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Statistical Investigation of the Relationship between Gold and Associate Minerals: A case Study of Kagara Area of Niger State Nigeria Soil

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ABSTRACT: *In the Kagara region of Niger State, north-central Nigeria, an investigation was conducted into the gold occurrence and availability of other economic-benefit associate minerals. 39 samples from the study area were subjected to fire assay analysis and multi-element analysis to determine the gold and other mineral recovery in the case study formation. Statistical examination Methods of Pearson correlation and R-mode varimax rotated factor analysis were used to interpret the results. The analysis revealed that the recovered gold (Au) had a grade between 0.01g per tonne and 0.19g per tonne. Li was also identified as the associate mineral with the lowest quantity, with a range of 1-20% and a mean value of 8.49%, whereas Manganes displayed some skewness with a minimum value of 156 and a maximum value of 3080 ppm. According to the Pearson correlation analysis, Lithium and Magnesium have a moderately positive correlation, indicating that they come from the same source. In addition, Mo and Ni have a strong positive correlation whereas Au and Na have a weak positive correlation. The factor analysis performed on the gold and associated mineral occurrences revealed that the deposit had been significantly altered by both environmental and mineralization factors in the study area's soil. Importantly, the study demonstrates that an associated mineral with gold has substantial economic value. Considering the capital and operating costs required for the exploration and exploitation of gold-bearing soil and rock, it has been determined that the refining of other associate minerals to improve the cost-benefit ratio is highly advantageous.*

KEYWORDS: Nigeria, mineral economics, gold occurrence, Soil Geochemical data, Statistical Analysis, Factor Analysis

INTRODUCTION

According to Antosik et al., a mineral is a solid, naturally occurring chemical compound with a relatively well-defined chemical composition [1]. Nigeria is endowed with abundant mineral deposits that must be explored, extracted, and refined to serve the nation's economic requirements [2, 3]. Due to its properties, gold is one of the most expensive commodities in the world [4]. As mention by [5], pure gold retains its vibrant yellow hue and lustre, which are traditionally regarded as attractive, without oxidizing in air or water. According to the Nigerian Mining Cadastral Office's (MCO) 2018 statistical report, gold is the most desired mineral in Nigeria. However, there are associated minerals with a very significant percentage and corresponding monetary value that accompany gold but are rarely recognized due to a lack of awareness, technical inputs, and rudimentary processing techniques [6].

According to Garba, the schist belt encompassing the western half of Nigeria, there are verified reserves of both alluvial and primary deposits of gold [7]. The most significant occurrences are located in the Maru, Anka, Malele, Birnin Gwari, Kagara, Tegina, Kwaga, Gurmana, Bin Yauri, Okolom Dogondaji, and Iperindo regions, which are all associated with the schist belts of western Nigeria. Artisanal and small-scale mining (ASM) is defined as the illegal exploitation of minerals such as coal, gold, and precious stones [8, 9]. An artisanal miner, also known as a small-scale miner (ASM), is a subsistence miner who does not hold a formal position with a mining company but rather works independently, typically by hand, to extract minerals. This operation requires the use of basic tools such as hoes, pick axes, chisels, and shovels, as well as manual labour such as digging, breaking, panning, arranging, and transporting. According to Hilson et al., the global ASM keeps on developing rapidly and now employs approximately 42 million people, of whom 13 million works in sub-Saharan Africa, 70–80 percent are independent contractors, and 30.5% are women [10]. Eighty percent of the world's sapphire supply, twenty percent of gold mining, and up to twenty percent of diamond mining is sourced from artisanal and small-scale mining [11]. Artisanal and small-scale mining are prevalent in Central and South America, Africa, Asia, and Oceania's underdeveloped nations. Despite the sector's generally low productivity as a result of its informality and general absence of mechanization, it is a significant source of income and livelihood. It ensures the survival of millions of families in rural regions of developing nations. Ediawe and Campus also estimate that approximately 13 million people worldwide rely solely on artisanal and small-scale mining for their livelihood [12]. Due to a lack of professionalism, these operations frequently have egregious ecological and social repercussions and rarely contribute to the government's revenue. Currently, the majority of alluvial gold deposits in Nigeria are mined by artisanal miners. In the northwest of Nigeria, however, a number of primary gold deposits of sufficient size for large-scale mechanized extraction have been identified [13]. The price of gold is significantly more sensitive to variations in sentiment (demand) than annual production (supply). In recent years, according to the World Gold Council in 2020, annual gold mine production has been close to 2,500 metric tonnes [14]. Gold has high thermal and electrical conductivity, as well as high corrosion and bacterial colonization resistance. Jewellery and industrial demand have fluctuated over the past few years due to the steady expansion of middle classes in emerging markets that aspire to Western lifestyles, which has been mitigated by the financial crisis of 2007–2010 and the widespread effects of the Corona virus pandemic. In terms of volume, China is the largest consumer, accounting for 27% of demand, followed by India and the United States. Mining and mineral refining are expected to be the primary source of income and the engines of industrialization and economic growth. However, this capability is not always realized. Mineral-dependent nations include some of the world's weakest and lowest-performing economies.

British African Dependencies [15] received the first report on Nigerian gold in 1935 as a form of education. The detailed report was titled "Annual Assessment of Indigenous Populations in Seven Locations, including Nigeria. Several authors [16, 17–23] contributed to the evaluation of gold extraction in Nigeria. Olomo et al. interpreted potential gold mineralization associated with mesothermal alteration zones in the western Ilesha schist belt, southwestern Nigeria, using airborne magnetic and radiometry data sets. This exploration was conducted to provide information on the potential extent of geologic changes that accompanied gold mineralization in the region [22]. Understanding the chemical composition of gold is crucial due to its devastating environmental impact. The impact of potentially hazardous elements in stream sediments around active and abandoned artisanal gold-mining communities in Nigeria was evaluated by [24] in order to evaluate the influence of gold extraction on the southwestern region of the country.

In the Kagara community, mining activities are performed manually and with antiquated tools, but the local miners appear oblivious to their hard labour because they are content with their earnings. It is crucial to have a report that serves as a guide during the preliminary stage of gold exploration, documenting all minerals associated with gold and the monetary value that can be generated during mining and beneficiation. This study seeks to evaluate the relationship between gold and other co-existing minerals, as well as the financial advantages and possible economic sustainability opportunities of these minerals. The overall purpose of this study is depicted in Figure 1.

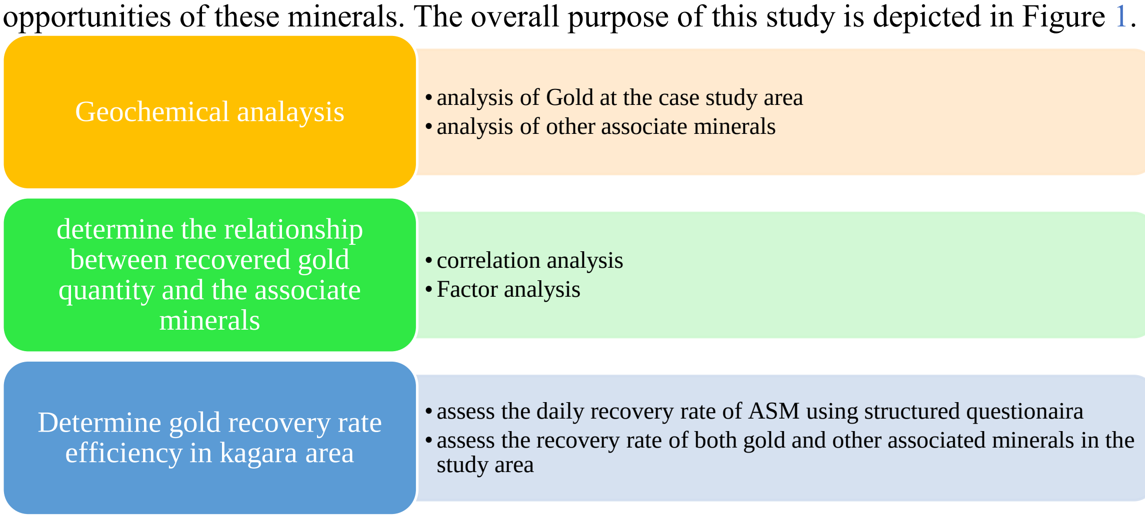


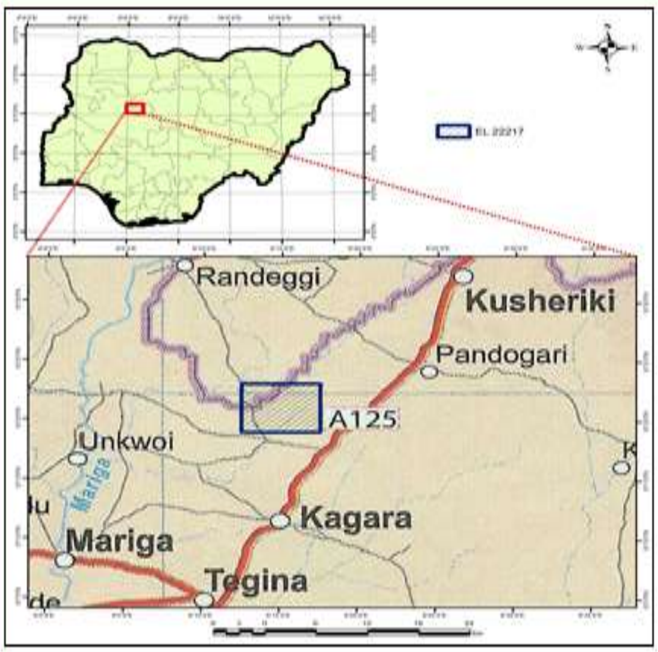
Fig. 1 Study objectives in sequence

METHODOLOGY

This section presents the methodology used for sample collection, preparation, and for the chemical composition analysis.

Site investigation

The research area is located approximately 13 kilometers north of Kagara. The landscape is predominantly undulating, with gentle hills separated by lowlands with level soil cover. From the northwest and south to the northeast, the elevation ranges from 280 m to 415 m above mean sea level and increases gradually. As depicted on the geological map (Figure 2), there are seasonal rivers and rivulets that flow from the highlands to the lowlands.



S/No	Longitude	Latitude
1	6° 12′ 30″	10° 19′ 00″
2	6° 12′ 30″	10° 23′ 00″
3	6° 17′ 30″	10° 23′ 00″
4	6° 17′ 30″	10° 19′ 00″

Fig.2 Geological Map of the Study Area in Kagara (modified after [25]).

Soil Sample Collection

In this investigation, systematic soil sampling was conducted throughout the entire study area (Figure 3). Using the UTM coordinate system, the maps were gridding into 400-m sampling intervals across the general foliation of the area. The world satellite datum (WGS84) was used to calibrate GPS sample coordinates. All GPS (WS84) points were entered into field notes before being transferred to GIS software. For each soil sample location, the colour, particle size, class to matrix ratio, and in situ or transported material were described and recorded. Using a trowel, a layer of topsoil between 10 and 20 centimeters was removed to expose an organic-rich bed. This was done to reduce the impact of agricultural chemicals, as the majority of the land is under cultivation. Below the oxidation zone, approximately 1 kg of labeled soil samples were collected using an agglomerate. The study area is located approximately 13 kilometers north of the Kagara Community. The landscape is predominantly undulating, with gentle hills separated by lowlands with level soil cover. From the northwest and south to the northeast, the elevation ranges from 280 m to 415 m above mean sea level and increases gradually. As depicted on the geological map (Figure 2), there are seasonal rivers and rivulets that flow from the highlands to the lowlands.

Fig.3 Soil sampling activity at the case study point

All samples were gathered at the base camp and later dispatched to the National Geosciences Laboratory Centre (NGRLC) in Kaduna for necessary preparation. Samples collected from the field were pulverized, and 60 grams of 75-micron sieve passing were used for chemical analyses. The samples chemical analysis was carried out in South Africa.

Geochemical analysis method

The elemental composition analysis for the determination of the quantity of gold and 10 other associate minerals was carried out using fire assay (FAA) and multi element analysis (MEA) in the SGS South Africa (PTY) Ltd. (Randfontein) Laboratory to determine the elemental composition and the percentage of association present with gold. Also, X-ray analysis was used to produce the diffraction pattern with sufficient wavelength, for sample elemental determination. Samples prepared from the field (soil samples, alluvial deposit samples, and rock samples) were pulverized to 50 m and subjected to an incident beam. A circle of film was used to record the diffraction pattern, as shown in Figure 4. Each cone intersected the film, giving diffraction lines. Eq. (1) illustrates the expression for the dimensional lines and arcs on the film (Bragg's law).

$$2d\sin\theta = n\lambda \quad , \qquad (1)$$

Where *d* is the spacing between diffracting planes, θ (theta) is the incident angle, *n* is an integer, and λ is the beam wavelength.

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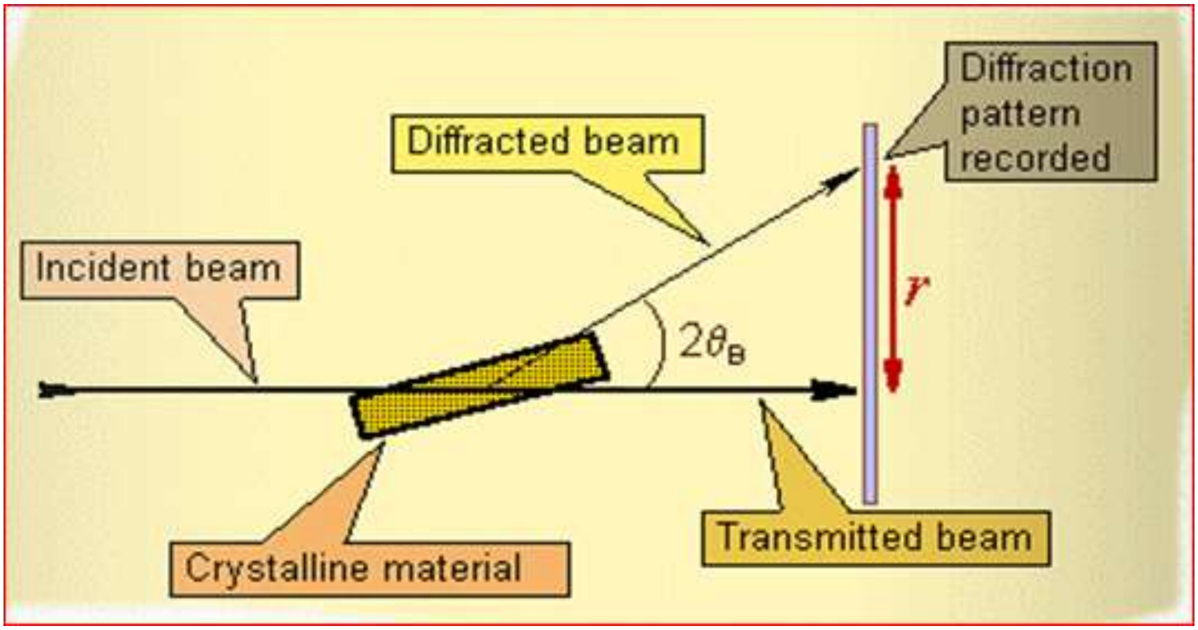

Fig.4 Diagram showing X-ray Diffraction

Statistical analysis methods

Analyzing geochemical data is simpler with statistical tools; geochemical data are compositional data in which the concentration of each element does not change freely and independently. Within the constant sum constraint of the closed composition, the data are compatible. The constant sum constraint resulted in the erroneous behaviour of the correlation effect, resulting in a negative bias. To make classical statistical methods pertinent to the available compositional data, the so-called negative bias and spurious correlation effects need to be log transformed. The area was sampled for a total of 39 soil samples during the study. The samples were analyzed for 25 different elements. To consolidate the data, descriptive statistics such as mean, minimum, maximum, and standard deviation were utilized. The data are analyzed using a multivariate statistical procedure such as factor analysis (FA). The extraction of principal components from the initial dataset constitutes factor analysis. Each principal component should represent a process or set of processes that impact the spatial variation of the parameter values. Utilizing the Kaiser criterion, the number of components to extract was determined. This method suggests that only factors with eigenvalues rigorously greater than or equal to 1 should be retained. Additionally, the screen plot can be used to determine the number of factors that constitute unique sources of variation in the dataset. All statistical analyses were conducted using the software applications SPSS (v26) and NCSS 12.0.

Correlation analysis techniques

The concept of geostatistical technique (correlation) was used to determine the degree of relationship in quantity between the gold and each of selected associated minerals. The Karl Pearson's product moment, was used to compute the elemental coefficient of Correlation as illustrates in Eq.(2).

$$r = \frac{n(\sum xy - \sum x \times \sum y}{\sqrt{[n\sum x^2 - (\sum x^2)] \times [n\sum y^2 - (\sum y^2)]}} \quad (2)$$

Where n is number of observations, x and y are variables, ∑ denotes the summation of x and

Multiple Regression Analysis

Multiple regression analysis illustrates the connection between two or more associated minerals and gold. This study adopted the method of using hypothetical data to compute the coefficient of multiple correlations, known as R. In addition, R-Statistical computing techniques as mentioned by Rossini et al. [26] were used to construct an interrelationship model for gold-associated minerals, as expressed in Eq. (3), based on the results obtained.

$$R^2{}_{1.23} = \frac{r^2{}_{12} + r^2{}_{13} - 2r_{12}\ r_{13}\ r_{23}}{1 - r^2{}_{23}} \quad , \quad (3)$$

Where $R_{1.23}$ is the square root of $R_{21.23}$

r_{12}, r_{13}, r_{23} is correlations between pairs of variables as indicated by their subscripts.

$R_{1.23}$ is Coefficient of multiple correlations between x_1 and a combination of $x_2$and x_3.

x_1, x_2 and x_3....... xn are all minerals with gold.

RESULTS AND DISCUSSION

Sample chemical composition

Table 1 present the statistical analysis of the chemical analysis results obtained for the 25 samples analyzed for the study. The result revealed that, the case study area had high percentage of manganese, Ranges between 156-3080 grams.

Table 1: Descriptive Statistics of Gold and Associated Minerals in g/ton

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Au	39	0.0100	0.1900	0.0600	0.0380	1.6100	3.1900
Al	39	0.4800	4.9100	3.0080	1.1200	-00.1600	-0.8800
Ca	39	0.0400	0.3400	0.1260	0.0700	1.4100	1.9200
Co	39	1.6000	55.8000	13.3850	12.5850	2.4200	5.9200
Cr	39	20.0000	251.0000	47.1500	39.1000	4.2500	20.5000
Cu	39	5.6000	113.0000	29.8280	27.9270	2.3200	4.4200
Fe	39	0.5100	7.9900	3.1330	1.6970	1.3100	1.7900
Ga	39	0.2000	16.3000	7.8620	3.1860	0.2300	0.6600
K	39	0.0700	0.4600	0.2230	0.0990	0.8800	0.7600
Li	39	2.0000	30.0000	8.4900	6.3070	1.6300	2.5800
Mg	39	0.0300	0.7300	0.1350	0.1210	3.4000	15.1900
Mn	39	156.0000	3080.0000	619.2600	588.2510	2.4500	7.3000
Mo	39	0.0900	15.7000	2.6510	2.4450	4.1900	21.9500
Na	39	0.0100	0.1300	0.0320	0.0250	3.0600	9.9600
Ni	39	0.2500	88.4000	18.6830	16.6590	2.5400	8.0200
P	39	0.0025	0.0220	0.0100	0.0050	0.7400	0.0200
Pb	39	0.2000	189.0000	24.0000	29.4210	4.9200	27.3500
Sc	39	0.0500	22.2000	5.6090	4.5620	2.0400	4.9600
Tb	39	0.0500	1.6200	0.6540	0.4110	0.8700	-0.2900
Th	39	2.6000	33.3000	12.5130	8.4410	1.3100	0.5200
Ti	39	0.0050	0.1000	0.0540	0.0230	0.3000	-0.3000
U	39	0.5300	5.5300	1.7820	1.2670	1.3800	0.8700
W	39	0.0500	0.6000	0.2550	0.1290	1.2700	2.3100
Zn	39	8.0000	56.0000	26.2800	11.1420	0.7700	0.5800
Zr	39	1.2000	22.3000	6.9210	3.9050	2.6400	8.8200

The case study area was also identified as a gold host soil with 0.01 minimum gold nuggets and 0.19 gram maximum. Likewise, the evidence of copper, cobalt, aluminum and many other elements existence in the formation was also unveiled as presented in Fig. 5.

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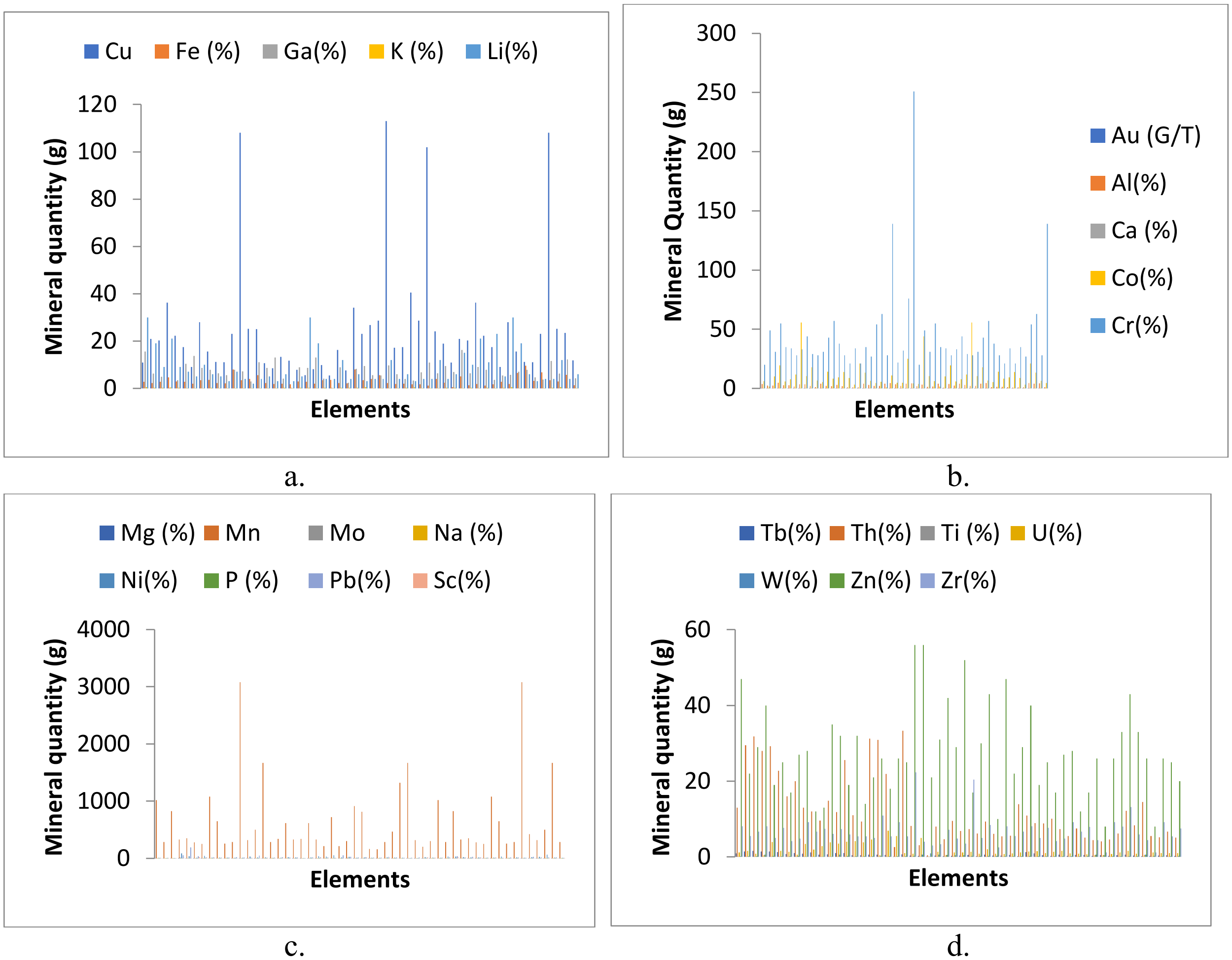

Fig.4 Chemical analysis result of several soil samples from Kagara case study

Correlation Analysis

Using a correlation matrix, the relationship between the amounts of gold recovered from the case study location and other associated minerals was analyzed. The correlation matrices for both the untransformed and logarithmically transformed data have been calculated and presented in Tables 2 and 3, respectively. Li and Mg have a moderately positive correlation (R = 0.518) with a significance level of 95%, as shown in Table 2. It was deduced that as the Li concentration in a sample increases, so does the Mg concentration. Mo and Ni had a high positive correlation of R = 0.719 at the 95% level of significance, whereas Au and Na had a low positive correlation of R = 0.384 but were significant at the 99% level. As shown in Table 3, the findings indicate that gold has a negative correlation with other associated minerals. From the log-transformed data (Table 3), the relationship between Li and Mg decreased to R = 0.452, which was also statistically significant at the 95% confidence level; the correlation coefficients of Mo and Ni decreased to R = 0.597, while those of Au and Na increased to R = 0.406. With the raw data and log-transformed data, the Varimax rotated factor matrix operations were conducted (Table 4). Ten (10) extracted components account for 80.93 percent of the total variance. Factor 1 accounts for 13.36% of the total variance, with a high loading in U and a negative loading in Pb, Ni, and Sc. Factor 2 accounts for 9,95% of the total variance with a positive loading in P and a negative loading in Th and Tb, while factor 3 accounts for 8,75% of the total variance with a positive loading in Li, Mg, and Cu. Factor 4 with factor loadings in Al and K accounts for 7.82%, while factor 5 with factor loadings in Ti and Ca accounts for 7.71%. Factor 6 has a positive loading for Cr and a negative loading for Mn, while factor 7 has a positive loading for Zn and Zr. Factor 8 explains 6.89% of the total variance with loadings in Na and Au; factor 9 explains 6.65% of the total variance with positive loadings in U and negative loadings in Ga; and factor 10 explains 5.83% with negative loadings in Co.

Table 2: Correlation matrix for raw data

	Au	Al	Ca	Co	Cr	Cu	Fe	Ga	K	Li	Mg	Mn	Mo	Na	Ni	P	Pb	Sc	Tb	Th	Ti	U	W	Zn	Zr
Au	1	0.134	0.034	0.081	-0.068	-0.059	-0.205	0.018	-0.129	0.137	-0.089	-0.164	-0.034	.384*	-0.045	0.293	-0.066	0.073	-0.203	-0.248	0.282	-0.076	0.07	-.343*	-0.085
Al		1	0.089	0.094	.365*	0.201	0.116	0.041	.467**	0.184	0.048	0.2	0.179	-0.022	0.205	0.233	0.051	0.083	0.009	-0.112	0.133	-0.107	0.268	0.083	0.043
Ca			1	.369*	0.176	0.23	.402*	0.001	-0.102	-0.121	-0.211	0.142	0.068	-0.079	-0.074	0.012	0.023	0.033	-0.058	-0.098	.528**	-0.017	0.111	0.188	-0.056
Co				1	-0.097	.322*	0.016	.383*	-0.046	0.133	-0.094	-0.044	0.127	-0.118	0.22	0.006	0.02	.420**	0.066	-0.055	0.164	-0.09	0.131	0.143	-0.18
Cr					1	0.008	0.003	-0.121	0.11	-0.028	0.05	-0.175	-0.052	-0.058	-0.029	0.233	0.023	-0.079	-0.107	-0.146	0.282	-0.103	.336*	0.028	.490**
Cu						1	0.009	0.1	-0.047	-0.135	-0.246	-0.113	-0.063	-0.016	0.139	-0.123	-0.052	0.105	0.11	-0.132	0.131	-0.018	.391*	0.146	-0.089
Fe							1	0.076	-0.126	-0.081	-0.077	.550**	0.24	-0.125	0.037	.332*	0.021	-0.047	-0.013	0.059	.323*	0.226	0.084	0.157	-0.112
Ga								1	-0.231	0.045	0.113	0.062	-0.297	-0.169	-0.063	0.301	-0.217	.456**	-0.303	-0.306	0.012	-0.017	-0.135	0.106	-0.002
K									1	0.159	0.055	0.011	0.243	0.012	.321*	-0.071	0.039	-0.05	-0.07	-0.036	-.317*	-.360*	0.174	0.269	-0.018
Li										1	.528**	-0.156	.361*	0.089	.330*	0.291	0.122	0.218	0.217	.408**	-0.013	-0.305	0.123	0.153	0.157
Mg											1	-0.078	0.209	-0.119	0.24	.377*	0.087	-0.085	0.013	0.235	-0.229	-0.049	0.163	.406*	.516**
Mn												1	-0.061	0.263	-0.172	0.052	-0.116	-0.166	-0.086	-0.03	0.15	0.14	-0.29	0.235	-0.155
Mo													1	-0.171	.719**	0.091	.390*	0.127	.481**	.497**	0.024	-0.122	.350*	0.161	-0.009
Na														1	-0.202	0.125	-0.132	-0.111	-0.198	-0.238	0.078	-0.113	-0.141	0.067	0.02
Ni															1	0.071	.333*	0.189	0.201	0.144	-0.042	-0.171	.393*	0.209	0.094
P																1	-0.006	0.104	-.332*	-0.213	0.176	-0.108	0.273	0.169	0.208
Pb																	1	0.15	.339*	.385*	-0.092	0.21	0.228	-0.053	-0.12
Sc																		1	0.22	-0.009	0.081	-0.251	-0.008	0.075	0.023
Tb																			1	.781**	-0.069	0.047	0.065	-0.029	-0.052
Th																				1	-0.167	0.066	0.05	-0.012	-0.12
Ti																					1	0.111	0.068	-0.06	0.063
U																						1	-0.177	-0.109	-0.033
W																							1	.325*	-0.028
Zn																								1	.345*
Zr																									1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 3: Correlation matrix for log-transformed data

	clr.Au (G/T)	clr.Al(%)	clr.Ca (%)	clr.Co(%)	clr.Cr(%)	clr.Cu	clr.Fe (%)	clr.Ga(%)	clr.K (%)	clr.Li(%)	clr.Mg (%)	clr.Mn	clr.Mo	clr.Na (%)	clr.Ni(%)	clr.P (%)	clr.Pb(%)	clr.Sc(%)	clr.Tb(%)	clr.Th(%)	clr.Ti (%)	clr.U(%)	clr.W(%)	clr.Zn(%)	clr.Zr(%)
clr.Au (G/T)	1	0.085	0.175	0.128	0.007	-0.117	-0.112	0.098	0.122	0.101	0.115	0.019	-0.255	.406*	-0.299	0.205	-.350*	-0.302	-.405*	-.353*	0.161	-0.021	0.118	-0.236	0.036
clr.Al(%)		1	0.105	-0.069	0.309	0.092	0.022	0.000	.402*	0.063	0.023	0.117	-.344*	0.003	-0.291	0.053	-.389*	-0.227	-0.140	-.337*	.316*	-0.016	0.116	-0.020	0.004
clr.Ca (%)			1	0.127	0.028	0.205	.334*	0.041	-0.077	-0.281	-0.188	0.047	-0.071	0.102	-.333*	-0.107	-0.276	-0.265	-0.195	-0.218	.492**	0.114	-0.031	-0.004	-0.134
clr.Co(%)				1	-0.161	0.146	-0.150	0.143	-0.131	-0.062	-0.155	-0.145	-0.096	-0.204	0.112	-0.009	-0.107	-0.012	-0.171	-0.194	-0.086	0.019	0.029	-0.087	-0.233
clr.Cr(%)					1	0.070	-0.031	-0.029	0.257	-0.113	0.122	-0.208	-.425**	0.099	-0.282	0.187	-0.157	-0.204	-0.220	-0.260	0.078	0.051	.341*	0.069	0.302
clr.Cu						1	0.070	-0.068	-0.037	-.367*	-.481**	-0.082	-0.231	0.003	0.038	-0.210	-0.062	0.047	0.046	-0.208	0.075	-0.028	.331*	0.006	-0.173
clr.Fe (%)							1	-0.011	-0.139	-0.244	-0.050	.384*	-0.062	-0.034	-.338*	0.167	-0.253	-.347*	-0.104	0.028	0.111	0.303	-0.075	0.132	-0.046
clr.Ga(%)								1	-0.044	-0.110	-0.053	0.120	-.437**	0.116	-0.310	0.193	-.317*	-0.018	-.336*	-0.274	-0.012	.320*	-0.142	0.027	0.044
clr.K (%)									1	0.179	0.151	0.063	-0.227	0.135	-0.209	-0.040	-0.296	-0.213	-0.232	-0.147	-0.284	-0.179	0.217	.327*	0.160
clr.Li(%)										1	.452**	-0.230	0.052	-0.048	-0.014	0.111	-0.113	0.005	0.018	0.115	-0.199	-.329*	-0.036	0.024	0.128
clr.Mg (%)											1	0.025	-0.179	0.021	-0.267	0.215	-0.280	-.459**	-0.125	0.273	-0.219	0.084	0.050	0.205	0.233
clr.Mn												1	-0.184	.429**	-0.296	-0.097	-0.247	-0.291	-0.111	-0.041	0.020	0.094	-0.309	0.262	-0.068
clr.Mo													1	-.349*	.597**	-0.217	.516**	.364*	.484**	.463**	-0.090	-.330*	-0.272	-0.304	-0.245
clr.Na (%)														1	-.414**	-0.018	-.341*	-.389*	-0.276	-0.227	0.170	0.131	-0.119	0.128	0.229
clr.Ni(%)															1	-0.167	.674**	.588**	0.218	-0.004	-0.161	-.418**	-0.027	-0.268	-.336*
clr.P (%)																1	-0.108	-0.096	-.550**	-0.285	-0.100	-0.027	0.170	-0.012	-0.014
clr.Pb(%)																	1	.701**	0.275	0.185	-0.213	-0.260	-0.090	-.368*	-.400*
clr.Sc(%)																		1	0.238	-0.101	-0.131	-.464**	-0.110	-0.308	-0.246
clr.Tb(%)																			1	.706**	-0.039	-0.019	-0.282	-0.232	-0.038
clr.Th(%)																				1	-0.290	0.140	-0.156	-0.035	-0.018
clr.Ti (%)																					1	0.171	-0.114	-0.211	0.004
clr.U(%)																						1	-0.234	0.037	0.200
clr.W(%)																							1	0.206	-0.110
clr.Zn(%)																								1	.470**
clr.Zr(%)																									1

Table 4: Gold and its associate minerals factor Analysis

	Component										
	1	2	3	4	5	6	7	8	9	10	communalities
clr.Au (G/T)								0.716			0.821
clr.Al(%)				0.863							0.893
clr.Ca (%)					0.714						0.741
clr.Co(%)										-0.836	0.772
clr.Cr(%)						0.514					0.755
clr.Cu			-0.808								0.744
clr.Fe (%)											0.81
clr.Ga(%)									-0.785		0.765
clr.K (%)				0.688							0.699
clr.Li(%)			0.748								0.716
clr.Mg (%)			0.625								0.759
clr.Mn						-0.863					0.872
clr.Mo											0.811
clr.Na (%)								0.800			0.869
clr.Ni(%)	-0.755										0.759
clr.P (%)		0.804									0.801
clr.Pb(%)	-0.676										0.841
clr.Sc(%)	-0.884										0.857
clr.Tb(%)		-0.864									0.875
clr.Th(%)		-0.664									0.907
clr.Ti (%)					0.861						0.816
clr.U(%)	0.588								-0.558		0.79
clr.W(%)											0.801
clr.Zn(%)							0.848				0.898
clr.Zr(%)							0.746				0.862
Eigenvalues	3.34	2.49	2.19	1.96	1.93	1.77	1.73	1.72	1.66	1.46	
% variance	13.36	9.95	8.75	7.82	7.71	7.07	6.91	6.89	6.65	5.83	80.93

Geochemistry result interpretation

Four vertical sections were chip-sampled from both high-grade and low-grade areas of the samples analyzed to acquire a range of values from the different sedimentological facies of the reef, as revealed by the geochemical analysis results. The maximum and minimal concentrations of gold recovered during the Kagara exploration project are 0.22 g/t and 0 g/t, respectively. It was discovered that the gold in the region occurs in quartzite and schist veins. The total gold concentration in the sample region of Kagara is 2.92 g/t. In addition, 33% of the Kagara gold vein was discovered in pegmatite or schist regions, while 67% of the gold was found in alluvial deposits. Figure 6 depicts the amount of gold recovered from various sampling locations in the Kagara region. TB/PB/063, TB/PB/035, and TB/PB/060 have the maximum gold recovery percentage, according to the findings.

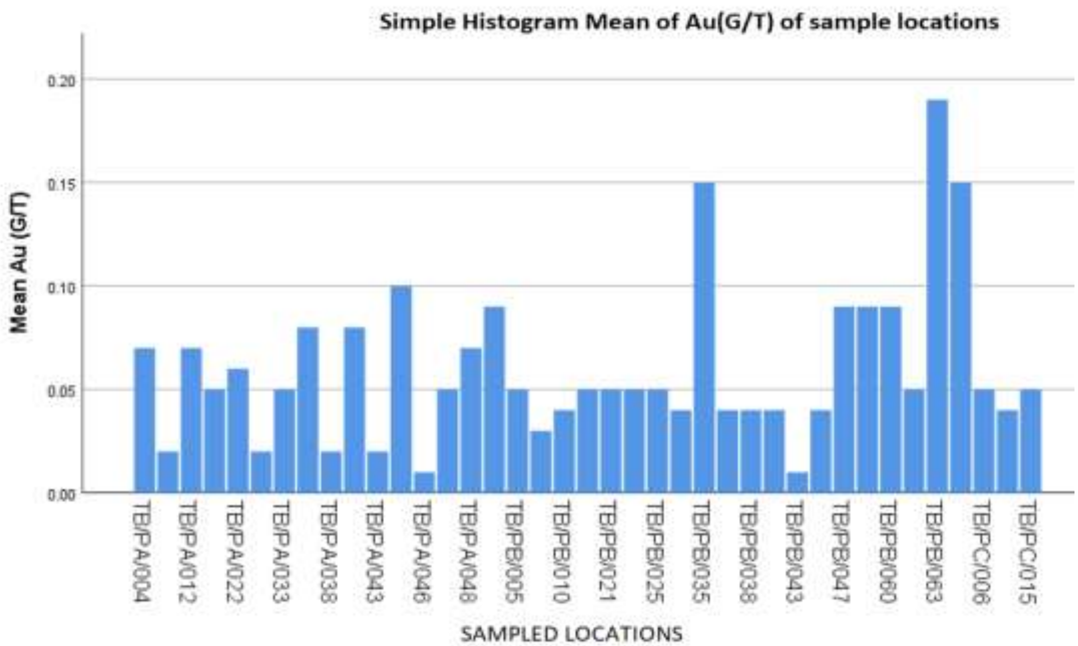

Fig.6: Histogram Mean of Gold Occurrence in Kagara.

Recoveries from Exploration Results

The analysis shows that strong relationships exist between individual pairs of elements associating with gold as summarized in a correlation matrix drawn from the Kagara study areas geochemical analysis. Values of recovered gold and associated minerals are as shown in Table 5.

Table 5: Values of Gold and Associated Minerals Recovered in Kagara

S/N	Gold and Associated Minerals	Values Recovered in Kagara (g/ton)
1	Gold (Au)	2.29
2	Copper (Cu)	1,358
3	Iron (Fe)	173.75
4	Lithium (Li)	481
5	Magnesium (Mg)	7.83
6	Manganese (Mn)	33,995
7	Nikel(Ni)	1,013
8	Lead (Pb)	1,160
9	Thorium (Th)	652.6
10	Uranium (U)	94.995
11	Zinc (Zn)	1,471

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Results of current gold production rate at the case study area

The information gathered from questionnaires was used to calculate the total variable cost and price of producing 1 gram of gold by artisans. According to Table 6, the monthly total average variable costs incurred by artisanal gold mines in the study areas are $843,456, while the monthly average total revenue is $3,837,600 and the total profit is $2,994,144. According to the findings, artisanal gold miners spend an average of $40,000 to produce 1 gram of gold, while their average monthly profit is $2,994,144. As shown in Tables 7 and Figure 7, the economic benefit of other associated minerals co-existing with the gold run-off mine in Kagara was considered for the purposes of this study.

Table 6: Cash Flows of Circle of Operations by Artisanal Gold Mining.

Descriptions	Capital and Variable costs(₦)	Quantity of gold(gram) produced daily	Monthly Revenues at 26 days per month
Quantity of Gold(gram)produced monthly		0.82	21.32
Cost of drilling accessories	25,000.00		
Cost of explosives and accessories	225,000.00		
cost of blasting permits with permits	170,000.00		
Cost of Blasting	25,000.00		
Haulage cost	32,000.00		
Crushing Cost	21,000.00		
Cost of Washing and panning	42,000.00		
days of work per month		26	
Other Variable costs			
Cost on transportation	2,402.00		
Labour cost	16,054.00		
fueling	150,000.00		
Maintenance	55,000.00		
Taxes	10,000.00		
Processing cost	70,000.00		
Average total monthly expenditures	843,456.00		
Total average monthly revenue			3,837,600.00
Total average monthly Profit			2,994,144.00

Table 7: Value of Gold and Associated Minerals in Kagara (Niger State Nigeria)

S/N	Gold and Associated Minerals	Value of Au and Associated Minerals (g/ton)	Approved Mkt Value(₦)	Output(₦)
1	Gold (Au)	2.29	180,000.00	412,200.00
2	Copper (Cu)	1,358	40,000.00	54,320,000.00
3	Iron (Fe)	173.75	6,500.00	1,129,375.00
4	Lithium (Li)	481	10,000.00	4,810,000.00
5	Magnesium (Mg)	7.83	5,000.00	39,150.00
6	Manganese (Mn)	33,995	10,000.00	339,950,000.00
7	Nikel(Ni)	1,013	10,000.00	10,130,000.00
8	Lead (Pb)	1,160	90,000.00	104,400,000.00
9	Thorium (Th)	652.6	25,000.00	16,315,000.00
10	Uranium (U)	94.995	54,000.00	5,129,730.00
11	Zinc (Zn)	1,471	45,000.00	66,195,000.00

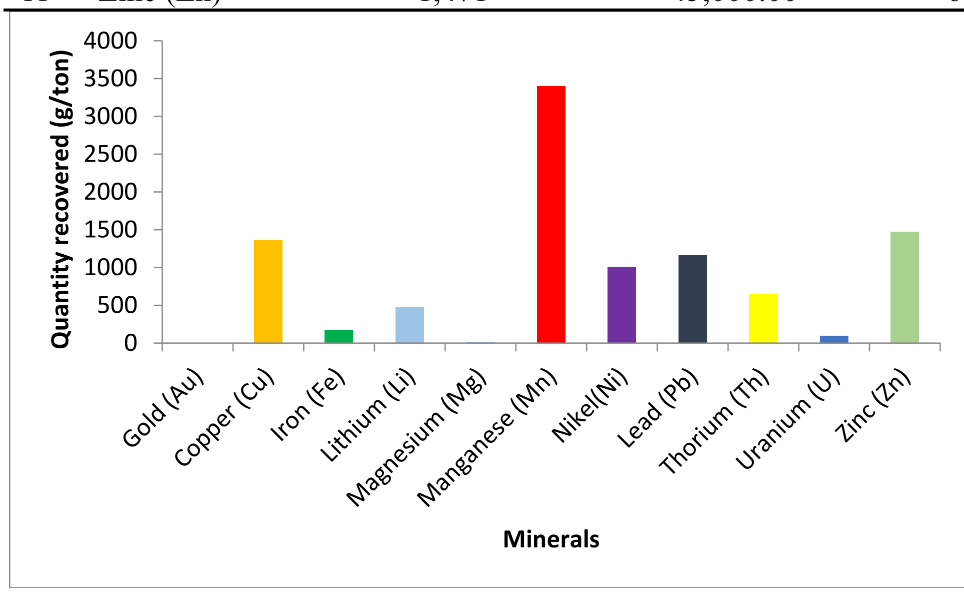

Fig.7 Quantity Recovery rate of gold and other associated Minerals

CONCLUSION AND RECOMMENDATION

Gold miners are primarily focused on extracting more gold concentrate, with no special regard for other associated minerals. These minerals associated with gold receive little to no consideration from mine operators, resulting in waste and economic loss. Before commencing full mining operations, it is necessary to have a clear understanding of the economic value of these gold-associated minerals at the time of exploration.

This study evaluates the amount and cost-benefit ratio of ten associated minerals recovered with gold feed in the Kagara region. The area was sampled representatively and subjected to both fire assay (FAA) and multi-element analysis. In the case study of the gold runoff mine, a total of 26 associated minerals were discovered. Ten minerals, including zinc, thorium, uranium, magnesium, manganese, nickel, copper, iron, lead, and lithium, were extracted from the result. The average recovery rate for each associated mineral was 1707 g/tonne, 914.7 g/tonne, 156.43 g/tonne, 9.9 g/tonne, 36306 g/tonne, 1264 g/tonne, 1501 g/tonne, 187.13 g/tonne, 1205 g/tonne, and 578 g/tonne, respectively.

The findings also indicate a correlation between the amount of associated minerals and the gold runoff. For instance, as the amount of lithium in a sample increases, so does the percentage of magnesium present. Similarly, the amount of Mo and Ni in the sample was found to have a high positive correlation of $R = 0.719$ at the 95% level of significance, whereas the correlation between Au and Na was low but significant at the 99% level of significance. In addition, the exploitation survey conducted on the extant ASM mining operation in the study area revealed that artisanal gold miners spent an average of $40,000 to produce 1 gramme of gold, whereas their average monthly profit was $2,994,144. The significance of the economic benefit of other associate minerals has been revealed by this study.

Considering the capital and operating costs required for the exploration and exploitation of gold-bearing soil and rock, it has been determined that the refining of other associate minerals to improve the cost-benefit ratio is highly advantageous. Therefore, gold extraction companies and individuals are made aware of the need to value gold gangues containing associated minerals. In addition, it is suggested that multiple mineral processing devices, such as technology capable of simultaneously processing multiple minerals, be developed.

Availability of data and materials
The data used in the study are available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

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Authors' contributions
All sections of the manuscript including data collection, analysis and interpretation were carried out by the author.

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