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Generation of Geochemical Exploration Targets from Regional Stream Sediment Data Using Principal Component and Factor Analysis: A Case Study of Kibaya-Kiteto, Manyara-Tanzania

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Abstract

A regional-scale stream sediment geochemical sampling was carried out with an average sampling density of one sample per nine square-kilometre in Kiteto District, Manyara Region. A total of 358 stream sediment samples were collected and analysed for major and trace elements by X-ray fluorescence (XRF) and fire assay with atomic absorption spectrometry (AAS) finish methods. In this study, Factor and Principal Component Multivariate (FPCM) analyses have been used to the stream geochemical data to delineate potential mineralization zones by plotting correlated factors as geochemical anomaly maps. Four factors that account for 73.7% of the total variance of the stream sediment geochemical data were established. Factor 1: Ni–Ba–Co–Cu–Sr which possibly defines the underlying metamorphosed granitic units with some contribution from mafic and ultramafic rocks. Factor 2: Cr–Zn–Mn which defines crustal forming elements reflecting the mafic rocks. Factor 3 which entails Rb and Pb probably attributed to metamorphosed granitic lithology. Factor 4 is arsenic, a chalcophile element with affinity to sulfide phases. The FPCM analyses have been successfully in delineating potential target areas for gold, nickel and copper exploration in the study area.

Keywords: Stream sediment; principal component; factor analysis; exploration targets; Kibaya-Kiteto, Manyara.

Introduction

Stream sediments and soil geochemical survey data have been successfully used to identify geochemical prospecting areas by using the factor analysis method (Odokuma-Alonge and Adekoya 2013, Mackie and Arne 2017). Likewise, the principal component analysis is also a powerful tool for combining several correlated variables into a single variable based on covariance or correlations of variables, which signifies the interelement relationships (Yuan et al. 2015). These methods have been widely used especially in the interpretation of stream sediment geochemical data, aiming to explain the variations of the multivariate data set by reducing to a few factors that would help to detect hidden concealed geochemical anomalies (Parsa et al. 2017).

The conventional methods for decades have been used by many researchers to discover geochemical anomalies by using stream sediments geochemical data (Darehshiri et al. 2015). However, the presence of geochemical barriers such as duricrust, thick overburden or deep burial ore deposit has hindered the manifestation of geochemical halos and made conventional methods difficult to discover mineral deposits (Ahadjie 2003, Carranza 2004, Carranza 2011, Odokuma-Alonge and Adekoya 2013, Darehshiri et al. 2015, Yuan et al. 2015, Liu et al. 2016, Mackie and Arne 2017, Awosusi et al. 2019, Macheyeki et al. 2020).

Consequently, as an alternative to conventional methods factor and principal component analyses, the nonconventional methods have been applied to analyse stream sediment samples in order to delineate hidden mineralized zones in the study area which is covered by thick overburdened materials. Therefore, factor and principal component analyses have been applied to the stream sediments data from the study area in order to delineate mineralized zones.

Geological setting of the area

The area belongs to the Neoproterozoic Mozambique Mobile Belt (NMMB) resulted from the collision of Eastern and Western Gondwana at around 640–620 Ma (Fritz et al. 2009, Leger et al. 2015). Based on the protolith age the NMMB is sub-divided into Western and Eastern Granulite Domains which are separated by flat thrusts and younger sedimentary basins (Leger et al. 2015). The study area is approximately 2916 km^2 and lies within Western Granulite with the protolith age of 2.6–2.3 and 1.8 Ga (Fritz et al. 2009). The Western Granulite Domain is characterized by rocks belonging to upper amphibolite facies such as orthogneisses, amphibolite, migmatitic paragneiss, mafic granulite and rare ultramafic rocks (Johnson et al. 2003, Fritz et al. 2009).

The latter is supported by Chada (1967) in the geological map of Kibaya where the study area is situated. The geological map indicates that, the most dominant units are metamorphosed igneous and sedimentary rocks overlain by superficial deposits. Mafic-ultramafic rocks occur sporadically in the north-eastern parts whereas metasedimentary rocks in the western parts comprise of mica-bearing quartzite, crystalline limestone, calc-silicate gneiss, kyanite gneiss with garnet, amphibolite with garnet, migmatitic biotite gneiss and granulite pyroxene and garnet.

These rocks are covered by superficial deposits including undifferentiated soils with reddish, yellowish to greyish sands (Figure 1). According to Chada (1967), two sets of faults in the area are interpreted to be of Neogene age; one trending in N-S and downthrown to the east and the other set trending in ESE direction. Moreover, foliations vary between ESE to E and less extent ENE to N.

Despite the Mozambique Belt traditionally being termed a gemstone belt because of the abundance of variety of gemstones found in this belt, recent works done by exploration companies identified the belt as prospective for gold mineralization (Pitfield 2015). The possible explanation for the presence of gold mineralization in the belt includes the presence of reworked Archean crust and the E-W trending structures characterizing the Archean Tanzania Craton (ATC) and greenstone belts extending into the Mozambique Belt (Kabete et al. 2012). As opposed to the ATC of central Tanzania with abundant gold, the Mozambique Belt has relatively few gold prospects. For instance, Mkurumu-Magambazi Gold Zone, gold is hosted by a complex of greenstone, mafic amphibolite gneisses, granitoid gneisses and different paragneisses (Leger et al. 2015). Most of these lithological units are folded and strongly metamorphosed with gold mineralization potential that is hydrothermal in origin (Kabete et al. 2012, Leger et al. 2015). Alteration mineral assemblages in gold-bearing structures within NMMB include sericite, chlorite, epidote and silica including the Kibaya area (Kabete et al. 2012).

Materials and Methods

The materials used for this study included global positioning system (GPS), Touchpad, a geological compass, cloth and plastic sample bags, tissue for cleaning, a 2 mm sieve and a small spade. The methods used include stream sediment sampling, X-ray fluorescence a PANalytical MiniPal 4 Energy Dispersive 12-position sample and fire assay with AAS finish. In addition, the collected data were processed by CoDa Pack, Arc GIS version 10.4, Surfer and XLSTAT.

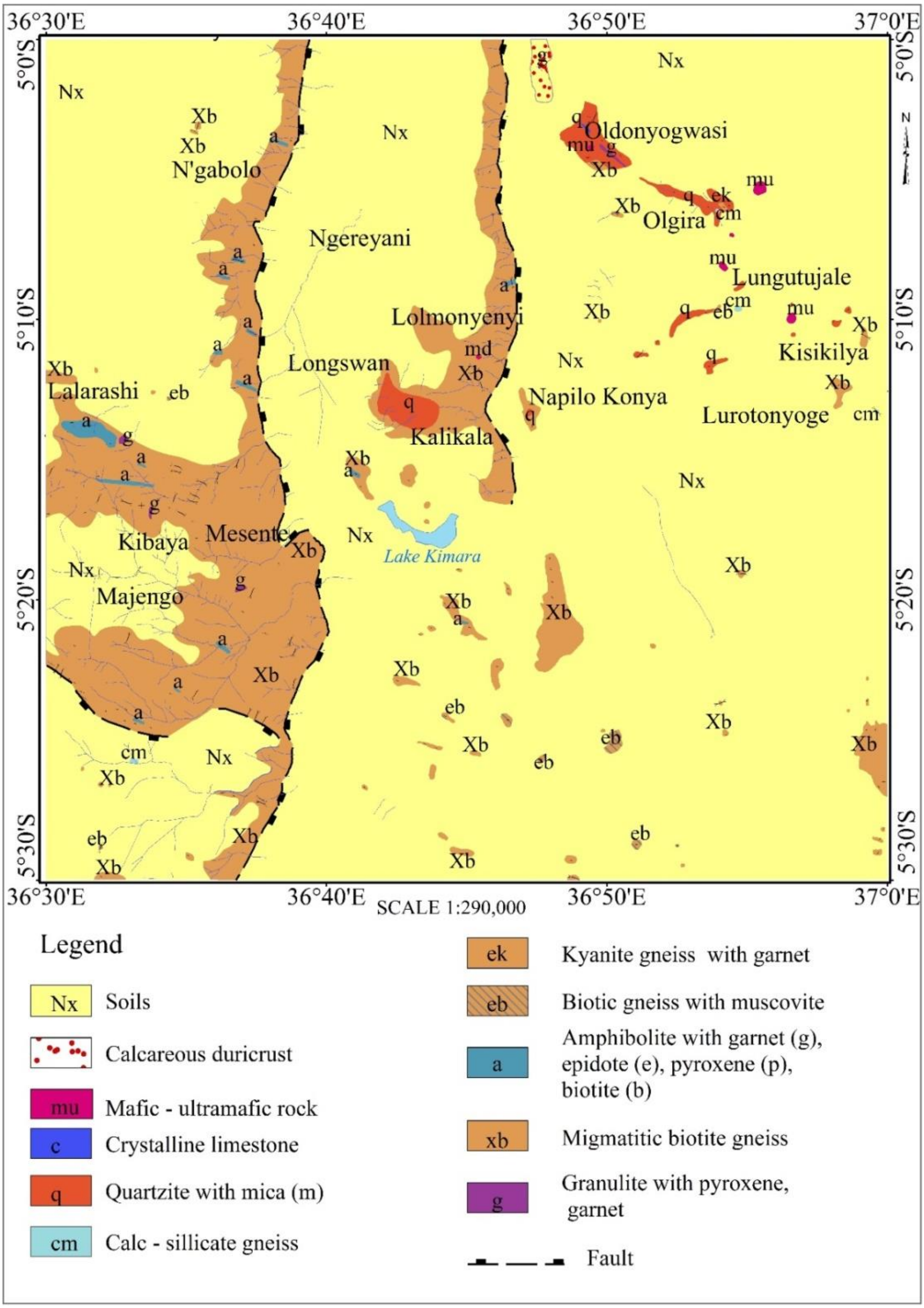

Figure 1: Geological map of QDS 126 showing the distribution of lithological units.

Stream sediment sampling

A total of 358 stream sediment samples were collected in the study area each weighing about 2 kg. Sampling was conducted on the grids of 3 km by 3 km per sample on the 1:100,000 scale map sheet of QDS 126. Stream sediment samples were sieved using a 2 mm sieve at the sampling site to reduce unwanted materials like stones and organic matter. Stream sediment sampling was used as sample media as it reflects the geogenic composition of a whole catchment basin for just one sample (Figure 3, Salminen et al. 2008).

Laboratory sample preparation and analyses

During preparation, all samples were sieved to minus 80 mesh (177 microns) at the Geological Survey of Tanzania (GST) Laboratory. Samples were homogenized and divided into two portions of 50 g and 10 g which were analysed for gold by fire assay with AAS finish and multielement by XRF. The model for AAS is Agilent 280 FS with 8 lamp capability, while the XRF machine was PANalytical MiniPal 4 Energy Dispersive 12-position sample.

For gold analysis, a flux mixture containing 50 g for each sample with 48 g PbO, 60 g Na_2CO_3, 40 g Borax, 15 g K_2CO_3, 10 g silica sand, and 5 ml $AgNO_3$ was placed in a furnace at 1050 °C for one hour to obtain slug. The slug was poured into an iron mould, and after cooling the lead button was separated using a geological hammer. This lead button was then placed in the furnace for cupellation and afterwards, a prill was obtained. Each sample was dissolved in aqua regia solution for 12 hours. Each solution was analysed using AAS for the determination of gold in parts per million (ppm).

On the other hand, the sieved samples for multielement determination were put in clean sample cups and loaded into the XRF machine equipped with gas. The reading for each sample was given after an interval of 3 minutes. The analysed elements included Ni, Cu, Co, Sr, Ba, Zn, Cr, Mn, Rb, Pb and As.

Standard (G903-10 with 0.21 ppm Au), duplicates and blank samples were analysed in concurrently with the sample regimes following QA/QC procedures. The results of the QA/QC turned up with acceptable range (Figure 2).

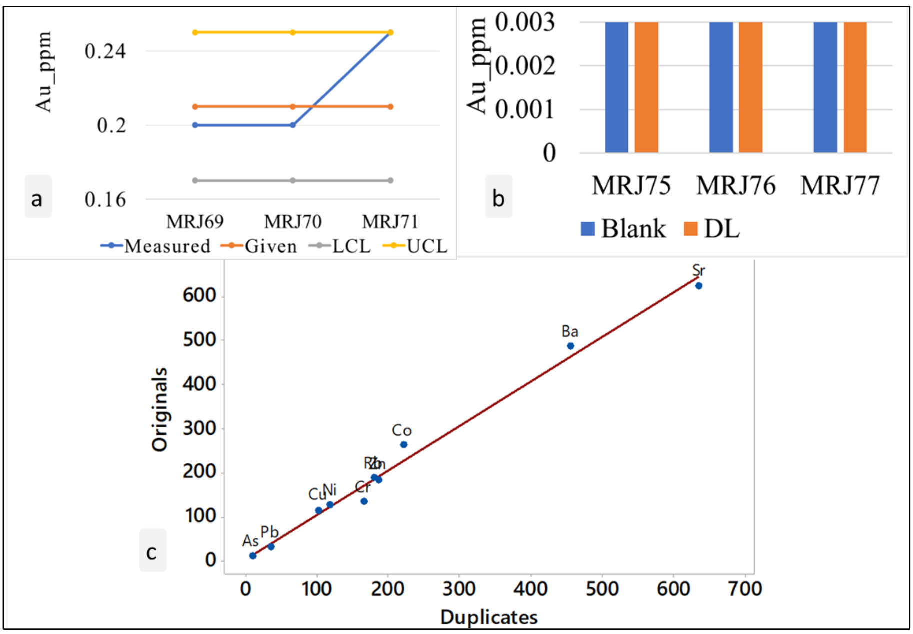

Figure 2: QA/QC plots. (a) Au standard showing blue, red, yellow and grey lines denoting measured, given, upper control limit (UCL), and lower control limit (LCL) (b) Blank sample blue bar = blank and red bar = detection limit, and (c) Duplicate samples.

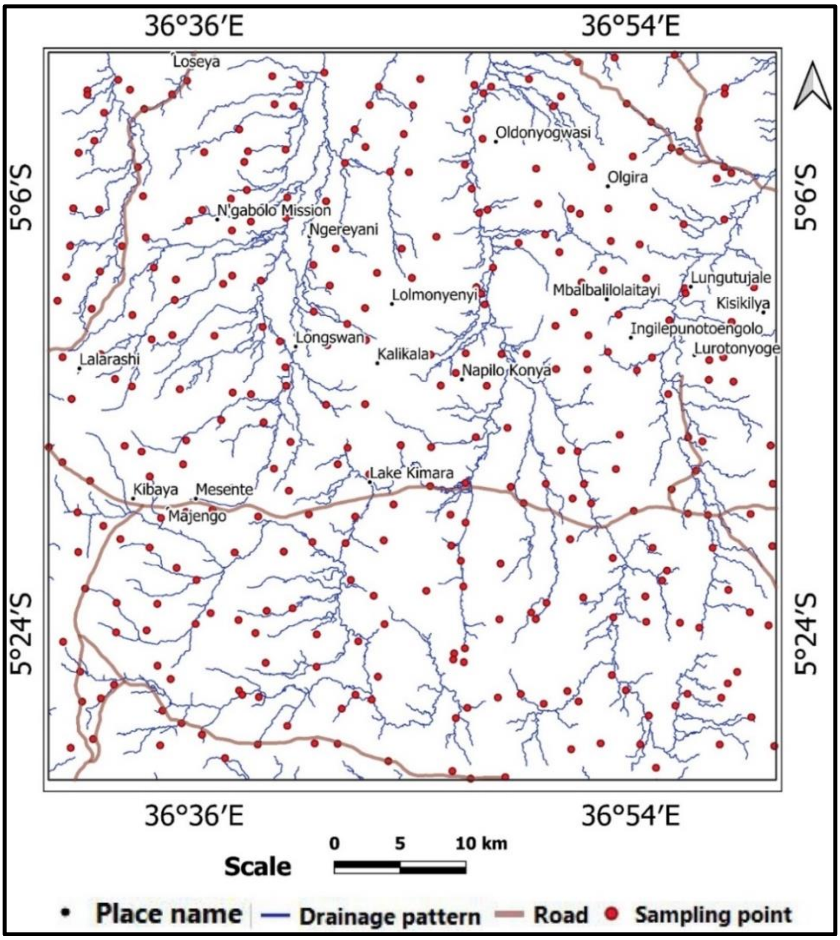

Figure 3: Stream sediment sample locations.

Data processing

The software used to process and analyse the data for different elements were XLSTAT excel, CoDaPack statistical analysis, Surfer Software and Arc GIS. The values of each element were loaded into an excel sheet and then imported into the named software. The variable results were imported into CoDaPack statistical analysis software. Each variable was transformed by a centred log-ratio (clr) tool to achieve normality and transformation as suggested by Carranza (2011) and Ghadimi et al. (2016). The transformed data were saved in excel and loaded into XLSTAT software for descriptive summary statistics, factor and principal component analyses.

Generally, factor and principal component analyses effectively reduce the number of observed variables into a smaller number that accounts for most of the variance in the data set (Rourke and Hatcher 2014). The total variance of each factor was given in the eigenvalue provided by the principal component using varimax rotation with Kaiser's normalization (Macheyeki et al. 2020). Additionally, the Pearson correlation coefficient was also calculated, including the scree-plot to identify variations in the principal components. The factors obtained after rotation were tallied to their respective coordinates and imported into Surfer Software and finally gridded as inverse distance weighted (IDW). Therefore, elemental groups from each factor were plotted as maps and the areas with more correlations were presented in pink to red colours.

Results and Discussion

Descriptive statistics

The variables entailing Ba, Sr, Zn, Cu, Ni,Cr, Co, As, Rb, Pb and Mn are presented in descriptive statistics analysis each with a corresponding minimum, maximum, mean, standard deviation, median, skewness, and kurtosis of clr transformed data from the study area (Table 1). The comparison of raw data of stream sediment in the study area with values of upper continental crust has shown that the mean values for all elements are lower (except for Pb and Rb) than that of average upper continental crust (Rudnick and Gao 2013, Ghadimi et al. 2016). Unfortunately, the values of gold were very low almost close to the detection limit, and therefore, were not included in the calculation.

Factor and principal component analyses

Principal component analysis is a very useful technique to extract factors for a large number of variables to a few uncorrelated variables (Macheyeki et al. 2020). Using the Pearson correlation coefficient (Table 2), the correlations between the variables were medium correlated, therefore, the varimax rotation of factors was chosen to obtain rotated factors (Ghadimi et al. 2016, Macheyeki et al. 2020).

Table 1: Statistics after clr transformation

Variable	**Mean**	**StDev**	**Minimum**	**Median**	**Maximum**	**Skewness**	**Kurtosis**
Ba	1.7848	0.5197	-2.3530	1.8270	3.1609	-3.07	21.21
Sr	0.9802	0.5315	-0.6495	1.0080	2.0715	-0.16	-0.65
Zn	-0.0563	0.2383	-0.9304	-0.0437	0.6849	-0.37	1.22
Cu	-0.6821	0.2720	-1.7670	-0.6820	1.4254	1.30	10.81
Ni	-0.3766	0.3212	-1.2556	-0.3837	1.0466	0.39	1.37
Cr	-0.2331	0.6840	-4.1977	-0.2541	2.3951	-0.32	3.77
Co	0.5166	0.3138	-0.6592	0.5715	1.1396	-1.08	1.33
As	-3.2949	0.4857	-4.6808	-3.3150	-0.5159	0.92	4.46
Rb	0.2252	0.2943	-1.4968	0.2548	0.9498	-1.11	3.78
Pb	-1.0983	0.2971	-2.2175	-1.0643	-0.0269	-0.26	1.10
Mn	2.2345	0.3171	0.7368	2.2599	2.9572	-0.65	1.44

Number of samples (n) = 358.

Table 2: Pearson correlation coefficient of clr data for stream sediments

Variables	Ba	Sr	Zn	Cu	Ni	Cr	Co	As	Rb	Pb	Mn
Ba	**1.00**										
Sr	**0.40**	**1.00**									
Zn	-0.45	-0.15	**1.00**								
Cu	-0.45	-0.41	**0.29**	**1.00**							
Ni	-0.56	-0.56	**0.21**	**0.29**	**1.00**						
Cr	-0.28	-0.39	-0.40	**0.12**	**0.43**	**1.00**					
Co	-0.35	-0.30	**0.51**	**0.18**	**0.34**	-0.18	**1.00**				
As	-0.06	-0.20	-0.32	-0.07	-0.20	**0.01**	-0.23	**1.00**			
Rb	-0.02	-0.06	**0.46**	-0.08	-0.14	-0.48	**0.05**	-0.21	**1.00**		
Pb	**0.28**	**0.09**	-0.16	-0.30	-0.47	-0.29	-0.40	**0.11**	**0.44**	**1.00**	
Mn	-0.21	**0.13**	**0.34**	**0.07**	**0.05**	-0.39	**0.28**	-0.29	-0.02	-0.24	**1.00**

Values in bold are different from 0 with a significance level alpha = 0.95.

In this study, four factors were selected according to the Scree plot (Figure 4). These factors have Eigenvalues greater than 1.0; therefore, according to Rourke and Hatcher (2014), only four factors have a meaningful variance for the computation of the principal component. The Eigenvalues show the amount of variance captured by a given component. Four factors that amounted to 73.7% of the total variance of the stream sediment geochemical data were established in the study area. The first factor has an Eigenvalue of 29.3% variance, while the second has 21.8% as shown in the loading plot in Figure 5.

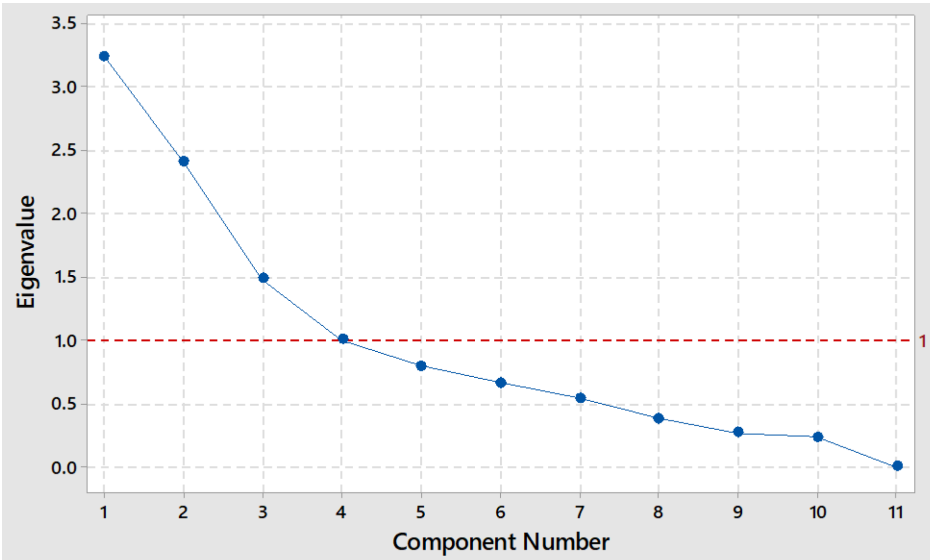

Figure 4: Scree plot of clr of variables for samples from the study area.

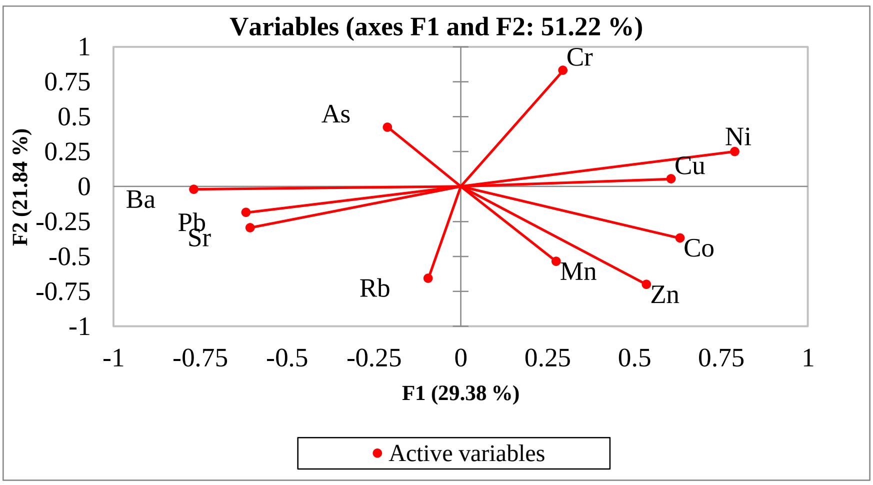

Figure 5: Principal component loading plot for first and second component for clr data.

Element associations and their maps

Four factors that account for 73.7% of the total variance of the stream sediment geochemical data were obtained and plotted (Figure 6). The variance of factors 1, 2, 3, and 4 are 29.3%, 21.8%, 13.45, and 9.1%, respectively. The element with high correlation was identified in each factor as shown in Table 3. Factor 1: Ni–Ba–Co–Cu–Sr probably defines the underlying metamorphosed granitic lithologies with some contributions from mafic and ultramafic rocks especially in Lungutujale, Olgira and Lurotonyoge Villages. With an exception of Ba and Sr, this element association corroborates with Barramiya gold mine stream sediment geochemical results in the Eastern Desert, Egypt as reported by Harraz et al. (2012).

Factor 2: Cr–Zn–Mn appears to correlate with the migmatite gneisses in Mesente, Majengo, Kalikala and Ngabalo Villages. Factor 3: Rb and Pb are attributed to granitic lithology, which represents the parent rock of the area, especially in Lomlonyenyi, Kibaya and Mesente Villages. Factor 4: (As). This factor accounts for 9.1% of the variance and is consistent with the Au results of the collected rock samples in the vicinity of the drainage pattern (Figure 6). Arsenic is strongly considered as one of the pathfinder elements for gold (Harraz et al. 2012). The arsenic anomalies within the active small scale gold mine at Lalarashi Village are associated with amphibolites, this corroborates with the gold mineralization in the Mkurumu-Magamba Province as reported by Kabete et al. (2012). As a result, arsenic anomaly map was generated and used to locate the potential target for gold prospecting in the study area (Figure 7).

Table 3: Elemental groups for four factors after clr transformation

	Factor 1	Factor 2	Factor 3	Factor 4
Ba	**0.590**	0.000	0.044	0.029
Sr	**0.366**	0.087	0.306	0.001
Zn	0.287	**0.492**	0.028	0.000
Cu	**0.368**	0.003	0.026	0.035
Ni	**0.623**	0.062	0.001	0.081
Cr	0.087	**0.689**	0.000	0.118
Co	**0.400**	0.136	0.015	0.009
As	0.044	0.180	0.115	**0.593**
Rb	0.009	0.430	**0.365**	0.067
Pb	0.381	0.035	**0.338**	0.010
Mn	0.076	**0.287**	0.242	0.058
Eigenvalue (%)	29.30	21.83	13.45	9.10

Since the values of gold in the streams are very low for this study, the gold values in rocks were plotted together with arsenic values. There is a very good correlation between gold values in the rock samples and arsenic anomalies as shown in Figure 6. An arsenic anomaly map has been used to generate a target for gold exploration in the area (Figure 7).

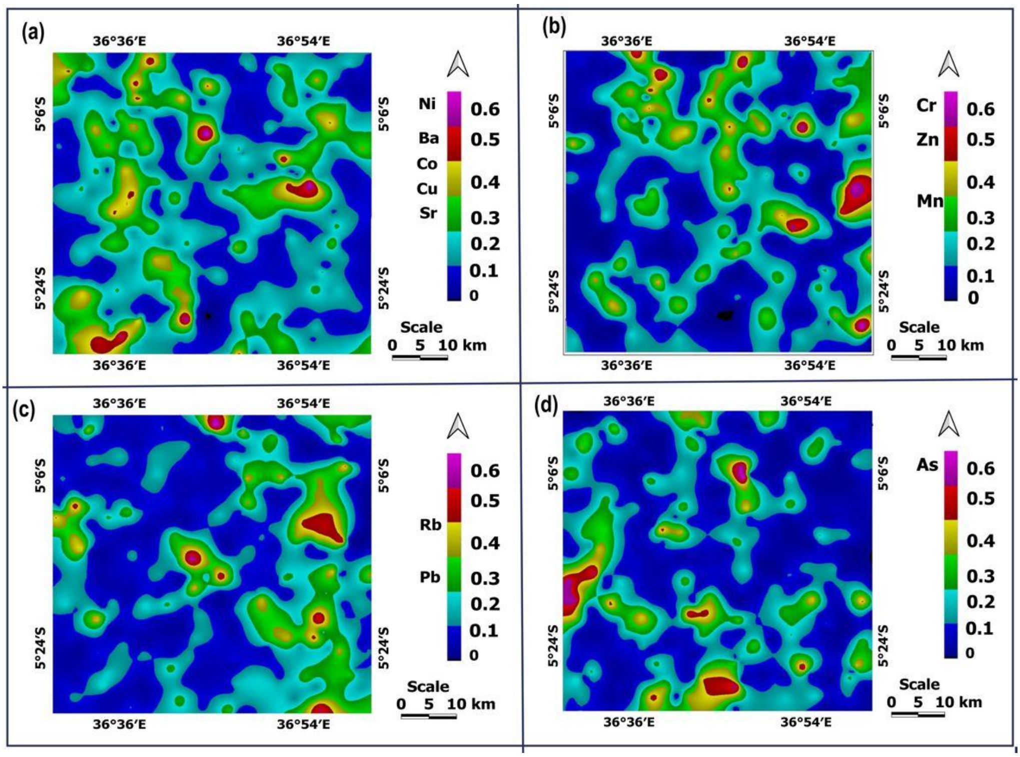

Figure 6: Factor maps of the study area (a) Ni–Ba–Co–Cu–Sr shows high anomalies in the northeastern corner, (b) Cr–Zn–Mn shows high anomalous in the northeastern corner just very close to an area, (c) Rb and Pb concentrated more on the centre and eastern part of the area, and (d) Arsenic which has a high anomaly in the western central part, the southern and northern part of the area.

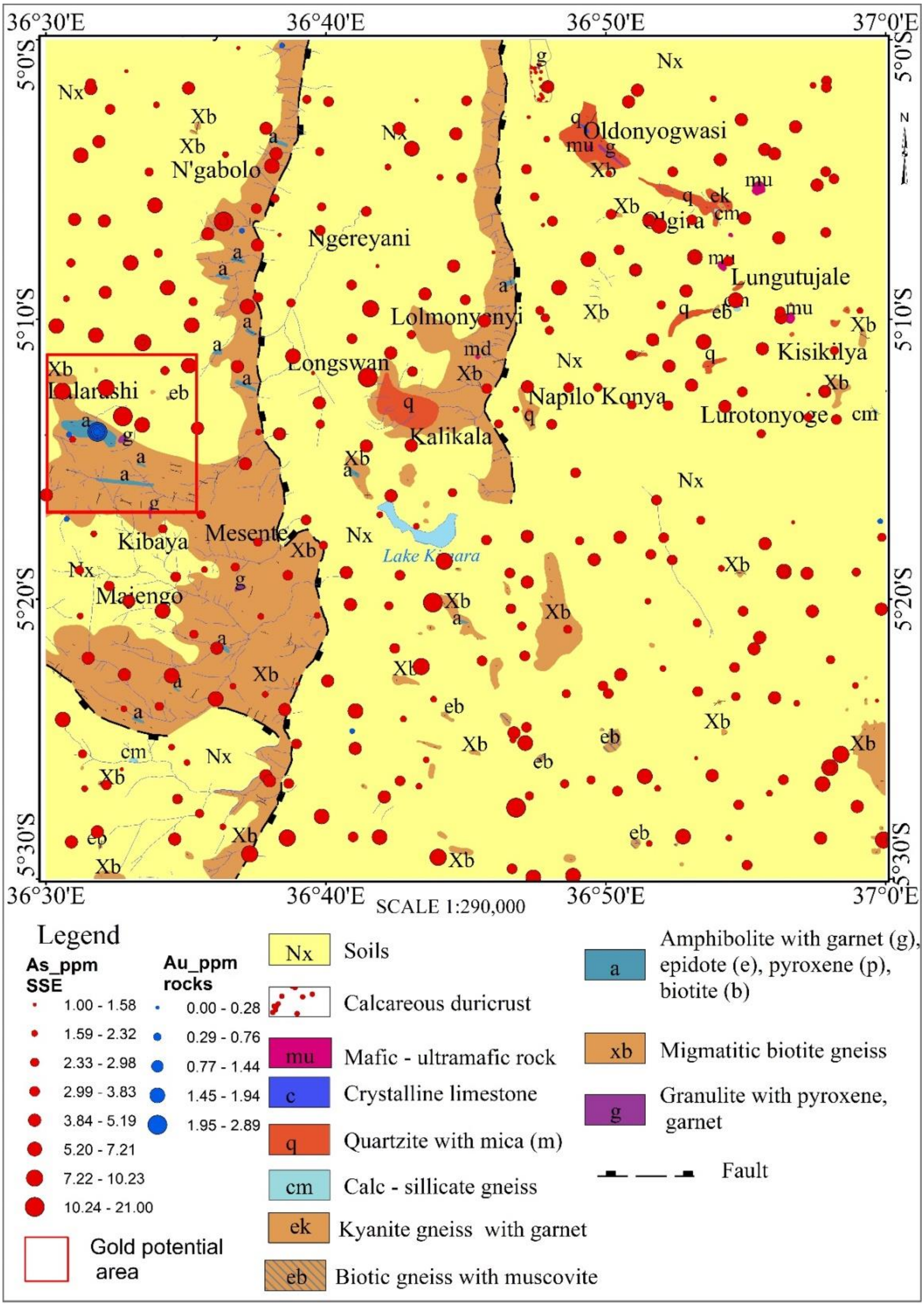

Figure 7: Map showing target area (red rectangles) for gold exploration (SSE-stream sediments).

Conclusions

The factor and principal component analysis for stream sediment samples has been successfully used to identify correlation variables in Kibaya–Kiteto, Manyara Region. Four factors were generated which account for 73.7% of the total variance of the stream sediment geochemical data. Factor 1 includes Ni–Ba–Co–Cu–Sr, which probably defines the underlying metamorphosed granitic lithologies with some contribution from mafic and ultramafic rocks especially in Lungutujale, Olgira and Lurotonyoge Villages; factor 2 is represented by Cr–Zn–Mn, which correlates with the migmatite gneisses in Mesente, Majengo, Kalikala and Ngabalo Villages; factor 3 is Rb and Pb, which reflects the parent rock of granitic rock unit in Lomlonyenyi, Kibaya and Mesente Villages. Arsenic is factor 4, which showed a strong association with Au mineralization hosted in amphibolites at Lalarashi Village. The factor anomaly maps were generated to delineate mineral targets for Au, Ni, and Cu indicative for further detailed exploration in the study area.

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