Mineralization Potential Assessment of Stream Sediment Geochemical Data Using R-Mode Factor Analysis in Nigeria

O. O. Awosusi, *A. L. Adisa and J. A. Adekoya

Abstract— Stream sediment geochemical data obtained from seventy stream sediment samples from Rivers Iyinsin and Ofosu were subjected to R-mode factor analysis. The two rivers drain an area underlain by migmatite, granite gneiss, coarse porphyritic biotite and biotite – hornblende granites, fine-grained biotite granite and pegmatite. The stream sediment were analysed for eighteen trace elements after the samples had been sieved using minus 80 mesh size. The results of R-mode factor analysis produced a six-factor model which accounts for 75.47% of the variability of the data. Factor 1(Ce, Fe, Ni, Zn, V) and Factor 4 (U, Mn),which account for 20.599% and 9.707%, respectively, of the variability of the model, are attributable to the scavenging actions of oxides and hydroxides of Fe and Mn on elements with which they are associated. Factor 2 (Rb, Pb, Ba) interpreted as a lithological factor accounts for 18.75 % of the variation. The sources of these elements are probably the felsic rocks underlying the study area. Factor 3 (As, Cu) and Factor 5 (Au, Ag), which account for 11.457% and 8.5 % of the variation, respectively, probably indicate the occurrence of gold and its associated sulphides, either as disseminations or gold bearing quartz –veins in the underlying rocks. While Factor 6 (Co, Ta, Cu) defines the probable occurrence of rare metal pegmatite in the area. In conclusion, there is the possibility of the occurrence of gold mineralization with sulphides in the area. Hydrous Fe and Mn-oxides also pay strong scavenging effect on some of the elements in the sediments.

Index Terms: Stream Sediment, Correlation Coefficient, Multivariate Statistical Technique, Scavenging effect.

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1. INTRODUCTION

Stream sediments, which are composite products of minerals and weathering of rocks, contain elements from several sources. It has been widely used by geochemists to understand complex geological processes [1]. These sources could be lithogenic, pedogenic or even anthropogenic. This makes interpretation of stream sediment geochemical data difficult. Thus, leading to the adoption of a wide range of methods by geochemists [1]. These methods include multivariate analysis, spectrum-area fractal technique, catchment basin analysis, singularity theory ([2]; [3] & [4]) to mention but a few. Furthermore, since ore deposits are usually assemblages of metals rather than a single one. Application of multivariate statistical techniques is, therefore, indispensable in exploration geochemistry [5] (Shiva and Atkin, 2004).

In this regard, multivariate statistical analytical methods have been widely used. These methods include cluster analysis, discriminant analysis, principal component analysis (PCA) and factor analysis (FA) ([6]; [7] & [8]). Of these methods, factor analysis (FA) is commonly applied by geochemists not only in exploration geochemistry but in environmental geochemistry as well ([9]; [10]; [11]; [12] & [13]). There is paucity of information on the mineralization potential of the study area. Although, occurrence of mineralized pegmatites has been reported at Ijero-Ekiti, about 80 km north of the study area (but not shown) ([14]; [15] & [16]). Therefore, there may be the likelihood of the existence of valuable minerals in the southern part (the study area) because of similarity in the geology with that of Ijero Ekiti area.

The research work, therefore, assesses the mineralization potential of the study area with the aim of : (i) assessing the geochemical inter-element relationship in the stream sediments from the Iyinsi and Ofosu Rivers, southwestern Nigeria; and (ii) interpreting the association between the elements in terms of geological and other processes.

1.1 Geology of the Area

The study area falls within latitudes 7° 00’ and 7° 15’N and longitudes 5° 11’ and 5° 19’E (**Figure 1**). It lies south of Akure and covers an area approximately 400 km^2. Geologically, the area is underlain by the Precambrian Basement Complex of Nigeria which has been sub-divided on a tectono-stratigraphic basis, into four major rock groups. These rock groups are: the Migmatite Gneiss-Quartzite Complex, the supracrustal Schist Belt, the Older Granites and associated granitoids and Minor felsic and mafic intrusive ([17]; [18]; [19] & [20]).

Rivers Iyinsin and Ofosu drainage systems drain an area underlain by the basement complex rocks. The

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rock units, arranged in the order of decreasing age, comprises migmatite, granite gneiss, undifferentiated Older granites with porphyroblastic gneiss, coarse porphyritic biotite and biotite-hornblende granites, fine-grained biotite granite and pegmatite (**Figure 2**). The oldest unit in the area is the migmatite which covers about 65% of the area and spanning from north to south. This unit was intruded by coarse porphyritic biotite and biotite-hornblende granite and undifferentiated granites. The coarse porphyritic biotite and biotite-hornblende granite occur as inselbergs in the southern part and extends as far as Idanre area forming the popular Idanre Hills. The youngest intrusive rock, pegmatite, is highly weathered and trend in the north-south direction.

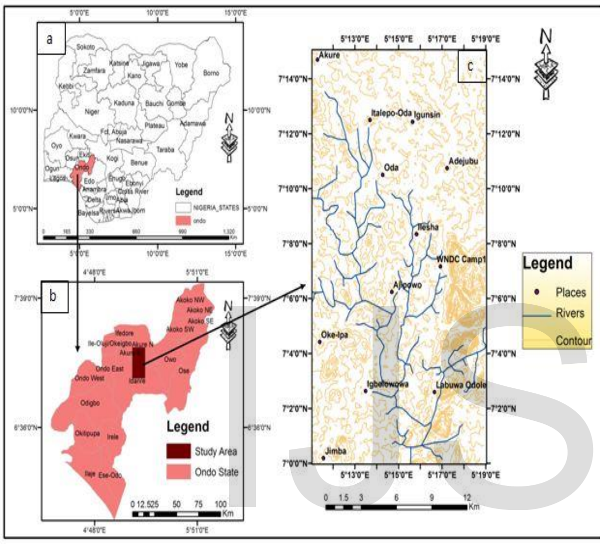


Figure 1. (a) Map of Nigeria showing Ondo state; (b) Administrative map of Ondo state (published by the office of the Surveyor-General of the state, 1998) showing the study area; and (c) map showing the drainage systems in the study area.

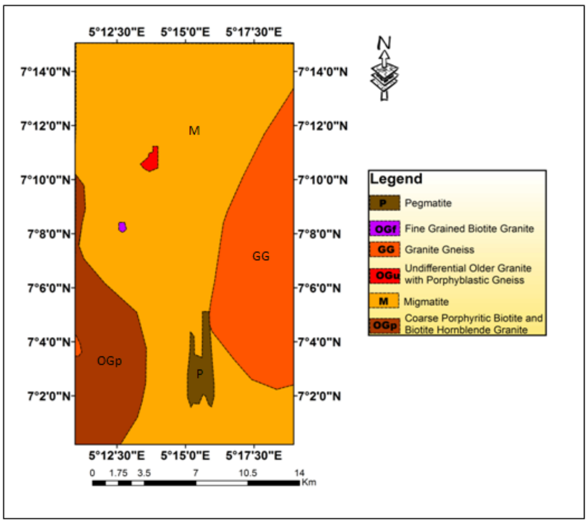


Figure 2. Geological Map of the study area (Akure-Oda-Idanre area) (adapted from [21]).

2. MATERIALS AND METHODS

2.1 Data acquisition

Systematic stream sediment sampling was conducted between February and March 2008 during which a total of eighty-seven stream sediment samples were collected along the channels of Iyinsin and Ofosu Rivers and their tributaries within Oda and Idanre areas respectively (**Figure 3**). The samples were collected at an average interval of 1 to 1.5 km along active stream channel, with a plastic scoop. At each sampling location, the surface materials were scrapped off and samples collected at a depth of 15 cm so as to obtain clay and silt-sized materials. The low sampling density was chosen because the geochemical survey is reconnaissance in nature. They were then put into pre-labelled sample bags. Global Positioning System (GPS) was used to accurately determine the coordinates of the sampling locations.

2.2 Geochemical Analysis

The samples were then taken to the laboratory, air-dried for two weeks at room temperature, disaggregated using porcelain mortar and pestles and sieved to minus 80 (177 microns). Thereafter, 70 samples were selected for processing and geochemical analysis. 200 g of the sieved samples was sent to Laboratory of the Earth Sciences Department, University of Western Cape, Bellville, South Africa. The sample preparation and analysis were carried- out at the Earth Sciences Department, University of Western Cape, Bellville, South Africa. The concentrations of eighteen trace elements in the stream sediment were determined by Wavelength Dispersive X-ray Fluorescence Spectrometry (WD-XRFS) on pressed powder pellets. The instrument used was the Phillips PW1480 automated spectrometer equipped with a Rhodium anode. Analytical precision for both major and trace elements was ensured by the analysis of duplicate samples. The precision, expressed as coefficient of variation, was found to be better than 8 %. Both accuracy and precision were reasonable and satisfactory.

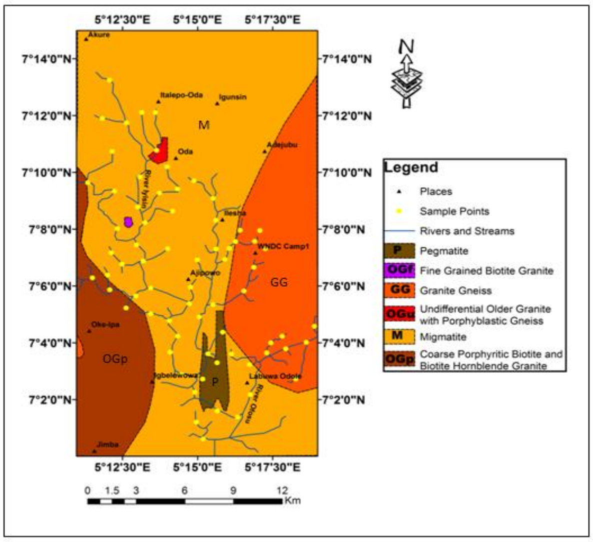


Figure 3. Geological Map of Akure-Oda-Idanre area showing the sampled points (adapted from [21])

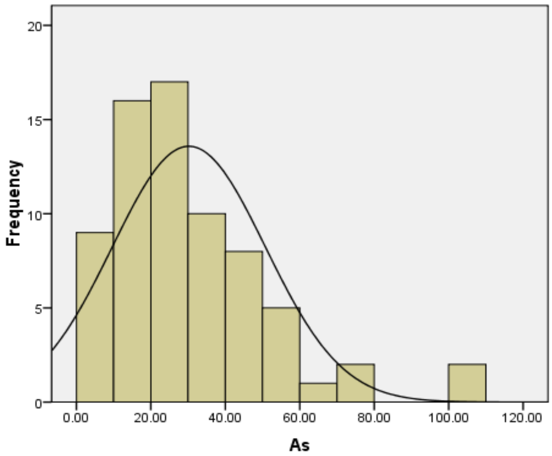
2.3 Statistical Analysis

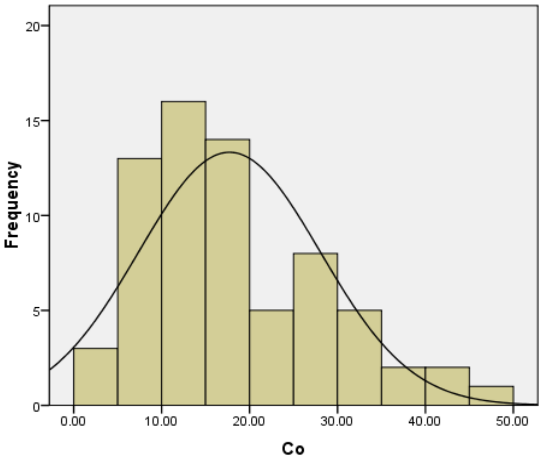
The geochemical data obtained from the analysis of the 70 stream sediment samples were subjected to R-mode factor analysis using Statistical Package for Social Sciences software version 16.0 (SPSS 16.0 for Windows. SPSS Inc., 2007). R-mode factor analysis is a multivariate statistical technique. It is employed in order to group elements influenced by the same factor into the same geochemical association.

Prior to the computation of R-mode factor analysis, the nature of the raw geochemical data was investigated. The analysed trace elements were found to be skewed (Figure 4). The data set were then log-transformed to normalize the skewed distribution (Figure 5). This was followed by the computation of Pearson correlation coefficient of the log-transformed data. The factor analysis for the eighteen elements was, then, computed using varimax rotation [22].

3. RESULTS AND DISCUSSION

The matrices of the simple correlation coefficient (**Table 1**) reveal a wide variation in the correlation coefficient (r). The values of “r” range from -0.417 between Ba and V to 0.755 between Pb and Rb. This wide variation between the pairs of elements could probably be as a result of the heterogeneous nature of the underlying lithology, environmental influence and/or possible occurrence of mineralization in the study area. For example, the positive correlation between Fe and Ce and Mn and Ti could probably be influenced by environmental factor. [23] stated that “the selection of the most appropriate model should be based on the recognition of metal associations considered meaningful in terms of geological and/or surface processes”. As a result, a six-factor model with eigen-value greater than 1.0 and accounting for 75.47% of the data variability was considered the most appropriate. This model explains the known geological and surface processes in the area (**Tables 2 and 3**). The factors are:





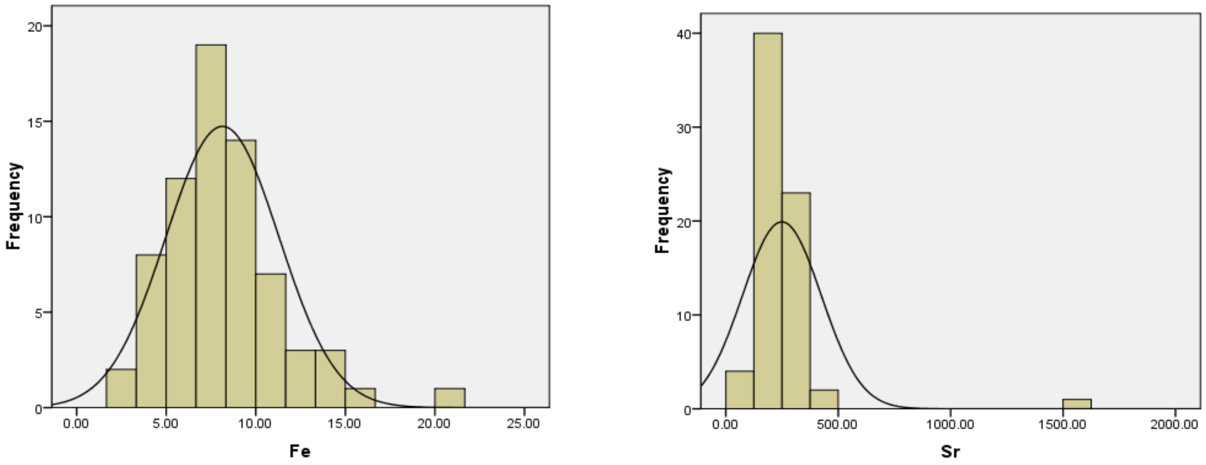


Figure 4: Frequency Distribution of Raw As (ppm), Co (ppm), Fe (%) and Sr (ppm) in the Stream Sediment of the Study Area.

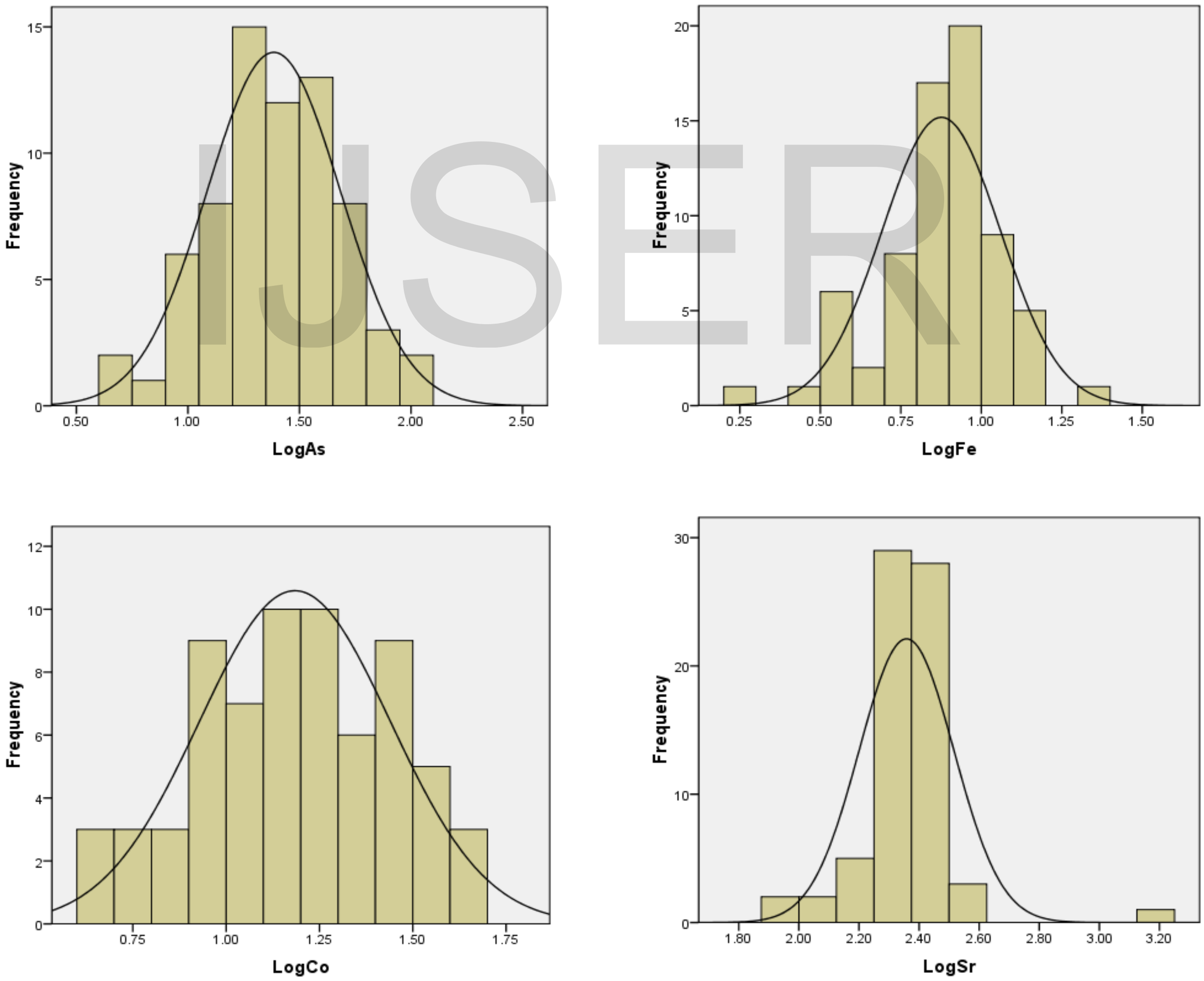


Figure 5: Frequency Distribution of Logarithmically Transformed As (ppm), Co (ppm), Fe (%) and Sr (ppm) in the Stream Sediment of the Study Area.

Table 1: Pearson correlation matrix for log-transformed stream sediment geochemical data of the study area.

	Ag	**As**	**Au**	**Ba**	**Co**	**Fe**	**Mn**	**Ni**	**Pb**	**Rb**	**Sr**	**Ta**	**Ti**	**U**	**Zn**	**Cu**	**Ce**	**V**
Ag	1.000																	
As	.149	1.000																
Au	.510	.070	1.000															
Ba	.104	-.132	.181	1.000														
Co	.135	.107	.096	.049	1.000													
Fe	.138	.405	.069	-.081	.285	1.000												
Mn	.174	.192	-.164	-.115	.243	.521	1.000											
Ni	.057	-.223	.201	.110	.126	.351	.054	1.000										
Pb	.017	-.092	.187	.551	.170	.287	-.083	.344	1.000									
Rb	-.04	-.096	.125	.539	-.076	.186	-.049	.054	.755	1.000								
Sr	.197	-.095	.170	.362	.069	-.288	-.159	.277	.159	-.200	1.000							
Ta	.140	-.056	.180	-.124	-.167	-.030	.055	-.063	-.108	-.013	.015	1.000						
Ti	.102	.241	-.114	-.386	-.076	.381	.600	-.123	-.380	-.296	-.232	.257	1.000					
U	.253	-.058	.167	.010	.170	.140	.273	.000	-.031	.055	-.121	.059	.104	1.000				
Zn	.016	-.277	.149	.366	.146	.433	.137	.683	.618	.453	.101	-.147	-.028	-.030	1.000			
Cu	.086	.457	.117	-.207	.417	-.023	-.219	-.213	-.093	-.148	-.023	-.191	-.305	-.164	-.351	1.000		
Ce	.030	.275	.099	.014	.238	.746	.285	.487	.386	.173	-.049	-.176	.236	.044	.544	-.060	1.000	
V	.116	.127	-.061	-.417	.053	.514	.399	.390	-.156	-.273	-.113	.265	.599	.042	.268	-.219	.343	1.000

Table 2. R-mode varimax rotated matrix for log-transformed raw data of seventy stream sediment sample from the study area.

Elements	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communality
Ce	0.811						0.766
Fe	0.760		0.436				0.887
Ni	0.748		-0.424				0.816
Zn	0.739	0.455					0.861
V	0.670	-0.478					.800
Rb		0.924					0.905
Pb		0.816					0.836
Ba		0.727					0.657
Ti		-0.473		0.470		-0.426	0.782
As			0.826				0.750
U				0.771			0.690
Mn				0.721			0.702
Ag					0.801		0.725
Au					0.792		0.682
Sr			-0.482		0.486		0.625
Co						0.742	0.706
Ta						-0.661	0.554
Cu			0.561			0.574	0.842
Eigen Value	3.708	3.376	2.062	1.747	1.530	1.161	

Table 3. Elemental Association of the Six-Factor Model

Factors	Element Association	% variation	Cumulative (%)
1	Ce, Fe, Ni, Zn, V	20.599	20.599
2	Rb, Pb, Ba	18.753	39.352
3	As, Cu	11.457	50.809
4	U, Mn	9.707	60.516
5	Ag, Au, Sr	8.500	69.016
6	Co, Ta, Cu	6.452	75.468

Factor 1: Ce, Fe, Ni, Zn, V

This factor account for 20.59% of the data variability of this model. This factor indicates lithological and environmental control. The strong positive correlation between Fe and Ce, Zn and V (**Table 1**) indicate the scavenging activity of hydrous Fe-oxides on these elements. This factor can be described as Fe scavenging factor.

Factor 2: Rb, Pb, Ba

This factor account for 18.75% of the variability of this model. The association is interpreted as a lithological factor. The sources of the elements in this factor may possibly be from the felsic rocks in the study area. For example, Ba has a strong association with K in felsic rocks. The sources of Pb in this factor may possibly be from feldspar and biotite in gneiss, granite and pegmatites in the study area. [24] has reported Pb in K-feldspar structure. Pb occurs in K-feldspar and mica where it substitutes for K. Lead has been observed to accumulate in pegmatite where it occurs in amazonite feldspar [25].

Factor 3: As, Cu

This association accounts for 11.457% of the variability of this model. This association is strongly chalcophile. The positive correlation between As and Cu probably suggest the presence of sulphide mineralization either in form of dissemination or as sulphide bearing quartz vein in the underlying rock in the study area.

Factor 4: U, Mn

This factor account for 9.707% of the variability of this model. This factor indicate both lithological and environmental controls. The presence of Mn in this association could indicate the scavenging action of Mn-oxide on uranium. Mn causes false anomaly because its ability to adsorb or co-precipitate a large number of elements with Mn-oxides. The source of the uranium could probably be from the pegmatite and granite. Uranium have been reported in zircon, apatite and allanite. [26] noted that mineralized pegmatite consist of quartz, k-feldspar, albite, muscovite and lepidolite, and accessory minerals like garnet, beryl, zircon, apatite and monazite.

Factor 5: Ag, Au

This factor explains 8.5% of the variance. It is interpreted as a mineralization factor. The positive correlation between Ag and Au (0.510) strongly suggest the presence of gold-bearing quartz veins with sulphides in the underlying gneiss in the area. Gold bearing quartz veins in Nigeria often contains some sulphides, galena and sphalerite being the most common [27]. Silver often occur as minor element in sulphides such as sphalerite and galena [28].

Factor 6: Co, Ta, Cu

This factor, accounts for 6.452% of the variance, has a high positive loading on Co and Cu and a high negative loading on Ta (**Table 2**). Furthermore, Co correlates positively with Cu while Ta correlates negatively with both elements. The Co-Cu association could be interpreted as a lithological factor with pegmatite or granite being the source of these elements. The source of Cu could possibly be from biotite in pegmatite in the study area. [29] noted that Cu is concentrated in proxenes, amphiboles, magnetite as well as biotite in intrusive rocks. Co is also enriched in magnesian pyroxene, olivine, as well as biotite in intermediate and acid rocks. Co could also occur in copper minerals [30]. The high negative loading on Ta probably represent a different source for this element probably rare-metal pegmatite. Ta is often concentrated in pegmatite and granitic pegmatite. Pegmatites in Nigeria are host to tin, tantalite, niobium, columbite etc. ([31]; [32] & [33]). Therefore, this factor could be interpreted as both lithological and mineralization factor.

4. CONCLUSIONS

This study underlines the importance of the R-mode varimax factor analysis in the interpretation of stream sediment geochemical data from the study area. The elemental association produced were interpreted in terms of underlying lithology, mineralization and/or environmental control. The association of Au and Ag in Factor 5 is indicative of the probable presence of gold-bearing quartz vein with sulphides in the study area. Minor sulphide mineralization of As and Cu are likely to occur as disseminations in the gneisses and granites in the area. There is also a high possibility of the occurrence of complex pegmatite which serves as the sources of Ta in the study area. Hydrous Fe and Mn-oxides have very strong scavenging effects on Ce, Ni, Zn V, etc. in the stream sediment.

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