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A GIS-BASED APPROACH FOR GEOSPATIAL MODELLING OF HEAVY METALS CONTAMINATION IN GROUNDWATER QUALITY AROUND SAGAMU INDUSTRIAL AREAS, SOUTHWESTERN NIGERIA

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ABSTRACT

Groundwater is the main source of water for domestic use in Nigeria because it is perceived to be clean. The presence of heavy metal contaminants, and the level of awareness of their presence in groundwater around industrial areas in Sagamu, Ogun State, Nigeria was examined in this study. A total of twenty (20) groundwater samples were collected from hand dug wells which tap into shallow aquifers and their location taken with the aid of a GPS. GIS-based method such as ArcGIS technology was adopted to analyze the spatial distribution of heavy metals in groundwater and to evaluate potential health risks. The results were compared with the WHO standard. Results showed that chromium ranged from 0. 01 to 0. 53 mg/L, copper (0.12 – 1.89 mg/L), nickel (0.04- 1.94 mg/L), zinc (0.04 -2.55 mg/L), and, lead (0.001 - 0.03 mg/L).The spatial distribution maps revealed significant heavy metal contamination (chromium, lead, nickel, copper, and zinc), exceeding WHO permissible limits in the southern part and declining towards the north, and west of the study area indicating localized source of contamination likely from domestic, industrial, and agricultural sources. The correlation matrix results showed that there exists a weak and positive correlation among elements, revealing the relationship among the heavy metals to their sources of origin. This study highlights the need to develop strategies for the effective management of water resources to mitigate anthropogenic impacts and safeguard human health in the area.

Keywords: Groundwater quality; Heavy metals; GIS-based modelling; Spatial distribution; Sagamu; Industrialization; Contamination

I. INTRODUCTION

Groundwater is utilized for home, farming, and commercial purposes and it's one of the world's important main sources of fresh water [1]. Groundwater provides drinking water to almost one-third of population in the world [2]. It is a very valuable resource in dryland areas with insufficient surface water and precipitation [3]. However, the quality of groundwater is seriously threatened by industrialization, urbanization, climate change, and agricultural practices [4,5,6,7,8,9]. Elemalai et al. [10] reported that natural and man-made sources could both contaminate groundwater.

Groundwater contamination has a big effect on people and ecosystems all around the world [11,12,13,14,15,16]. Water is an essential resources for all living things, both plants and animals [17,18]. People usually get water from two main natural sources: surface water like lakes, rivers, and streams, and groundwater like water from boreholes and wells [19,20,21,22,23]. Water has special chemical properties because of the way its molecules are connected, which allows it to mix with, hold, carry many different substances [24]. Because of this, water in nature isn't pure. It picks up contaminants from its surroundings, as well as from human and animal activities, and other natural processes [24,26,27,28,29,30]. A major issue in groundwater is heavy metals [31,32,33,34,35,36,37]. Certain metals are essential for the body's growth, development, and overall health, while others are unnecessary and potentially harmful [38,39,40,41,42,43].

The severity of these metals relies on the quantity found within the environment. When concentrations of heavy metals rise, they can leach into groundwater and soil, particularly when the soil can no longer retain them [44,45]. These toxic metals can accumulate in organisms and move up through the food chain [46]. A census conducted in Nigeria in the year 2006 revealed that 50% of households depend on groundwater for daily activities. This is due to the belief that groundwater is safer than surface water, as it is thought to contain fewer harmful pathogens [46]. Groundwater may contain various types of chemicals dissolved in it due to the interaction of water with soil and rocks. These substances, originating from the ground, may pose risks to human health. Although consuming water containing elevated heavy metal levels can be hazardous, limited research has been conducted to determine the concentrations of chromium, lead, copper, zinc, and nickel in Nigeria's groundwater [47,48]. Furthermore, there is minimal knowledge regarding the extent of people's awareness of these natural pollutants. Knowing the locations of these toxic metals is crucial, as numerous individuals, particularly in low-income regions, depend on untreated groundwater for their daily requirements [49]. Numerous research efforts on groundwater quality have utilized GIS for mapping and value estimation. A study employed ArcGIS in combination with a technique known as Analytic Hierarchy Process (AHP) to assess groundwater potential. It integrated hydro-geophysical data and water recharge estimates to enhance understanding [50]. Additional research has employed dynamic maps to evaluate the quality of groundwater. For example, they utilized the DRASTIC index, which examines seven factors including depth to water, recharge, aquifer classification, soil classification, land inclination, effects of the vadose zone, and permeability of water in the soil [51]. These elements were examined in ArcGIS to indicate locations where groundwater may be at higher risk [52]. Additionally, governmental organizations have developed interactive maps to provide comprehensive water resource data, aiding in improved decision-making [53,54,55]. This research examines variations in groundwater quality throughout different seasons, focusing particularly on heavy metals. It evaluates the concentrations of heavy metals in groundwater around the industrial areas in Sagamu. It verifies if the water is safe for consumption and contrasts the findings with the criteria established by the World Health Organization (WHO).

II. MATERIALS AND METHODS

2.1 The study area description

This study is conducted in Sagamu, situated in Ogun State, in the southwestern region of Nigeria. The latitude extends from $6^0$49' N to $7^0$00' N, with the longitude ranging from $3^0$35' E to $3^0$45'E, as depicted in Figure 1. Sagamu is adjacent to Odogbolu Local Government in Lagos State, followed by Ikenne Local Government, and then Obafemi Owode Local Government. Sagamu was selected as the research location due to its abundance of industries, frequent inproper waste disposal, and significant industrial activity in the region. The region is linked by narrow roads that traverse various villages, with footpaths allowing access to more secluded areas. The approach taken in this research consists of a primary component: developing spatial and dynamic maps with ArcGIS to illustrate the distribution of heavy metals in the groundwater within the study region.

2.2 Geology and Hydrogeology of the study area

The study area is located at a transition zone which is underlain partly by the rocks of the basement complex of Southwestern Nigeria, and the sedimentary formations of the Dahomey Basin. The dominant rocks in the Northeastern part of the study area are biotite granite gneiss, porphyroblastic gneiss, porphyritic biotite granite, biotite schist and migmatite (Rahaman, 1976). The remaining southern portion of the area is covered by sedimentary rocks of Dahomey basin. The formations in the basin include Abeokuta, Ewekoro, Ilaro and Benin formations. The major river in the area is River Ona which runs almost North-South and River Ibu which flows from the crystalline uplands southward to the coastal lagoon, showing a dendritic to sub-dentritic drainage pattern. Groundwater occurrence in the northern parts of the study area is limited to the fractured and in-situ weathered portions of the rocks. The aquifer occurs within the in-situ weathered portion which overlies the fresh basement or within fractured fresh basement rocks.

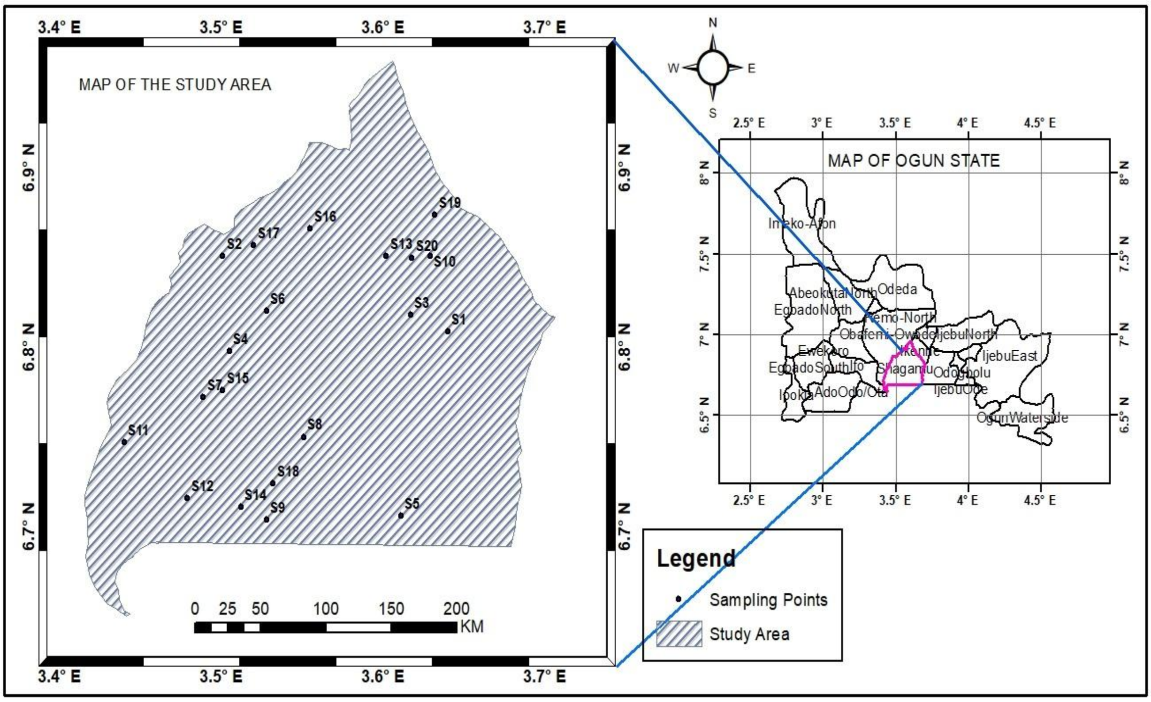


Figure 1. Map showing the study of Shagamu, Ogun State. ArcGIS (Source: This Study)

2.2 Groundwater sampling and analysis

A total of twenty (20) groundwater samples were gathered in the research area as shown in Table 1. The sampling occurred in May and June 2025, amidst the rainy season, as well as in March and April 2025, marking the onset of the rainy season. Every sample was collected in a previously cleaned polyethylene bottle, and a GPS reading was recorded at each site. The Hitachi U-1500 UV/Vis single beam spectrophotometer was utilized to assess the concentrations of lea, copper, zinc, nickel, and chromium. The water analysis laboratory of Geotechnical Limited in Lagos and Geoearth Project Limited conducted these tests to guarantee precise outcomes. The concentrations of these pollutants were subsequently represented using ArcGIS software.

Table 1: Study area groundwater samples

Sampling points	Lat	Long	Cr (mg/L)	Cu (mg/L)	Zn (mg/L)	Ni (mg/L)	Pb (mg/L)
S1	6.809	3.64	0.04	0.65	0.06	0.04	0.005
S2	6.851	3.501	0.01	0.43	1.73	0.16	0.015
S3	6.818	3.617	0.03	0.09	0.94	1.03	0.008
S4	6.798	3.505	0.03	0.83	0.27	0.93	0.02
S5	6.706	3.611	0.11	0.27	0.13	1.35	0.009
S6	6.82	3.528	0.03	0.35	0.28	1.07	0.025
S7	6.772	3.489	0.02	0.46	0.74	0.53	0.012
S8	6.75	3.551	0.01	0.27	2.55	0.85	0.003
S9	6.704	3.528	0.03	1.89	0.04	0.36	0.007
S10	6.851	3.629	0.02	0.12	1.44	1.26	0.013
S11	6.747	3.44	0.03	0.18	1.01	0.91	0.01
S12	6.716	3.479	0.13	0.28	1.49	0.84	0.002
S13	6.851	3.602	0.39	0.39	0.11	1.35	0.018
S14	6.711	3.512	0.53	1.71	1.44	0.56	0.009
S15	6.776	3.501	0.22	0.32	0.31	0.74	0.007
S16	6.866	3.555	0.03	0.14	1.44	1.26	0.011
S17	6.857	3.52	0.23	0.22	1.21	1.35	0.02
S18	6.724	3.532	0.4	0.16	0.93	1.94	0.004
S19	6.874	3.632	0.04	0.25	0.5	0.46	0.03
S20	6.85	3.618	0.04	0.12	0.68	0.46	0.001
Min			0.01	0.12	0.04	0.04	0.001
Max			0.53	1.89	2.55	1.94	0.03
Average			0.13	0.57	1.00	0.85	0.01
WHO limit			0.05	2.00	3.00	0.07	0.01

2.3 Development of Spatial Map using ArcGIS

The research employed WGS 1984 as the coordinate framework for the ArcGIS project. Initially, the grounwater samples data was collected and saved into a CSV file, subsequently transformed into a multipoint vector layer. IDW was selected over OK interpolation due to certain problems with the ArcGIS software. OK requires an alternate coordinate system, namely UTM, to function effectively over extensive regions. However, UTM consists of multiple zones, each featuring its own coordinate system, leading to a complication. The research area spanned two UTM zones, 31N and 32N, and the Kriging plugin in ArcGIS cannot perform interpolation over multiple zones. Thus, IDW was employed as another option. Previous studies indicate that IDW frequently outperforms Kriging in more extensive regions. IDW was employed to generate a raster layer illustrating the distribution of groundwater quality values within the study area. This procedure was carried out for every heavy metal throughout the study duration to monitor fluctuations in groundwater quality over time. Ultimately, distinctive value reports from the raster layers were generated to analyze the distribution patterns of groundwater quality, and maps were developed to visually represent groundwater quality values for each heavy metal examined in the study.

III. RESULTS AND DISCUSSION

3.1 Concentrations of heavy metals in groundwater

The risk assessment maps (Figure 2a-2e) illustrate the distribution of heavy metals within the study area, emphasizing key chemical contaminants in the groundwater. Table 1 presents the varying concentrations of heavy metals found in twenty (20) groundwater samples.

The levels of chromium (Cr) in the samples vary from 0. 01 mg/L to 0. 53 mg/L, with an average of 0.13mg/L, presented in Table 1. The southwestern region has elevated levels, while sample S13 in the northeastern part (Fig. 2a) is relatively high while [56] recommended 0.05 mg/L as permissible limit. Chromium is an element that occurs naturally in volcanic gases, soil, rocks, plants, and animals. The primary forms are trivalent (Cr^{3+}) and hexavalent (Cr^{6+}), both of which may be found in drinking water. The primary causes of chromium presence in groundwater samples could be due to the natural erosion of mineral deposits and the stripping of coatings from water pipes [57]. Every water sample showed chromium concentrations under the WHO's permissible threshold of 0. 05 mg/L, except for S5, S12, S13, S14, S15, S17, and S18. Excessive exposure to chromium can damage the liver and kidneys, and chromate dust is recognized as a carcinogen [58,59] chromium level found in your study is leess than the permissible level, then why do you about say about adverse effects of excess level of chromium.

The prolonged impact of lead exposure in drinking water raises significant concerns for individuals [59]. Upon testing the water samples for lead, each sample contained some level of lead. Among these, 8 samples, representing 40% of the total, exhibited lead levels exceeding the permitted maximum of 0.01mg/L. The maximum quantity detected was 0. 03 mg/L, as indicated in Table 1 and Fig. 2d. The elevations in the northwest and northeast sections of the study area are comparatively high. This raises concern since lead has long been recognized as a toxin that accumulates in the body [60]. It impacts the nervous system and is the most prevalent form of metal toxicity in people [61]. Research indicates that even minimal levels of lead can increase blood pressure [62], reduce children's IQ [63], and lead to attention difficulties [63].

In this research, the concentration of nickel in the water varied from 0.04 to 1.94 mg/L, averaging at 0. 85mg/L, as indicated in Table 1. No definite threshold for nickel in groundwater has been established. According to the World Health Organization [25] the health hazards associated with nickel in drinking water are most effectively assessed by examining the impacts of water-soluble nickel salts. Upon exposure to nickel, individuals may develop stomach and neurological issues, and they might also become reactive to it via their skin or through inhalation [65]. Elevated nickel concentrations were detected in the southern and northwestern regions of the study area, as illustrated in Fig. 2c.

Zinc (Zn) concentrations are elevated in the Southern region and reasonably elevated in the Northeastern part of the study area as shown in Fig. 2e. These levels fall within the permissible range of 3.0 mg/L as established by [59]. The groundwater samples indicate zinc concentrations varying between 0.04 to 2.55 mg/L, as depicted in Table 1. In different regions of Nigeria, Folorunsho et al. [58] discovered reduced zinc levels, ranging from 0. 003 to 0.054 mg/L, in manually excavated wells near waste disposal sites in Okene, Kogi State. Tsor et al. [66] discovered values ranging from 0. 08 and 0. 50 mg/L in Makurdi, Benue State. Zinc is a vital mineral for people. It is crucial for a baby's development during pregnancy when consumed in appropriate quantities [67]. Nevertheless, if zinc concentrations are either insufficient or excessive, it can be detrimental. In children, insufficient zinc can result in underdeveloped brains and a higher susceptibility to infections [68]. Conversely, elevated zinc levels may impact bone growth and the proper operation of the reproductive system in adults [67].

Table 1 indicates that the concentration of copper in the groundwater complied with the standards established by WHO in 2011. Nevertheless, it was quite elevated in the southern section of the study area. The S9 and S14 sites exhibited the greatest concentrations of copper, as illustrated in Figure 2b. The likely cause of these elevated copper levels is the discharge of wastewater and various human activities from industrial firms. Furthermore, copper contamination in water can occur when there is significant industrial and domestic waste [68]. Mining, agriculture, production, and the release of wastewater from urban areas or industries into waterways can all result in copper pollution [68]. Copper can enter drinking water either by directly contaminating well water or through the corrosion of copper pipes, especially in acidic water conditions. Corrosion of pipes poses the greatest threat. In this research, the copper concentrations varied from 0.12 to 1.89 mg/L, averaging 0.57 mg/L.

3.2 Correlation analysis

Correlation analysis serves as a useful approach for examining water quality. It assists in identifying trends and relationships among various water quality elements. For instance, it can demonstrate how the concentrations of heavy metals are connected to their potential sources. If two metals exhibit a strong positive connection, it indicates they likely originate from the same source, whether natural or artificial. This research revealed evident relationships among various elements when examining the correlation of heavy metals. A moderate correlation existed between nickel and chromium, indicating they act similarly in the environment. Conversely, zinc exhibited a slight negative association with chromium and copper, while nickel showed a more significant negative relationship with copper. Lead also exhibited an inverse relationship with zinc, suggesting they could originate from distinct sources or behave differently in the environment (Table 2). These patterns indicate that metals such as copper, lead, zinc, nickel, and lead may originate from human actions, particularly industrial processes. Zinc, nickel, and lead may also originate from discarded batteries, tires, paints, pipes, and electronic waste present in landfills

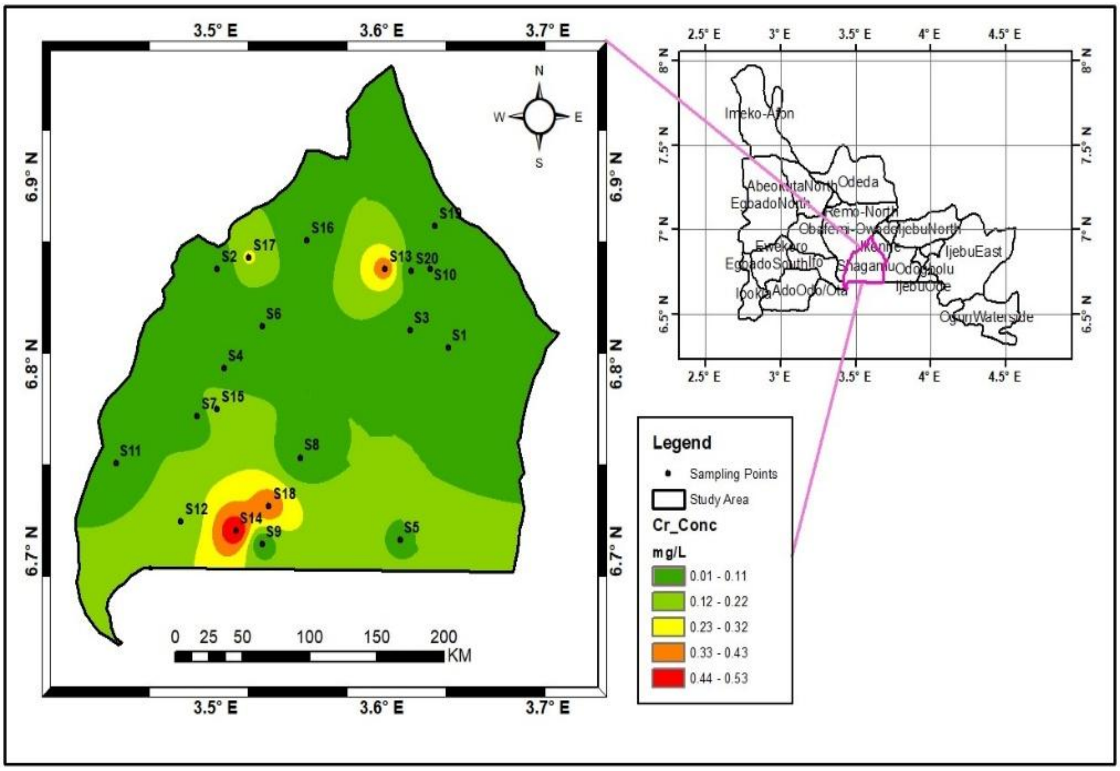
Table 2 show the correlation matric between the heavy metals

	Cr	Cu	Zn	Ni	Pb
Cr	1				
Cu	0.066	1			
Zn	-0.031**	-0.146**	1		
Ni	0.370*	-0.250**	0.068	1	
Pb	-0.078**	0.076	-0.253**	0.064	1

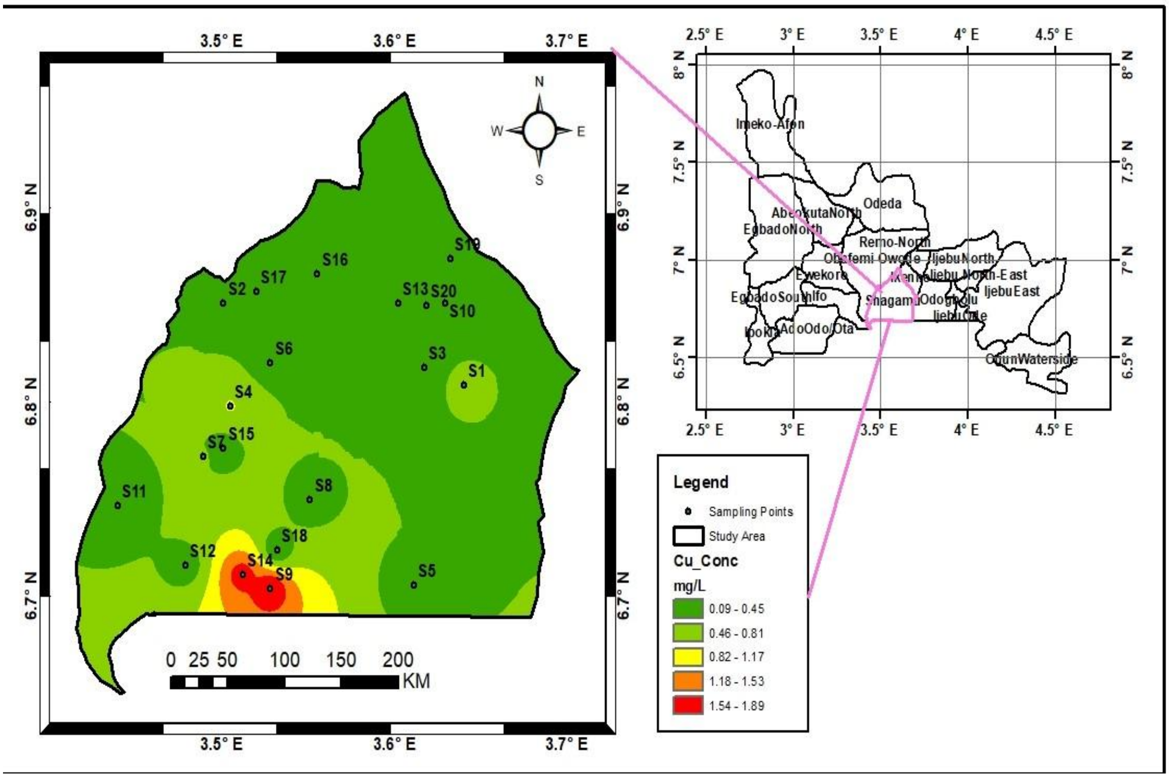
** Weak correlation
*Strong correlation

V. CONCLUSION

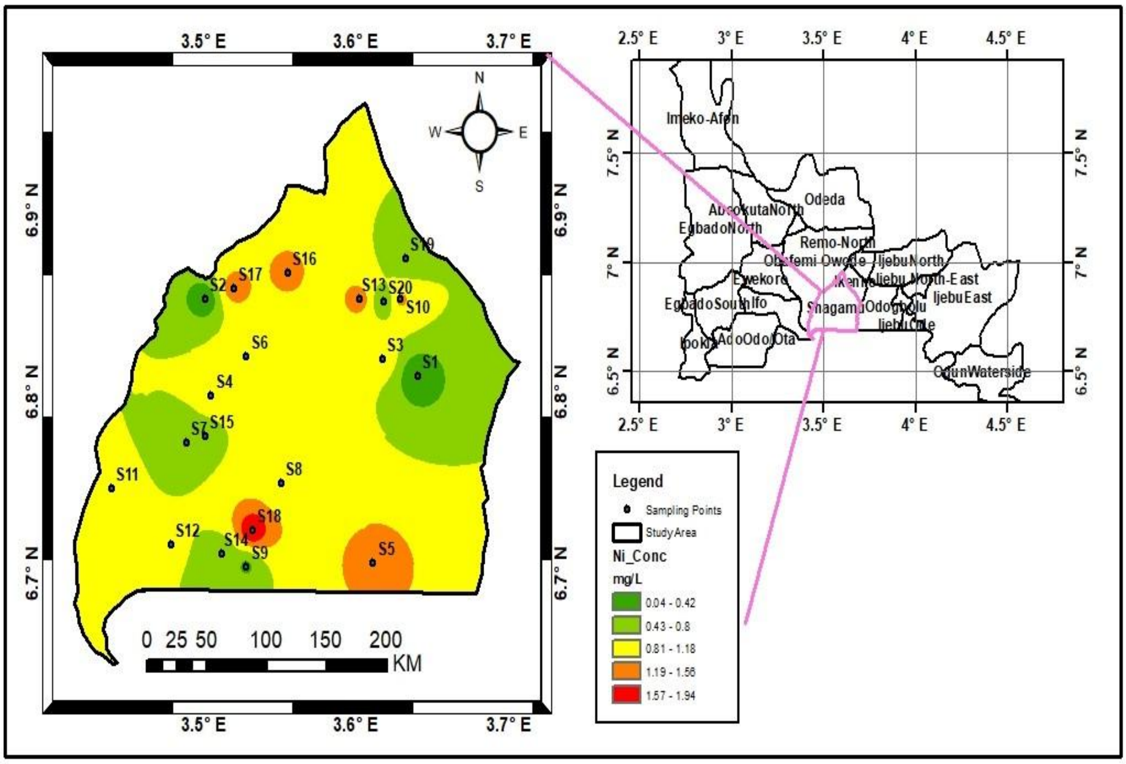
This research indicates that significant concentrations of heavy elements exist in the groundwater adjacent to industrial zones in Sagamu, Ogun State. The study detected increased levels of heavy metals such as chromium, iron, and lead in the southern section of the research area, indicating potential contamination from human activities. The outcomes highlight the significance of implementing targeted strategies to oversee water quality and mitigate the impacts of both natural and human-induced pollutants. The government must take swift action by establishing regular assessments and examinations of water quality in this area to identify the sources of pollution. Stringent regulations must be implemented to prohibit the discharge of urban waste, industrial waste, and agricultural runoff into the water sources within the study area.



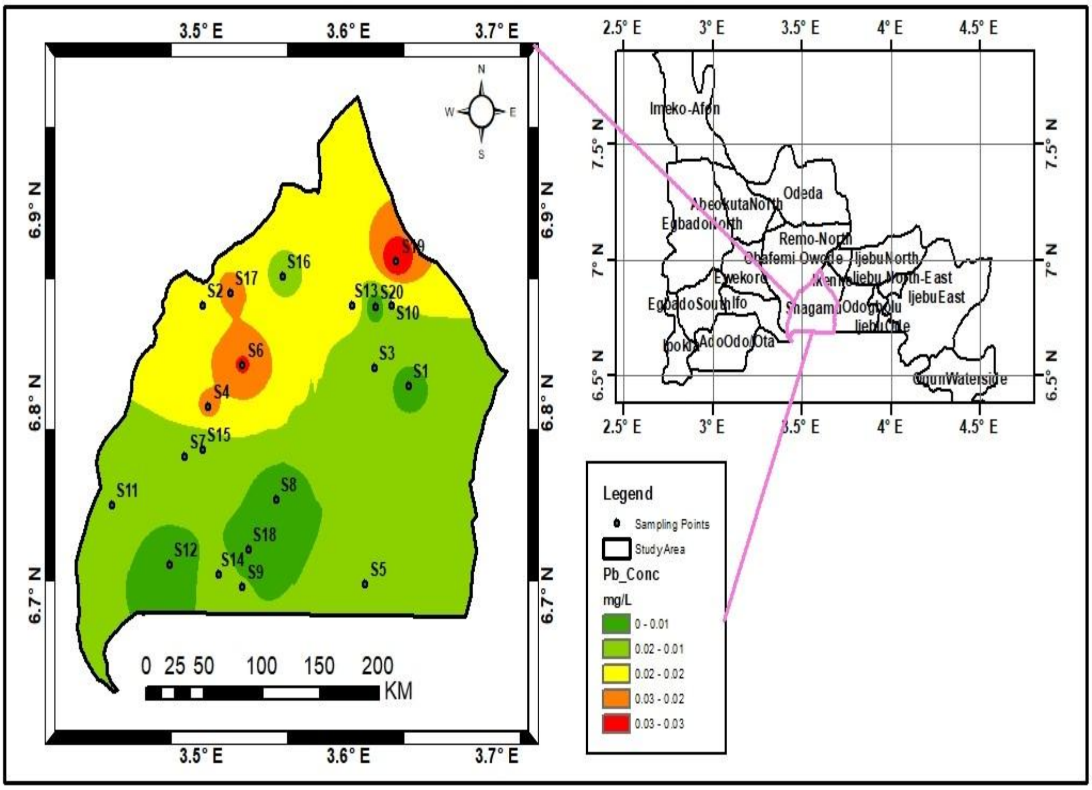
Fifgure 2a: Spatial distribution of Cr (mg/L) for the study area



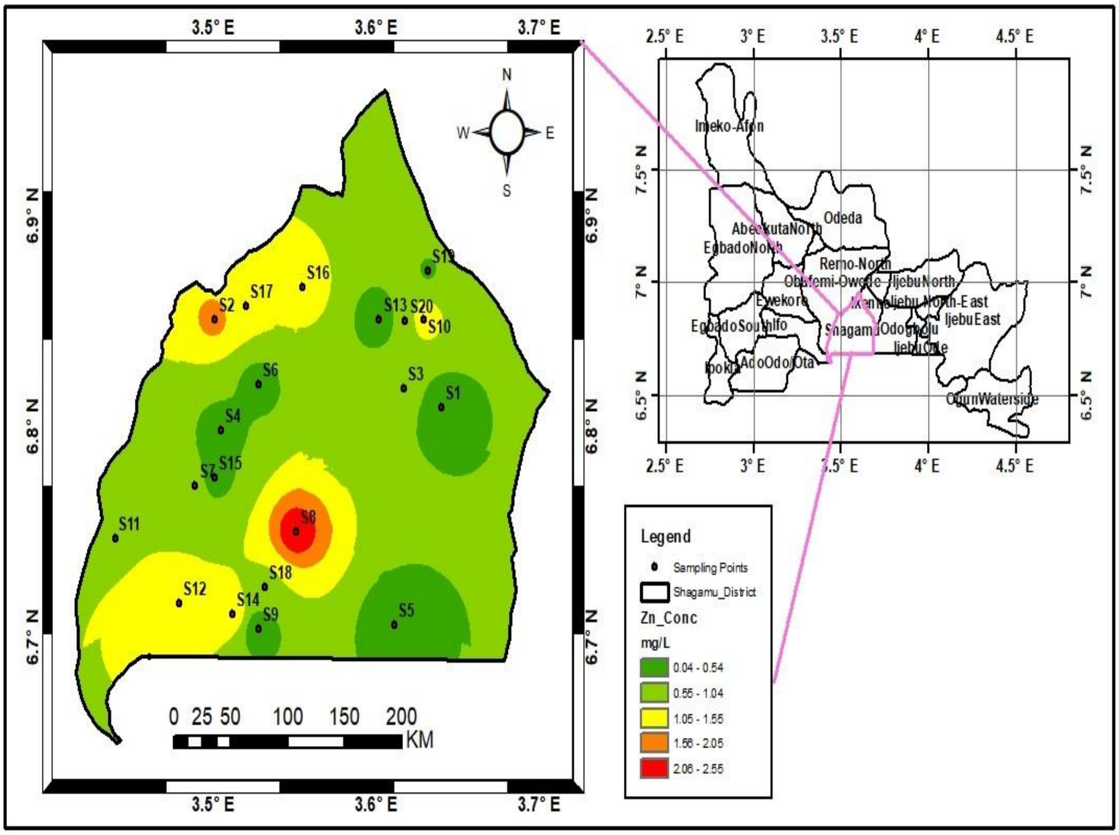
Fifgure 2b: Spatial distribution of Cu (mg/L) for the study area



Fifgure 2c: Spatial distribution of Ni (mg/L) for the study area



Fifgure 2d: Spatial distribution of Pb (mg/L) for the study area



Fifgure 2e: Spatial distribution of Cu (mg/L) for the study area

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