aderogbin@acu.edu.ng (J.A.A.); nikeojo717@gmail.com (O.O.O.)

* Correspondence: ra.isibor@acu.edu.ng

Article history: *received, May 1, 2023; revised, May 27, 2023; accepted, June 2, 2023; published: June 4, 2023.*

Abstract

Groundwater is the predominant source of drinking water in Oyo Town. Consequently, this work was designed to evaluate the concentration of some potentially toxic elements in the groundwater in order to determine its health risk and potability for human consumption. A total of 20 samples, 10 samples per area, were collected from boreholes at Ladigbolu and Ojongbodu areas of Oyo town during the dry season. Total Dissolved Solid (TDS), Conductivity, and pH of the samples were measured at the point of collection. Pb, Cd, Cr, Ni, Fe, Zn, Cu, Co, and Mn concentrations were determined using Fast Sequential Atomic Absorption Spectrophotometer. The Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} concentrations were measured using flame photometry while Spectrophotometer was employed to measure the concentrations of NO_3, SO_4^{2-}, Cl, $CO_3^{2-}$and HCO_3. The concentration of major cations and anions in ppm at Ladigbolu were in the order of Ca^{2+}> Na^{+}> Mg^{2+}>K^{+} and HCO_3^{-} > SO_4^{2-} >NO_3> Cl> CO_3, while at Ojongbodu the order was Ca^{2+}> Mg^{2+} >Na^{+} >K^{+} and HCO_3^{-} >SO_4^{2-}>NO_3> Cl> CO_3^{2}. The concentration of potentially toxic elements at Ladigbolu and Ojongbodu were in the order Fe > Mn > Cu > Cr > Pb > Zn > Ni > Co > Cd and Fe > Mn> Cu > Pb > Zn > Cr > Cu> Co > Cd respectively. The hydrogeochemical facies of the groundwater is dominantly $CaHCO_3$. Chronic Daily Iingestion (CDI) across all age groups was relatively low for the two communities. The hazardous quotient (HQ) was less than one (HQ <1) for Pb, Cu, Cr, Mn, Co, and Cd but greater than one (HQ >1) for Fe, Zn, and Ni which indicated potential health risk across all age groups in the two communities.

Keywords: Groundwater potability, Health risk, Chronic Daily Ingestion, Hazardous Quotient, Oyo town.

1. Introduction

Water is a valuable natural resource required for life to exist and sustain. Its unique chemical and physical properties and use by man make it a valuable natural resource. Groundwater, an essential component of the ecological and geological environment that exists in the microscopic pore spaces and fractures in rocks and sediments beneath the Earth's surface, is a reliable and unique source of water supply. Groundwater, a fairly well-distributed resource throughout the world has been estimated to account for about 98% of the world's freshwater [1] while it has been projected that nearly 30% of the world's population directly utilize groundwater resource for drinking, domestic, industrial and agricultural uses [2]. Consequently, groundwater influences daily living in most rural and urban areas in the world [3,4].

The quality of groundwater can be influenced and changed when subjected to natural geological conditions and various human activities [5]. Human existence and activities on Earth have led to the generation of various potentially toxic elements in the environment. Some of these elements such as zinc, iron, copper, chromium, and manganese are essential for the growth and healthy development of living organisms, although their presence in excess amounts may be toxic, while others such as cadmium, mercury, arsenic, and lead are categorized as non-essential and known to be very toxic to living organisms when ingested even at a very low concentration [6].

Several studies have shown a gradual deterioration in groundwater quality and its subsequent contamination resulting from urbanization, rapid increase in population, industrialization, agricultural, effluents discharge from domestic and animal wastes. Geological processes such as dissolution of host rock constituents have also been shown to contribute to heavy metals contamination of groundwater [7,8]. Studies carried out in various locations in the world have shown the contamination of groundwater with potentially toxic elements, such as Arsenic (As), Lead (Pb), Iron (Fe), Manganese (Mn), Cadmium (Cd), Copper (Cu), Mercury (Hg) and Chromium (Cr) [8-11].

Potentially toxic elements have been shown to be highly persistent and bioaccumulate in the tissues of biological organisms and when consumed above the permissible standard level can lead to lingering ailments such as kidney problems, high blood pressure, liver crisis, and skin irritations [12]. Potentially toxic elements have also been shown to cause poor growth and development, cancer, nervous system damage, metabolic interference, mutagenesis, and death [13].

In Nigeria, Urban areas are commonly characterized by high population density and auto congestion, high industrial activities, environmental pollution, and indiscriminate disposal of domestic and industrial waste [14]. Groundwater contamination has been reported in several parts of Nigeria due mainly to anthropogenic contributions. The municipal water supply in most cities in Nigeria is irregular, unreliable, and inadequate where available to a large proportion of the populace. Also, urban groundwater quality in most cities in Nigeria is under threats of pollution from different sources portending a danger of health hazard to consumers of untreated groundwater [14]. Untreated groundwater is the predominant source of drinking water and other domestic use by the inhabitants of Oyo Town because of the popular assumption in the area that groundwater is naturally portable for consumption. However, sources of pollution such as uncontrolled waste disposal sites, vehicular activities, and several local food processing industries exist at various locations around Oyo town.

Man is commonly exposed to heavy metal toxicity through the pathways of ingestion and dermal absorption [15]. The Hazardous Quotient (HQ) has been applied by several workers to assess the potential health risk associated with heavy metals exposure to various environmental media such as groundwater (15, 16] stream sediments [17], and stream water [17].

This study, therefore, evaluates the concentration levels of some potentially toxic elements in the groundwater of the study areas in order to determine the possible health risk associated with the consumption of the groundwater by calculating the various health risk parameters such as Chronic Daily Ingestion (CDI), Hazardous Quotient (HQ) and comparing results of the analytical tests with the permissible standard limits of World Health Organization (WHO) and Standard Organization of Nigeria (SON) for drinking water. Also, the hydrochemical facies of the groundwater was determined using the Piper Diagram.

2. Methods

2.1 Study Area

This study, involving water sampling, laboratory and data analysis, was carried out at Ladigbolu and Ojongbodu areas of Oyo town which lies between latitude 07^0 49′12″N and longitude 003^0 54′44″E to latitude 07^0 51′36″N and longitude 003^0 55′10″E within the crystalline basement complex of Southwestern Nigeria (Fig. 1). The area which is largely residential with such facilities as schools, markets, worship centers, mechanics workshops and pure water factories, is an undulating terrain with altitude ranging between 278m, and 322m above sea level. The drainage pattern influenced by relief is dendritic, with irregular branching of tributaries flowing down slope in the northwest and southwest direction. The area is within the transitional climatic zone between the southern rain forest and the tropical savannah climatic zone marked by mild forest with grasses and shrubs.

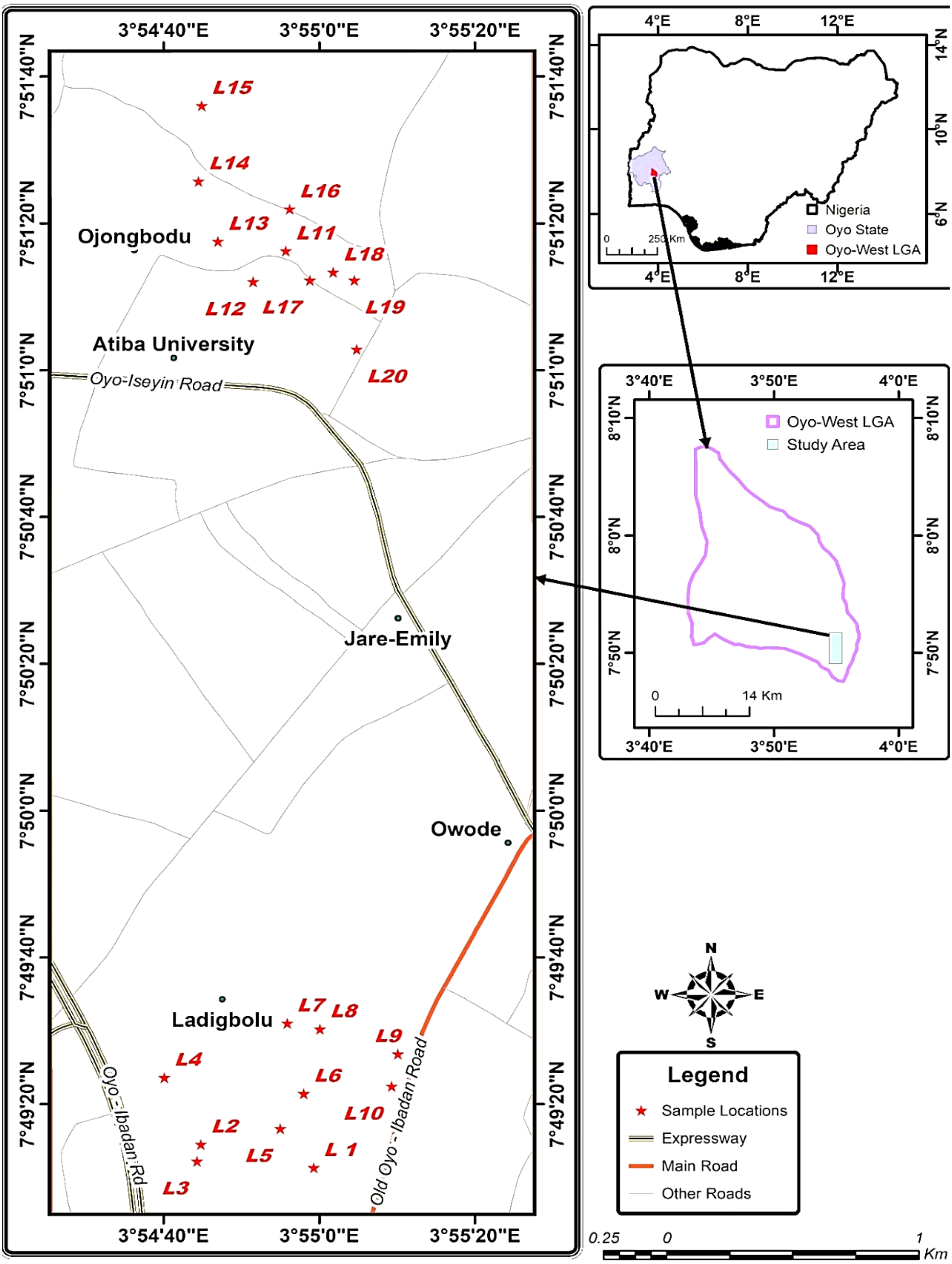

Figure 1: Location Map of the study area showing water sample points.

The study area falls within the basement complex of Southwest Nigeria which is made up mainly of Precambrian metamorphic rocks with some intrusions of granitic rocks [18,19]. Specifically, Ladigbolu and Ojongbodu areas of Oyo town are underlain by hornblende-biotite-granite-gneiss, pegmatite veins, variably migmatised undifferentiated biotite and biotite-hornblende-gneiss with intercalated amphibolite and schists.

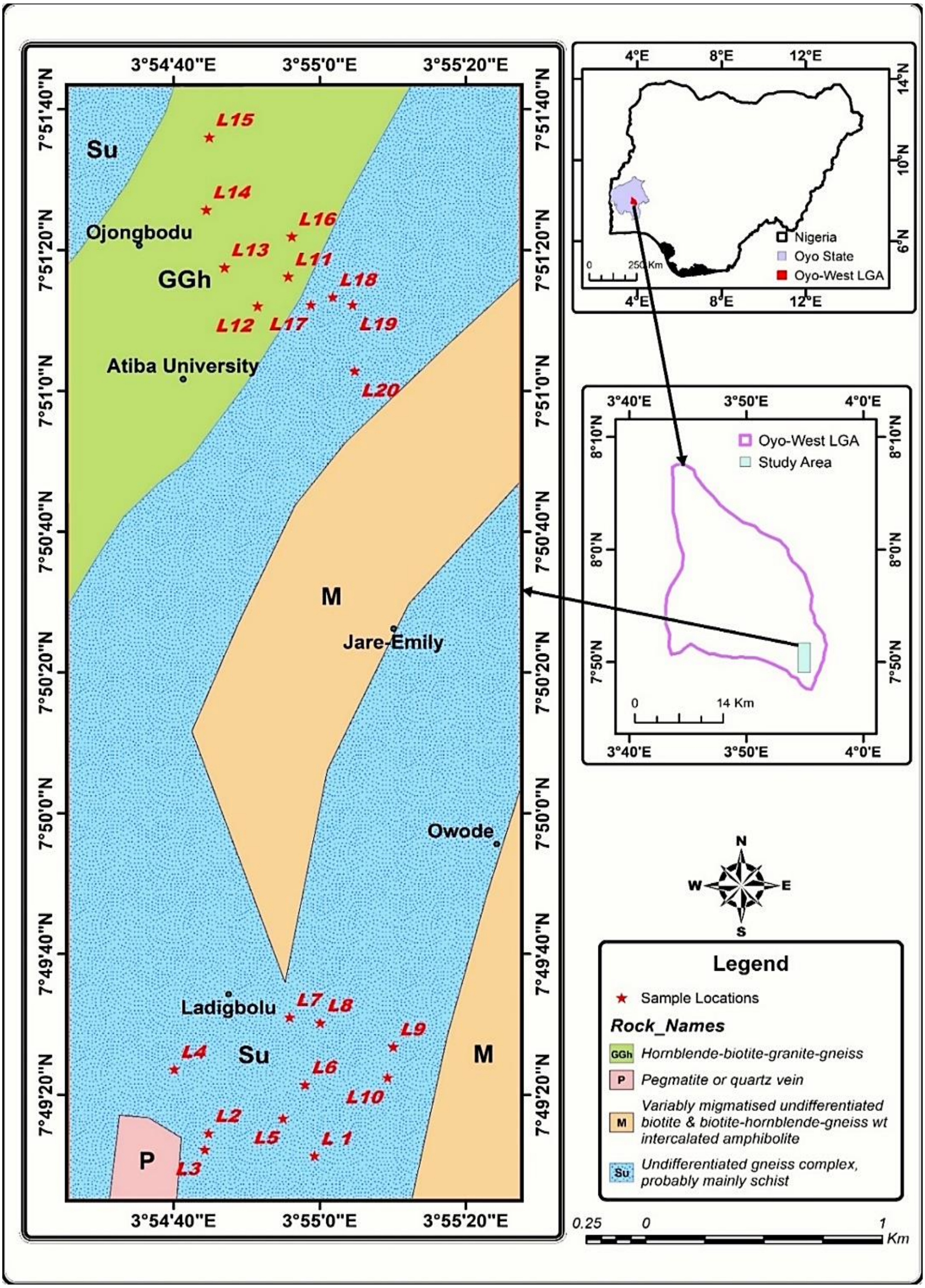

Figure 2: Geological map of the study area

2.2 Sample Collection

Plastic bottle (1 litre) was used for water collection on the field in line with World Health Organization (WHO) and Standard Organization of Nigeria (SON) recommendations. A total of 20

Samples were collected during the dry season from twenty (20) different boreholes in two different communities which are Ladigbolu (Samples 1-10) and Ojongbodu (Samples 11-20) areas of Oyo town at a distance of at least 45 meters between each sampled borehole. The water from the boreholes was allowed to run for a minimum of 20 minutes before collection. The plastic containers were rinsed thoroughly with each location borehole water before being filled and labeled accordingly.

The geographical coordinates of each sampled borehole were taken on the field with the aid of a Global Positioning System (GPS) device; Garmin 72 GPS. Sensitive parameters like Total Dissolve Solid (TDS), Electrical conductivity (EC), and pH of the water sampled that can change during transportation were measured at the point of collection and recorded. pH of the sampled water for each location were measured with a pocket Digital pH meter. The electrode of the pH meter was immersed in the water sample in such a way that the bulb at the tip of the electrode is covered completely by the water and the reading was obtained from the meter screen and recorded in the field note. The TDS was measured by the use of portable TDS meter, HM Digital COM-100, while an LF 95 WTW conductivity meter with its specified units were used for measuring the electrical conductivity of the sampled water.

2.3 Analytical Procedure

The qualitative analysis of the samples was carried out according to the analytical procedure for water and wastewater (APHA,1995) at SMO Laboratory Services Ibadan. office 5, Joyce B Office Complex, Joyce B Ibadan.

The concentration of heavy metals such as lead (Pb), iron (Fe), copper (Cu), nickel (Ni), cobalt (Co), cadmium (Cd), chromium (Cr), manganese (Mn) and Zinc (Zn) were carried out using Fast Sequential (FS Varian 2400 AAS) Atomic Absorption Spectrophotometer (AAS). Agilent FS2400AA has an accuracy level of 99.8% and precision of 97.6%. The samples were aspirated into the energy source of respective cathode of different metals. The concentration of the tested parameter was shown on the readout screen of the Atomic Absorption Spectrophotometer.

Flame photometry method was used to determine the concentration of calcium (Ca^{2+}) Magnesium (Mg^{2+}), Potassium (k^{+}) and Sodium (Na^{+}) in the water samples. Samples were aspirated into the flame through an inlet hose, in which the flame photometer has been calibrated by a series of known standards of the tested parameter; the concentration of the tested parameter will be displayed on the screen.

Spectrometry method was used to determine the concentration of major anions such as Nitrate (NO_3^-), Sulfate (SO_4^{2-}), Chloride (Cl^-), Carbonate (CO_3^{2-}) and Hydrogen carbonate (HCO_3^-), in the water samples. The parameter to be analyzed was selected by the test manager of the spectrometer. Two 10ml sample cells were filled with samples to be tested, and 1 pillow of the tested parameter was added to one of the samples in the sample cell and shaken. It was allowed to stay for a reaction time of between 5 to 10 minutes. The blank was then placed in the sample chamber to be calibrated or zeroed, then the second sample cell was placed in the chamber, and the concentration of the tested parameter in mg/l was displayed on the spectrometer screen.

The total hardness of the sampled water was determined by titration, using 0.01N di-sodium salt of EDTA solution (titrant). 50ml of the sample was pipette into a 250ml conical flask, 2ml of buffer solution was added to increase the pH of the sample to above 10.2 drops of solochrome black T indicator was added, the mixture was titrated against 0.01N EDTA until the endpoint reached. The titre valve was obtained and the total hardness was calculated thus:

Total Hardness in mg/L $CaCO_3$ = N × titre value × 1000/ ml sample

Where N is the normality of EDTA.

Total Alkalinity was done by titration, 50ml of the sample was pipette into a 250ml conical flask, and 2 drops of methyl orange indicator were added and titrated against 0.02N HCl acid (titrant) until the endpoint and attire valve was obtained and total alkalinity was calculated thus:

Total Alkalinity in mg/l $CaCO_3$ = N × titre value × 50,000/ ml sample.

Where N is the normality of HCl

The turbidity of the sampled water was determined using a spectrophotometer, and two 10ml sample bottles were filled with distilled water and sample respectively. The distilled water sample bottle was first placed in the sample chamber and the calibration button on the spectrophotometer was pressed to zero. Then the second sample bottle was placed in the sample chamber, and enter button was pressed, and the turbidity reading was displayed on the spectrophotometer screen and recorded accordingly.

2.4 Analysis of The Potential Health Risk

The potential health risk associated with the groundwater of the study area was determined by calculating the chronic daily ingestion and hazardous quotient parameters established in US Environmental Protection Agency [20] report.

The CDI was calculated in order to determine the extent, occurrence, and period of exposure to investigated metals in the study area (equation 1).

$$CDI = \frac{C \times DI \times ED \times EF}{BW \times AT} \quad \text{… equation (1)}$$

Where:

(i) Chronic Daily ingestion (CDI) signifies the average dose contacted through ingestion;

(ii) C is the concentration of metal (mg/l) in the water of the studied area,

(iii) DI denotes the daily intake rate or daily ingestion rate of water (2, 1, and 0.75 L/day for adults, children, and infants respectively [21].

(iv) ED represents the exposure duration (the life expectancy of a Nigerian resident as of the year 2022 which is 55 years)

(v) Exposure frequency to pollutants (EF) was taken as 365 days/1 year;

(vi) BW signifies the average body weight in kg; 60, 10, and 5 kg for adults, children, and infants respectively and

(vii) AT is the average time of exposure to the pollutants which is ED x EF [22], which is 55 years × 365 days which equals 20,075 days.

Using AT = EF × ED, then equation (1) becomes

$$CDI = \frac{C \times DI}{BW}$$

The hazardous quotient (HQ) in contaminated groundwater for cancer risk factors is evaluated by adopting the expression:

$$HQ = \frac{CDI}{RfD} \quad \text{… equation (2)}$$

The Chronic Daily Ingestion (CDI) and Reference Dose (RfD) are the means of the standard daily limits by WHO (World Health Organization) and SON (Standards Organization of Nigeria). The HQ value higher than 1 is the probability of cancer-causing impacts on human health. HQ value less than 1 shows that the consumption of groundwater would not have any consequence on the consumers [23].

3. Results and Discussion

The summary of the hydrochemical and physiochemical results for the groundwater of the study area are presented in Tables 1-6. At Ladigbolu area, the mean concentration value, in percentage, of Ca, Mg, Na, K, SO_4, HCO_3, Cl, NO_3, and CO_3 are 27.77, 11.56, 12.34, 8.11, 107.60, 12.20, 37.65, 3.22 and 0.00, respectively (Table 1), while at Ojongbodu area, the mean concentration of Ca, Mg, Na, K, HCO_3, SO_4, Cl, NO_3 and CO_3 are 53.93, 18.30, 12.09, 9.34, 196.40, 19.80, 44.45, 2.42 and 0.00. respectively (Table 2). The order of concentration of major cations showed that Ca>Na>Mg>K, while for the major anions HCO_3>Cl>SO_4>CO_3. This order is typical for the basement complex of Nigeria. For the potentially toxic elements (PTEs) in Ladigbolu area, the mean concentration value, in ppm, of Fe, Pb, Cu, Cr, Mn, Ni, Co, and Cd are 0.747, 0.010, 0.030, 0.012, 0.036, 0.010,0.004,0.003 and 0.002ppm respectively, while at Ojongbodu area, the mean concentration, in ppm, of Fe, Pb, Cu, Cr, Mn, Ni, Co and Cd are 0.702, 0.012,0.032, 0.010, 0.033, 0.010, 0.004, 0.004, 0.002ppm respectively (Table 3).

Table 1: Statistical Summary of the concentration of major ions at Ladigbolu area

Elements	Minimum	Maximum	Mean	Std. Deviation	Variance
Ca	20.82	31.21	27.77	3.11	9.676
Mg	8.01	16.59	11.56	2.22	4.929
Na	9.68	14.82	12.34	1.70	2.904
K	6.18	10.00	8.11	1.04	1.073
HCO_3	74.00	122.00	107.60	15.13788	229.156
SO_4	8.00	16.00	12.20	2.57337	6.622
Cl	29.11	41.88	37.65	3.63330	13.201
NO_3	1.90	4.82	3.22	1.03009	1.061
CO_3	0.00	0.00	0.00	0.00000	0.000

Table 2: Statistical Summary of the concentration of major ions at Ojongbodu

Elements	Minimum	Maximum	Mean	Std. Deviation	Variance
Ca	48.00	60.00	53.93	4.21634	17.778
Mg	13.73	20.59	18.30	1.86606	3.482
Na	10.84	14.12	12.09	1.15540	1.335
K	7.36	10.81	9.34	1.01599	1.032
HCO_3	140.00	224.00	196.40	23.37710	546.489
SO_4	10.00	26.00	19.80	5.02881	25.289
Cl	33.31	53.25	44.45	6.33084	40.080
NO_3	0.83	3.81	2.42	1.14399	1.309
CO_3	0.00	0.00	0.00	0.00000	0.000

Table 3: Statistical summary of the concentration of the potentially toxic elements in the study area

	LADIGBOLU				OJONGBODU			
Elements	**Min.**	**Max**	**Mean ± std**	**Variance**	**Min.**	**Max.**	**Mean ± std**	**Variance**
Fe	0.524	0.921	0.747±.135	0.018	0.563	0.819	0.702±.084	0.007
Pb	0.005	0.015	0.010±.003	0.00	0.007	0.014	0.012±.002	0.00
Cu	0.017	0.049	0.03 ±.012	0.000	0.020	0.052	0.032±.010	0.000
Cr	0.008	0.016	0.012±.003	0.000	0.006	0.015	0.010±.003	0.000
Mn	0.022	0.052	0.036±.009	0.000	0.023	0.042	0.033±.007	0.000
Zn	0.007	0.014	0.010±.002	0.000	0.006	0.016	0.010±.003	0.000
Ni	0.003	0.006	0.004±.001	0.000	0.003	0.006	0.004±.001	0.000
Co	0.003	0.004	0.003±.001	0.000	0.003	0.006	0.004±.001	0.000
Cd	0.002	0.003	0.002±.000	0.000	0.002	0.003	0.002±.000	0.000

Table 4: Statistical summary of the values of the physiochemical parameters at Ladigbolu

	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
pH	6.86	7.07	6.9900	0.06218	0.004
EC	120.00	300.00	212.0000	49.17090	2417.778
TDS	80.00	200.00	142.5000	32.68112	1068.056
Turbidity	0.00	0.04	0.0114	0.01482	0.000
TH	80.00	120.00	107.8000	13.24806	175.511
Alkalinity	74.00	122.00	107.6000	15.13788	229.156

Table 5: Statistical summary of the values the physiochemical parameters at Ojongbodu

	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
pH	6.91	7.11	7.0480	0.06408	0.004
EC	230.00	320.00	278.0000	26.58320	706.667
TDS	155.00	215.00	187.0000	17.98147	323.333
Turbidity	0.00	0.04	0.0140	0.01506	0.000
TH	168.00	220.00	198.8000	15.75366	248.178
Alkalinity	140.00	224.00	196.4000	23.37710	546.489

The mean concentration of the potentially toxic elements of the sampled borehole water (Table 6) was compared with standard permissible limits for drinking water of WHO [24], SON [25].

Table 6: Comparison of the potentially toxic elements of the study area with the WHO and SON drinking water standard.

Toxic elements	**Ladigbolu**	**Ojongbodu**	**WHO (2017)**	**SON (2007)**
Fe	0.747	0.702	0.030	0.030
Pb	0.010	0.012	0.010	0.010
Cu	0.030	0.032	2.000	1.000
Cr	0.012	0.010	0.050	0.050
Mn	0.036	0.033	0.200	0.200
Zn	0.010	0.010	3.000	3.000
Ni	0.004	0.004	0.020	0.020
Co	0.003	0.004	0.010	0.010
Cd	0.002	0.002	0.003	0.003

The Fe content with a mean concentration value of 0.747 was the only element with values above the standard permissible limits (0.03) for drinking water at Ladigbolu while the mean concentration of Fe and Pb were above permissible limit (0.03 and 0.01ppm) at Ojongbodu with mean concentration values of 0.702 and 0.012 respectively (Tables 6).

In the study areas, NO_3, Cl, SO_4, and NO_3 and Ca were within the permissible limits for drinking water. However, the concentrations of Mg, Na and K were higher than the permissible limits for the two communities. (Figs. 3 and 4).

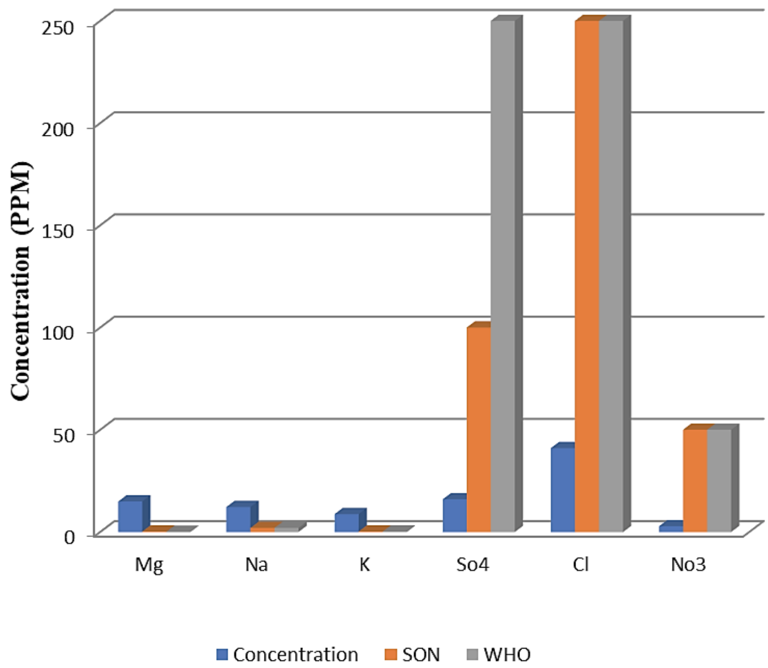

Figure 3: Chart of the concentration of the major ions in the groundwater at Ladigbolu compared with WHO and SON permissible limits.

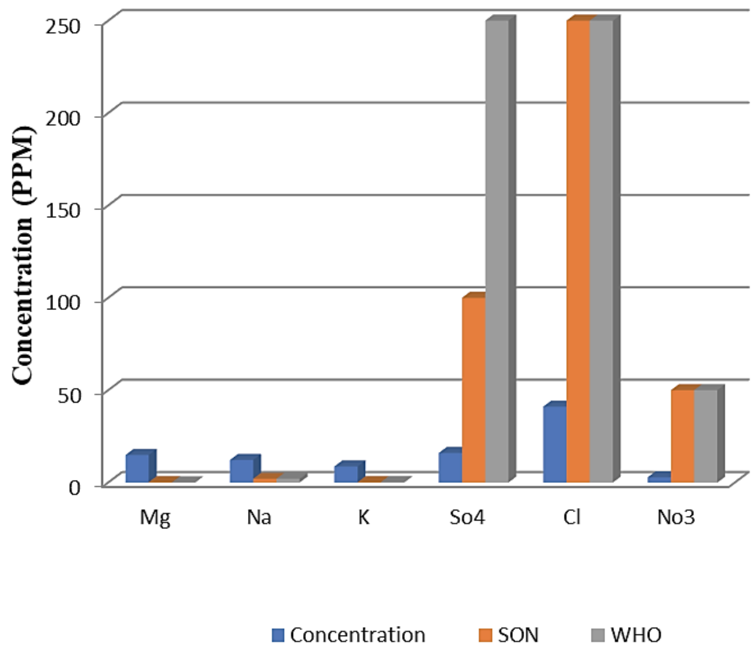

Figure 4: Chart of the concentration of the major ions in the groundwater at Ojongbodu compared with WHO and SON permissible limits.

The pH, EC, TDS, Turbidity and TH were within the standard permissible limit for both Ladigbolu and Ojongbodu areas (Figs 5 and 6).

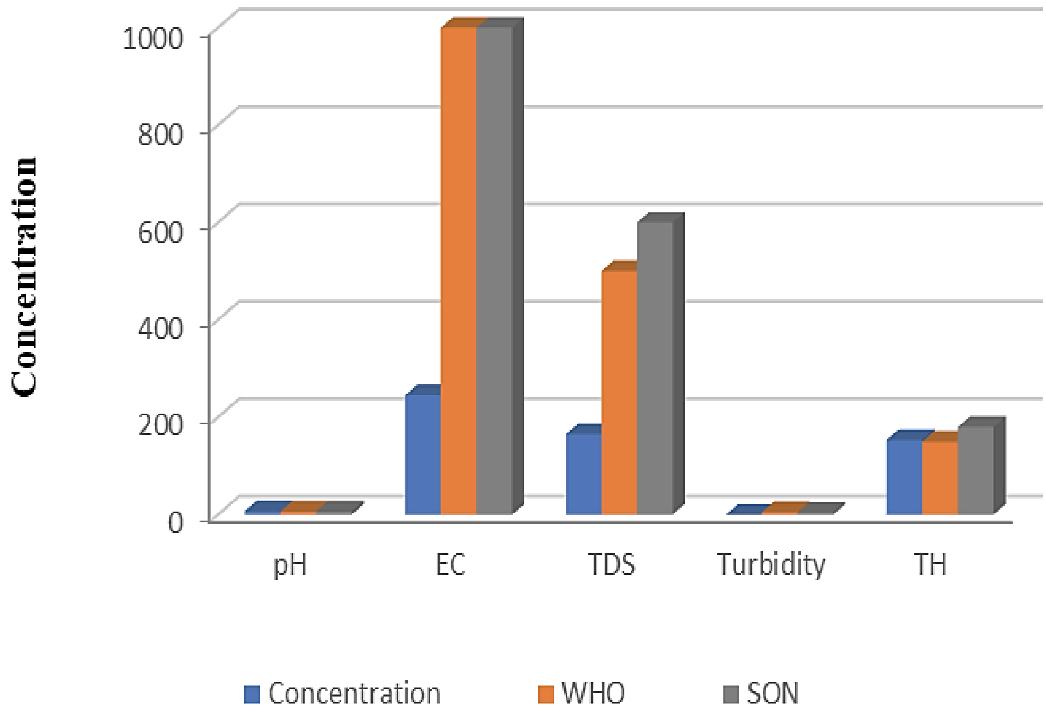

Figure 5: Chart showing the concentration of physiochemical parameters at Ladigbolu compared with WHO and SON permissible limits for drinking water.

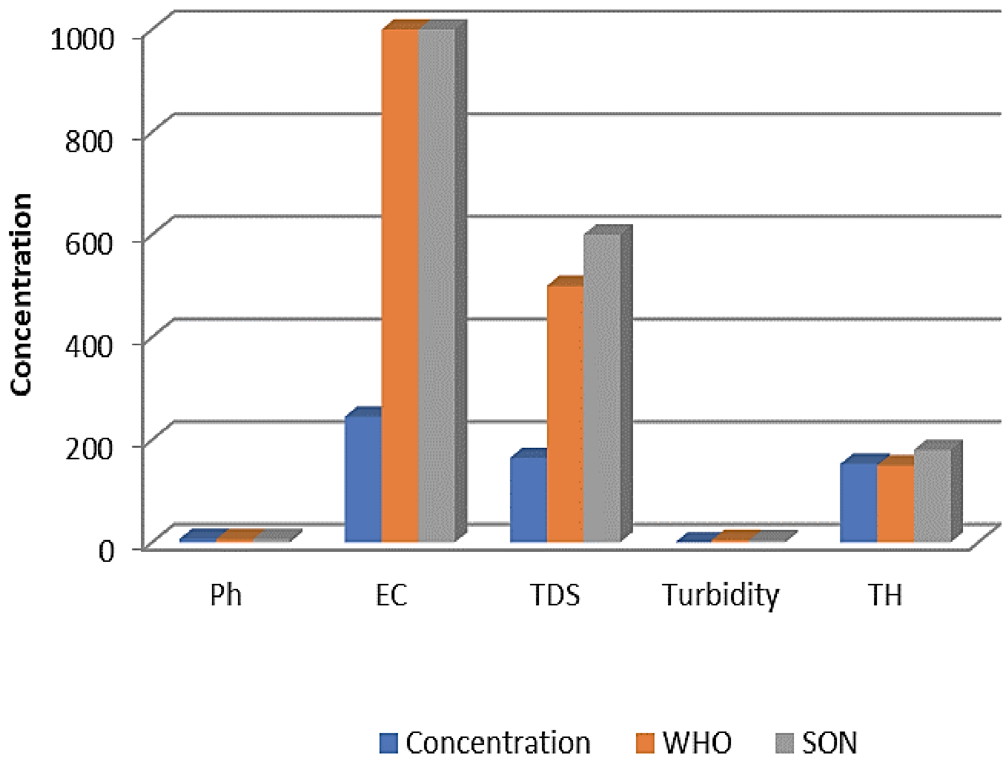

Figure 6: Chart showing the concentration of physiochemical parameters at Ojongbodu compared with WHO and SON permissible limits for drinking water.

3.1. Hydrogeochemical Facies of the Study Area

Hydrogeochemical facies describes the distribution and genesis of principal groundwater types [26]. The facies also provide information on progressive ion enrichment during the residence time of water in the subsurface and the extent of rock-water interaction [27]. The Piper diagram is a graphical representation of the classification of natural waters [28]. The diagram is made up of two triangles, one for plotting cations and the other for plotting anions. The cations and anion field are combined to show or represent the total ionic concentration in a diamond-shaped field, from which inferences are drawn on the basis of the hydrogeochemical facies concept [29]. Calcium, Sodium, and Carbonate enrichment in groundwater is commonly attributed to the dissolution of aluminosilicate minerals of mostly feldspar-rich bedrocks by CO_2-stimulated groundwater [30].

The Hydrogeochemical facies of the groundwater as shown from the piper plot of the sampled groundwater (Fig 7) showed a single major water type Ca-HCO_3 for both Ojongbodu and Ladigbolu areas with Ca and HCO_3 being the major ions indicating dissolution of mineral constituents of the rock or aquifer zone as the dominant process responsible for the ions in the groundwater [31].

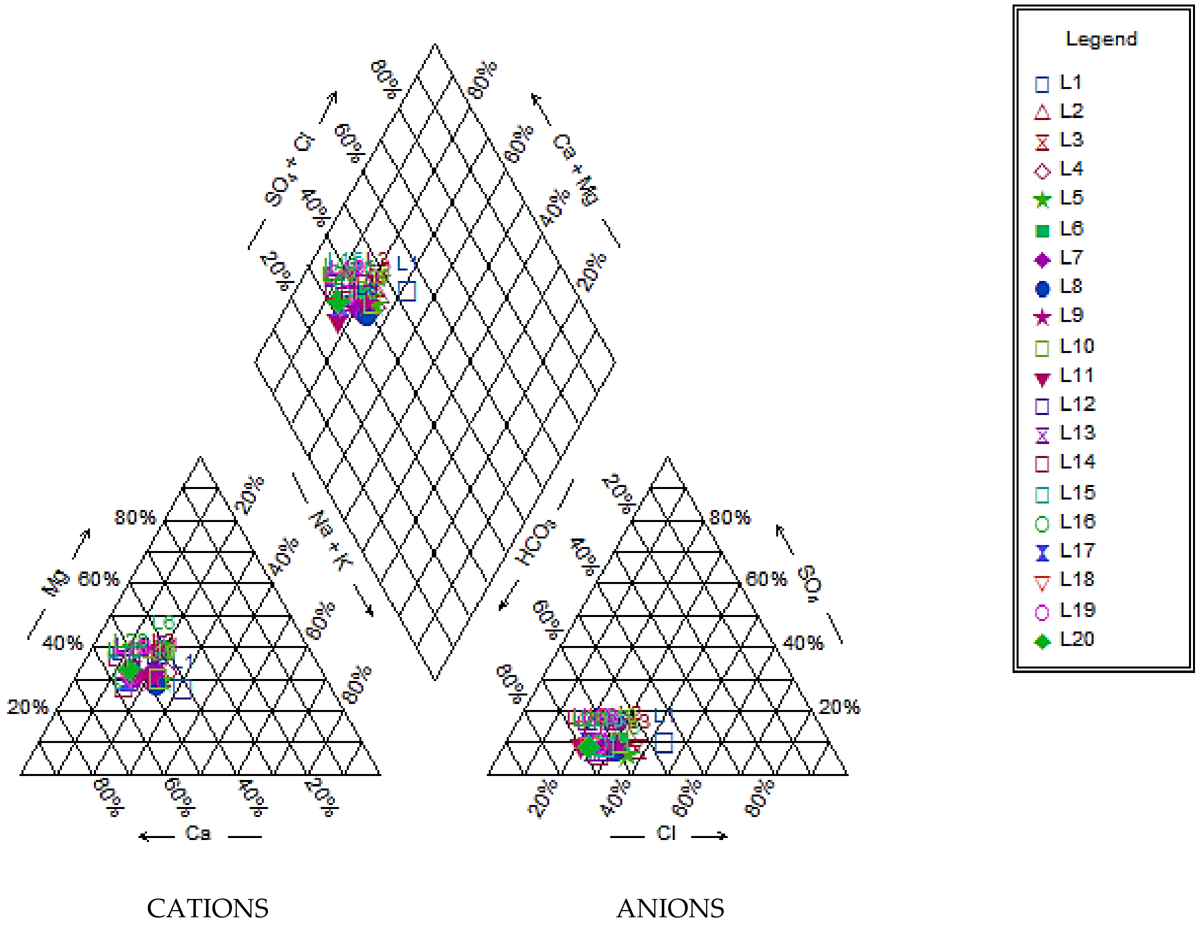

Figure 7: Piper diagram showing hydrochemical facies of groundwater of the study area.

3.2 Health Risk Assessment

The chronic daily ingestion (CDI) assessment across three different age groups (Adult, Children and Infants) in the study area is presented in Tables 7 - 9. The average chronic daily ingestion (CDI) of the studied elements showed that Fe is the most ingestible elements in infants and children; 0.112035mg^{-1} Kg^{-1} day^{-1} bodyweight^{-1} and 0.07469 mg^{-1} Kg^{-1} day^{-1} bodyweight^{-1}, respectively, at Ladigbolu and 0.105345mg^{-1} Kg^{-1} day^{-1} bodyweight^{-1} and 0.07023 mg^{-1} Kg^{-1} day^{-1} bodyweight^{-1} at Ojongbodu respectively, while Cd is the most ingestible for adult with a value of 5.36 at both communities.

Table 7: Statistical analysis of calculated/ assessed CDI for Adult at the study area

Area	N	Elements	Minimum	Maximum	Mean
Ladigbolu	10	Fe	0.01747	0.03057	0.02744
Ladigbolu	10	Pb	0.00017	0.0005	0.00032
Ladigbolu	10	Cu	0.00057	0.00163	0.00112
Ladigbolu	10	Cr	0.00027	0.00053	0.0004
Ladigbolu	10	Mn	0.00073	0.00173	0.00118
Ladigbolu	10	Zn	0.00023	0.00047	0.000346
Ladigbolu	10	Ni	0.0001	0.0002	0.000134
Ladigbolu	10	Co	0.0001	0.00013	0.000109
Ladigbolu	10	Cd	0.0001	6.7E-05	5.36002
Ojongbodu	10	Fe	0.01877	0.02683	0.2341
Ojongbodu	10	Pb	0.00023	0.00047	0.00035
Ojongbodu	10	Cu	0.00067	0.00173	0.0008937
Ojongbodu	10	Cr	0.0002	0.0050	0.000329
Ojongbodu	10	Mn	0.00077	0.0013	0.001080
Ojongbodu	10	Zn	0.0002	0.00053	0.000321
Ojongbodu	10	Ni	0.0001	0.0002	0.00013
Ojongbodu	10	Co	0.0001	0.0002	0.00012
Ojongbodu	10	Cd	0.0001	6.7E-05	5.36002

Table 8: Statistical analysis of calculated/ assessed CDI for Children at the study area

Area	N	Elements	Minimum	Maximum	Mean
Ladigbolu	10	Fe	0.0524	0.0917	0.07469
Ladigbolu	10	Pb	0.0007	0.0015	0.00096
Ladigbolu	10	Cu	0.0017	0.0049	0.00336
Ladigbolu	10	Cr	0.0008	0.0016	0.0012
Ladigbolu	10	Mn	0.0022	0.0052	0.00356
Ladigbolu	10	Zn	0.0007	0.00014	0.000104
Ladigbolu	10	Ni	0.0003	0.0006	0.0004
Ladigbolu	10	Co	0.0003	0.0004	0.00033
Ladigbolu	10	Cd	0.0002	0.0003	0.00022
Ojongbodu	10	Fe	0.0786	0.0819	0.07023
Ojongbodu	10	Pb	0.007	0.0014	0.00107
Ojongbodu	10	Cu	0.002	0.0052	0.00305
Ojongbodu	10	Cr	0.0006	0.0015	0.00104
Ojongbodu	10	Mn	0.0023	0.0042	0.00325
Ojongbodu	10	Zn	0.0006	0.0016	0.00098
Ojongbodu	10	Ni	0.0003	0.0006	0.004
Ojongbodu	10	Co	0.0003	0.0006	0.00036
Ojongbodu	10	Cd	0.0002	0.0003	0.00021

Table 9: Statistical analysis of calculated/assessed CDI for Infants at the study area

Area	N	Elements	Minimum	Maximum	Mean
Ladigbolu	10	Fe	0.0786	0.13815	0.112035
Ladigbolu	10	Pb	0.00075	0.00225	0.00144
Ladigbolu	10	Cu	0.000255	0.00735	0.00504
Ladigbolu	10	Cr	0.0012	0.0024	0.0018
Ladigbolu	10	Mn	0.0033	0.0078	0.00534
Ladigbolu	10	Zn	0.00105	0.0021	0.00156
Ladigbolu	10	Ni	0.00045	0.0009	0.0006
Ladigbolu	10	Co	0.00045	0.0006	0.000495
Ladigbolu	10	Cd	0.0002	0.0003	0.0003
Ojongbodu	10	Fe	0.08445	0.12075	0.105345
Ojongbodu	10	Pb	0.00105	0.0021	0.001605
Ojongbodu	10	Cu	0.003	0.0078	0.004575
Ojongbodu	10	Cr	0.0009	0.00225	0.00156
Ojongbodu	10	Mn	0.00345	0.0063	0.004875
Ojongbodu	10	Zn	0.0009	0.0024	0.00147
Ojongbodu	10	Ni	0.00045	0.0009	0.0006
Ojongbodu	10	Co	0.00045	0.00075	0.000495
Ojongbodu	10	Cd	0.0002	0.0003	0.000315

The average hazardous quotients (HQ) obtained in the analyzed groundwater samples across the different age group (Table 10) showed that Ni and Zn have values, 1.2585013 and 1.555086, which are greater than 1(HQ>1) for adult while Fe for children (2.41057) and infants (3.623) has hazardous quotients greater than 1 (HQ>1) indicating possible negative health effects. However, the HQ values for Pb, Cu, Cr, Mn, Co and Cd were found to be less than one (HQ<1) across different age groups of the study area.

Table 10: Statistical analyses of assessed hazardous quotient (HQ) across age groups of the study area.

Age groups	Elements	N	Minimum	Maximum	Mean
Adult	Fe	20	0.077	1.0233	0.770
Children	Fe	20	1.7466	3.0566	2.411
Infants	Fe	20	2.69	4.605	3.623
Adult	Pb	20	0.0167	0.0467	0.032665
Children	Pb	20	0.05	0.15	0.1015
Infants	Pb	20	0.0105	0.615	0.262425
Adult	Cu	20	0.00057	0.00733	0.0016985
Children	Cu	20	0.00057	0.00733	0.0016985
Infants	Cu	20	0.00255	0.00705	0.0045983
Adults	Cr	20	0.004	0.106	0.0122625
Children	Cr	20	0.012	0.03	0.021401

Infants	Cr	20	0.018	0.048	0.0336
Adults	Mn	20	0.00087	0.0087	0.00787
Children	Mn	20	0.011	0.0195	0.017025
Infants	Mn	20	0.0165	0.03525	0.0255375
Adults	Zn	20	0.0001	8.9E-05	1.555086
Children	Zn	20	0.0002	0.0005	0.00032415
Infants	Zn	20	0.00035	0.008	0.000865
Adults	Ni	20	0.000002	3.34E-05	1.2585013
Children	Ni	20	0.015	0.03	0.02025
Infants	Ni	20	0.0225	0.045	0.040125
Adults	Co	20	0.01	0.0167	0.011495
Children	Co	20	0.03	0.06	0.036
Infants	Co	20	0.045	0.075	0.052
Adults	Cd	20	0.02222	0.0333	0.0238865
Children	Cd	20	0.0667	0.1	0.0671695
Infants	Cd	20	0.1	0.15	0.1075

The concentrations of Cu, Cr, Mn, Zn, Ni, Co and Cd in the area wer below the permissible standard limits and therefore constitute no health risk. However, the concentrations of Fe and Pb exceeded the standard permissible limit and constitute a potential health risk.

The mean concentration value of Fe obtained at Ladigbolu (0.747 ppm) and Ojongbodu (0.702 ppm) are higher than the permissible drinking water standard limit (0.03 ppm). Water containing very high concentration of iron has been reported to constitute a human health hazard leading to hemochromatosis, whose signs include fatigue and eventually heart disease, liver complications, and diabetes [32]. Excessive intake of iron can also cause a serious unfavorably susceptible response such as rashes, hives, tingling, fatigue, diabetes, joint and abdominal pain, trouble in breathing, snugness in the chest, loss of sex drive and impotence [32].

The mean concentration of Pb in Ojongbodu (0.012 ppm) is higher than the standard permissible limit (0.010 ppm). High ingestion of lead can cause anemia, weakness, abdominal pain, constipation, headache, inability to have children, kidney and brain damage and even death.

3.3 Distribution Patterns

The distribution patterns of the studied elements in the groundwater are presented in figures 8 to 16. The concentration of Fe is highest at locations L3, L4, L5, L7, L9, L11, L14, L15 and lowest at location L20 while Pb is highest at locations L 9, L10, L18 and lowest at locations L2, L3. The concentration of Cu is highest at locations L5, L9, L15 and lowest at locations L4, L12, L18, and L20 while the concentration of Cr is highest at locations L2, L5, L15, L16 and lowest at L12, L18, L19. The concentration of Mn is highest at L2, L4, L15 and lowest at locations L5, L6, L8, L12, L18, L19 while concentration of Zn is highest at locations L15 and lowest at location L10, L13, L18. The concentration of Ni is highest at locations L5, L11 and lowest at locations L1, L2, L4, L6, L10 and lowest at L12, L14, L17, L18 while the concentration of Co is highest at location 15 and lowest at locations L1, L2, L 4, L5, L6, L8, L10, L12, L13, L16, L17, L18, L19, L20 while concentration of Cd is highest at locations L4, L7, L15 and lowest at 2, 3, 5, 6, 8, 9, 10, 11,12,13,14, 16, 17, 18, 19, 20.

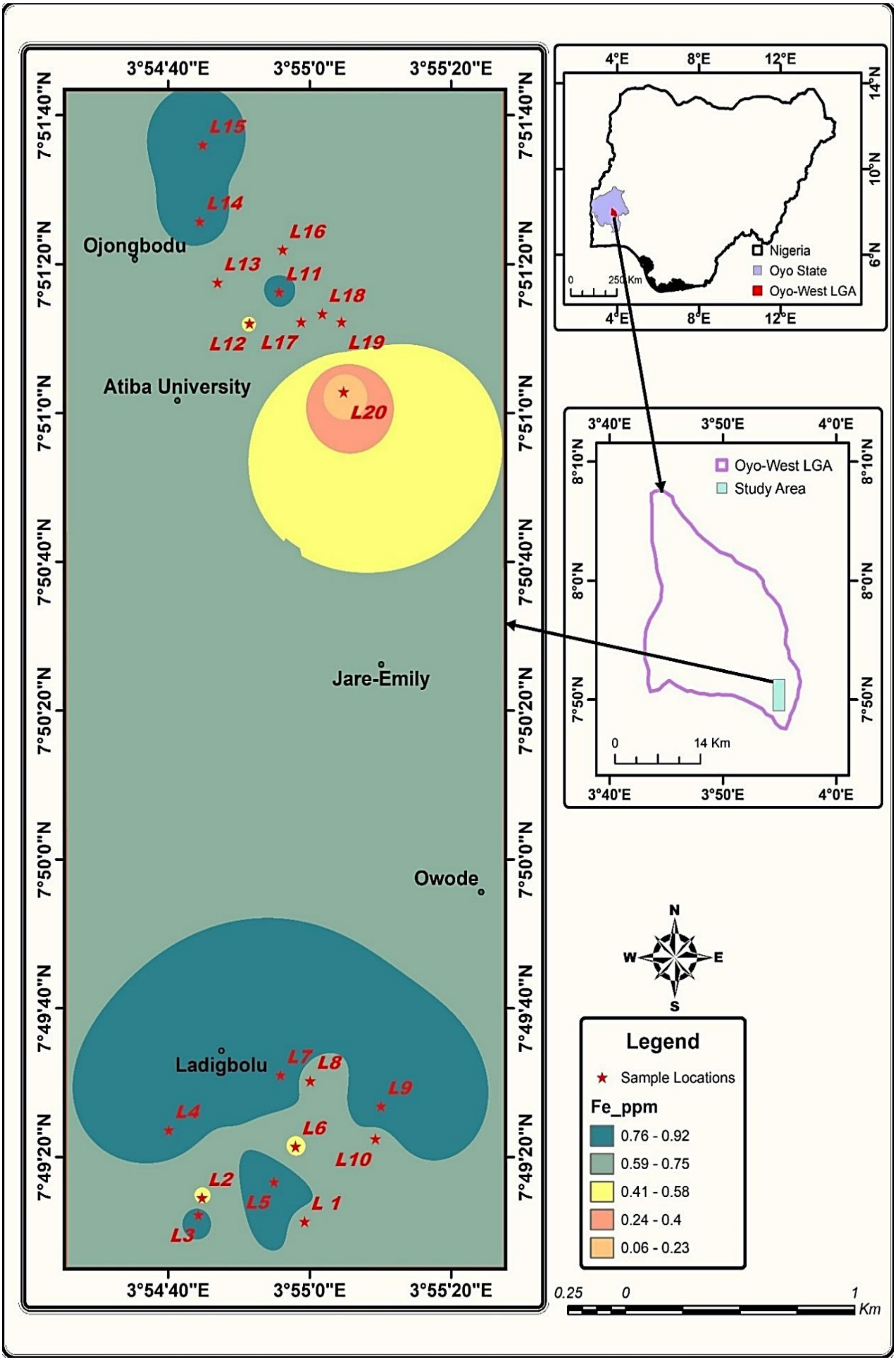

Figure 8: Thematic map of dissolved Iron (Fe) in groundwater in the study area

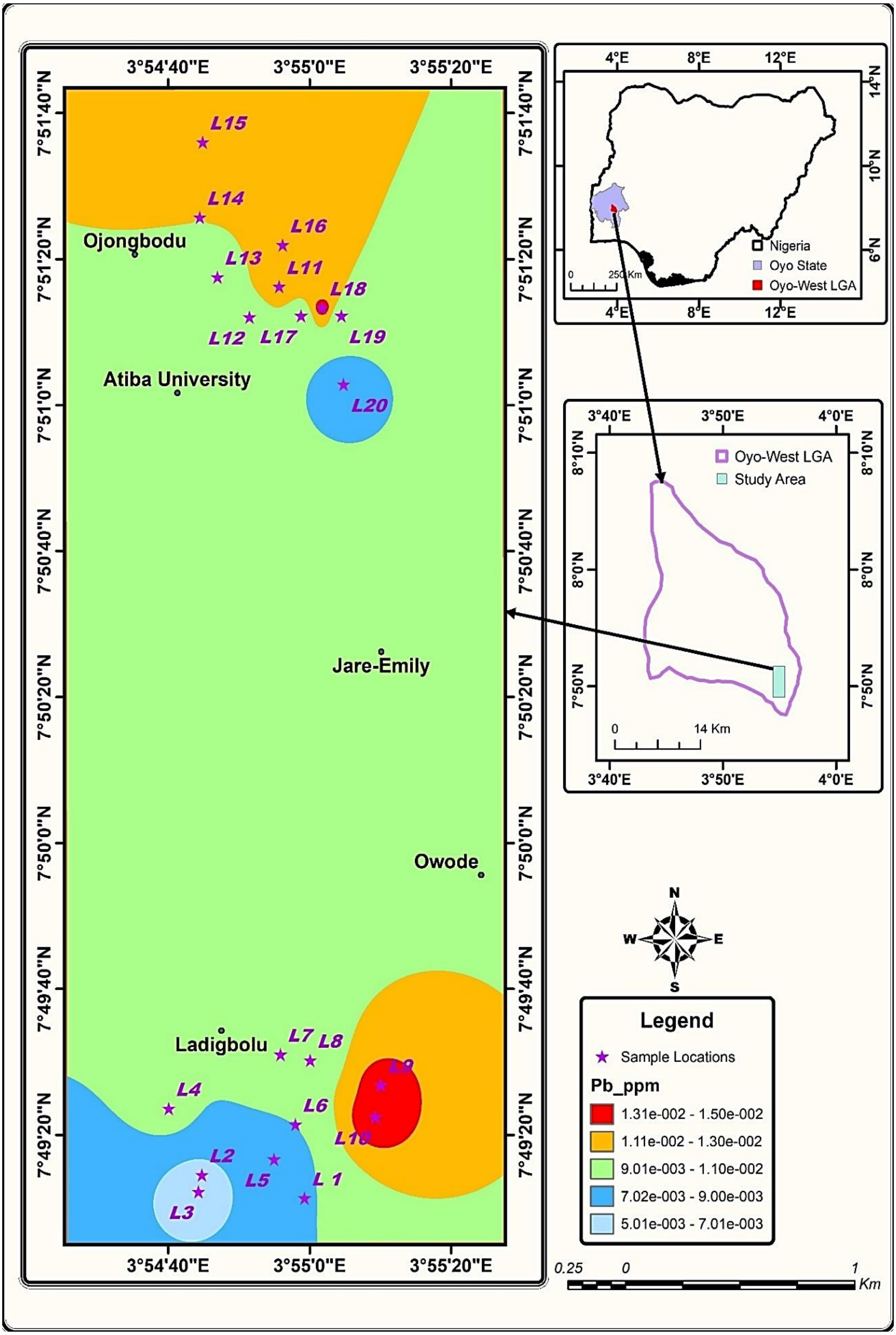

Figure 9: Thematic map of dissolved Lead (Pb) in groundwater in the study area

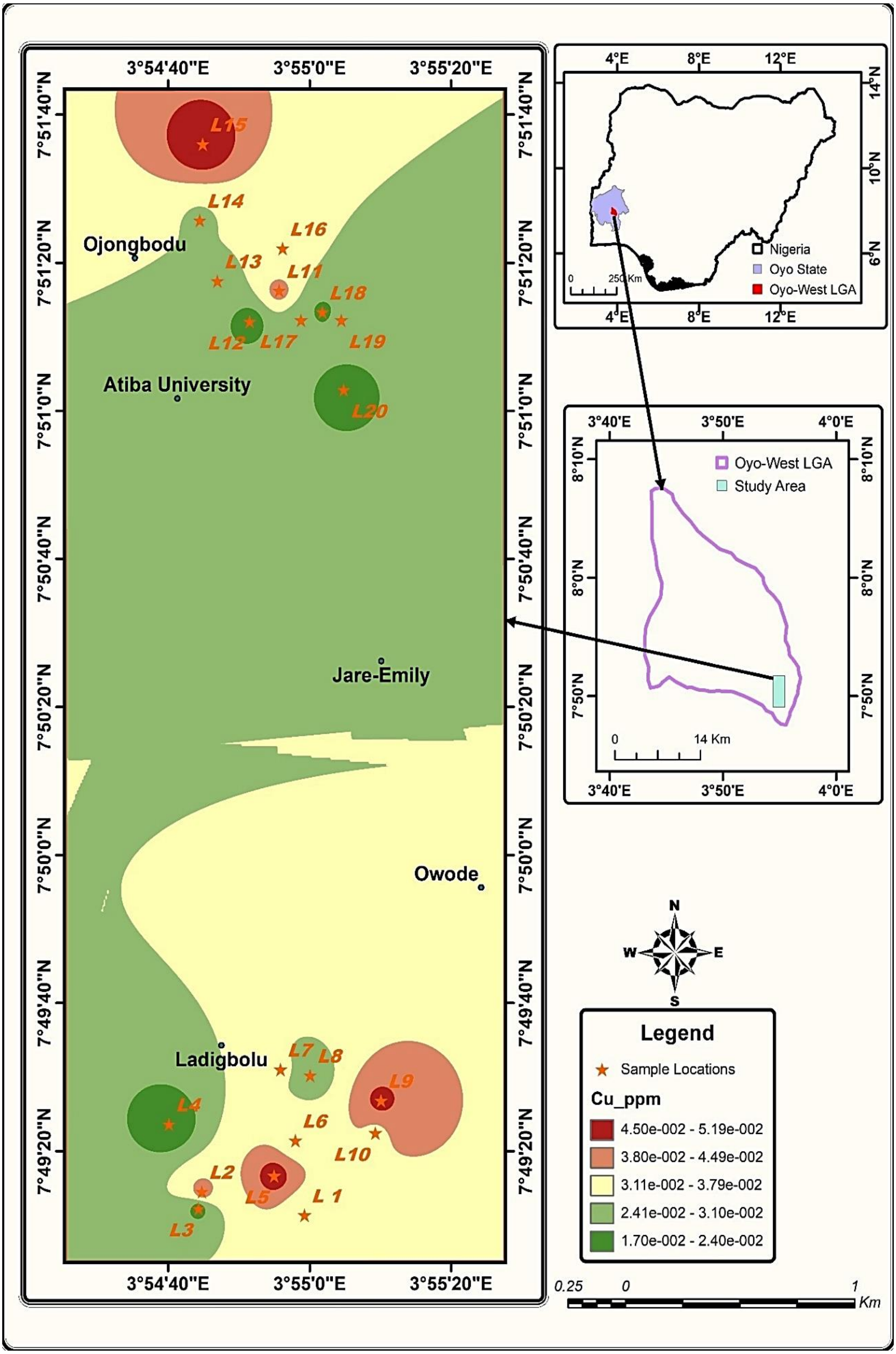

Figure 10: Thematic map of dissolved Copper (Cu) in groundwater in the study area

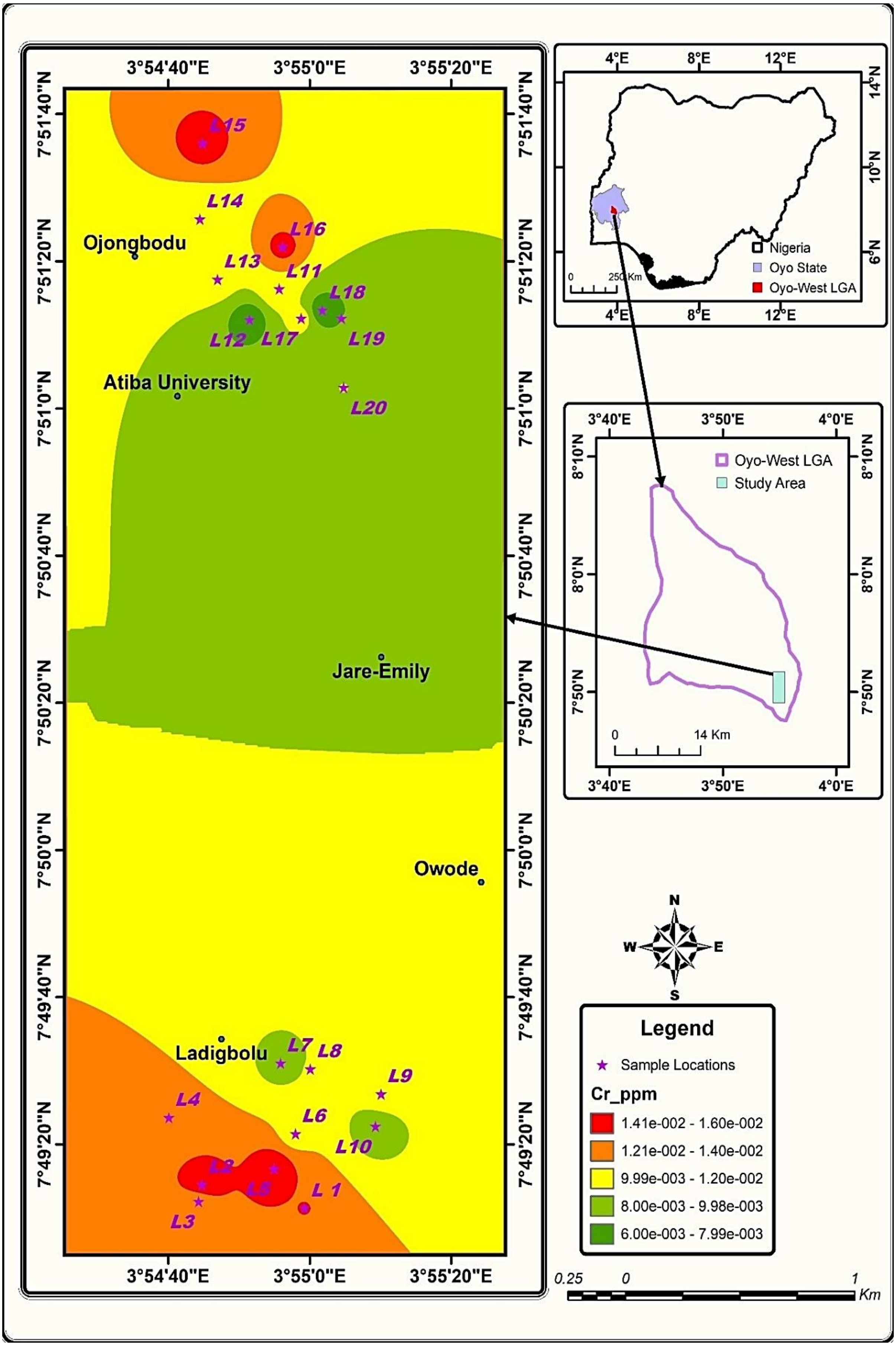

Figure 11: Thematic map of dissolved Chromium (Cr) in groundwater in the study area

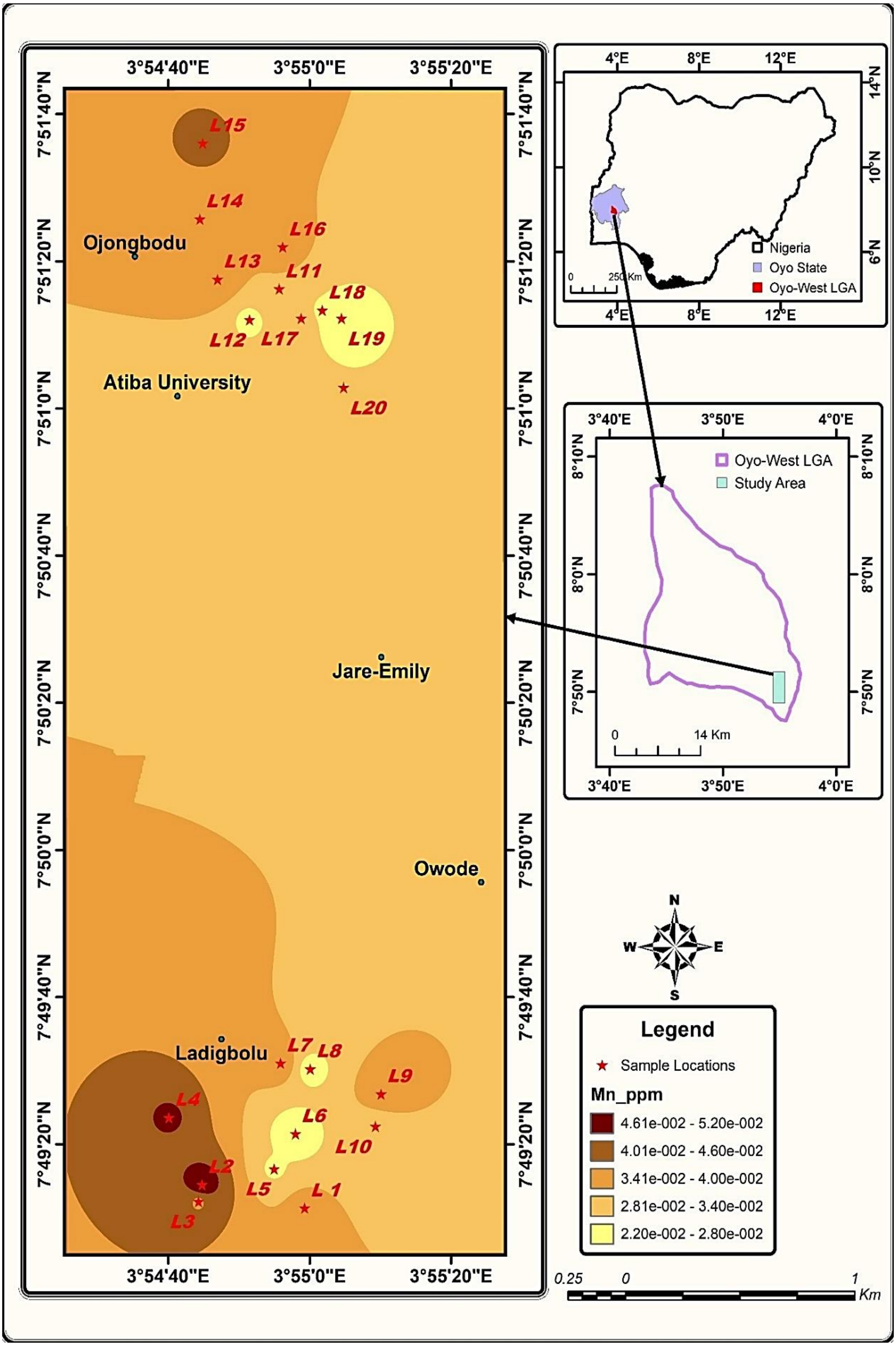

Figure 12: Thematic map of dissolved Manganese (Mn) in groundwater in the study area

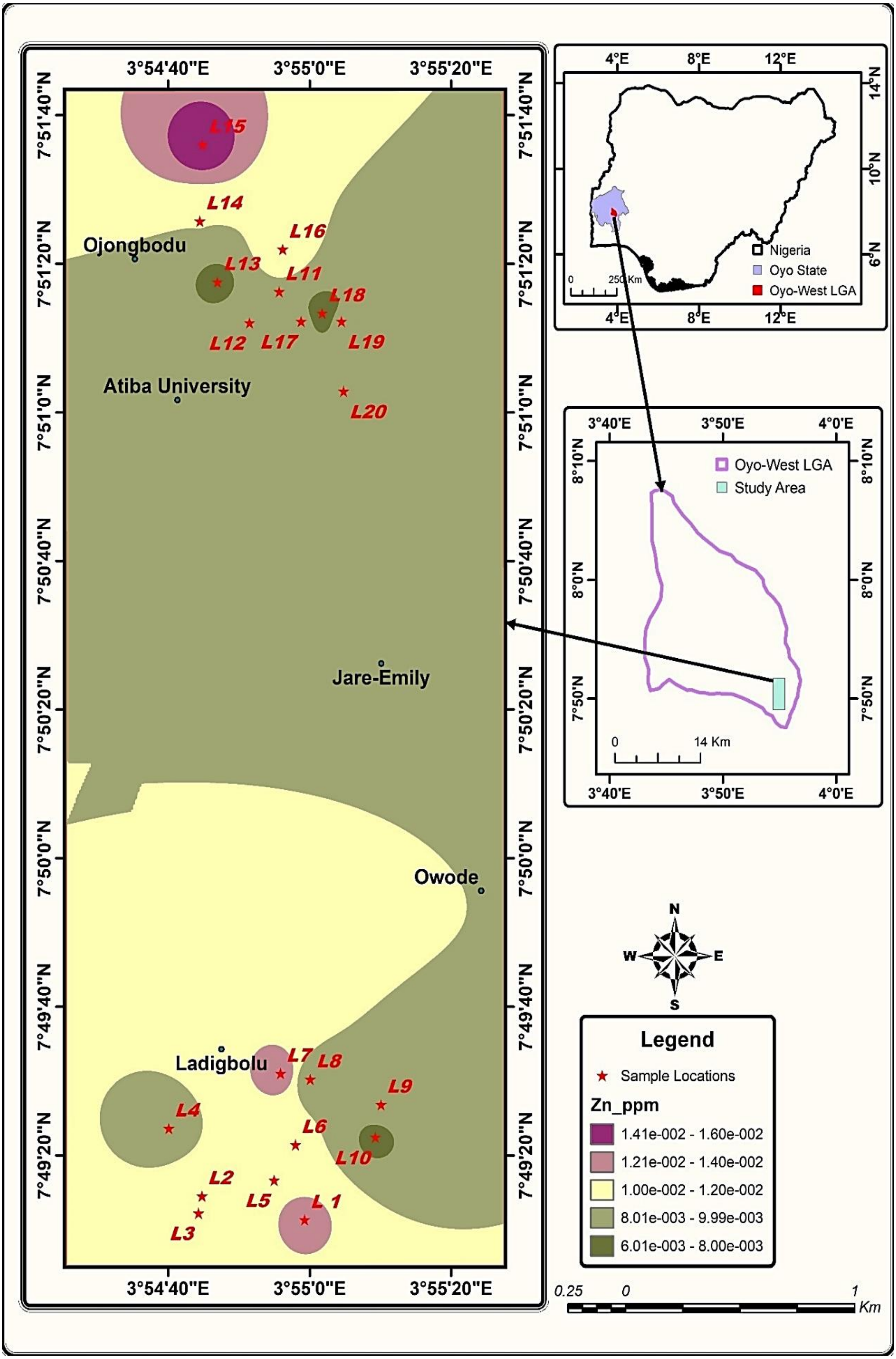

Figure 13: Thematic map of dissolved Zinc (Zn) in groundwater in the study area

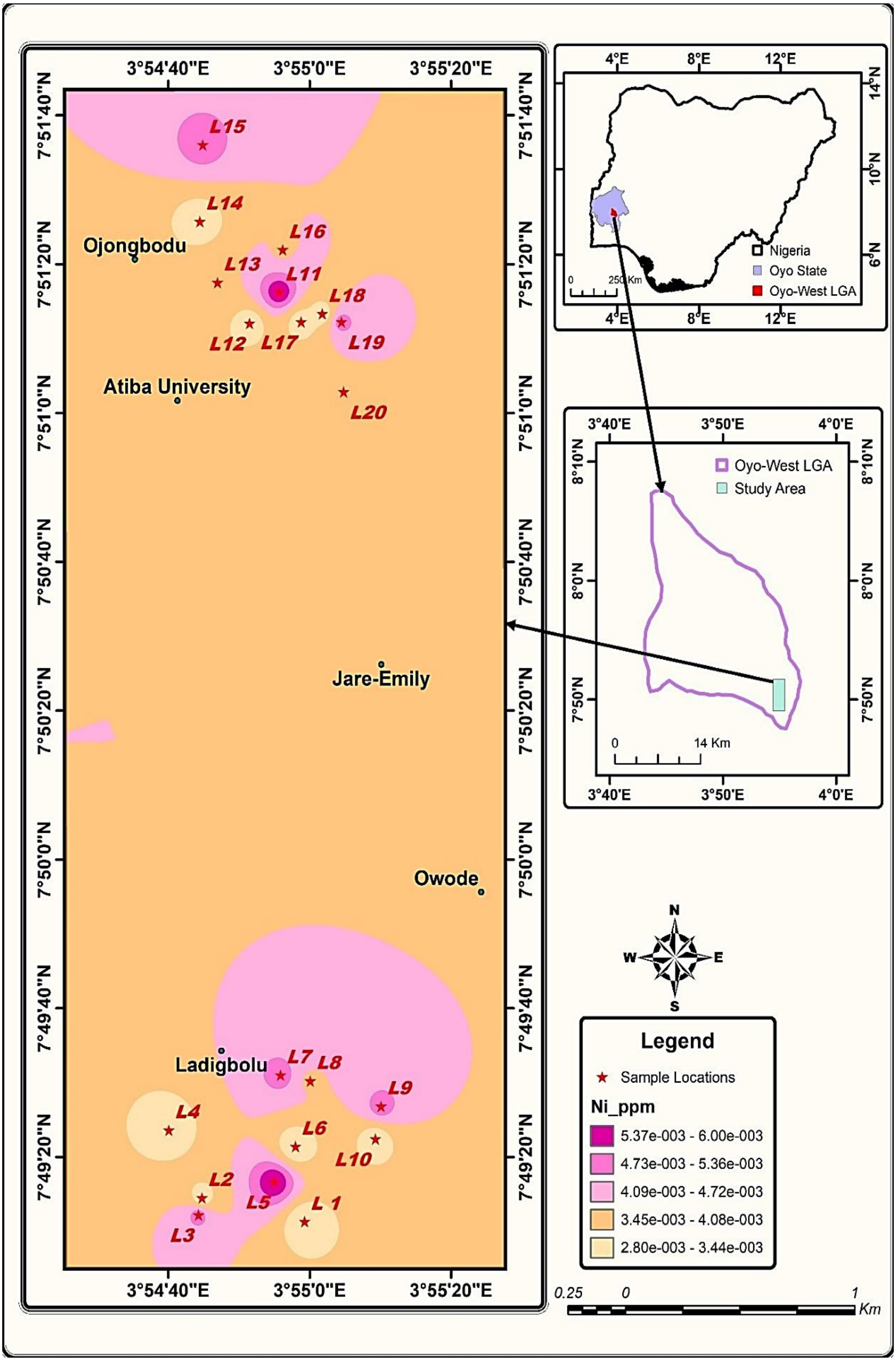

Figure 14: Thematic map of dissolved Nickel (Ni) in groundwater in the study area

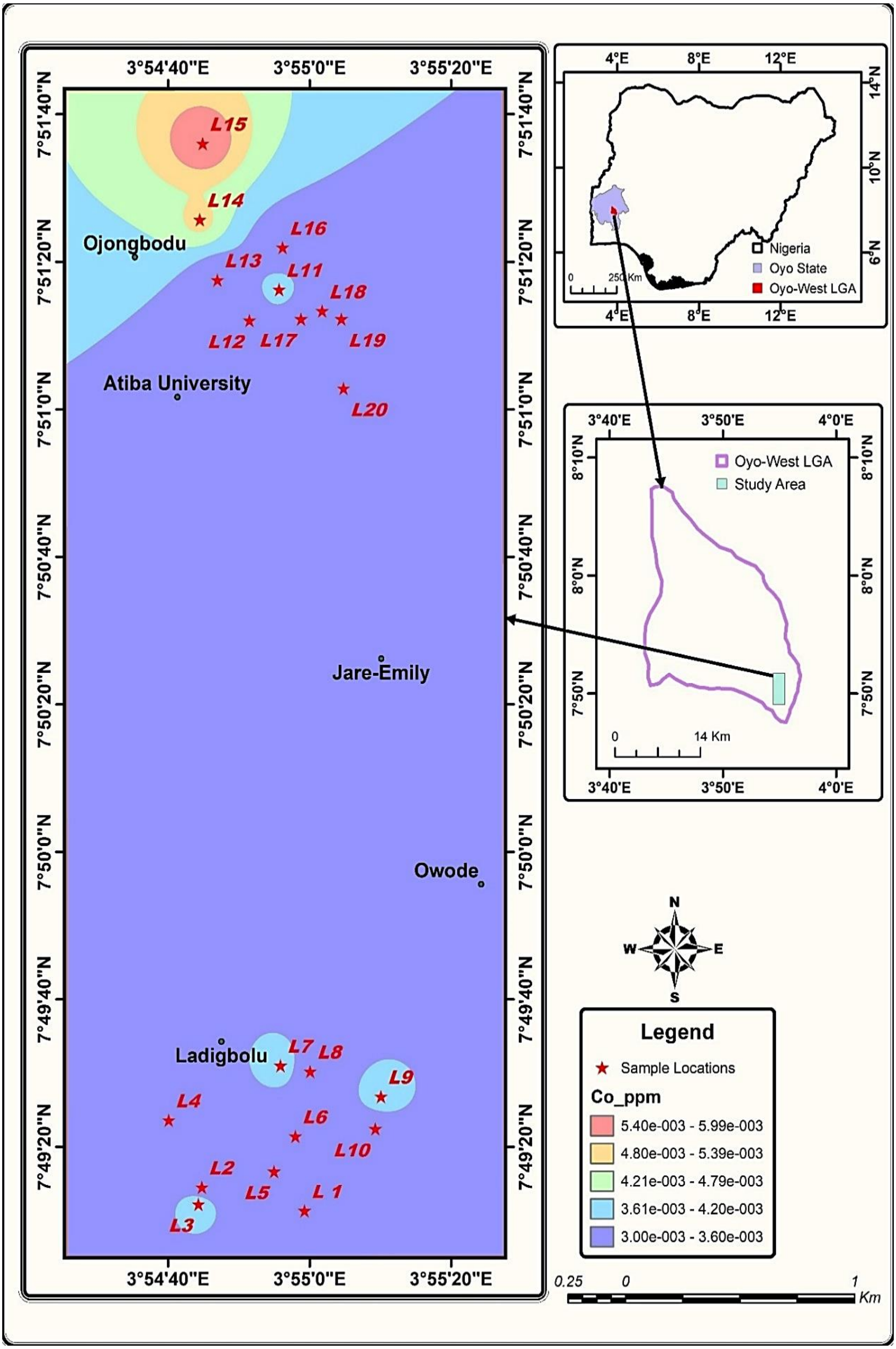

Figure 15: Thematic map of dissolved Cobalt (Co) in groundwater in the study area

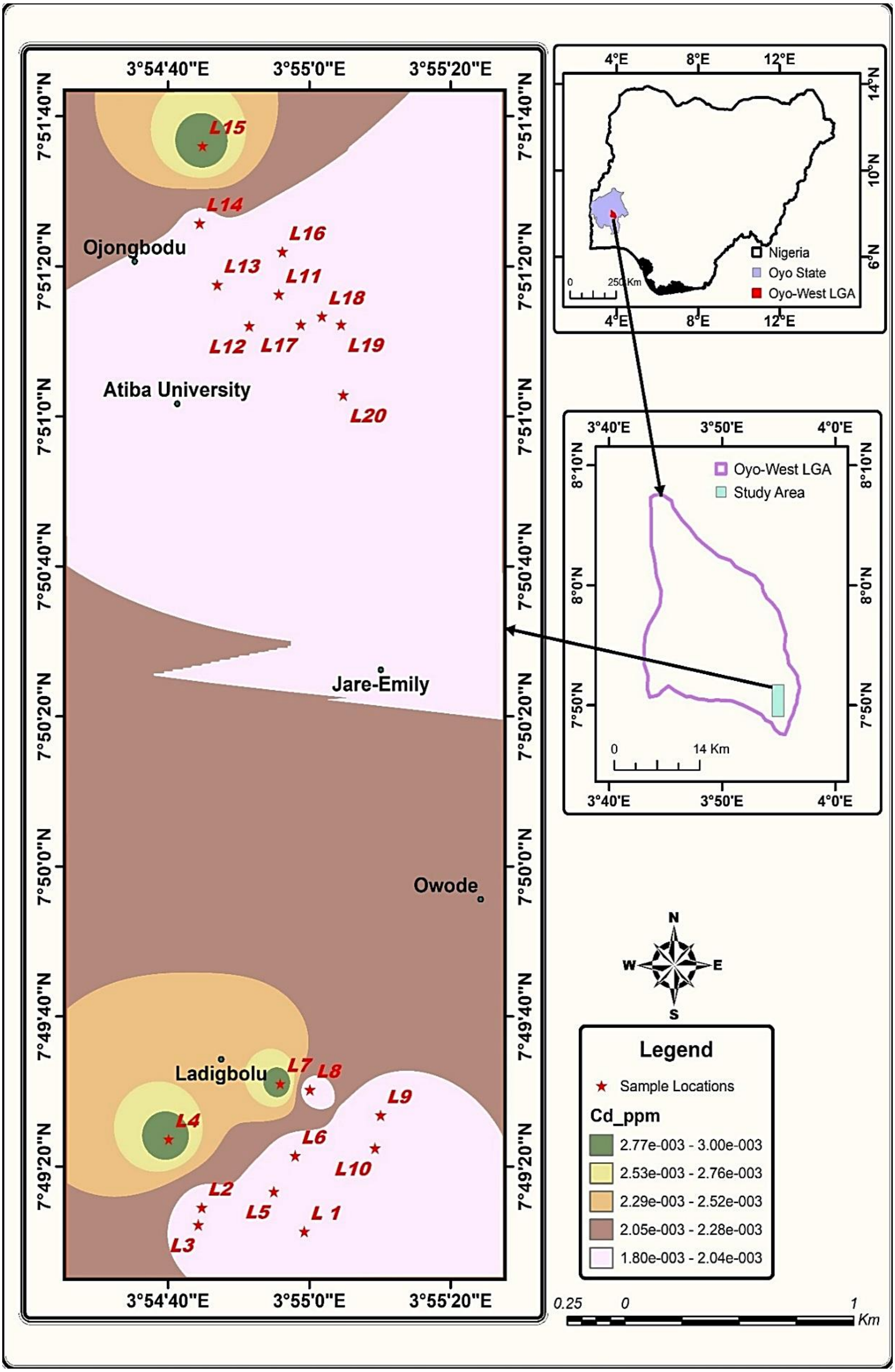

Figure 16: Thematic map of dissolved Cadmium (Cd) in groundwater in the study area

4. Conclusions

This study was carried out to assess the groundwater quality and risk of exposure to dissolved potentially harmful elements (PHEs) at Ladigbolu and Ojongbodu areas of Oyo town. The heavy metals studied include Fe, Pb, Cu, Cr, Mn, Zn, Ni, Co and Cd. The mean concentration of the heavy metals in groundwater samples for Fe, Pb, Cu, Cr, Mn, Zn, Ni, Co and Cd were 0.747, 0.010, 0.030, 0.012, 0.036, 0.010, 0.004, 0.003 and 0.002 in ppm respectively at the Ladigbolu area, while at Ojongbodu area, the mean concentration values were 0.702, 0.012, 0.032, 0.010, 0.033, 0.010, 0.004, 0.004 and 0.002 in ppm respectively. The distribution patterns of the studied elements showed that L15 has the highest concentrations of Fe, Cu, Cr, Mn, Zn, Co and Cd while L18 has the lowest concentrations of Cu, Cr, Mn, Zn, Ni, Co and Cd.

A plot of the Piper diagram showed that Ca-HCO_3 water type as the dominant hydrogeochemical facies in the study area. Mineral dissolution was the main process responsible for the hydrogeochemical evolution of the groundwater. This affirmed there is dissolution of mineral constituents of the rock or aquifer zone. The physiochemical and hydrogeochemical parameters of the groundwater fall within the World Health Organization (WHO, 2017) and Standard Organization of Nigeria (SON, 2007) permissible limit for drinking water ecxept for Fe, Pb and TH which were above the permissible limit and may constitute a health hazard to the residents within the study area.

The average chronic daily ingestion (CDI) of the studied elements showed that Fe is the most ingestible elements in infants and children, while Cd is the most ingestible for adult. The hazardous quotients (HQ) obtained for the groundwater across different age group showed that Ni and Zn have values greater than 1(HQ>1) for adult, while for children and infants, Fe has hazardous quotients greater than 1 (HQ>1) indicating possible negative health effects and threat. However, the HQ values for Pb, Cu, Cr, Mn, Co and Cd were found to be less than one (HQ<1) across different age groups of the study area. The Hazardous Quotient (HQ) of Zn and Ni in the groundwater of the study area portend high risk in adults while that of Fe showed high risk in children and infants. The data recorded in this study revealed that water consumption around these areas might be harmful due to metal toxicity. Current studies will be useful in the determination of the potability of the groundwater in Ladigbolu and Ojongbodu areas of Oyo town and the maintenance of public health.

Funding: Not applicable.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: Not applicable

Conflicts of Interest: The authors declare no conflict of interest

References

1. Bouwer H (2002). Artificial Recharge of Groundwater. *Hydrol. Eng. Hydro-geol. J.* 10(1):121-142
2. Singh R.K, Sengupta. B, Bal. R, Shukla B.P, Gurunadharao. V.S. and Srivatstava. R. (2009) Identification and mapping of chromium (VI) plume in groundwater for remediation: a case study at Kanpur, Uttar Pradesh, *J. Geol. Soc. India* 74 (1) (2009) 49–57. **doi:** https://doi.org/10.1007/s12594-009-0103-z.
3. Masood, N., Farooqi, A. and Zafar, M.I., (2019). Health risk assessment of arsenic and other potentially toxic elements in drinking water from an industrial zone of Gujrat, Pakistan: a case study. *Environ. Monit. Assess* 191 (2): 95. **doi:** https://doi.org/10.1007/s10661-019-7223-8.
4. Opoku, P.A., Anornu, G.K., Gibrilla, A., Owusu-Ansah, E.-G., Ganyaglo, S.Y., Egbi, C.D. (2020). Spatial distributions and probabilistic risk assessment of exposure to heavy metals in groundwater in a peri-urban settlement: case study of AtonsuKumasi, Ghana. *Groundwater. Sustain. Dev.* 10, 100327. doi: https://doi.org/10.1016/j.gsd.2019.100327.
5. Barzegar, R., Moghaddam, A. A., Soltani, S., Fijani, E., Tziritis, E., Kazemian, N. (2019) Heavy metal (loid)s in the groundwater of Shabestar area (NW Iran): source identification and health risk assessment. *Expo. Health* 11 (4), 251–265. **doi:** https://doi.org/10.1007/s12403-017-0267-5.
6. Li L, Yang X. (2018). The essential element manganese, oxidative stress, and metabolic diseases: Links and interactions. Oxidative Medicine and Cellular Longevity. 2018; 2018:7580707. **doi**: https://doi.org 10.1155/2018/.580707
7. Adewoyin. O. O, Kayode O. T, Omeje O, Odetunmibi O.A, (2019). Risk assessment of heavy metal and trace elements contamination in groundwater in some parts of Ogun state, *Cogent Eng.* 6 (1): (2019) 1632555. **doi:** https://doi.org/10.1080/23311916.2019.1632555.

8. Ahmed, I., Tariq, N., Al Muhery, A., (2019). Hydrochemical characterization of groundwater to align with sustainable development goals in the Emirate of Dubai, UAE. *Environmental. Earth Science.* 78 (1): 44. **doi:** https://doi.org/10.1007/s12665-018- 8030-1.
9. Tabassum, R.A., Shahid, M., Dumat, C., Niazi, N.K., Khalid, S., Shah, N.S., Imran, M., Khalid, S., (2020). Health risk assessment of drinking arsenic-containing groundwater in Hasilpur, Pakistan: effect of sampling area, depth, and source. *Environ. Sci. Pollut. Res.* 26 (20): 20018–20029. **doi:** https://doi.org/10.1007/s11356-018-1276-z.
10. Khalid, S., Shahid, M., Natasha, Shah, A.H., Saeed, F., Ali, M., Qaisrani, S.A. and Dumat, C. (2020). Heavy metal contamination and exposure risk assessment via drinking groundwater in Vehari, Pakistan. Environ. Sci. Pollut. Res. 27 (32), 39852– 39864. **doi:** https://doi.org/10.1007/s11356-020-10106-6.
11. Shaji, E., Santosh, M., Sarath, K.V., Prakash, P., Deepchand, V., Divya, B.V., (2021). Arsenic contamination of groundwater: A global synopsis with focus on the Indian Peninsula. Geosci. Front. 12 (3), 101079. **doi:** https://doi.org/10.1016/j.gsf.2020.08.015.
12. WHO (2011) Guidelines for Drinking-Water Quality, (4th Ed.), Environmental health criteria, Geneva, Switzerland,2011.
13. Nguendo-Tongsi H.B (2011). Microbiological evaluation of drinking water in a sub-saharan urban community (Yaoundé), *Am. J. Biochem.* I (2011) 68–81. **doi:** https://doi.org/10.3923/ajbmb.2011.68.81.
14. Ocheri, M.I, L.A.Odoma., Umar, N. D. (2014). Groundwater Quality in Nigerian Urban Areas: A Review. *Global Journal of Science Frontier Research: H, Environment & Earth Science* 14(3): 2249-4626.
15. Nyambura, C.., Hashim, N.O., Chege, M.W., Tokonami, S. and Omonya, F.W. (2020). Cancer and non-cancer health risks from carcinogenic heavy metal exposures in underground water from Kilimambogo, Kenya, Groundwater for Sustainable Development. 10: 100315. https://doi.org/10.1016/j.gsd.2019.100315.
16. Tajudeen, Y., Muhammed A., Onyeziri, J.A., Abdulmalik, A., Shemishere, U., Bakare, T., Yusha'u, B.K. (2022). Health Risks of Ecosystem Services in Ologe Lagoon, Lagos, Southwest Nigeria. Pollution, 8(2): 681-692 **doi**: https://doi.org/10.22059/POLL.2021.333654.1265
17. Kolawole, T.O., Laniyan, T.A., Bello, E.O., Isibor, R.A. (2022). Assessment of some potentially harmful elements and their associated health risk in stream sediments of rural gold-mining communities in Southwestern Nigeria. *Arabian Journal of Geosciences* 15:941. doi: https://doi.org/10.1007/s12517-022-10164-9
18. Okunlola O.A, Adeigbe O.C, Oluwatoke O.O (2009). Compositional and petrogenetic features of schistose rocks of Ibadan area, southwestern Nigeria. *Earth Sci Res J.* 3(2): 20–43
19. Bolarinwa A.T (2017). Hydro geochemistry of groundwater within the lateritic profiles over migmatite and pegmatized schist of Ibadan. *Nigeria. J Geol Min Res* 9(4): 28–42. https://doi.org/10.5897/JGMR2016.0261.
20. USEPA (1992). Exposure Factors Handbook 2011 edition (final), in: *United States Environmental Protection Agency* E (Ed.), Washington, DC.
21. Egbueri J.C, Mgbenu C.N. (2020). Chemometric analysis of pollution source identification and human health risk assessment of water resources in Ojoto Province, southeast Nigeria. *Appl Water Sci* 10: 98. https://doi.org/10.1007/s13201-020-01180-9.
22. Ujile, A. A, Omo-Irabor, O.O. and Ogbonna, J. (2012). Groundwater Contamination at Waste disposal sites at Ibadan, Nigeria. Journal of Solid Waste Technology and Management, 38(3): 147-155. **doi:** https://doi.org/10.5276/JSWTM.2012.149.
23. Vinodhini, R. and Narayanan, M. (2008). Bioaccumulation of heavy metals in organs of fresh water fish Cyprinus carpio (common carp). *International Journal of Environment Science and Technology* 2(5): 179-182.
24. World Health Organization (2017). Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum. World Health Organization, Geneva, Switzerland, 2017. Available at https://www.who.int/publications/i/item/9789 241549950.
25. SON (Standards Organization of Nigeria) (2007). Nigerian Standard for drinking water quality. Nigeria Industrial standard NIS 554:2007 study. *Pollution Research* 27: 721-724.
26. Back, W (1960). Origin of Hydrogeological Facies in Groundwater in the Atlantic Coastal Plain. *Geochemical Cycles: Internat. Geol. Cong. Proc.* 1: 87-96.
27. Subba Raao, N (2017). Hydrogeology-Problems with Solutions (265p.) Delhi: PHI Learning Private Limited
28. Piper, A.M (1944) A Graphic Procedure in the Geochemical Interpretation of Water analysis. *Transactions, American Geophsical Union* 25: 914-923.
29. Back, W and Hanshaw, B.B, (1965). Chemical Geohydrology. In:Chow V T (Editor) Advances in Hydroscience. Academic Press, New York. pp. 49-109.
30. Tijani, M.N and Abimbola, A.F (2003). Groundwater Chemistry and Isotope Studies of Weathered Basement Aquifer: A Case Study of Oke Ogun Area, WW., Nigeria. *Africa Geoscience Review*10(4): 373-387.
31. Gibbs R.J (1970): Mechanisms Controlling World Water Chemistry. *Science* 17: 1088-10090
32. Nwachukwu, R. A., Vitus, N. and Frances, J. (2014). Health risk assessment in relation to heavy metals in water sources in rural regions of south east, Nigeria. *Int. J. Phys. Sci.* 9(6): 109–116.

Cite article as:

Isibor, R.A., Aderogbin, J.A., Ojo, O.O. Hydrochemical and Health Risk Assessment of Groundwater of Ladigbolu and Ojongbodu in Oyo Town, Southwestern Nigeria. *Ajayi Crowther J. Pure Appl. Sci.* **2023**, 2(2), pp. 26-50. | **doi:** https://doi.org/10.56534/acjpas.2023.02.02.26.