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Investigation of the spatial variation of sediments heavy metals along the Nun River using kriging interpolation technique

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ABSTRACT

This study employs geospatial statistical technique to assess the spatial distribution of heavy metals along the Nun River. Core sediment samples were collected from relatively undisturbed areas (twenty-five different stations) using Uwitec Triple sediment cutter. The rectangular coordinates of the sediment sample location were determined with the aid of Germin handheld GPS receiver. The concentrations of cadmium, lead chromium and zinc present in the sediments was determined with the aid of an atomic absorption spectrophotometer. For geospatial analysis, five semi-variogram models (stable, circular, spherical, exponential and K-Bessel) were fitted for each of the four critical parameters (heavy metals). In addition, four goodness-of-fit statistics (mean square error, root mean square error, root mean square standardized error and average standard error) were utilized to decide the most suitable model used to develop the final prediction map for each parameter. From the results obtained, it was observed that; regions with red color codes signify higher concentrations of cadmium, lead, chromium and zinc. Further assessment of the results showed that Otuan, Obeleli, Angiama, Odobio, Kasama, Akedda and Akele experienced high concentration of cadmium while Tombia, Ewoi, Abilabio, Agudama and Yenikpa experienced high concentration of lead.

1. Introduction

Sediment deposition and erosion issues has placed a serious burden on the people around the Nun River. In recent time, there has been a massive reduction in the population of aquatic organisms as proclaimed by fishermen and other concern authorities. Apart from the loss of lives and properties, which normally occur after every flood event [1], there is also the issue of environmental pollution [2]-[3], which has affected the quality of water and soil; thus, resulting in decreased yield of agriculture and other farming activities [4]. The increased concentrations of heavy metals in water samples from rivers including sediments from the river banks reflects current reality.

Geostatistics is an arm of statistics that focuses on spatial datasets [5]. It is a statistical technique, which is utilized for estimation of values at unsampled sites from limited sample data. Geostatistics identifies spatial patterns and provides accurate and reliable estimations in locations where no measurements are available [6]. Since Geostatistics is centered on statistics, these methods produce not only projection surfaces

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but estimate values of errors as well; hence, giving a suggestion of how good the estimates are [7]. Geostatistics is a valuable scheme in handling spatially distributed data such as groundwater pollution, soil, mining, meteorology, hydrology, geology as well as environmental sciences [8]-[9]. Geostatistical analysis has been beneficial in ascertaining water variables in time and space [10]-[11].

Geostatistics has the variogram as its main tool [12]. Variogram analysis comprises experimental variogram computed from, as well as the variogram model fitted to, the data. The model is selected from a set of algebraic functions, which describe spatial relations. A suitable model is determined by fitting the curve of the investigational variogram to that of the mathematical function [13]. Spatial interpolation is a process of utilizing points with established values to estimate values of other points. This method can also be called a surface interpolation, which is a procedure for estimating values of characteristics at unsampled locations within a region captured by existing observations. Nevertheless, for estimation to be effective, known points should be well distributed within the area involved [14].

The focus of this study is to investigate the effects of heavy metals on sediment quality in the Nun River and to evaluate the spatial variability.

2. Methods

2.1. Study Area

Fig. 1 shows the Landsat imagery of Nun River. This river is considered the largest situated in Bayelsa state [15]. River Nun is a bifurcation of the River Niger down in the Niger Delta. It has an aggregate length of 195 km with a mean width of 370 m. It flows via several communities in the state, through sparingly settled areas of freshwater, mangrove swamps and coastal sand ridges before completing its 160 km course to the Gulf of Guinea [16]. The river is used for several purposes comprising domestic, fishing and recreational, as well as ecological assets. As a result of the rapidly growing activities within its channels, the river is exposed to effects of human activities and other interference. It is also prone to flooding especially when the dams up the Niger River are opened. Dredging both at local and industrial scales are common activities in this river.

2.2. Sediment Sample Collection/Analysis

Sediment core samples were collected from nine (9) different stations at three different depths (0, 5 and 10 m) using Uwitec Triple sediment cutter presented in Fig. 2. The description of the sampling locations, which includes the stations name and rectangular coordinates is presented in Table 1. Concentration of selected heavy metals, namely, cadmium, lead, chromium and zinc were analyzed with the aid of x-ray fluorescence. The analysis was done in triplicates and the mean concentration of the heavy metal was recorded.

2.3. Geospatial Analysis Techniques

The step-by-step methodology involved in the creation of interpolation surface for sediment yield concentration includes:

(a) measurement of sediment concentration at designated locations along the Nun River;
(b) collection of spatial data (northings, easting and elevation) at selected locations within the study area using Garmin Hand-held GPS; and
(c) modeling the spatial distribution of sediment yield parameter using kriging interpolation in ArcGIS.

The procedures utilized for implementing the kriging interpolation technique for geospatial analysis of sediment concentration have been described in [17]. To study the spatial variation of heavy metals, present in sediments around the Nun River, five semi-variogram models (stable, spherical, circular, exponential and K-Bessel) were fitted for each of the four critical parameters (heavy metals) used for geospatial analysis. To choose the model that best described each of the four critical parameters, four goodness-of-fit statistics expressed in equations (1) – (4) [18], namely, mean square error (MSE), root mean square error (RMSE), root mean square standardized error (RMSSE) and average standard error (ASE) were utilized.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i^* - Y_i)^2} \quad (1)$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}[(Y_i^* - Y_i)/\sigma_i^2] \quad (2)$$

$$ASE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\sigma_i^2} \quad (3)$$

$$RMSSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}[(Y_i^* - Y_i)/\sigma_i^2]^2} \quad (4)$$

Where, σ^2 is the kriging variance, n is the number of samples, while Y_i and Y_i^* are the observed and predicted values, respectively.

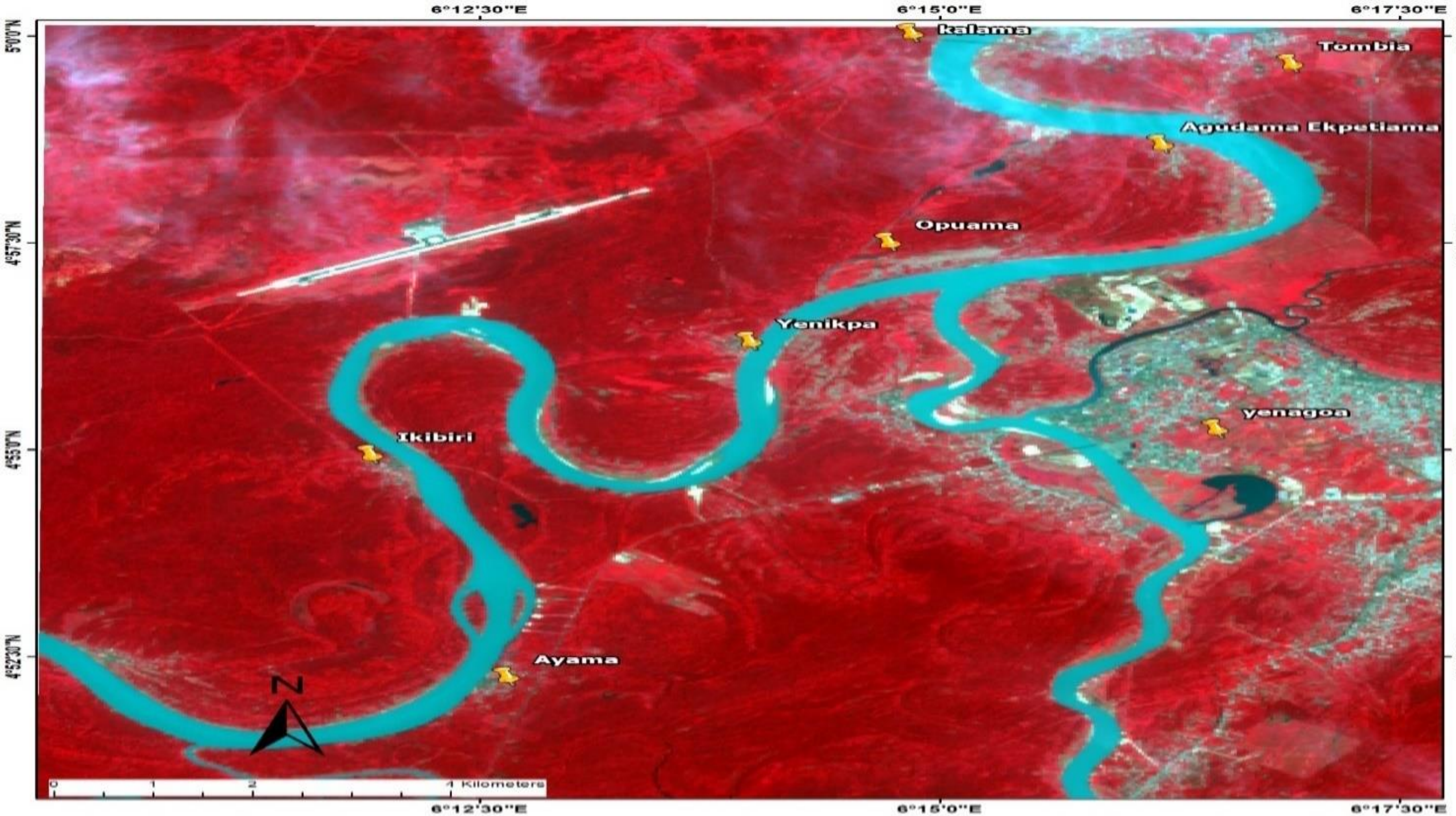

Fig. 1 Landsat Imagery of the Nun River.

Table 1 Description of sampling locations.

Station	Community	Northing (deg. min, sec)	Easting (deg. min, sec)
1	Ikibiri	4⁰54'50.21''	6⁰12'3.64''
2	Yenikpa	4⁰56'18.64''	6⁰13'59.89''
3	Tombia	4⁰59'50.91''	6⁰15'46.36''
4	Kaiama	5⁰08'25.85''	6⁰21'15.86''
5	Opokuma	5⁰05'7.03''	6⁰15'29.33''
6	Agudama Ekpetiama	5⁰00'28.37''	6⁰15'26.96''
7	Ogbogoro	4⁰50'41.97''	6⁰55'44.26''
8	Yenagoa	4⁰55'13.40''	6⁰16'27.94''
9	Polaku	5⁰02'0.54''	6⁰17'2.70''

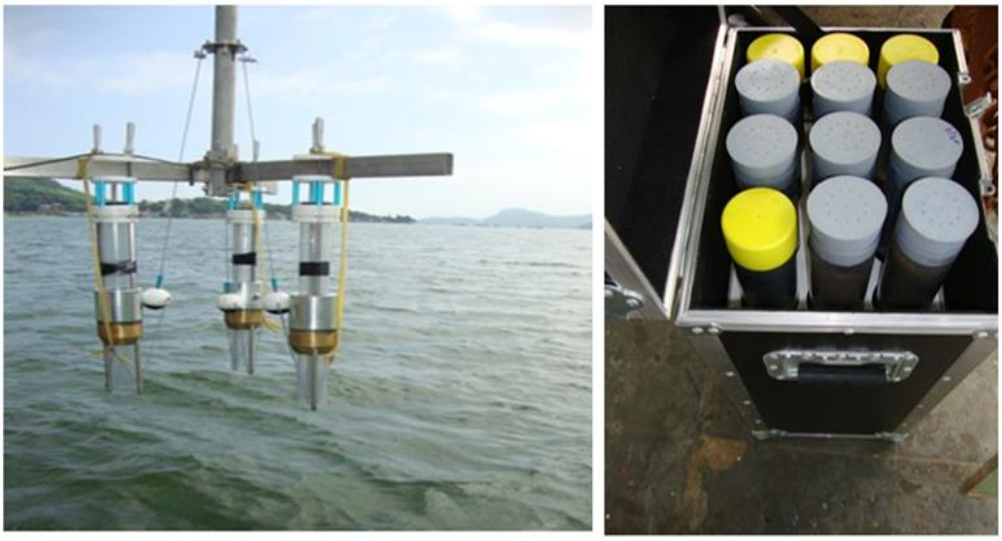

Fig. 2 Uwitec gravity triple sediment corer fitted with plexy glass tubes of 50 cm length and 10 cm internal diameter.

The accurate estimation, the MSE, RMSE and ASE indices should be as small as possible whereas the RMSSE index should be as close to unity as possible. If RMSSE is greater (less) than 1, then the variability of the estimations is underestimated (overestimated) [18]. The choice of considered indices was based on their ability to adequately evaluate the fitted distribution and determine the goodness-of-fit between observed and estimated parameters. The most suitable model deduced for each parameter was used to develop the final estimation map.

3. Results and Discussion

Using the different models, the semi-variogram parameters deduced for cadmium, lead, chromium and zinc are shown in Table 2. Fitted semi-variogram models presented in Table 2 provide information about the model parameters (range, nugget and partial sill), which were utilized to determine the degree of spatial dependency. It also specifies the input parameters that were utilized for the kriging interpolation. Table 3 shows the estimated goodness-of-fit statistics for the considered models. Following the application of different models, the errors were calculated using cross validation and the model that gives the best result was chosen. Based on the RMSE index, the most suitable model selected for each parameter is presented in Table 4.

Table 5 shows the estimated spatial dependence of sediment parameters. The sill (C) is the sum total of partial sill and nugget (C_n) whereas the ratio of C_n to C (C_n/C) is a measure of the degree of the spatial dependence [17]. If the value of C_n/C is less than 25 %, the variable has strong partial dependence; between 25 % and 75 %, it has moderate spatial dependence; otherwise, it displays only weak spatial dependence. As observed (Table 5), the sediment parameters exhibited relatively strong degree of spatial dependency, which made it possible to generate the spatial distribution map for the selected heavy metals. The deduced prediction map, which can be used to estimate the concentration of cadmium, lead, chromium and zinc around the Nun River is presented in Figs. 3 – 6, respectively.

Table 2 Semi-variogram parameters of fitted models for selected heavy metals.

Parameter	Model type	Nugget	Major range	Partial sill
Cadmium	Stable	61.80197	1.781869	209.1735
	Circular	60.17988	1.781869	91.18179
	Spherical	60.23832	1.781869	77.5875
	Exponential	61.26413	1.781869	46.21658
	K-Bessel	61.74055	1.781869	183.9007
Lead	Stable	5.7000	0.502153	41.04647
	Circular	2.3300	0.502153	41.65407
	Spherical	1.0560	0.502153	37.08536
	Exponential	12.0002	0.502153	44.39273
	K-Bessel	8.0034	0.502153	39.35510
Chromium	Stable	97.46164	1.781869	4989.283
	Circular	33.00971	1.781869	2413.467
	Spherical	23.47002	1.781869	2057.055
	Exponential	11.09763	1.781869	1282.202
	K-Bessel	47.09345	1.781869	4377.398
Zinc	Stable	382.515	1.781869	24184.78
	Circular	67.8930	1.781869	11103.20
	Spherical	134.568	1.781869	9462.305
	Exponential	109.506	1.781869	5913.782
	K-Bessel	383.524	1.781869	21061.04

Table 3 Calculated cross validation statistics of fitted models for selected heavy metals.

Parameter	Model Type	RMSE	MSE	RMSSE	ASE
Cadmium	Stable	0.8727	-0.0101	0.9825	9.0899
	Circular	1.2525	0.0071	1.0021	9.2471
	Spherical	1.2565	-0.0069	1.0022	9.2501
	Exponential	1.3262	-0.0036	1.0022	9.3016
	K-Bessel	0.8854	-0.0103	0.9833	9.0947
Lead	Stable	0.4678	0.0685	1.0761	3.9900
	Circular	0.7011	0.0697	1.0176	4.1658
	Spherical	0.6323	0.0596	0.9872	4.2181
	Exponential	1.7442	0.0511	0.9667	4.3807
	K-Bessel	0.4192	0.0654	1.0908	3.9572
Chromium	Stable	1.3321	0.0753	1.8831	14.6558
	Circular	0.08640	0.0812	1.4396	16.9078
	Spherical	1.0423	0.0802	1.4364	16.9381
	Exponential	1.9150	0.0687	1.3110	17.8162
	K-Bessel	1.1117	0.0768	1.8545	14.8116
Zinc	Stable	0.3065	-0.0144	1.9836	29.8732
	Circular	0.2194	0.0834	1.5141	36.2651
	Spherical	0.1763	0.0835	1.5113	36.3279
	Exponential	0.1061	0.0830	1.3820	38.2622
	K-Bessel	0.9825	-0.0064	1.9467	30.3999

Table 4 Summary table for estimating spatial dependence.

Parameter	Best model	Nugget	Major range	Partial sill
Cadmium	Stable	61.80197	1.781869	209.1735
Lead	K-Bessel	8.0034	0.502153	39.35510
Chromium	Circular	33.00971	1.781869	2413.467
Zinc	Exponential	109.506	1.781869	5913.782

Table 5 Estimated spatial dependence of sediment parameters.

Parameter	Best model	Nugget (C_n)	Partial sill	Sill (C)	[C_n/C]	Degree of dependency
Cadmium	Stable	61.80197	209.1735	270.97550	0.22807	Strong
Lead	K-Bessel	8.0034	39.35510	47.358500	0.16900	Strong
Chromium	Circular	33.00971	2413.467	2446.4767	0.01368	Strong
Zinc	Exponential	109.506	5913.782	6023.2880	0.01852	Strong

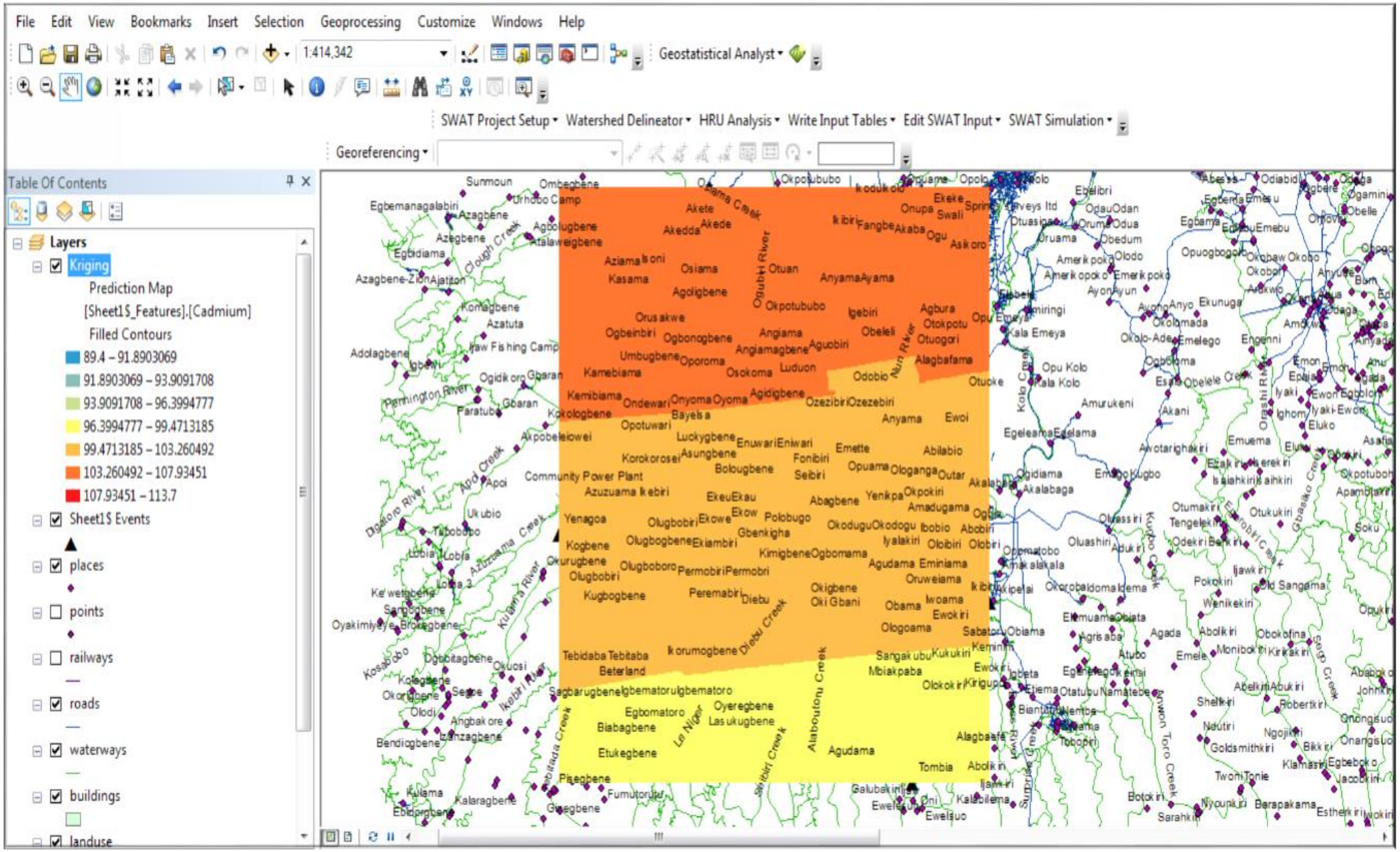

Fig. 3 Final prediction map for the spatial distribution of cadmium around the Nun River.

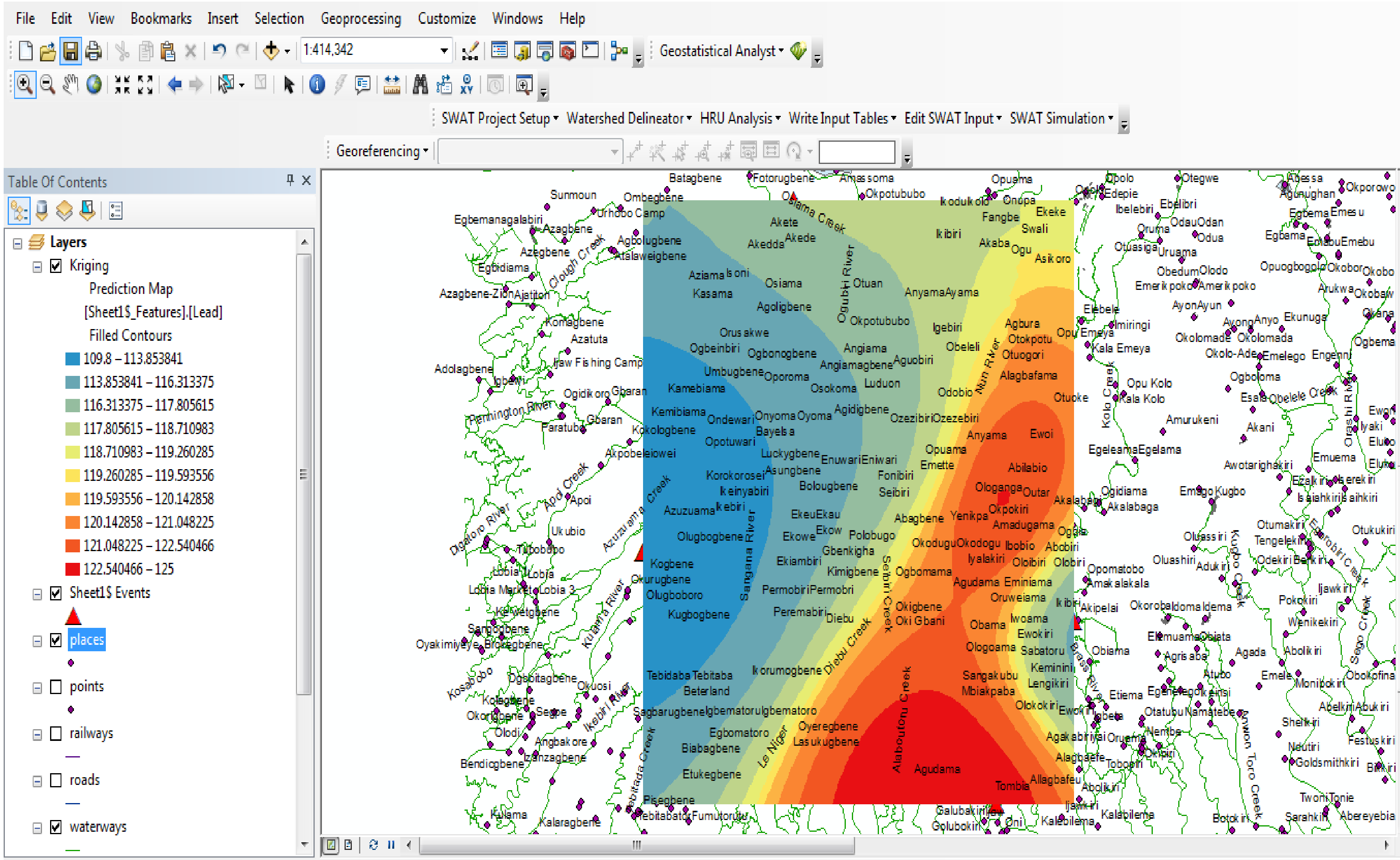

Fig. 4 Final prediction map for the spatial distribution of lead around the Nun River.

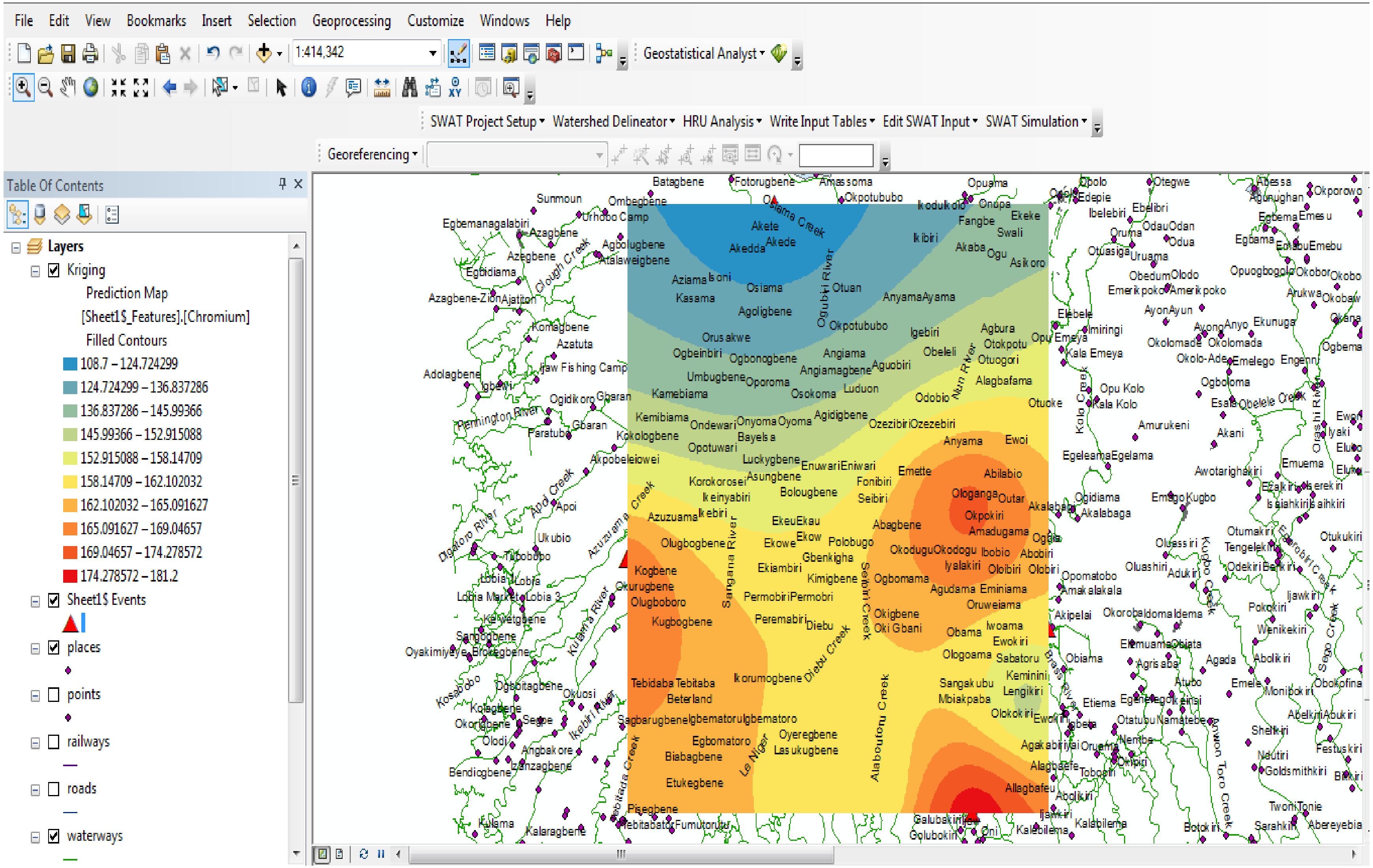

Fig. 5 Final prediction map for the spatial distribution of chromium around the Nun River.

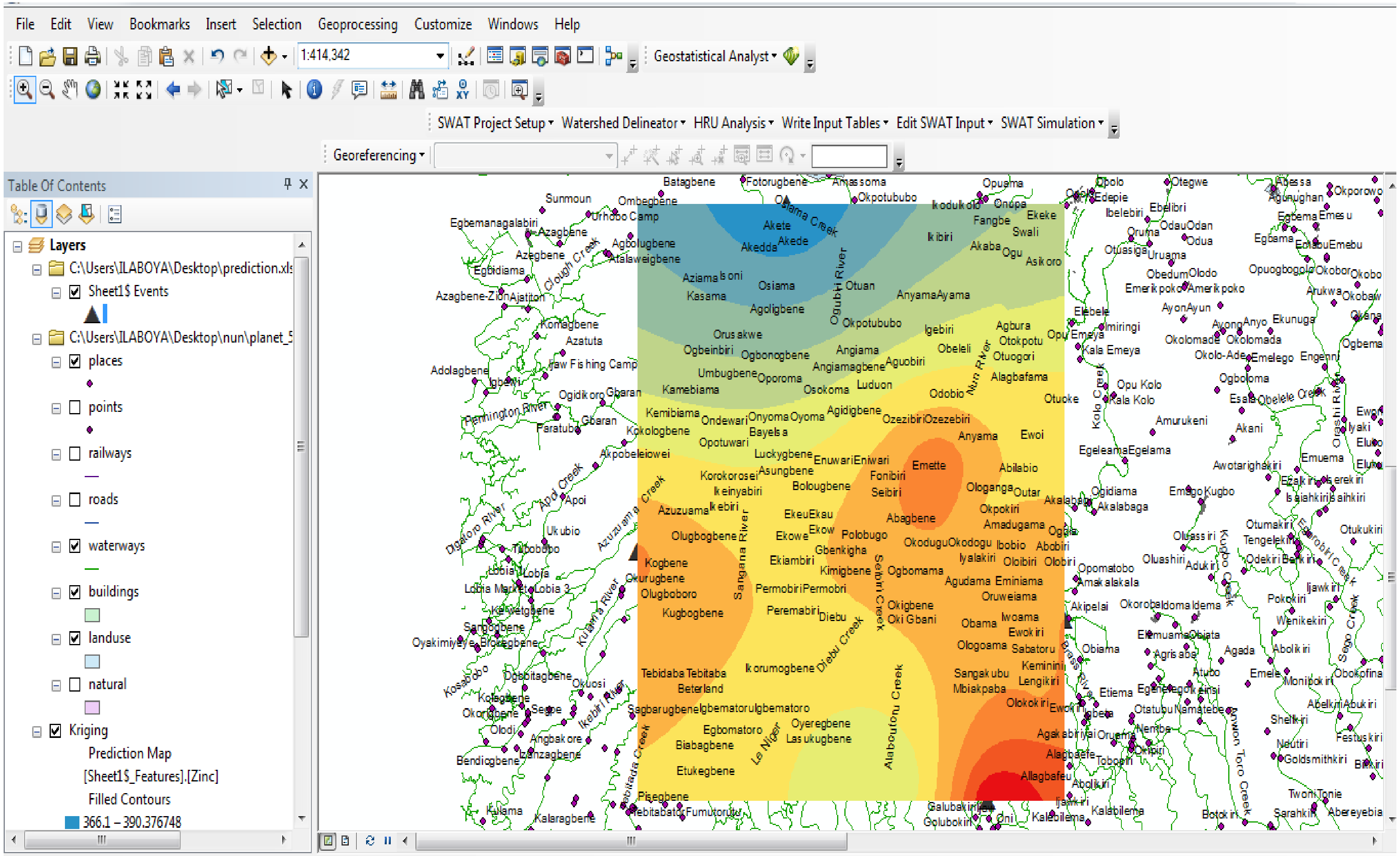

Fig. 6 Final prediction map for the spatial distribution of zinc around the Nun River.

Analysis of Figs. 3 – 6 reveals that; regions with red color codes signify higher concentration of cadmium, lead, chromium and zinc. In Fig. 3, it was noticed that high concentrations of cadmium are present in areas such as Otuan, Obeleli, Angiama, Odobio, Kasama, Akedda, and Akele etc. The observed high concentrations of lead (Fig. 4) are present in areas such as Agudama, Tombia, Ewoi, Abilabio, Agudama, and Yenikpa. Similarly, high concentrations of chromium are present in Okpokiri, Ologanga, Abilabio, Allagbafeu and Emette as seen in Fig 5 high concentrations of zinc are present Abagbene, Emette, Allagbafeu, Anyama, Olokokiri and Seibiri.

4. Conclusion

Analysis of spatial variation of heavy metals around the River Nun revealed that Abagbene, Emette, Allagbafeu, Anyama, Olokokiri and Seibiri communities are expected to experience high concentration of zinc in both the underlying sediments, groundwater and surface water. Okpokiri, Ologanga, Abilabio, Allagbafeu and Emette communities are expected to experience high concentration of chromium in both the underlying sediments, groundwater and surface water respectively. In addition, Agudama, Tombia, Ewoi, Abilabio, Agudama and Yenikpa communities are expected to experience high concentration of lead in both the underlying sediments, groundwater and surface water. Otuan, Obeleli, Angiama, Odobio, Kasama, Akedda and Akele communities are expected to experience high concentration of cadmium in both the underlying sediments, groundwater and surface water respectively.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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