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Contaminants Study of Heavy Metals in Soils from Fodwookrom and Its Environs, Western-North Region, Ghana

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Abstract

The study focuses on heavy metal distribution and contamination in agricultural soils in Fodwookrom and its environs. One hundred and ten (110) soil samples were collected and analyzed using the X-ray florescent Analytical Method for heavy metals such as Nickel (Ni), Chromium (Cr), Copper (Cu), Zinc (Zn), Vanadium (V), Manganese (Mn) and Lead (Pb). The laboratory results were preprocessed to eliminate data noise and normalized. Geochemical data analytical methods such as the Principal Component Analyses (PCA), Correlation Analyses and Spatial Distribution Plots were applied to the preprocessed data to deduce the heavy metal elemental sources, associations and distribution patterns. The heavy metal 'Mn' had the highest mean concentration of 344.13 ppm from the statistical mean distribution estimations. This was followed by Cr (89.37 ppm), Zn (20.56 ppm), Cu (17.42 ppm), Ni (14.13 ppm), Pb (9.34 ppm) and V (8.87 ppm) respectively. The applied PCA determined the sources of the heavy metals from three extracted principal components. The heavy metals from natural sources loaded in the first extracted principal component made up of V, Cr, Mn, Ni and Zn. The heavy metal 'Pb', loaded in the second principal component which shows an anthropogenic source while 'Cu' is loaded in the third principal component, which is associated with both natural and anthropogenic sources. All the studied heavy metals showed direct associations in the study area but heavy metal pairs such as Mn-V, Ni-Cr, Ni-Mn and Zn-Mn showed higher positive correlation coefficient values above '0.5'. This indicates that the pair of heavy metals has a stronger positive association in the study environment. All the studied heavy metals were within their permissible guideline values by WHO and constitute no source of contamination in the study area, hence, the area is suitable for agricultural works.

Keywords

Heavy Metals, Statistical Methods, Geochemical Analyses, Contaminant Assessments

1. Introduction

Soil geochemical analyses for agricultural purposes involve soil sampling and testing for elemental components to identify abnormal concentrations of elements that may show abundance or depletion. This enables the concentrations of elements to be determined for assessing the quality of arable land (Pour et al., 2024). Earth materials such as rocks, soils, sediments and vegetation are essential factors to consider for plant growth analyses. During the breakdown of rocks to form soils, they leave behind traces of unusually high concentrations of some elements. These elements can also be introduced artificially into an area by human activities. Some elements in exceedingly high concentrations affect plant growth and may become dangerous for human consumption. Heavy metals are elements in smaller quantities in soils but become harmful when they exceed their allowable levels for crop production. The spatial analysis of these elements can help locate areas of higher or lower concentrations for remediation. Geochemical analyses have become an important part of modern agricultural land assessment programs due to its effectiveness in delineating the chemical components of the various chemical elemental groupings from soils. The characteristic of soil contaminated by heavy metals is influenced by the total heavy metal content. The study area lies within latitude 7.0011˚N to 6.7489˚N and longitude 2.5072˚W to 2.7462˚W. Soils used for agricultural purposes must be checked for heavy metal sources and relationships. This is critical for monitoring and assessment of agricultural soils. There are two main sources of heavy metals in soils: 1) natural background which represents heavy metal concentration derived from parent rocks 2) anthropogenic sources resulting from human activities such as application of agrochemicals and organic manure. The assessment of heavy metal distribution patterns in this work will offer essential information for evaluating agricultural soils in the study area. The main aim of the study was to determine the levels of elemental contamination in agricultural soils. The contamination of soil by heavy metals has significant implications for human health and the environment. Exposure to heavy metals is linked to various health issues including neurological, organ diseases and cancer (Kyere et al., 2016). Crop yields and ecosystem functions are disrupted by excessive heavy metal concentrations which impact soil fertility (Silva et al., 2021). The identification of heavy metal sources in the study area will offer essential information for monitoring and assessing farm soils. The determined sources will be useful for designing rigorous management policies to minimize elemental contamination in the study area. Also, knowledge of the spatial distribution of these metals will prevent further contamination in higher zones of occurrence.

2. Geology and Tectonic Setting

Ghana's geological framework is part of the West African Craton, a stable Precambrian crustal block composed predominantly of Archean and Paleoproterozoic rocks (Leube et al., 1990). The craton is one of the major crustal units of the African Plate and is subdivided into two principal shields: the Reguibat Shield in the north and the Leo-Man Shield in the south, separated by the Taoudeni Basin. The Man (Leo-Man) Shield is characterized by Paleoproterozoic terranes formed during major crustal growth events between approximately 2.2 and 2.0 Ga. These terranes extend across Ghana, Côte d'Ivoire, Burkina Faso consisting of volcanic belts, sedimentary basins and granitoid intrusions formed during the Eburnean Orogeny (Leube et al., 1990). This orogenic event was responsible for crustal accretion, deformation, metamorphism and mineralization throughout the West-African region. The geology of Ghana is dominated by Precambrian rocks that have undergone extensive deformation, metamorphism and magmatism (Kesse, 1985). The two principal lithostratigraphic units are the Birimian Supergroup and the Tarkwaian Group (Boadi et al., 2013). The Birimian Supergroup consists mainly of metavolcanic and metasedimentary rocks formed during volcanic and sedimentary processes associated with the Eburnean Orogeny (Leube et al., 1990). These rocks are organized into a series of belts and basins that generally trend northeast-southwest. The belts include Kibi-Winneba, Ashanti, Sefwi-Bibiani, Bui-Banda, Bole-Nangode, and Lawra while the basins include the Kumasi, Sunyani, Cape Coast, Accra-Winneba and Maluwe. The rock types present in the metasedimentary belt are greywackes, phyllites, slates, schists, tuffs and sandstones. Meta-basalts and meta-andesites magmas and dykes make up the metavolcanic sequence (Atta, 2023) which includes amphibolites and greenstones (Breakey & Breakey, 1977). The felsic rocks present consist of undifferentiated volcaniclastic deposits and rhyolitic flows. The study area (**Figure 1**) covers a section of the Sefwi-Bibiani belt and its adjoining Sunyani basin which forms part of the Proterozoic Birimian terrane of Ghana. In Ghana, the Sefwi-Bibiani belt measures 40 to 60 km in width and extends 220 km south-west to the Gulf of Guinea. Structurally, the Sefwi-Bibiani belt has been remobilized into numerous fault-networks with extensive shearing along the contact with the Sunyani basin. The Sunyani basin is located north of the Sefwi-Bibiani belt and is composed of the basin-type metasediments and volcaniclastics. The area is characterized by undulating topography with elevation ranging from 700 to 1100 ft.

3. Materials and Methods

3.1. Field Data Collection

Geochemical field data collection for elemental contaminant assessments starts with a field survey design which shows locations where samples were picked. This was done in this study by gridding the survey area into an equal 1 km quadrant where samples were collected at the vertices. Thus, Soil samples were picked from the vertices of a 1 km × 1 km grid across the study area. Soil samples were collected

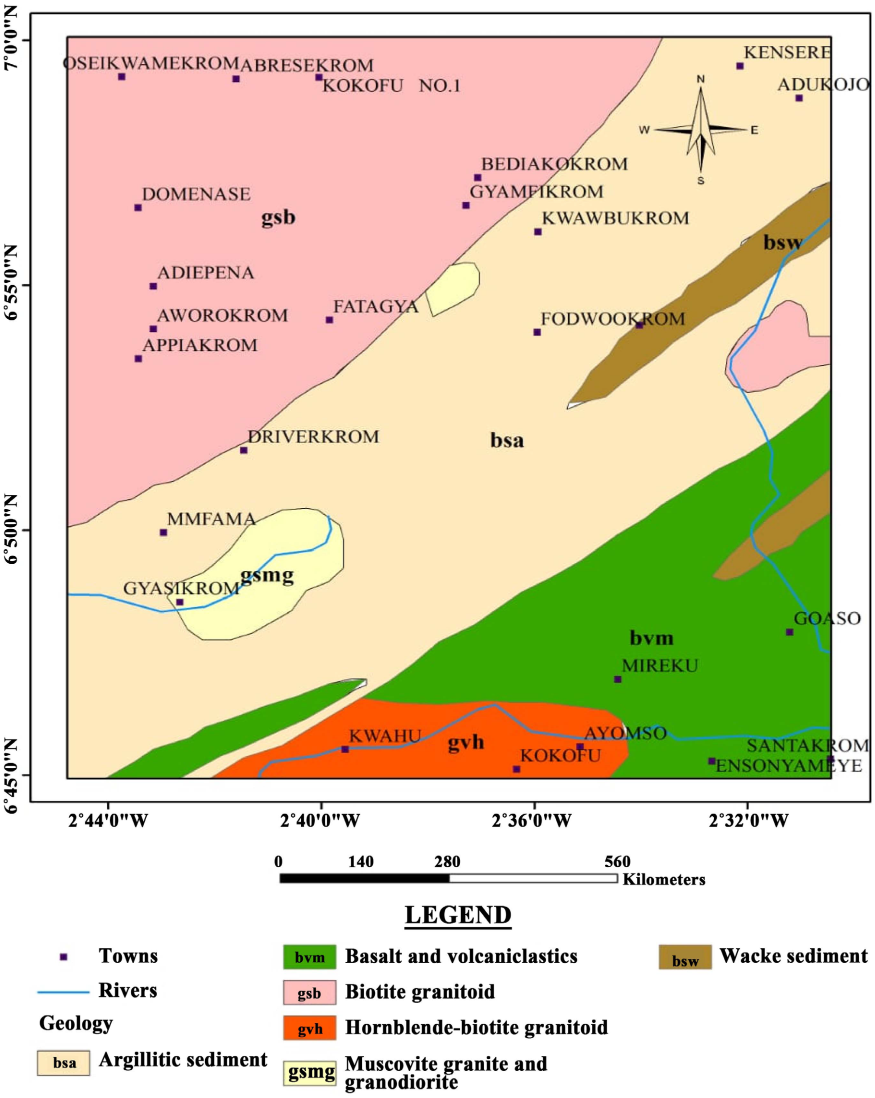

Figure 1. Geology map of the study area.

at the apex of a triangle drawn around the exact Global Positing System (GPS) positions on the gridded data. Soils were collected at 50 m depth to remove possible transported soils that do not relate to the rock's distribution in the area. The sampled material was representative of the survey location which makes the analyzed results from the samples accurate by reflecting the geochemical signatures of the sampled area. The two important decisions in heavy metal analysis work are the field survey design and the type of material to be sampled (Demetriades, 2013). In this survey, soil sampling field procedure was used after a careful review of the area's geography. Soil sampling is considered most effective especially in tropical regions like Ghana where weathering has led to thick overburden (Etutu et al., 2022). Ninety-eight sampling lines were gridded along which samples were taken. A total of one hundred and ten (110) samples were collected across the entire study area. The samples were collected using plastic sample bags, which were cleaned and flushed with soil from the sample sites. The collected samples were sealed and labelled according to the site number. Sample identification (ID) numbers were written on cards and placed in the sampled soils in the sample bags. The sample 'ID's were legibly written on the sample bags with a permanent marker. Precautions were taken during sampling to ensure that each sample collected was a true reflection of the conditions in the hole they were sampled. A sufficient number of duplicate samples were taken for quality control analyses by splitting the original samples into different sampling bags.

3.2. Sample Preparation and Analyses

Sample preparation is a crucial activity in ensuring the accuracy and reliability of data analysis. The acquired samples were transported to the laboratory for sorting, drying and crushing. The process of drying in an oven helped to remove soil moisture which prepared the sample for sieving. A two-millimeter mesh size sieve was used for sieving the dried soil samples. Coarse particles and debris were removed, leaving finer soil fractions. The sieved soil samples were mixed to achieve a uniform composition through homogenization which reduced the variability within each sample for analyses. Representative samples were obtained by compressing the samples into smaller disk shapes for XRF analyses. The final samples were packaged, cleaned, labeled and stored for analytical processing. Each soil sample was subjected to the X-rays florescent analytical procedure by striking the processed sample surface with X-rays. A characteristic emission of fluorescent X-rays representing energies from the different elemental atoms in the sample, enabled measurement levels of the different elemental constituents. Various quality control measures were applied during the XRF analyses, duplicate samples were analyzed twice to measure precision in terms of the relative percent difference at 5%. The detection limit for all the reported elements was within the range of 0.01 ppm. The XRF analytical procedure was chosen for its non-destructive nature which preserves sample quality. It enables a large number of soil samples to be analyzed concurrently. These characteristics make the procedure a perfect choice for this research. Certified standards with the expected concentration ranges of key target elements were submitted to monitor the accuracy of the results produced by the XRF analytical procedure.

3.3. Data Analytical Procedures

1) Principal component analysis (PCA)

Principal component analysis (PCA) was applied to reduce the dimensionality of the data set in order to determine heavy metal sources in the study area. PCA is a multivariate statistical technique applied to reduce data variance by simplifying a complex data structure into meaningful groups while preserving as much information in the data as possible. It explores numerous associations between variables before assembling homogeneous groups for the purposes of ascertaining variable strength in the new groups. The method reduces several related variables into a smaller number of new variables called principal components (PCs), thereby minimizing the number of variables in the data. An extracted component is a combination of the original variables which has a portion of the variance in the original dataset. The amount of variance extracted by the various principal components varies among the total extracted principal components. The first principal component explains the most variance in the data, followed by the successive principal components (Davis, 2002). In heavy metal studies, PCA helps classify the key factors which control heavy metal distribution patterns. Elements from similar sources are loaded together in one principal component making it easier to interpret elemental data. PCA scores are loaded for each data sample to show the strength of various elements at a particular location. A field data is standardized before the application of the PCA Method, which enables the elements to contribute equally to the analysis irrespective of their initial elemental concentration levels.

2) Correlation analysis (CA)

Correlation analysis (CA) is a geostatistical method used to measure the strength of the linear relationship between two variables and compute their association (Hartigan, 1967). Thus, it is used to establish elemental relationships in a dataset (Davis, 2002). The method computes the levels of change between two variables. A pair of elements can be related positively or negatively but may also show no significant relationship. In heavy metal studies, CA is applied to identify groups of heavy elements that commonly have some form of relationship. These elemental relationships are built from common material sources and field processes such as rock weathering, mineralization dissemination and soil erosion (Adams et al., 2024). The Pearson correlation coefficient (r) measures the strength and direction of a relationship between a pair of data. It gives a value ranging from −1 to +1 indicating the highest positive and negative associations. A value close to +1 shows a stronger positive relationship where both elements increase or decrease together. Also, a value closer to -1 indicates a stronger negative relationship where one parameter increases while the other decreases and vice versa. A value near ‘0’ shows there is no linear relationship between the pair of variables (Davis, 2002). Thus, a variable change has no effect on the other. The analysis is done using transformed normalized data giving only statistically significant correlation values for interpretation, thereby improving the reliability of the results. The output values are arranged in a correlation matrix table with color codes showing the relevant relationships between the elements. The CA method was used in elemental relation studies in the Damang area of Southwestern, Ghana, to identify Arsenic and Gold association for gold exploration (Adams et al., 2024). In soil assessment studies, heavy metal relations are assessed by applying the CA method to an acquired dataset where it is used to establish elemental relationships.

3) Spatial distribution plot

Spatial distribution plots are graphical maps used to show a parameter variation laterally. The produced maps show data distribution over an area making it easier for interpretation. Areas of higher and lower heavy metal concentrations can be mapped for further work based on a background value. The elemental data is spread along contour lines to create distribution maps using software such as the Golden Software Surfer. The process involves sampled data interpolation over a study area using a method of interpolation known as Kriging. The Kriging technique is a statistical procedure that uses spatial relations between data points to calculate values in unsampled areas (Davis, 2002). The output is displayed as a color-filled map with contour lines showing areas of different concentration. Higher and lower concentration zones called anomalies are interpreted by using a cut-off point such as the mean plus two standard deviations (mean + 2σ). These anomaly zones are emphasized on the maps for further work. The graphical contoured maps are used for pattern recognition and direct comparative analysis. The applied heavy metals' geographical distributions were plotted using the Surfer software from the heavy metal concentration raw data. A graphical representation of the spatial distribution patterns showed the relationship between heavy metals in the study area. Three types of spatial distribution patterns were recognized including uniform, random and clumped style distributions. For a uniform spatial distribution pattern, concentration values were equally spaced apart throughout the area of recognition. The random spatial distribution pattern gave an unpredictable distribution style while the clumped spatial distribution pattern showed concentration values clustered at various localities by creating patches.

4. Results and Discussions

4.1. Descriptive Statistics

The descriptive statistics of the studied heavy metals are shown in **Table 1**. The table shows the Minimum, Maximum and Mean Concentration Values of the analyzed heavy metals. Manganese has the highest mean concentration of 344.13 ppm in the study environment, followed by Chromium 89.37 ppm, Zinc 20.56 ppm, Copper 17.42 ppm, Nickel 14.13 ppm, Lead 9.34 ppm and Vanadium 8.87 ppm respectively. This shows that Manganese has a high average concentration compared to the other elements and can be attributed to a higher concentration of manganese in the volcaniclastic rock which forms part of the bedrock. Although Lead (Pb) showed an average concentration of 9.34 ppm, the value is higher by comparing it to the Environmental Protection Agency's allowable value for agricultural purposes. The variances in the measured data are determined from the range of the individual heavy metal given by the difference between the maximum and minimum measured values for the heavy metals. Higher data variability is shown by the heavy metal manganese compared to the other heavy metals which indicate a higher inconsistency and less reliability in the manganese data. Nickel showed the least variability indicating a higher consistency and reliability in measured data values.

4.2. Correlation Analysis

A correlation analysis was performed using the Pearson's method with the Pearson's correlation coefficient values of the studied heavy metals shown in **Table 1**.

Table 1. Descriptive statistics of heavy metals.

Heavy Metals	Minimum Value (ppm)	Maximum Value (ppm)	Mean Value (ppm)
Vanadium	2.10	14.47	8.87
Chromium	51.00	114.35	89.37
Manganese	224.00	472.28	344.13
Nickel	8.20	17.65	14.13
Copper	13.00	31.73	17.42
Zinc	5.30	37.14	20.56
Lead	7.20	12.70	9.34

Data preprocessing involved data editing to remove spike values using the nearest neighbor interpolation method, and the data was transformed using the lognormal transformation procedure. The significance threshold for the reported correlation is $p > (+/-0.02)$ where ‘p’ is the Pearson’s correlation coefficient value. The heavy metal pairs gave positive association values in the study area except the heavy metal pair, ‘Pb’ and ‘Cr’ which showed a weaker negative association value of -0.005. Heavy meal pairs such as Mn-V, Ni-Cr, Ni-Mn and Zn-Mn have higher positive correlation coefficient values between 0.5 and 1 indicating a direct association in the study environment where a pair of heavy metals either increases or decreases together in the study area. Moderate positive correlation coefficient values of 0.2 - 0.4 were recorded for heavy metal pairs such as Cr-V, Mn-Cr, Ni-V, Cu-V, Cu-Mn, Cu-Ni, Zn-V, Zn-Cr, Zn-Ni and Zn-Cu indicating the various pairs move together in the study area. The heavy metal ‘Pb’ showed weaker positive association values with all the studied elements. This shows an insignificant increase or decrease in ‘Pb’s association with all the other heavy metals. In all, Ni-Cr showed the strongest positive relationship with a correlation coefficient value of 0.667 indicating the heavy metal pair increases or decreases together in the study area. Manganese has a stronger direct association with Zircon and Vanadium which can be attributed to their +2 affinity for electrons, hence, they replace each other easily in a weathering environment. Nickel, a large lithophile element is strongly positively correlated with Manganese and Chromium probably due to their similar mobility rate in the study area. Geochemical properties such as ionic size and mobility rate of the heavy metals account for some of the relationships observed. Scatter plots showing graphically the heavy metal distribution are shown in **Figure 2**. In scatter plots, the level of scattering or clustering of data points determines the degree of association or disassociation while the orientation of the line of best fit establishes the type of association whether direct or inverse. To demonstrate the level of clustering, a circle was placed around the data points. Most of the data points in **Figure 2** are clustered with positive intercept values from the lines of best-fit leaving fewer data points outside the circles. This demonstrates a higher positive association of the heavy metal pairs used in the scatter plots. The levels of association of the heavy metal from the Pearson's correlation coefficient values were confirmed by the scatter plot. The plots corresponded well with the estimated correlation coefficient values in **Table 2**.

Table 2. Pearson's correlation coefficient matrix of heavy metals.

Heavy Metals	V	Cr	Mn	Ni	Cu	Zn	Pb
Vanadium	1.000						
Chromium	0.362	1.000					
Manganese	0.517	0.257	1.000				
Nickel	0.435	0.667	0.514	1.000			
Copper	0.279	0.167	0.194	0.212	1.000		
Zinc	0.398	0.210	0.513	0.419	0.213	1.000	
Lead	0.163	0.005	0.122	0.054	0.030	0.157	1.000

🟥 : Relatively high correlation [+/– 0.5 - 1];

🟨 : Moderate correlation [+/– 0.2 - 0.4];

🟩 : Nearly no correlation [+/– 0 - 0.2].

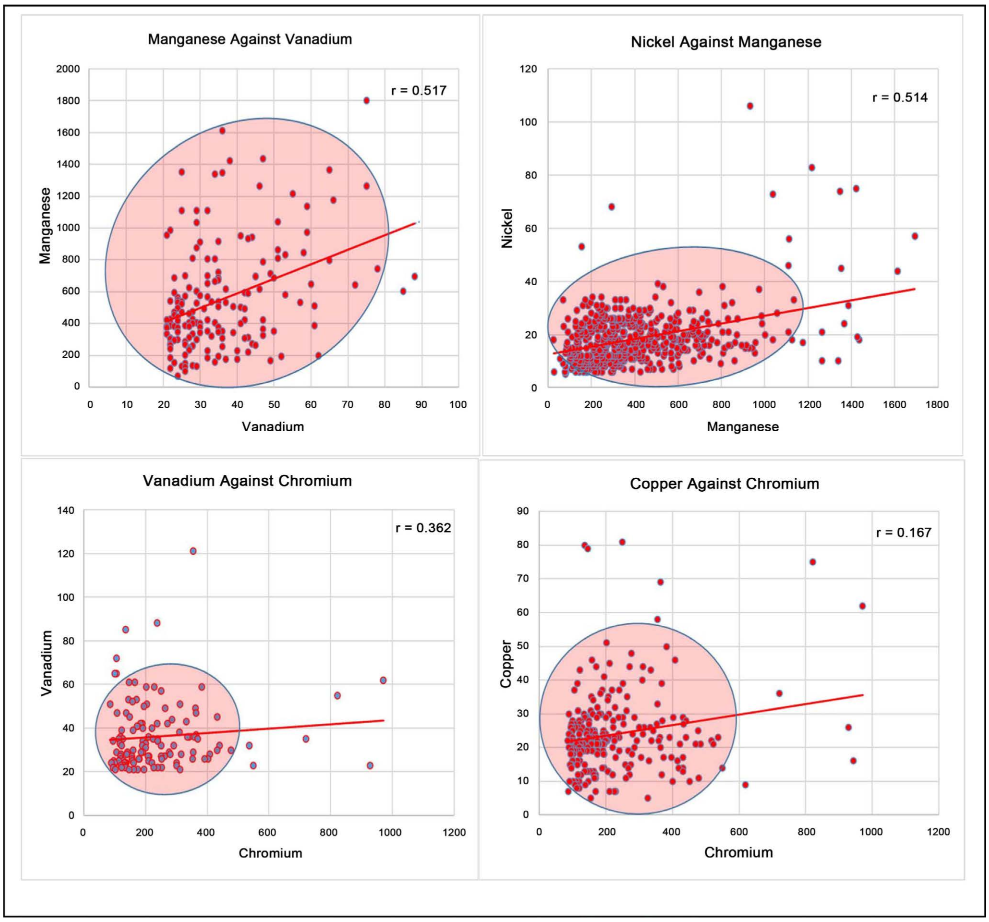

Figure 2. Scatter plots of heavy metals in the study area.

4.3. Principal Component Analysis

The sources of heavy metals in the study area were deduced using a multivariate statistical method known as the Principal Component Analysis from the elemental data. The total variance explained by the extracted principal components in cumulative percentages is shown in Table 3, while Table 4 shows the principal component loadings for heavy metals in the study area extracted in three components. The data variables were normalized before applying the correlation analyses to avoid skewing the derived component structures. The Covariance Matrix was extracted for further processing because all reported variables shared the same unit of measurement. Only components with eigenvalues greater than one (1) were retained. The rotated component after varimax rotation gave three extracted principal components. The first component accounted for 41.15% of the total variance in the data, while the second component loading expresses 15.721% of the total variance in the data. The third component also accounted for 13.985% of the total variations in the data. The observed heavy metal principal component loads indicate the sources of the heavy metals in the soils. The principal component one showed significant positive loads for all the heavy metals in the group and contains elements from natural sources in the study area which include Vanadium, Chromium, Manganese, Nickel and Zinc. Lead has a significant positive component load of 0.763 in principal component two, showing an anthropogenic source. Loaded in principal component three is the heavy metal copper representing a heavy metal from mixed sources of both natural and anthropogenic.

Table 3. Total variance explained by the three extracted principal components.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Heavy Metals	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Vanadium	2.881	41.159	41.159	2.881	41.159	41.159
Chromium	1.100	15.721	56.880	1.100	15.721	56.880
Manganese	0.909	12.985	69.865	0.909	13.985	70.865
Nickel	0.818	11.680	81.545			
Copper	0.583	8.324	89.869			
Zinc	0.449	6.418	96.287			
Lead	0.260	3.713	100.000			

Table 4. Extracted principal component matrix.

Heavy Metals	Component		
	1	2	3
V	**0.744**	0.134	0.072
Cr	**0.647**	−0.530	−0.259

Continued

Mn	**0.756**	0.184	−0.028
Ni	**0.812**	−0.317	−0.215
Cu	0.418	0.025	**0.829**
Zn	**0.681**	0.292	0.040
Pb	0.199	**0.763**	−0.318

4.4. Spatial Distribution Plot

Graphical representations of the various data concentrations were spatially plotted using the Golden Software Surfer. The spatial distribution patterns of the various heavy metals were summarized as uniform, random and clumped from the raw data. The used software presented the data in the form of contours with various concentration ranges displayed in different scale colours. The spatial distribution plots of the elements in the study area are shown in Figure 3. The heavy metals Zn and Mn showed a similar random distribution pattern as indicated by their strong positive correlation coefficient value of 0.513. Random high concentrations in red are scattered throughout the study area with intermittent lower concentration distribution for the heavy metals Zn and Mn. The spatial distribution of 'Pb' is of a clustered pattern across the study area. Higher concentrations occur to the northeast of the study area. The central part of the study area to the southwest portion showed clustered lower concentrations. The spatial distribution of the heavy metal 'Ni' is approximately uniform across the entire study area except in the southwest where an anomalous higher concentration occurs. This means that, the heavy metal Nickel has a similar concentration in all the rocks types in the area. A high concentration of Ni, Zn and Mn only occurs in the southeast of the study area occupied by the basaltic rocks. All the studied heavy metals showed lower spatial distribution within areas occupied geologically by the metamorphosed argillitic sediments of the Birimian Supergroup. Although lead showed a general random distribution pattern, it was highly concentrated in the northeast of the study area where the granitoids occur compared to the southeast, which was occupied by basaltic rock. It had no relation to the other studied heavy metals. The heavy metal pairs Ni/Mn, Ni/Zn and Mn/Zn are directly associated with their high positive correlation coefficient values. These relationships were demonstrated by their spatial distribution plots where higher and lower concentration areas occur in similar geographical areas.

4.5. Contamination Analysis

The levels of soil contamination in the study area were assessed by comparing the mean values of the heavy metal concentrations to the permissible guideline values for heavy metals distribution in global soils by the World Health Organization (WHO). WHO's permissible guideline limits for heavy metal concentrations in soils and mean concentration values of assessed heavy metals are shown in Table 5. The use of the WHO's permissible guideline limits for assessing soils in Ghana

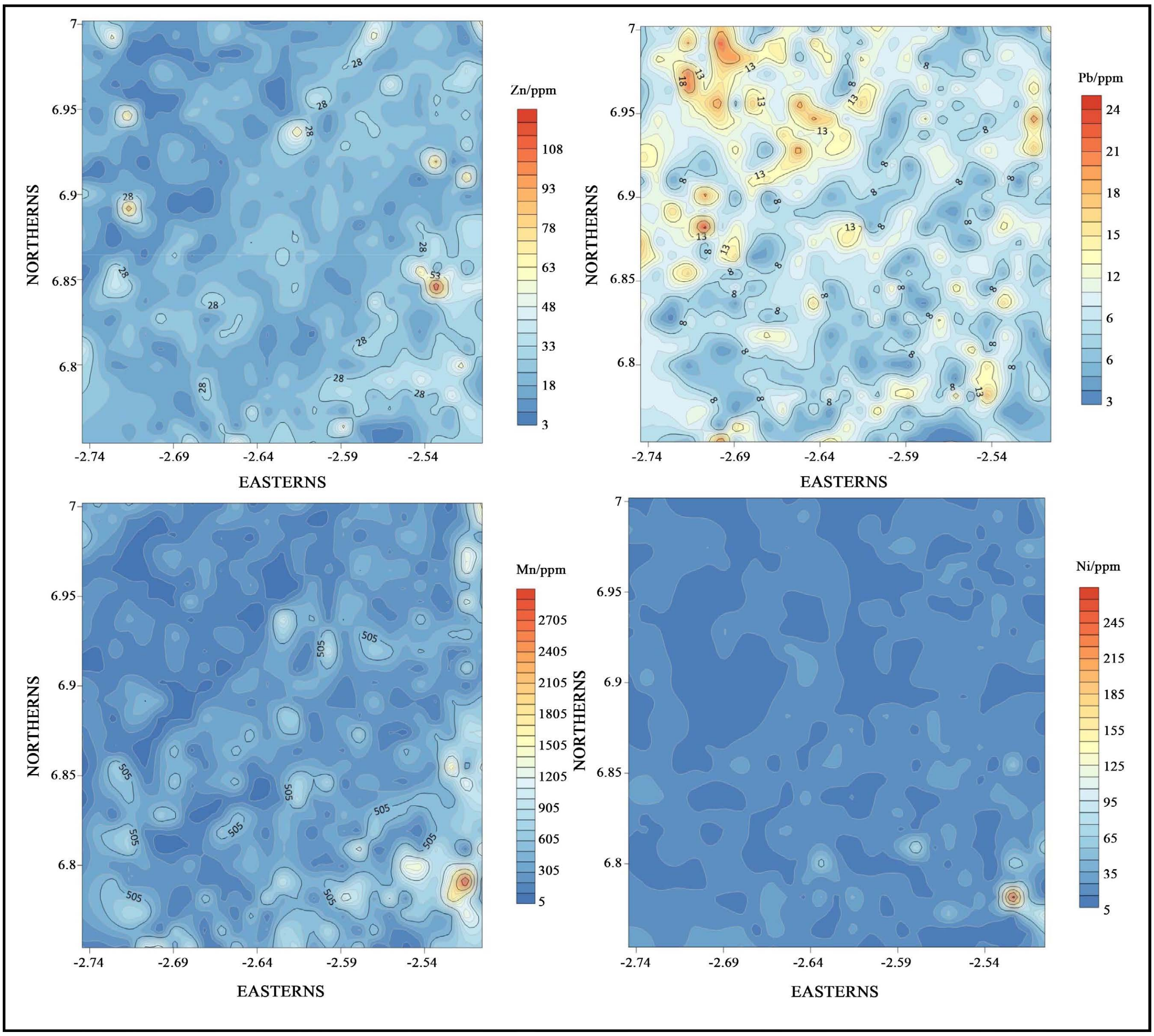

Figure 3. Spatial Distribution Plot of heavy metals in the study area.

is appropriate because geographically, Ghana is within the tropical rainfall region of sub-Saharan Africa. All the assessed heavy metals gave values within the acceptable guideline values limits and do not constitute a source of contamination in the study area. Although lead gave a far lower mean concentration value compared to the guideline values, its presence in agricultural produce may negatively impact human's health when consumed. The WHO's guideline values are international standardized values for monitoring soil toxicity for agricultural land use. The results demonstrate that heavy metal sources are a key influence for soil use assessment as both natural and anthropogenic sources can cause soil contamination.

5. Discussion

The study applied statistical methods to assess the usability of an arable land

Table 5. Comparison of mean concentration to WHO permissible values.

Heavy Metals	WHO's Permissible Values (ppm)	Mean Value (ppm)
Chromium	100	89.37
Nickel	35	14.13
Copper	36	17.42
Zinc	50	20.56
Lead	85	9.34
Manganese	1500	344.13
Vanadium	50	8.87

within Western-North Region, Ghana. The applied methods were effective in determining heavy metal associations, sources and their degree of contamination in the study area. From the statistical mean concentrations, the heavy metal 'Mn' showed the highest mean value of 344.13 ppm. This was followed by Cr, Zn, Cu, Ni, Pb and V respectively. The element 'Mn' was highly distributed in the basaltic rocks to the southeast of the study area compared to the remaining study area. All the investigated heavy metals showed direct relationships with each other. Elemental pairs such as Mn-V, Ni-Cr, Ni-Mn and Zn-Mn were highly positively associated compared to the rest of the heavy metal pairs. This shows that the heavy metals studied occur in higher and lower quantities spatially at similar locations in the study environment. The study deduced the different sources of heavy metals in the study environment as the heavy metal V, Cr, Mn, Ni and Zn were established to originate from natural source. Thus, the bedrock produced most of the heavy metal concentrations in the study area. The established source of the heavy metal 'Cu' is anthropogenic while 'Pb' is from both natural and anthropogenic sources. Graphical distribution plots of the heavy metal concentrations showed their lateral degree of variation in the study region. Higher concentrations of Zn, Mn and Ni occupy the southeastern part of the study where the basaltic rocks occur while lower concentrations of these heavy metals occupy areas with metasedimentary and granitoid rocks. All the studied heavy metals gave mean concentration values within WHO's permissible guideline values, and hence, do not constitute a source of contamination in the study area.

6. Conclusion

The main focus of the study was to establish the suitability of the study area for agricultural work. Heavy metals from soil samples were analyzed for heavy metal associations, sources and degree of contamination in soils from Fodwookrom and its environs, Western-North Region, Ghana. Statistical methods were used to investigate the data and the results were interpreted to establish the study area's usability for agricultural works. Geochemical data analytical methods such as the Principal Component Analyses, Correlation Analyses and Spatial Distribution Plots were applied to the preprocessed data to deduce the heavy metal sources, their relations and their spatial distribution patterns. The following conclusions were drawn from the study.

1) The heavy metal 'Mn' had the highest mean concentration in the study area. This was followed by Cr (89.37 ppm), Zn (20.56 ppm), Cu (17.42 ppm), Ni (14.13 ppm), Pb (9.34 ppm) and V (8.87 ppm) respectively.

2) All the studied heavy metals were within the allowable guideline values by WHO and pose no contamination in the study area.

3) The sources of the studied heavy metals were determined from three origins. The heavy metals V, Cr, Mn, Ni and Zn originated from natural sources, 'Pb', shows anthropogenic source while 'Cu' was associated with both natural and anthropogenic sources.

4) All the studied heavy metals showed direct positive associations in the study area with heavy metal pairs such as Mn-V, Ni-Cr, Ni-Mn and Zn-Mn showing strong positive association. These pairs of heavy metals occur in higher and lower concentrations spatially at similar places in the study area.

The study area is suitable for agricultural works such as farming subject to the remediation of the heavy metals Mn and V. Although the heavy metal 'Pb' had a concentration below the WHO's guideline value, much attention should be given to its level of absorption by plants for human consumption.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

Adams, S. J., Sunkari, E. D., Hanson, J. E. K., Tandoh, K. K., Tetteh, S. E. K., Nude, P. M. et al. (2024) Geochemistry of the Winneba-Mankoadze Pegmatites in Southern Ghana: A Clue to the Petrogenesis of the Pegmatites. *Ore and Energy Resource Geology, 17,* Article 100051.

Atta, S. K. (2023). Mapping Subsurface Geological Structures in the Birimian Supergroup, Ghana Using Airborne Magnetic and Radiometric Data: Implications for Gold Exploration. *Journal of African Earth Sciences, 205,* Article 105003. https://doi.org/10.1016/j.jafrearsci.2023.105003

Boadi, B., Wemegah, D. D. & Preko, K. (2013). Geological and Structural Interpretation of the Konongo Area of the Ashanti Gold Belt of Ghana from Aeromagnetic and Radiometric Data. *International Research Journal of Geology and Mining, 3,* 124-135.

Breakey, A., & Breakey, E. (1977). *The Geology of 1/4° Field Sheets of 0603/A3 (117) Goaso SW and 0603/A4 (118) Goaso SE.* Geological Survey of Ghana.

Davis, J. C. (2002). *Statistics and Data Analysis in Geology* (3rd ed.). Wiley.

Demetriades, A. (2013). Basic Considerations: Sampling, the Key for a Successful Applied Geochemical Survey for Mineral Exploration and Environmental Purposes. In *Treatise on Geochemistry* (pp. 1-31). Elsevier. https://doi.org/10.1016/b978-0-08-095975-7.01401-7

Etutu, M. E. M., Mafany, G. T., & Suh, C. E. (2022). Application of Multi-Element Soil Geochemistry and Particulate Gold Exploration in the Kambele Plain, Batouri Gold District, Southeast Cameroon. In *Advances in Science, Technology & Innovation* (pp. 375-379). Springer. https://doi.org/10.1007/978-3-030-72547-1_80

Hartigan, J. A. (1967). Representation of Similarity Matrices by Trees. *Journal of the American Statistical Association, 62,* 1140-1158. https://doi.org/10.1080/01621459.1967.10500922

Kesse, G. O. (1985). *The Mineral and Rock Resources of Ghana*. Springer.

Kyere, A., Noye, R., & Menyeh, A. (2016). Prospecting for Groundwater in the Bawku West District of the Upper East Region of Ghana Using the Electromagnetic and Vertical Electrical Sounding Methods. *Journal of the Ghana Science Association, 7,* 68-78.

Leube, A., Hirdes, W., Mauer, R., & Kesse, G. O. (1990). The Early Proterozoic Birimian Supergroup of Ghana and Some Aspects of Its Associated Gold Mineralization. *Precambrian Research, 46,* 139-165. https://doi.org/10.1016/0301-9268(90)90070-7

Pour, A. B., Parsa, M., & Eldosouky, A. M. (2024). *Geospatial Analysis Applied to Mineral Exploration: Remote Sensing, GIS, Geochemical, and Geophysical Applications to Mineral Resources*. https://doi.org/10.1016/C2021-0-02624-9

Silva, H. F., Silva, N. F., Oliveira, C. M., & Matos, M. J. (2021). Heavy Metal Contamination in Soils: A Review. Portugal. *Soil Systems, 5,* Article 27. https://doi.org/10.3390/soilsystems5020027