# STATISTICAL ANALYSIS OF STREAM SEDIMENT GEOCHEMICAL DATA FROM OYI DRAINAGE SYSTEM, WESTERN NIGERIA

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(Received: 4th July, 2015; Accepted: 28th Nov., 2015)

## ABSTRACT

Sixty-one stream sediment samples were collected at sampling intervals that varied between 1.5 km and 2.0 km along the channels of River Oyi and its tributaries. The samples were air-dried, disaggregated and sieved to obtain the minus 80 mesh (177 microns) fraction. Half a gram of each of the sieved samples was digested with aqua regia, and then analysed for twenty-four elements using Inductively Coupled Plasma Mass Spectroscopy (ICP-MS). The results of concentrations of twenty-four elements treated with both univariate and multivariate statistical analytical techniques revealed that all the elements analyzed except Co, Cr, Fe and V had log-normal distributions. The cumulative probability plots of the elements showed that Mn and Cu consisted of one population. Ni, Pb, Ag, La, Th, Co, Sc, Ga, Cr, Tl, Au, Bi, U, Sr, Fe, and Zn had two populations while the remaining elements were made up of three populations. The Simple Person correlation analysis revealed that there were strong positive correlations between the pairs of the following elements: Fe-Mn-Ni-Co-Sc-Tl-Ba-V-Mo; La-Pb-Th; Zn-Cu-Ag-Au-Sb; Bi-Cr and Cr-La, with 'r' values ranging from -0.74 to 0.98. These correlations were significant at 95% and above confidence level. R-mode varimax factor analysis produced a Four-Factor model, accounting for 90.08% of the data variability with the following metal associations: Ga-Fe-Ni-Co-Sc-Mn-Tl-Ba-V-Mo-Zn-Cu-Ag-Au; Pb-La-Sr-Th-U-Cd; Cu-Ag-Au-Sb and Bi-Cr. The results of the statistical analyses suggested the occurrence of potential mineralization containing Cu-Zn-Ag-Au in the gneisses of the study area.

**Keywords**: Stream Sediment, Multivariate Analysis, Cumulative Probability, Precision.

## INTRODUCTION

Geochemical reconnaissance survey was undertaken in parts of Lafiagi area (Figure 1) because some of the rocks in the study area are believed to harbour gold mineralization. This is evident in the fact that gold is being mined illegally by a large number of artisans in the area. The dearth of research work on the mineralization potential of the area makes this research necessary. Therefore, this study, which is reconnaissance in nature, is aimed at investigating the mineralization potential of the study area. Stream sediment geochemical survey technique was employed because it has been found useful for reconnaissance studies in drainage basins (Yilmaz, 2007; Ranassinghe *et al.*, 2008; Ayodele, 2011; Ekwere *et al.*, 2013) when the samples collected are representative of the products of weathering and erosion upstream of the sampling site (Levinson, 1974).

The use of statistical methods in the analysis and interpretation of stream sediment geochemical data have been found to be successful (Closs and Nichol, 1975; Garret *et al.*, 1980; Ajayi, 1981; Adepoju and Adekoya, 2008; Adesiyan and Adekoya, 2008; Ariyibi *et al.*, 2010; Bamigboye and Adekeye, 2011; Olaolorun and Oyinloye, 2012). However, there is the need to be cautious when these methods are applied. This is due to the fact that geochemical data rarely represent a single population. The variability in sampling methods, sampling media and the level of analytical precision make geochemical data set imprecise. As a result, a range of techniques are usually employed in order to explore the nature of geochemical data before anomalous values are selected (Reimann *et al.*, 2008). The techniques that have been employed in the past include univariate, multivariate, exploratory data analyses etc. In this paper, both univariate and multivariate statistical methods were employed in the analysis of stream sediment data from the study area.

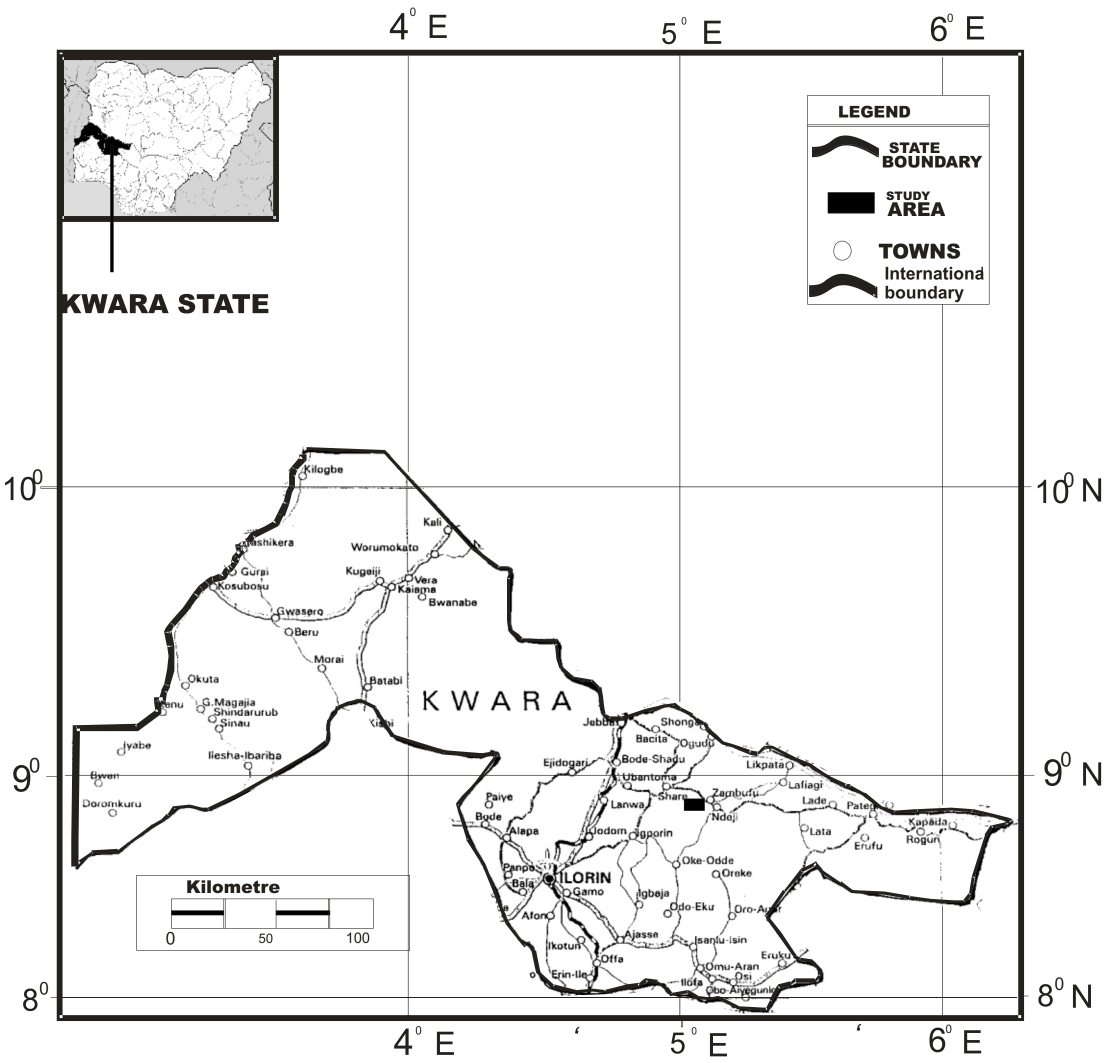



**Figure 1: Map of Kwara State Showing the Study Area.**

## Geology of the Study Area

The study area is well drained by River Oyi and its tributaries which form the drainage system. River Oyi runs essentially in the northwest direction before discharging into the River Niger. A critical study of the drainage pattern showed that it is essentially dendritic. Apart from some few streams, all the rivers (including River Oyi), and streams in the area are seasonal as most of their channels were dry during the raining season.

The study area is underlain by both the Precambrian Basement Complex rocks and the Cretaceous Sandstone of the Bida Basin (Figure 2). The geology of Nigeria consists of the Basement Complex rocks which are Precambrian in age, the Younger Granite and the Cretaceous to Tertiary sedimentary rocks (Grant, 1970; McCurry and Wright, 1971 and Rahaman, 1976). The Precambrian Basement Complex of Nigeria lies within the Pan-African mobile belt situated between the West African Craton to the west and the Congo craton to the southeast. It is polycyclic and consists of a wide range of igneous and metamorphic rocks. Its isotopic ages range from 2800 Ma to 450 Ma (Rahaman, 1988). Workers such as Oyawoye (1972), McCurry (1976), Odeyemi (1981), Ajibade *et al.*, (1987), Adekoya (1991) and Adekoya *et al.*, (2003) have grouped the rocks of the Basement complex into four petro-lithological units:

(I) The Migmatite-Gneiss-Quartzite Complex;
(ii) The Schist Belt;
(iii) The Pan-African granitoids (Older Granites) with associated charnokitic rocks and syenites; and
(iv) The minor felsic and mafic intrusive.

The Basement Complex rocks underlying the study area as shown on the geological map of Lafiagi (1: 250,000,NGSA) consist of: fine-grained flaggy, quartz-biotite gneisss; undifferentiated schist; pegmatite;

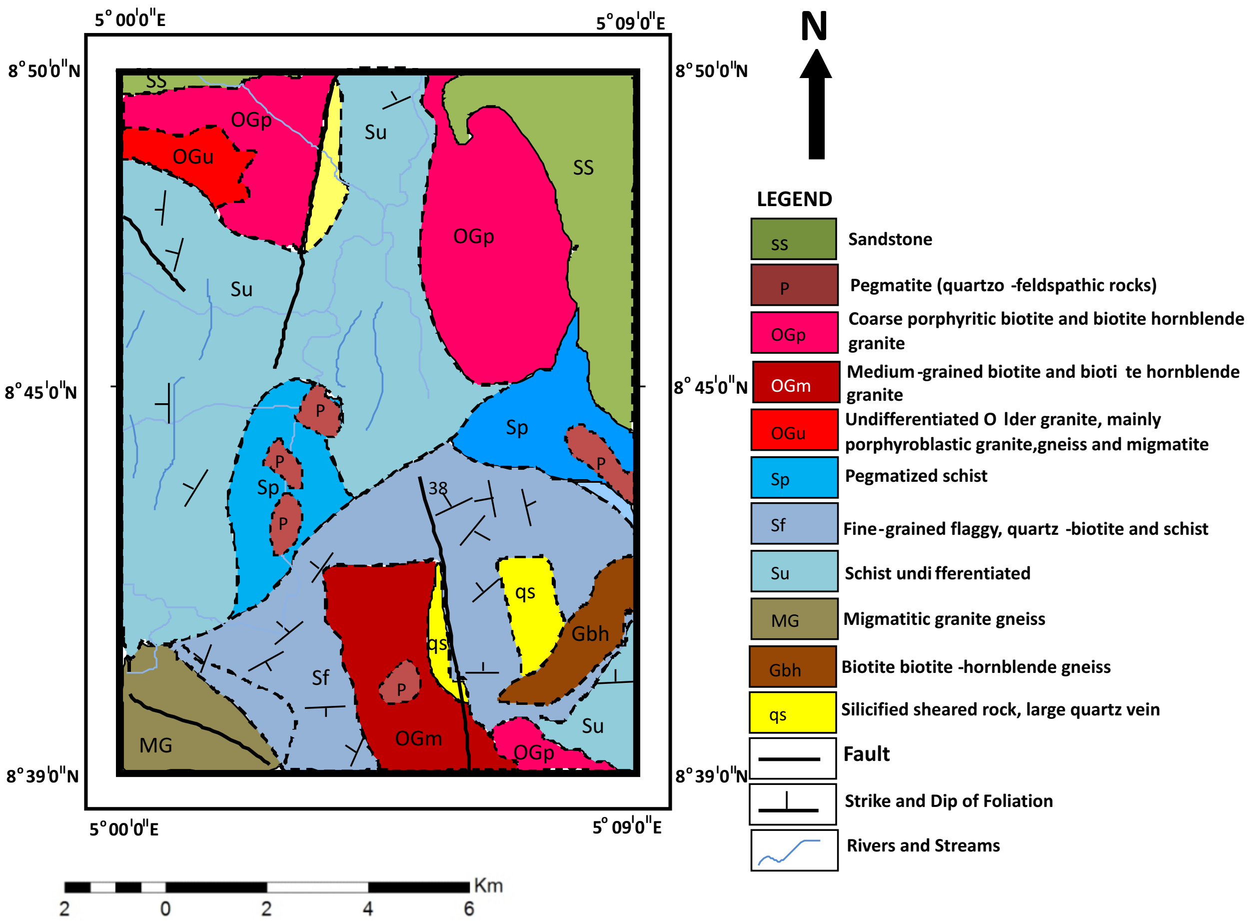



**Fig. 2: Geological Map of the Study Area. (adapted from NGSA 2008)**

undifferentiated Older Granite etc. The undifferentiated schist dominates the study area as it covers about half of the area. Next in dominance, is the fine-grained flaggy, quartz-biotite and schist which covers the southern part of the area sharing boundary with the pegmatized schist to the northwest and migmatitic granite gneiss to the southwestern part of the area. Rocks of the Older Granite suite, which include the medium-grained biotite and biotite-hornblende granite, and the undifferentiated granite etc., occupy the northwestern, southern and the northeastern parts of the area. Pegmatite, which occur as intrusions, are hosted by granites and schist. In the northwestern and northeastern parts are the sedimentary portions where the basement is overlain by the Nupe sandstone.

Artisinal mining for gold is usually carried out in the study area. This activity is confined to mainly the rivers and streams. The gold mineralization is found associated with gneisses and schists at Bishewa and Ologomo as well as in Gidan Sani in the sandstone beds at the contact between the Basement Complex and the Cretaceous sediments of the Bida Basin (Malomo, 2012). The Lema-Ndeji field in the Lafiagi area is one of the seven mineralized Ta-Nb pegmatite fields within the Precambrian Basement Complex of Nigeria. (Okunlola, 2005). According to Okunlola (2005), other rare – metal Ta-Nb pegmatite fields in Nigeria are Kabba–Isanlu, Keffi–Nassarawa, Ijero – Aramoko, Okeogun, Ibadan-Oshogbo and Kushaka – Birnin Gwari. The pegmatite in the Lema –Ndeji area are hosted by Older granite (Adedoyin *et al.*, 2006) and they are host to metals such as niobium, tin, tungsten, columbite as well as mica, feldspar, quartz and a host of gemstones, including black tourmaline, beryl etc.

## MATERIALS AND METHOD OF STUDY

### Sampling and Laboratory Analytical Methods

The reconnaissance stream sediment sampling survey, which was based on 1: 100,000 topographic map, sheet 203 (Lafiagi sheet), was carried out in May 2009 and January 2010. During this survey, a total of sixty-one (61) stream sediment samples were collected at an interval of 1.5 km to 2.0 km along the channels of River Oyi and its tributaries (Figure 3). The geographic co-ordinates of each sampling point were determined with a Global Positioning System (GPS) and then plotted on the drainage map of the area (Figure 3). The samples were collected, with the aid of a plastic scoop at a depth of 15 cm, in a clean sample bag. This was done in order to avoid contamination of the samples.

In the laboratory, the samples were air-dried, disaggregated and sieved to obtain the minus 80 mesh fraction (177 microns) (Thompson 1986; Rose *et al.*, 1991). 0.5 g of the sieved sample was digested with aqua regia (1:3 $HNO_3$: HCl) and then analysed for Ag, As, Au, Ba, Bi, Cd, Co, Cr, Cu, Fe, Ga, La, Mn, Mo, Ni, Pb, Sb, Sc, Sr, Th, Tl, U, V and Zn by Inductively Coupled Plasma Mass Spectroscopy (ICP-MS). Both the digestion and the ICP-MS analysis were done at ACME Analytical Laboratories, Vancouver, Canada.

Duplicate samples were used to assess data quality and were excluded from the statistical analysis. ACME's in-house reference materials (STD DS8 and STD OREA) were analyzed to assess the accuracy. The statistical analysis of the duplicates indicated that the precision is reasonable and satisfactory as only few elements had relative error greater than 15%. The contents of all the elements in the blanks were below the detection limits. Consequently, contributions from the blanks were, therefore, negligible. The detection limits for the elements determined were Au 0.2 ppb, Ag 2 ppb, As 0.1 ppb, Ba 0.5 ppm, Bi 0.02 ppm, Cd 0.01 ppm, Co 0.1 ppm, Cr 0.5 ppm, Cu 0.01 ppm, Fe 0.01%, Ga 0.1 ppm, Mn 1 ppm, Mo 0.01 ppm, Ni 0.1 ppm, Pb 0.01 ppm, Sb 0.02 ppm, Sc 0.1 ppm,Sr 0.5 ppm, Th 0.1 ppm, Tl 0.02 ppm, U 0.05 ppm and Zn 0.1 ppm.

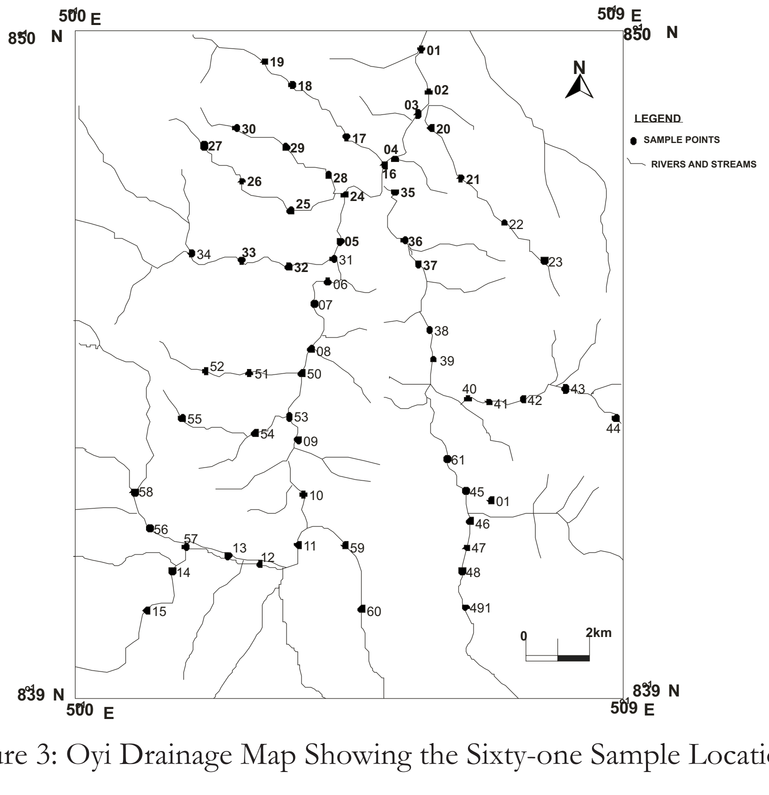



Figure 3: Oyi Drainage Map Showing the Sixty-one Sample Locations.

### Statistical Analysis of Data

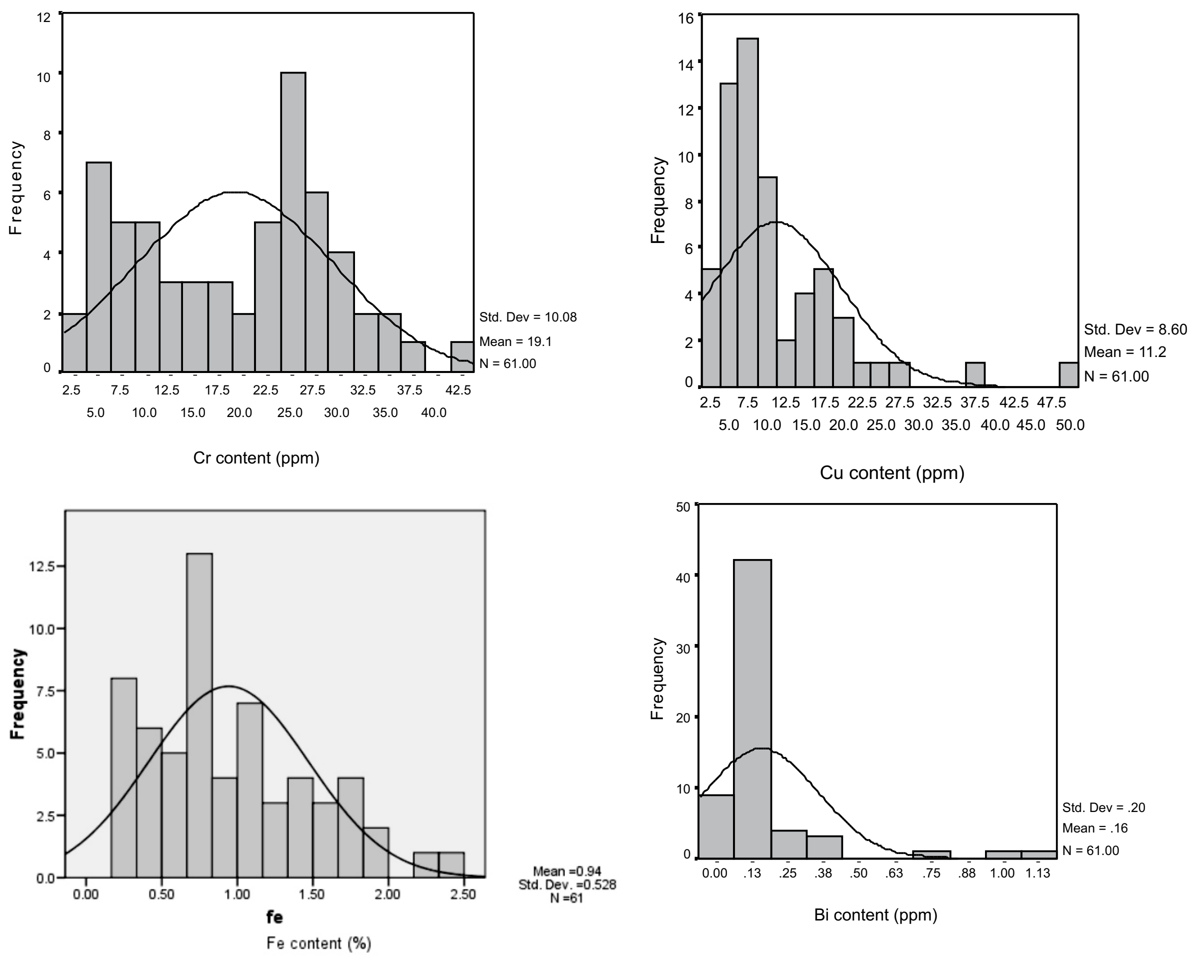
The frequency distribution plots (i.e. histograms and curves) for the raw and the log-transformed data as well as the R-mode factor analysis were prepared using the Statistical Package for Social Sciences (SPSS) version 16.0 software. These histograms display the values of mean, standard deviation and the number of samples where the particular element has been detected (i.e. N). The cumulative probability plots were prepared using Probplot software designed by Stanley (1987) and following Lepeltier's (1969) method. Each plot gives information on the number of samples in which the particular element was detected, the standard deviation, the mean, the number of statistical populations for the element and the threshold values for each population. Pearson linear correlation matrix was generated from the logarithmically transformed data using SPSS version 16.0 software.

## RESULTS AND DISCUSSION

### Frequency Distribution Plots

Table 1 shows the basic statistical parameters of the raw data. A study of the raw data frequency plots (Fig. 4) revealed that twenty of the twenty-four elements (viz: Ag, As, Au, Ba, Bi, Cd, Cu, Ga, La, Mn, Mo, Ni, Pb, Sb, Sc, Sr, Th, Tl, U and Zn) were positively skewed. The remaining elements i.e. V, Co, Fe and Cr showed approximately normal distribution. The raw data were then log-transformed and a new set of histograms plotted. There was a decrease in the absolute values of the skewness of these elements (Tables 1, 2 and Fig. 5) after log-transformation. Hence, the distribution of these elements in the study area obeyed Ahrens' law of log-normality (Ahrens', 1954). However, eight of the log-normally distributed elements (i.e. Cu, Ag, Bi, La, U, Th, Sr, Cd) showed strong positive skewness while the others were less skewed.

All the raw data histograms, except Au, Mn, Sc and Tl, showed breaks in distribution,



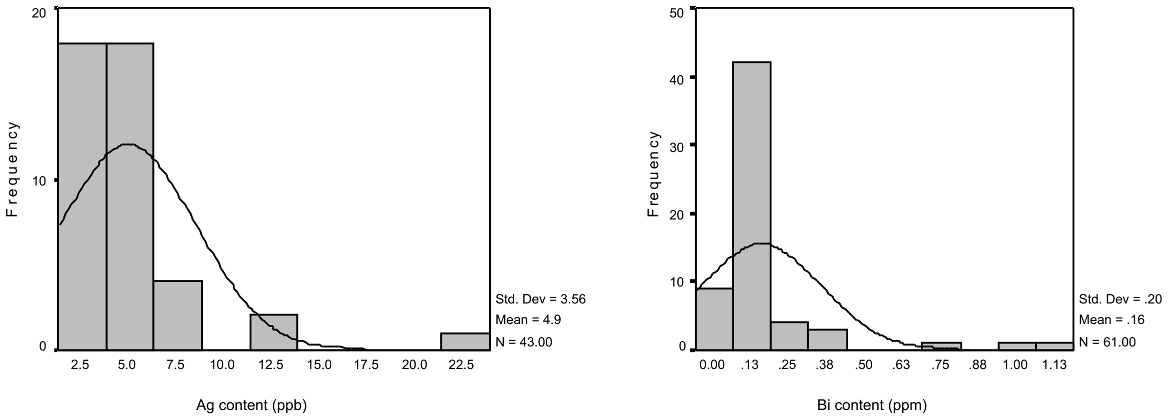



Figure 4: Frequency Distribution of Raw Data on some Elements in the Stream Sediment of the Study Area.

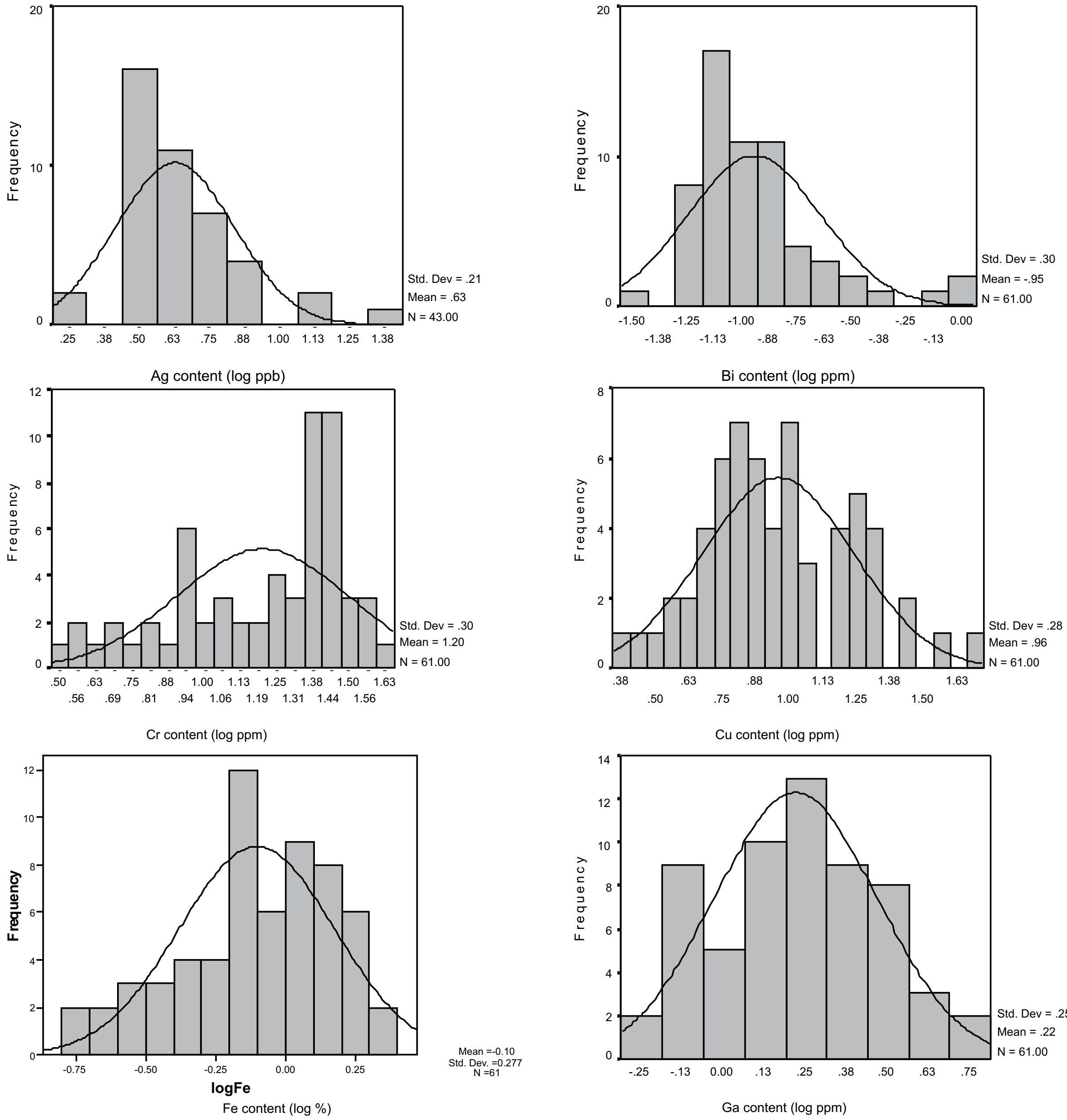



Figure 5: Frequency Distribution of Logarithmically Transformed Data on some Elements in the Stream Sediment of the Study Area.

Table 1: Summary of Raw Data Statistics of Trace Elements in Stream Sediment from Lafiagi Area.

| Elemnt | Minimum Concentration in ppm(unless Otherwise indicated) | Maximum Concentration in ppm(unless Otherwise indicated) | Skewness (ppm) | Arithmetic Mean (X) | Standard Deviation (S) | Threshold[1] (X+2S) | Coefficient[2] Of Variation |
|---|---|---|---|---|---|---|---|
| *Ag | 2.00 | 22.00 | 3.16 | 4.88 | 3.56 | 12.01 | 12.95 |
| As | 0.10 | 0.90 | 1.64 | 0.27 | 0.18 | 0.621 | 67.17 |
| *Au | 0.30 | 1.60 | 0.99 | 0.67 | 0.37 | 1.41 | 54.99 |
| Ba | 13.20 | 180.00 | 0.86 | 66.84 | 41.26 | 149.36 | 61.74 |
| Bi | 0.03 | 1.08 | 3.60 | 0.16 | 0.20 | 0.55 | 125.90 |
| Cd | 0.01 | 0.78 | 4.48 | 0.05 | 0.16 | 0.36 | 351.55 |
| Co | 0.60 | 14.30 | 0.68 | 5.30 | 3.46 | 12.22 | 65.32 |
| Cr | 3.30 | 41.80 | 0.04 | 19.09 | 10.08 | 39.25 | 52.77 |
| Cu | 2.52 | 50.88 | 2.27 | 11.21 | 8.60 | 28.41 | 76.76 |
| **Fe | 0.18 | 2.38 | 0.69 | 0.94 | 0.53 | 1.997 | 56.10 |
| Ga | 0.50 | 5.20 | 1.05 | 1.92 | 1.08 | 4.08 | 56.28 |
| La | 4.50 | 108.50 | 2.45 | 21.61 | 19.96 | 61.53 | 92.41 |
| Mn | 77.00 | 652.00 | 1.09 | 261.44 | 153.77 | 568.99 | 58.82 |
| Mo | 0.03 | 0.42 | 2.45 | 0.10 | 0.06 | 0.22 | 61.52 |
| Ni | 0.50 | 20.70 | 0.90 | 6.65 | 4.61 | 15.87 | 69.32 |
| Pb | 2.31 | 20.55 | 1.32 | 7.40 | 4.46 | 16.32 | 60.27 |
| Sb | 0.02 | 0.07 | 1.40 | 0.04 | 0.02 | 0.06 | 41.19 |
| Sc | 0.30 | 4.10 | 0.98 | 1.46 | 0.80 | 3.07 | 55.04 |
| Sr | 1.90 | 42.70 | 2.63 | 8.50 | 6.41 | 21.31 | 75.38 |
| Th | 1.50 | 135.60 | 3.94 | 14.00 | 21.24 | 56.49 | 151.73 |
| Tl | 0.02 | 0.31 | 1.64 | 0.09 | 0.06 | 0.21 | 73.50 |
| U | 0.20 | 12.30 | 3.87 | 1.23 | 2.08 | 5.39 | 169.05 |
| V | 5.00 | 51.00 | 0.25 | 22.85 | 12.91 | 46.87 | 52.55 |
| Zn | 4.60 | 70.60 | 1.66 | 18.23 | 13.15 | 44.52 | 72.14 |

* Given in ppb and ** in %

[1]Threshold (mean + 2 std. dev.) obtained from histogram of raw data

[2]Coefficient of Variation = (S/X) x 100%

Table 2: Summary of Log-transformed Data Statistics of Trace Elements in the Stream Sediment from Lafiagi Area.

| Element | Minimum Concentration in ppm(unless otherwise indicated) | Maximum Concentration in ppm(unless otherwise indicated) | Skewness (ppm) | Geometric Mean (X) | Standard Deviation (S) | Threshold[1] (Antilog (X+2S)) | Coefficient[2] of variation |
|---|---|---|---|---|---|---|---|
| *Ag | 0.30 | 1.34 | 1.39 | 0.60 | 0.21 | 11.30 | 33.58 |
| As | -1.00 | -0.05 | 0.27 | -0.66 | 0.26 | 0.74 | 0.41 |
| *Au | -0.52 | 0.20 | 0.29 | -0.23 | 0.23 | 1.66 | 0.98 |
| Ba | 1.12 | 2.26 | -0.31 | 1.74 | 0.29 | 209.07 | 16.79 |
| Bi | -1.52 | 0.03 | 1.39 | -0.95 | 0.30 | 0.45 | 31.82 |
| Cd | -2.00 | -0.11 | 3.65 | -1.85 | 0.40 | 0.09 | 21.48 |
| Co | -0.22 | 1.16 | -0.67 | 0.61 | 0.36 | 20.54 | 57.79 |
| Cr | 0.52 | 1.62 | -0.72 | 1.20 | 0.30 | 61.55 | 24.60 |
| Cu | 0.40 | 1.71 | 0.38 | 0.96 | 0.28 | 32.51 | 29.11 |
| **Fe | -0.75 | 0.38 | -0.52 | -0.10 | 0.28 | 2.85 | 268.71 |
| Ga | -0.30 | 0.72 | -0.11 | 0.22 | 0.25 | 5.13 | 113.35 |
| La | 0.65 | 2.04 | 0.75 | 1.22 | 0.30 | 64.94 | 24.41 |
| Mn | 1.89 | 2.81 | 0.06 | 2.35 | 0.25 | 707.13 | 10.70 |
| Mo | -1.52 | -0.38 | 0.22 | -1.06 | 0.23 | 0.25 | 21.85 |
| Ni | -0.30 | 1.32 | -0.90 | 0.69 | 0.39 | 29.59 | 56.71 |
| Pb | 0.36 | 1.31 | 0.11 | 0.80 | 0.25 | 19.75 | 31.06 |
| Sb | -1.70 | -1.15 | 0.63 | -1.48 | 0.16 | 0.07 | 10.62 |
| Sc | -0.52 | 0.61 | -0.33 | 0.10 | 0.25 | 3.97 | 256.60 |
| Sr | 0.28 | 1.63 | -0.12 | 0.83 | 0.31 | 27.44 | 36.90 |
| Th | 0.18 | 2.13 | 0.53 | 0.90 | 0.44 | 58.76 | 48.45 |
| Tl | -1.70 | -0.51 | 0.10 | -1.17 | 0.29 | 0.26 | 24.75 |
| U | -0.70 | 1.09 | 1.15 | -0.15 | 0.39 | 4.29 | 256.76 |
| V | 0.70 | 1.71 | -0.62 | 1.28 | 0.28 | 68.90 | 21.57 |
| Zn | 0.66 | 1.84 | 0.29 | 1.17 | 0.28 | 53.72 | 24.07 |

* Given in ppb and ** in %

[1]Threshold ( Antilog (mean + 2 std. dev.)) obtained from histogram of logarithmically transformed data

[2]Coefficient of Variation = (S/X) x 100%

some of which could be interpreted as revealing a mixture of multiple populations. The log-transformed histograms also showed breaks in the distributions for Mo, Cu, Zn, Ag, Th, Sr, Bi, Ba, Tl, Cd, and Sb.

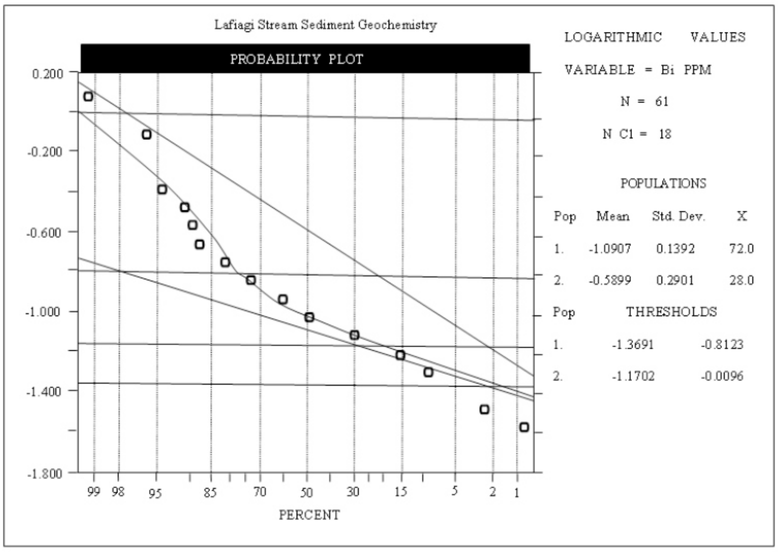
**Cumulative Probability Plots**

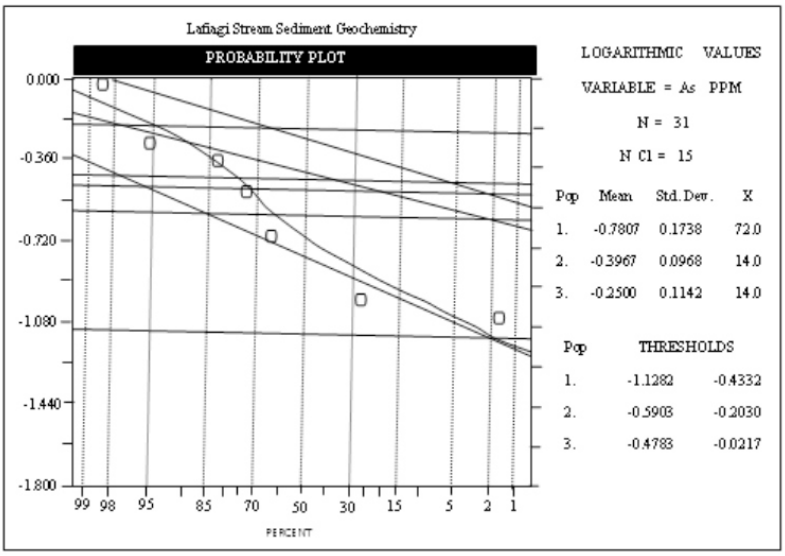
The plots (Fig. 6) indicated that the concentrations of Mn and Cu consisted of single population which represented background population. Ni, Pb, Ag, La, Th, Co, Sc, Ga, Fe, Cr, Tl, Au, Bi, U, Sr, and Zn had two populations. This is interpreted as probably representing background and anomalous populations or the heterogeneous nature of the underlying rocks in the study area while Ba, Cd, Sb, As, V and Mo were made up of three populations which probably represent the background, a mixture of background and anomalous population, and anomalous population (Saager and Sinclair, 1974).

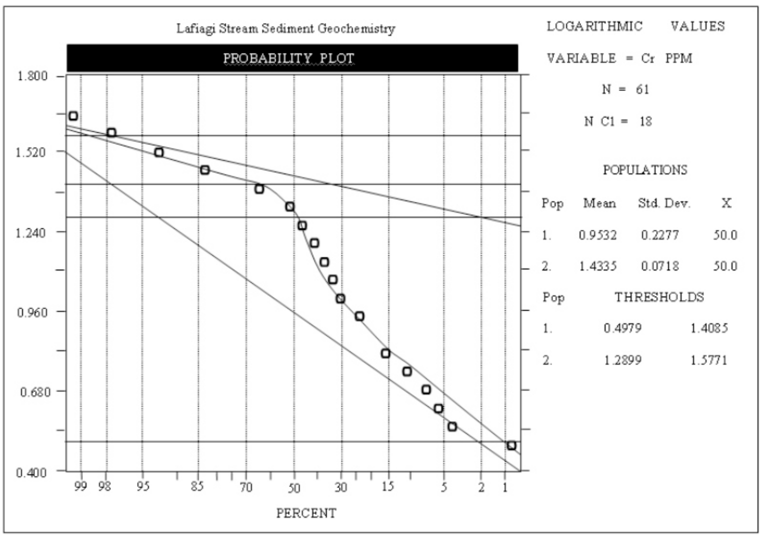
Presented in Table 3 are the relative proportions of the two and three populations exhibited by the analyzed elements. For example, Co showed the existence of two distinct populations (Table 3). The background population had a relative proportion of 4% while the anomalous population has a proportion of 96%. Since it is impossible to have anomalous population having higher relative proportion than the background population, this could probably indicate the heterogeneous nature of the underlying rocks than being an evidence of background and anomalous populations. It probably reflects the contribution of Co from more than one lithology or the scavenging action of Mn-oxide on the element.

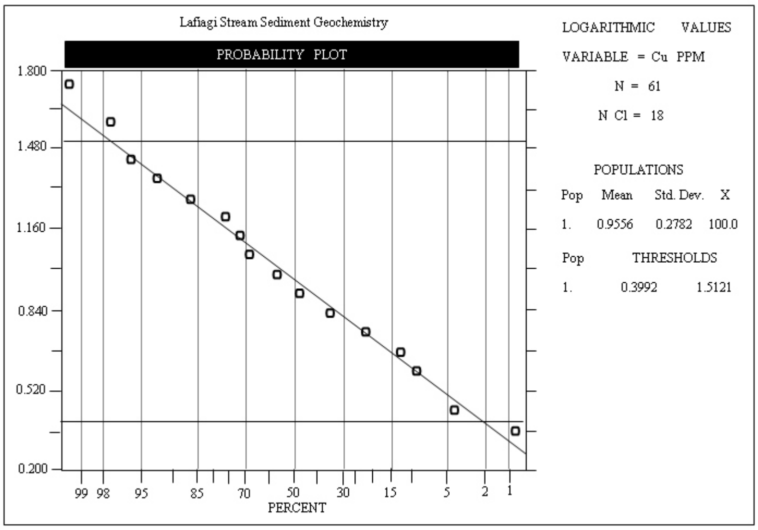
**Pearson Correlation Coefficients**

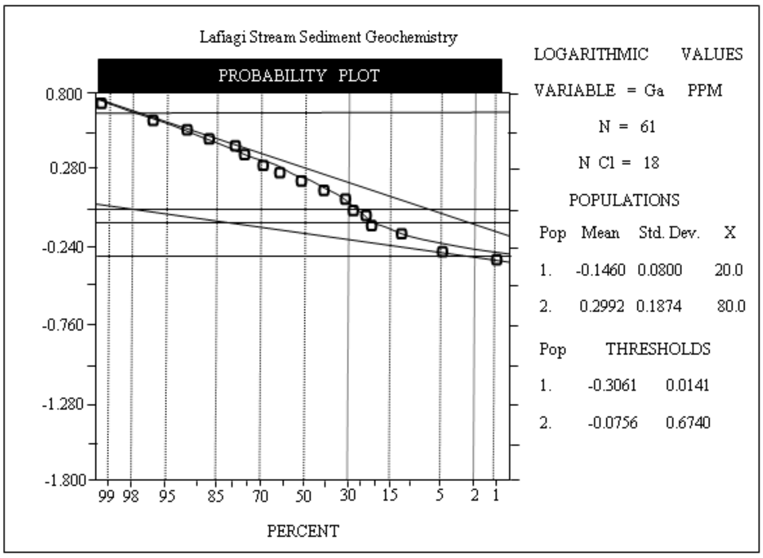
Table 4 reveals that 'r' range from -0.74 for La/Sr to 0.98 for Ga/Sc. Pairs of Fe-Mn-Ni-Co-Sc-Tl-Ba-V-Mo; La-Pb-Th-U-Cd; Zn-Ag-Cu-Au-Sb; Bi-Cr and Cr-La-Th were the elements that showed the best correlations. These associations probably reflect the heterogeneous


Lafiagi Stream Sediment Geochemistry
PROBABILITY PLOT
LOGARITHMIC VALUES
VARIABLE = Bi PPM
N = 61
N Cl = 18
POPULATIONS
Pop Mean Std. Dev. X
1. -1.0907 0.1392 72.0
2. -0.5899 0.2901 28.0
Pop THRESHOLDS
1. -1.3691 -0.8123
2. -1.1702 -0.0096
PERCENT


Lafiagi Stream Sediment Geochemistry
PROBABILITY PLOT
LOGARITHMIC VALUES
VARIABLE = As PPM
N = 31
N Cl = 15
Pop Mean Std. Dev. X
1. -0.7807 0.1738 72.0
2. -0.3967 0.0968 14.0
3. -0.2500 0.1142 14.0
Pop THRESHOLDS
1. -1.1282 -0.4332
2. -0.5903 -0.2030
3. -0.4783 -0.0217
PERCENT


Lafiagi Stream Sediment Geochemistry
PROBABILITY PLOT
LOGARITHMIC VALUES
VARIABLE = Cr PPM
N = 61
N Cl = 18
POPULATIONS
Pop Mean Std. Dev. X
1. 0.9532 0.2277 50.0
2. 1.4335 0.0718 50.0
Pop THRESHOLDS
1. 0.4979 1.4085
2. 1.2899 1.5771
PERCENT



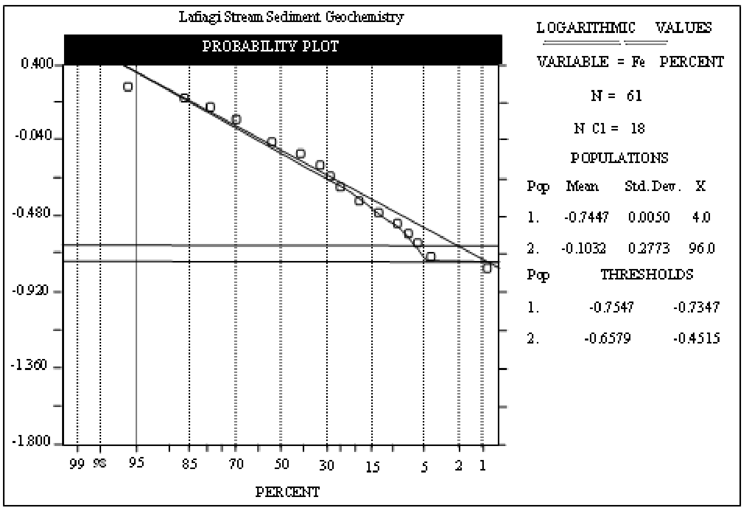




Figure 6: Cumulative Probability Plots of some Elements in the Stream Sediment from the Drainage System of River Oyi and its Tributaries

Table 3: Graphically Determined Statistical Parameters for Trace Elements Concentration in the Stream Sediment of the Study Area.

| Element | Population | Mean | Standard Deviation | Threshold | Sample % in Population |
|---|---|---|---|---|---|
| Ag (ppb) | 1 | 3.47 | 1.65 | 5.56 | 80 |
| | 2 | 7.27 | 6.84 | 18.05 | 20 |
| As (ppm) | 1 | 0.17 | 0.14 | 0.37 | 72 |
| | 2 | 0.40 | 0.18 | 0.63 | 14 |
| | 3 | 0.56 | 0.30 | 0.95 | 14 |
| Au (ppb) | 1 | 0.46 | 0.32 | 0.91 | 70 |
| | 2 | 1.08 | 0.55 | 1.78 | 30 |
| Ba (ppm) | 1 | 17.84 | 5.74 | 24.58 | 15 |
| | 2 | 57.99 | 55.73 | 146.60 | 75 |
| | 3 | 151.35 | 26.48 | 180.24 | 10 |
| Bi (ppm) | 1 | 0.08 | 0.05 | 0.15 | 72 |
| | 2 | 0.26 | 0.37 | 0.98 | 28 |
| Cd (ppm) | 1 | 0.01 | - | 0.01 | 50 |
| | 2 | 0.01 | 0.01 | 0.02 | 44 |
| | 3 | 0.15 | 1.52 | 15.34 | 6 |
| Co (ppm) | 1 | 0.60 | 0.01 | 0.61 | 4 |
| | 2 | 4.06 | 7.33 | 20.54 | 96 |
| Cr (ppm) | 1 | 8.98 | 9.85 | 25.62 | 50 |
| | 2 | 27.13 | 9.01 | 37.77 | 50 |
| Cu (ppm) | 1 | 9.03 | 12.38 | 32.51 | 100 |
| Fe (%) | 1 | 0.18 | 0.004 | 0.18 | 4 |
| | 2 | 0.79 | 1.08 | 2.83 | 96 |
| Ga (ppm) | 1 | 0.71 | 0.27 | 1.03 | 20 |
| | 2 | 1.99 | 1.77 | 4.72 | 80 |
| La (ppm) | 1 | 11.71 | 8.58 | 23.99 | 70 |
| | 2 | 37.05 | 40.95 | 106.47 | 30 |
| Mn (ppm) | 1 | 220.58 | 270.27 | 703.12 | 100 |
| Mo (ppm) | 1 | 0.04 | 0.02 | 0.06 | 20 |
| | 2 | 0.09 | 0.08 | 0.21 | 77 |
| | 3 | 0.27 | 0.22 | 0.59 | 3 |
| Ni (ppm) | 1 | 0.50 | 0.01 | 0.51 | 5 |
| | 2 | 4.89 | 10.04 | 29.58 | 95 |
| Pb (ppm) | 1 | 2.59 | 2.37 | 3.24 | 15 |
| | 2 | 7.24 | 9.23 | 18.73 | 85 |
| Sb (ppm) | 1 | 0.02 | - | 0.02 | 20 |
| | 2 | 0.03 | 0.01 | 0.05 | 65 |
| | 3 | 0.05 | 0.03 | 0.09 | 15 |

Table 3: Contd.

| **Element** | **Population** | **Mean** | **Standard Deviation** | **Threshold[1]** | **Sample % in Population** |
|---|---|---|---|---|---|
| Sc (ppm) | 1 | 0.37 | 0.11 | 0.50 | 5 |
| | 2 | 1.28 | 1.49 | 3.86 | 95 |
| Sr (ppm) | 1 | 3.23 | 2.50 | 6.88 | 40 |
| | 2 | 10.68 | 8.30 | 22.81 | 60 |
| Th (ppm) | 1 | 2.08 | 0.73 | 2.95 | 15 |
| | 2 | 9.77 | 20.10 | 59.31 | 85 |
| Tl (ppm) | 1 | 0.03 | 0.01 | 0.04 | 15 |
| | 2 | 0.07 | 0.10 | 0.25 | 85 |
| U (ppm) | 1 | 0.48 | 0.46 | 1.22 | 75 |
| | 2 | 2.24 | 3.80 | 10.44 | 25 |
| V (ppm) | 1 | 6.91 | 3.19 | 10.91 | 20 |
| | 2 | 19.23 | 12.83 | 37.04 | 50 |
| | 3 | 36.47 | 10.55 | 48.65 | 30 |
| Zn (ppm) | 1 | 4.77 | 0.31 | 5.08 | 5 |
| | 2 | 15.30 | 20.24 | 53.09 | 95 |

Table 4: Pearson Correlation Matrix for Log-Transformed Stream Sediment Geochemical Data of Oyi Drainage System.

| | **Ag** | **Au** | **Ba** | **Bi** | **Cd** | **Co** | **Cr** | **Cu** | **Fe** | **Ga** | **La** | **Mn** | **Mo** | **Ni** | **Pb** | **Sb** | **Sc** | **Sr** | **Th** | **Tl** | **U** | **V** | **Zn** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ag** | 1.0 | | | | | | | | | | | | | | | | | | | | | | |
| **Au** | .76 | 1.0 | | | | | | | | | | | | | | | | | | | | | |
| **Ba** | .51 | .42 | 1.0 | | | | | | | | | | | | | | | | | | | | |
| **Bi** | -.27 | -.09 | -.16 | 1.0 | | | | | | | | | | | | | | | | | | | |
| **Cd** | -.10 | -.03 | -.50 | -.19 | 1.0 | | | | | | | | | | | | | | | | | | |
| **Co** | -.61 | .53 | .91 | -.19 | -.54 | 1.0 | | | | | | | | | | | | | | | | | |
| **Cr** | -.05 | .19 | .06 | .72 | -.32 | .02 | 1.0 | | | | | | | | | | | | | | | | |
| **Cu** | .85 | .68 | .57 | -.04 | -.25 | .62 | -.06 | 1.0 | | | | | | | | | | | | | | | |
| **Fe** | .70 | .64 | .84 | -.17 | -.32 | .92 | .15 | .59 | 1.0 | | | | | | | | | | | | | | |
| **Ga** | .63 | .56 | .85 | -.37 | -.29 | .90 | .02 | .52 | .96 | 1.0 | | | | | | | | | | | | | |
| **La** | -.30 | -.03 | -.32 | .25 | .38 | -.42 | .62 | -.51 | -.12 | -.13 | 1.0 | | | | | | | | | | | | |
| **Mn** | .41 | .46 | .96 | -.08 | -.45 | .85 | .17 | .52 | .80 | .80 | -.17 | 1.0 | | | | | | | | | | | |
| **Mo** | .61 | .70 | .78 | -.14 | -.31 | .79 | .27 | .58 | .90 | .88 | .07 | .83 | 1.0 | | | | | | | | | | |
| **Ni** | .69 | .61 | .87 | -.32 | -.52 | .94 | .08 | .63 | .92 | .94 | -.28 | .81 | .85 | 1.0 | | | | | | | | | |
| **Pb** | .26 | .32 | .03 | -.03 | -.59 | -.04 | .26 | -.02 | .33 | .27 | .70 | .12 | .38 | .04 | 1.0 | | | | | | | | |
| **Sb** | .23 | .19 | -.23 | -.05 | .18 | -.08 | -.17 | .39 | -.12 | -.17 | -.33 | -.29 | -.23 | -.05 | -.15 | 1.0 | | | | | | | |
| **Sc** | .70 | .59 | .87 | -.40 | -.31 | .91 | -.08 | ,60 | .94 | .98 | -.27 | .70 | .86 | .93 | .18 | -.16 | 1.0 | | | | | | |
| **Sr** | .36 | .23 | .48 | .14 | -.71 | .53 | -.07 | .62 | .26 | .17 | -.74 | .45 | .23 | .41 | -.60 | .02 | .28 | 1.0 | | | | | |
| **Th** | -.18 | .00 | -.15 | .04 | .21 | -.25 | .56 | -.43 | .05 | .08 | .94 | -.02 | .25 | -.06 | .67 | -.40 | -.06 | -.67 | 1.0 | | | | |
| **Tl** | .74 | .64 | .81 | -.52 | -.35 | .88 | -.10 | .61 | .89 | .95 | -.26 | .75 | .85 | .96 | .15 | -.10 | .95 | .31 | -.02 | 1.0 | | | |
| **U** | -.05 | .20 | .22 | -.11 | .05 | .15 | .47 | -.23 | .39 | .46 | .76 | .35 | .59 | .31 | .61 | -.45 | .31 | -.50 | .88 | .34 | 1.0 | | |
| **V** | .51 | .49 | .81 | .17 | -.51 | .86 | .38 | .48 | .91 | .82 | -.10 | .76 | .78 | .79 | .19 | -.19 | .80 | .33 | .01 | .68 | .30 | 1.0 | |
| **Zn** | .93 | .77 | .63 | -.33 | -.12 | .72 | -.14 | .91 | .78 | .76 | -.37 | .57 | .74 | .79 | .21 | .28 | .81 | .37 | -.22 | .83 | .04 | .56 | 1.0 |

nature of the underlying geology, environmental influence and possible occurrence of mineralization.

For example, the correlation between Th-U and La-Pb could be related to felsic lithology or mineralization. The strong positive correlation between Au and Cu, Au and Zn etc. probably suggest the presence of gold-bearing quartz veins with sulphides, within the underlying rocks of the study area. Woakes *et al.* (1987) reported that gold – bearing quartz veins in the Nigerian Basement carry some sulphides, galena and sphalerite being the most common. In the Iperindo primary gold deposit, the association of pyrite, pyrrhotite, chalcopyrite, argentopyrite and sphalerite has been reported (Oyinloye and Steed, 1996). Other correlations such as Fe-Ni, Fe-Co, Mn-Co etc. could indicate the scavenging actions of both Fe and Mn-oxides on Ni and Co. Horsnail and Elliot (1971), in their study of the scavenging effects of Fe and Mn oxides on heavy metals in the drainage channels in British Columbia, noted that Mn-rich precipitates have high Co contents. The weak positive correlation (r = 0.21) between Pb and Zn, which are known to exhibit similar geochemical behavior, probably suggests that they are from different sources. All the correlations between the metals are significant at 95% confidence level and above.

**R-Mode Factor Analysis**

The R-mode factor analysis is a multivariate statistical technique which measure correlation between variables on the basis of their mutual linear correlation coefficients (Ajayi, 1981). The main aim of factor analysis is to detect hidden multivariate data structure and to reduce the multivariate data set into a number of factors (Reimann *et al.*, 2002).

In this study, the log-transformed data were subjected to the Principal Component Analysis (PCA) with varimax (orthogonal) rotation. Four-Factor model with eigen value greater than 1.0, accounting for 90.08% of the data variability is considered appropriate (Table 5a). The factors are:

Factor 1: Ga-Fe-Ni-Co-Sc-Mn-Tl-Ba-V-Mo-Zn-Cu-Ag-Au

This factor accounts for 49.78% of the variability of the model. This association indicates environmental and mineralization controls dominated by the scavenging actions of Fe - and Mn-oxides on these elements. The strong positive correlations of Mn with Ba, Co, Ni, V, and Sc (Table 4) and between Fe and Ni, Tl, Sc, Ga, V and Zn indicate the scavenging activity of hydrous Fe - and Mn-oxides on other elements with which Fe and Mn occur together in Factor 1. Co and Mn-oxides are known to occur together in the secondary environment as a result of the substitution of Co with Mn and the adsorption of Co on the surface of Mn-oxides (Loganathan and Burau , 1973 and Burns, 1976). Au also exhibited a strong positive correlation with Cu, Zn, Ag and Sb suggesting the possible occurrence of gold-bearing quartz-vein with sulphide in the study area.

Factor 2: Pb-La-Sr-Th-U-Cd

This factor accounts for 20.71% of the variability of the model. The metal association is interpreted as a lithological factor. The strong positive correlation between these elements suggests the concentration in felsic lithology. The pegmatite veins and dykes being the sources of the elements in the study area. The source of Pb may possibly be from the feldspar within the pegmatite. Pb replaces potassium and this element has been reported in K-feldspar (Wedepohl, 1970). Quartz, K-feldspar, albite, muscovite, biotite and lepidolite, as well as accessory minerals like beryl, zircon, apatite and monarzite have been reported in mineralized pegmatites (Jacobson and Webb, 1946). The source of lanthanum and thorium could possibly be from monarzite which could be found in pegmatite. The negative loading of Sr (Table 5a) coupled with the fact that it correlates negatively with all the other elements in this factor (Table 4) suggests a different source for the strontium minerals in the study area.

Table 5a: R - Mode Varimax Rotated Factor Matrix for Log-transfomed Data of Sixty-One Stream Sediment Samples from the Study Area.

| ELEMENTS | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 | COMMUNALITY |
|---|---|---|---|---|---|
| Ni | 0.955 | | | | 0.943 |
| Ga | 0.955 | | | | 0.968 |
| Sc | 0.950 | | | | 0.970 |
| Fe | 0.943 | | | | 0.949 |
| Co | 0.939 | | | | 0.953 |
| Ba | 0.927 | | | | 0.892 |
| Tl | 0.927 | | | | 0.965 |
| Mo | 0.911 | | | | 0.936 |
| Mn | 0.899 | | | | 0.830 |
| V | 0.859 | | | | 0.858 |
| Zn | 0.708 | | | | 0.976 |
| La | | 0.909 | | | 0.992 |
| Th | | 0.901 | | | 0.919 |
| Pb | | 0.873 | | | 0.855 |
| Sr | | -0.812 | | | 0.871 |
| U | 0.414 | 0.811 | | | 0.926 |
| Cd | -0.497 | 0.549 | | -0.427 | 0.834 |
| Sb | | | 0.717 | | 0.653 |
| Cu | 0.547 | | 0.711 | | 0.921 |
| Ag | 0.600 | | 0.705 | | 0.870 |
| Au | 0.554 | | 0.652 | | 0.768 |
| Bi | | | | 0.920 | 0.913 |
| Cr | | | | 0.893 | 0.956 |
| **Eigen Value** | 11.450 | 4.763 | 2.587 | 1.918 | |

Table 5b: Elemental Association of the Four Factor Model

| Factors | Elements Association | % Variation | Cummulative(%) |
|---|---|---|---|
| 1 | Ga,Fe,Ni,Co,Sc,Mn,Tl,Ba,V,M o,Zn,Cu,Ag,Au | 49.784 | 49.784 |
| 2 | Pb,La,Sr,Th,U,Cd | 20.708 | 70.491 |
| 3 | Ag,Cu,Au,Sb | 11.247 | 81.739 |
| 4 | Cr,Bi | 8.339 | 90.078 |

Factor 3: Cu-Zn-Ag-Au-Sb

This accounts for 11.25% of the model variance and was interpreted as a mineralization factor. The strong positive correlation of Cu, Ag, and Zn with Au (Table 4) probably suggests the presence of gold-bearing quartz-vein with sulphide in the underlying fine-grained quartz-biotite gneiss in the study area. Sulphides, galena and sphalerites being the most common have been reported in some gold-bearing quartz veins in Nigeria (Woakes *et al.*, 1987). The inclusion of Sb in this factor (Table 5a) could be as a result of the fact that it is a chalcophile element just like all the other elements in this factor. Therefore the relationship in this group could partly be due to similar chemical properties and partly due to mineralization.

Factor 4: Bi-Cr

This factor accounts for 8.34% of the model variance. It is interpreted as a lithological factor. Bi has a strong positive correlation with Cr (r= 0.72) but weak negative correlations with all the other elements (Table 4). Hence, this factor is a lithological factor with the mafic rock being the source of the elements.

## CONCLUSION

The application of statistical techniques in the interpretation of stream sediment geochemical data from the study area have been found to be useful. The distribution of the metallic elements in the study area has been explained in terms of lithological, mineralization and environmental factors. There is a high possibility of occurrence of Au mineralization in the form of gold-bearing quartz veins with associated sulphides in some of the rocks underlying the study area, most probably gneiss. Th-U- La association has been interpreted as a lithological factor , with granitic/pegmatitic rocks being the source of these elements. Fe and Mn- oxides also have a strong scavenging effect on the abundance of some elements. This is evident in the strong positive correlation betweeen Fe and Mn and these elements.

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