Scientific Research Publishing

Open Journal of Geology, 2023, 13, 806-827
https://www.scirp.org/journal/ojg
ISSN Online: 2161-7589
ISSN Print: 2161-7570

Geochemical Orientation Study of Stream Sediment Samples in the Southern Part of Nuggihalli Schist Belt: Ore Mineral Phases and Their Implications on the Bedrock Potential for Ores

B. G. Dayanand, S. Santhosh, B. C. Prabhakar

Department of Geology, Bangalore University, Bangalore, India
Email: dayanandbg22@gmail.com, geosantu@gmail.com, bcprabhakar@rediffmail.com

How to cite this paper: Dayanand, B.G., Santhosh, S. and Prabhakar, B.C. (2023) Geochemical Orientation Study of Stream Sediment Samples in the Southern Part of Nuggihalli Schist Belt: Ore Mineral Phases and Their Implications on the Bedrock Potential for Ores. *Open Journal of Geology*, **13**, 806-827.
https://doi.org/10.4236/ojg.2023.138036

Received: June 30, 2023
Accepted: August 12, 2023
Published: August 15, 2023

Abstract

Stream sediment sampling is a significant tool in geochemical exploration. The stream sediment composition reflects the bedrock geology, overburden cover, and metalliferous mineralization. This research article focuses on assessing selected trace element concentrations in stream sediments and interpreting their inter-element relationships using multivariate statistical methods. Tagadur Ranganathaswamy Gudda and its surroundings in the Nuggihalli schist belt of southern India have been investigated in the present work. The geology of the study area is complex, with a diverse range of litho units and evidence of strong structural deformation. The area is known for its mineralization potential for chromite, vanadiferous titanomagnetite, and sulfides. The topography of the region is characterized by an undulating terrain with a radial drainage pattern. Most part of the schist belt is soil covered except the Tagadur Ranganathaswamy Gudda area. For this study, a discrete stream sediment sampling method was adopted to collect the samples. Stream sediment samples were collected using a discrete sampling method and analyzed for trace elements using an ICP-AES spectrophotometer: Fe, Cr, Ti, V, Cu, Ni, Zn, Pb, Mn, Cd, and As have been analyzed. The analytical data were statistically treated using the SPSS software, including descriptive statistics, normalization of data using natural log transformation, and factor analysis with varimax rotation. The transformed data showed a log-normal distribution, indicating the presence of geochemical anomalies. The results of the study provide valuable insights into the geochemical processes and mineralization potential of the study area. The statistical analysis helps in understanding the inter-element relationships and identifying element groups and their implications on bedrock potential mineralization. Additionally, spatial analysis using inverse distance weighting interpolation provides information about the distribution of geochemical parameters across the study area. Overall, this research contributes to the understanding of stream sediment geochemistry and its application in mineral exploration. The findings have implications for future exploration efforts and can aid in the identification of potential ore deposits in the Nuggihalli schist belt and similar geological settings.

Keywords

Geochemical Exploration, Stream Sediment, Sediment Sampling, Heavy Mineral Concentrates, Nuggihalli Schist Belt, Dharwar Craton

1. Introduction

Stream sediment sampling is one of the most useful and widely accepted techniques used in geochemical prospecting. The technique has played a major role in mineral exploration for the discovery of ore bodies. Stream sediment geochemistry reflects drainage basin geology [1]. Stream sediments can contain low metal concentrations derived from the composite products of weathering of mineralized rocks within the upstream catchment [2]. The sources of stream sediments could be of both geogenic origin and anthropogenic origin. Geogenic sediments are derived by the weathering of parent rocks including ore deposits and anthropogenic sediments are derived by direct or indirect results of human activities. To understand the geochemical process, the study of stream sediment geochemical data plays a vital role. Various approaches have been developed to identify geochemical processes by using stream sediment geochemical data, such as multivariate analysis, spectrum-area fractal technique, catchment basin analysis, singularity theory, and composition data analysis, and among these, multivariate statistical analytical methods have been widely accepted [3]. The multivariate statistical method is commonly used to find out element associations and their parent sources and this method includes discriminant analysis, principal component analysis (PCA), and factor analysis (FA). Of these methods, factor analysis is commonly applied in exploration geochemistry [4].

The present study attempts to assess the selected trace element concentrations and interpret their inter-element relationship in stream sediments regarding geological processes and their implications with bedrock using multivariate statistical methods. The Tagadur Ranganathaswamy Gudda and the surrounding areas of the Nuggihalli schist belt covering an area of 8 square kilometers have been selected for this research work.

2. Review of Literature

The literature review provided a comprehensive overview of previous research conducted on geochemical orientation studies of stream sediment samples and the application of statistical methods for these studies. Rossiter (1976) carried out oriented geochemical studies in the Westmoreland area, northern Australia, and the study indicates that stream sediment sampling is a powerful potential exploration technique and multivariate statistical analysis provides useful insights into the metallogeny of the area [5]. Cruikshank *et al.*'s (1993) study indicates that stream sediment sampling is an effective geochemical technique for mineral assessment, despite overall poor drainage development in Davenport province, Northern Territory. Both sieved samples and heavy mineral concentrates were considered for the study [6]. Obied *et al.*'s (2001) study of stream sediment samples characterizes the Sn, Nb, Be and Li rare metals enrichment in the Gabal El mueilha area drainage system, and the factor analysis provided the vital results for the exploration of rare metal mineralization in the study area [7]. Odokuma-Alonge and Adekoya (2013) applied factor analysis for stream sediment geochemical data from the Onyami drainage system within the Iggara area in southwestern Nigeria and concluded this technique as an aid to the interpretation of reconnaissance stream sediment analytical data. The element association identified in the study is related to underlying parent rocks or mineralization [8]. Adisa and Adekoya's (2016) application of statistical technique for interpretation of stream sediment geochemical data found to be useful in the Oyi drainage system, western Nigeria, and the results of the statistical analysis suggested the occurrence of potential mineralization containing Cu-Zn-Ag-Au in the gneisses of the study area [9]. Liu and Cheng's (2016) stream sediment geochemical data multivariate analysis results indicate that the factor analysis (FA) applied to log ratio-transformed data can be used to effectively identify geochemical processes and to determine the extent of anthropogenic and natural influences such as mineralization, weathering, and diagenesis, heavy metal accumulation or contamination, or a combination of these factors [3]. Ayodele's (2016) data evaluation using statistical analysis for stream sediment geochemical data results showed that the heavy metal distribution patterns and chemical compositions of stream sediments of Ikoro and Ijero is greatly influenced by the local geology of the area. The study also confirmed that the studied areas are rich in base and precious metals [10]. Tian *et al.*'s (2018) results of stream sediment geochemical data processing show that anomalies of raw data correspond worse with the known deposits. By contrast, the method of mapping anomalies with log transformed data performs better [11]. Awosusi *et al.*'s (2019) 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 was interpreted in terms of underlying lithology, mineralization and/or environmental control [4]. These studies provide an overview of the geochemical studies conducted on stream sediment samples, focusing on their significance in understanding environmental processes, identifying mineral deposits, and assessing the bedrock potential for ores in specific geological regions.

3. Geology of the Study Area

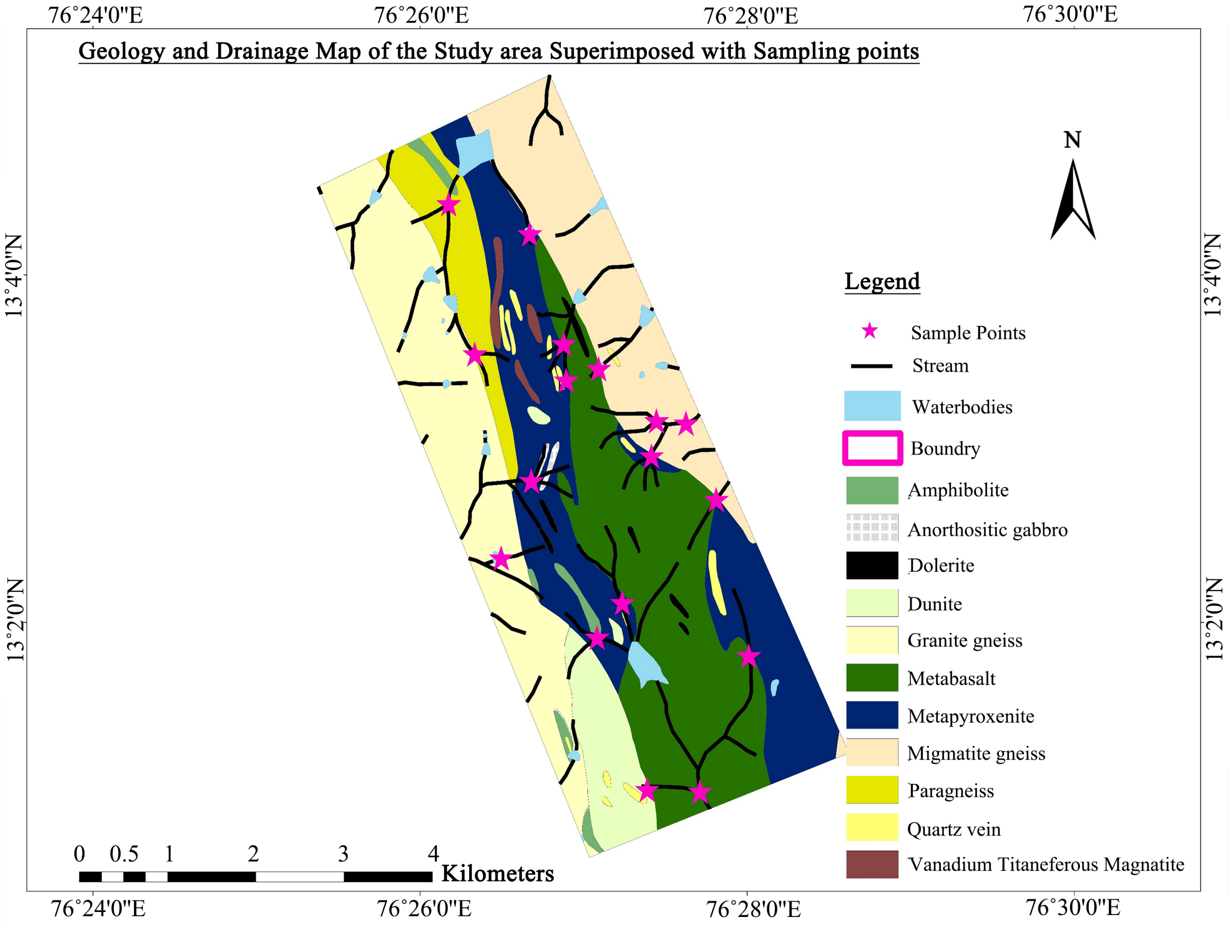
The Tagadur Ranganathaswamy Gudda and surrounding areas are part of the Nuggihalli schist belt which falls in Hassan District of Karnataka State in southern India (Toposheet No. 57 C/8). Nuggihalli schist belt is a linear greenstone belt trending NNW-SSE in the southern part of Western Dharwar Craton and represents one of the early supracrustal, formed about a 3.3 Ga period [12] [13]. It extends from Kempinkote in the south to Arsikere in the north for over 60 km, with a maximum width of 2 km. The Nuggihalli schist belt is dominated by serpentinized ultramafic sequences, and amphibolites, underlaid by basement granite gneiss with significant amounts of metasediments. Amphibolites occupy about one-third of the area and appear as dark, jointed, and weathered bands with an NNW-SSE strike and a steep eastward dip. The ultramafics in the central axis of the belt include dunite, peridotite, serpentinite, and pyroxenite. They transition into greenschists at the borders, which are composed of minerals like talc, chlorite, actinolite, and tremolite. Gneisses border the ultramafics, amphibolites, and greenschists. Quartz veins, epidiorite dykes trending ENE-WSW and dolerite dykes intrusion parallel to the regional trend of all formations indicating their young age and prominence (**Table 1**). The layered nature of the belt is strongly indicated. This belt is known for its high metallogenic value. Several chromite-bearing areas dot the belt, especially in the middle and southern parts. Gold mineralization in its southern part near Kempinkote witnessed a brief mining activity during the period 1893-1896. Titaniferous vanadium-bearing magnetite is also distinct for this belt and was mined for some time. Subsurface exploration near Aladahalli in this belt has provided strong indications for sulfide mineralization. However, as a large part of this belt is under soil cover, further exploration and development of the mineralized zones has become a challenge.

Table 1. Litho stratigraphy succession of Nuggihalli schist belt (after Geological Survey of India memoir).

INTRUSIVES	1	ULTRAMAFIC ROCKS	➔ Actinolite-Talc-Tremolite-Chlorite Schist ➔ Dunite/Serpentinites ➔ Peridotites ➔ Pyroxenites
	2	MAFIC ROCKS	➔ Gabbro and Anorthosites
	3	ORES	➔ Chromite ➔ Titaniferous Magnetite
SARGUR GROUP	4	META-SEDIMENTARY ROCKS	➔ Amphibolites Interbedded with Kyanite-Quartz-Mica Schist and Quartzite ➔ Fuchsite-Quartzite ➔ Garnet-Kyanite-Sillimanite Schist
PENINSULAR GNEISS (Basement of the Schist Belt)			

The mineral assemblage of kyanite, garnet, and biotite in pelite and hornblende-andesine in basite reflect the P-T conditions of Regional Metamorphism of upper amphibolite facies. The deformation and probably the emplacement of gneissic precursors adjoining the belt are closely related to this metamorphic episode. The schist belt's rock types experienced three deformation phases. The first phase had a recognizable penetrative schistosity parallel to bedding and lithological boundaries. It was folded by tight isoclinal folds, mainly observed at Tagadur and other locations. The second phase created upright, tight isoclinal folds along north-south axial planes. The third phase involved folding with axial traces striking north or northeast, influencing the earlier regional folds.

The geology of the Tagadur Ranganathaswamy Gudda and the surrounding area is complex and varied involving magmatic and metamorphic processes and mineralization (**Map 1**). The litho units observed in the study area are dunite, serpentinite, gabbro, anorthosite, pyroxenite, talc-chlorite schist, talc-tremolite schist, norite, amphibolite, and economic minerals such as chromite, vanadiferous titanomagnetite, and sulfides. The presence of strong foliation mineral alteration, cleavages, and boudinages indicate that the study area has undergone strong structural deformation.



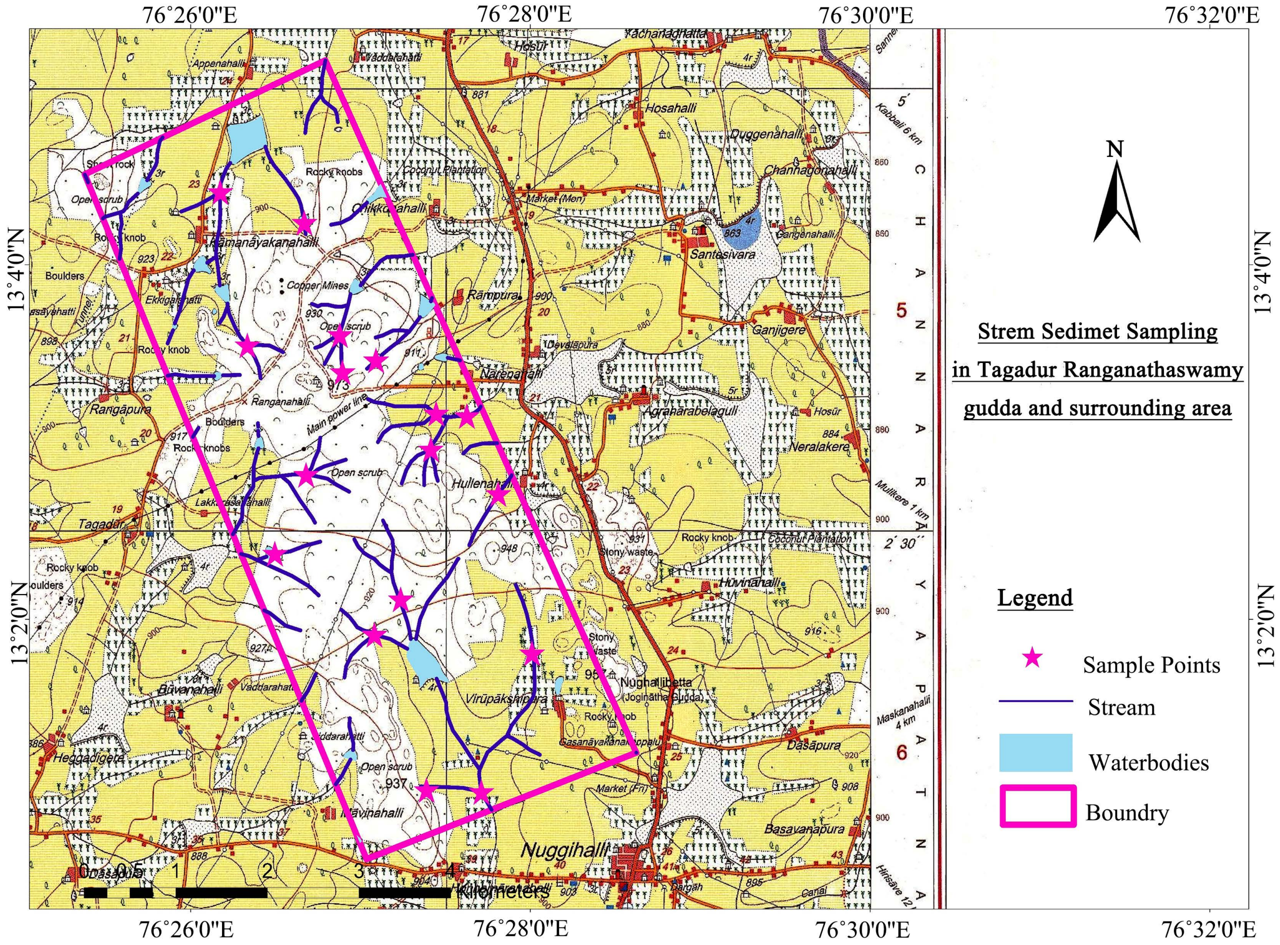
Map 1. Geology and drainage map superimposed with stream sediment sampling points of the study area.

4. Sampling and Analytical Methods

4.1. Location and Physiography

Stream sediment sampling was planned and carried out in the central part of the Nuggihalli schist belt around Ranganathaswamy Gudda and the surrounding area. Previous fieldwork observations and the reports of the Geological Survey of India (GSI) and Mineral Exploration Corporation Limited (MECL) were also referred before planning the work. A sample location map for stream sediments has been prepared using toposheet no 57 C/8 in the study area covering 8 square kilometers for systematic stream sediment sampling (Map 2).

Topographically, the study area is an undulating terrain that appears as a low-relief narrow, dome-like mount with a gentle slope on both easterly and westerly sides with the highest elevation of 973 m above MSL giving rise to a radial drainage stream pattern surrounding it. Most of the study area is uncultivated barren land and the topography changed from mound to plains. The drainage stream orders observed are 1st order, 2nd order, and 3rd order. Few streams flow only during monsoon and in other seasons remain dry. The area falls under a sub-tropical climate with temperatures ranging from 170˚C - 280˚C



Map 2. Toposheet map superimposed with boundary demarcation of the study area.

and receives moderate rainfall ranging from 600 - 900 mm annually. The study area reflects the regional metamorphism of upper amphibolite facies. There is marked topographic variation between the ultramafic-mafic sequences and their surrounding basement granite gneiss outcrops in the study area. The ore minerals present in the bedrock mineral assemblages are chromite, magnetite, ilmenite, chalcopyrite, pyrite, Goethite, Sphene, Sphalerite, and negligible traces of Gold and PGEs.

4.2. Sampling

A discrete sampling method has been adopted to collect the samples at the preliminary intersection of two streams at predetermined locations. The tools used for stream sediment sampling are a spade, hand shovel, sieve (2.6 mm), brush, plastic bucket, alluvial pan with riffles, sample covers for sediment sample collection, and vials (25 gm) for storing panned heavy concentrations [2]. 17 sieved sediment samples weighing approximately 1 kg were collected by sieving onsite and 17 raw sediment samples weighing 5 kg were collected for the alluvial panning process to extract heavy concentrations.

The raw sediment samples weighing 5 kg each were panned to extract heavy metals concentration. The raw sediment samples collected during fieldwork were panned using an alluvial panner of 10-inch diameter with coarse and fine riffles, which helped extract heavy metal concentrations of variable sizes. Extracted heavy metals were stored in vials and part was used for the preparation of polished sections. The polished sections prepared from extracted heavy concentrations by the panning process were studied under reflected light microscope.

4.3. Analytical Method

The sieved stream sediment samples weighing 1 kg each were dried at room temperature and kept separately to dry further in a hot air oven for complete moisture removal. To maintain uniform representation the sieved stream sediment sample weighing 1 kg each was reduced to 100 gm approximately by coning and quadrant method and the samples were ground. Before grinding the sieved stream sediments were dried in a hot air oven for an hour @ 180˚C and later cooled in open air condition, and pulverized in a cup mill to obtain the size of −200 mesh. Care has been taken to avoid contamination by cleaning the crushing and grinding surface after every sample is processed in all stages. The powdered samples were used for geochemical analysis to determine selected trace elements by using an ICP-AES spectrophotometer.

The geochemical analytical results of stream sediment samples obtained were statistically treated using the SPSS (statistical package for social sciences) software. Before the detailed statistical analysis, it is desirable to investigate the nature of raw data in exploratory analysis using the descriptive statistics method [11]. Normal frequency distribution for each element data was examined using a histogram, Q-Q plot, Z-Test, and Shapiro-Wilk test. For a sample size of less than 50, the Z-Test and Shapiro-Wilk test is used to detect non-normality [14]. The data was found to be nonnormal. The raw data were normalized using the natural log-transformation method [11]. To determine the inter-element relationship and element groups the natural log-transformed data were processed employing factor analysis using the varimax rotation method [3] [4] [9] [15].

Spatial analysis of the stream sediment analytical data was carried out to identify trends and patterns in the geochemical parameters. The interpolation method was used to create the inverse distance weighting (IDW) map in ArcGIS software, to understand the distribution of the geochemical parameters across the study area.

5. Discussion and Result

5.1. Reflected Light Microscopic Study of Panned Concentrates

To understand the relationship between the mineral composition of the heavies and their chemical relationship, they were studied microscopically, by preparing polished sections. Panned heavy concentrates obtained are of variable sizes ranging from less than 1 mm to 0.5 cm. Most panned heavy mineral concentrations appear oxidized with little relics of fresh surfaces. Under a reflected light microscope, chromite, magnetite, ilmenite, goethite, sphalerite, and sulfide specs were observed. Detrital magnetite grains are exhibiting subangular to subrounded shapes and pitted nature due to weathering. Due to the oxidation process during weathering, ilmenite is replacing magnetite, and a few magnetites are completely altered to goethite (**Figures 1-3**).

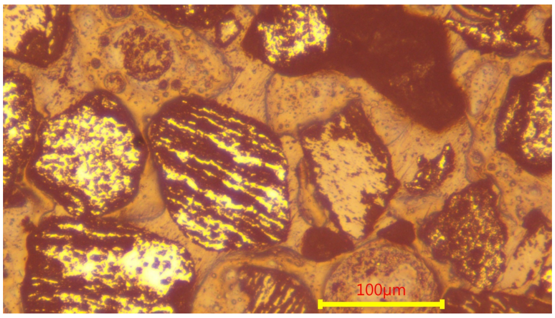


Figure 1. Sub-angular to rounded magnetite grains.

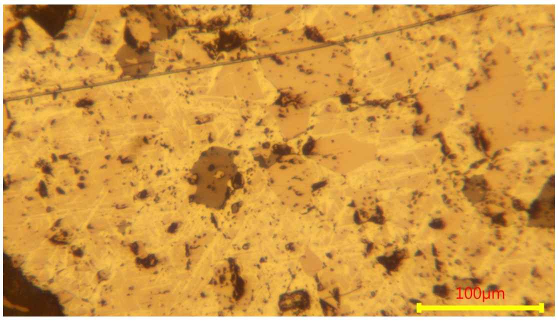


Figure 2. Titanomagnetite with exsolution of ilmenite, goethite and martitisation can be seen.

Detrital chromite grains are subhedral in shape and resistant to oxidation. The intense disintegration of chromite grains is observed resembling break apart texture which indicates the detrital transportation and martitisation could be noticed on its surface indicating the partial oxidization process (**Figure 4** and **Figure 5**).

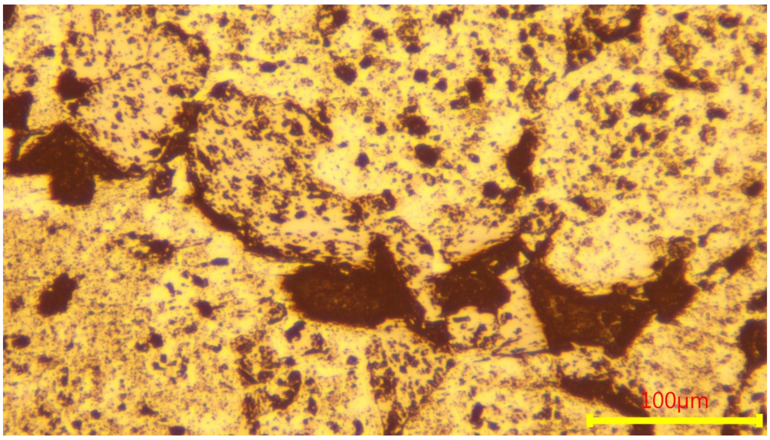


Figure 3. Magnetite replaced by hematite.

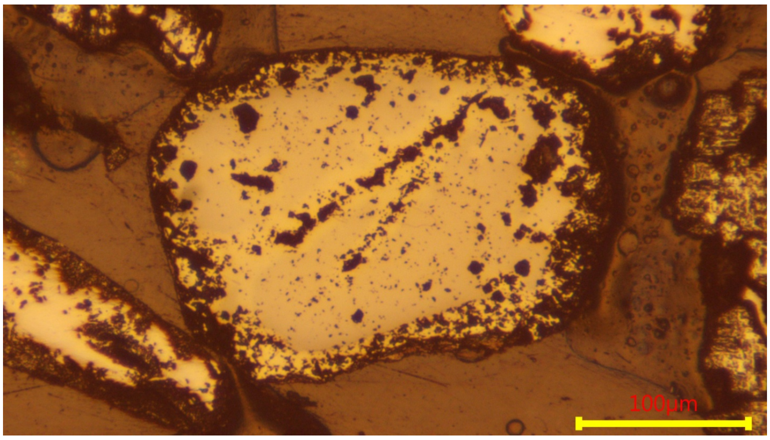


Figure 4. Sub-rounded chromite.

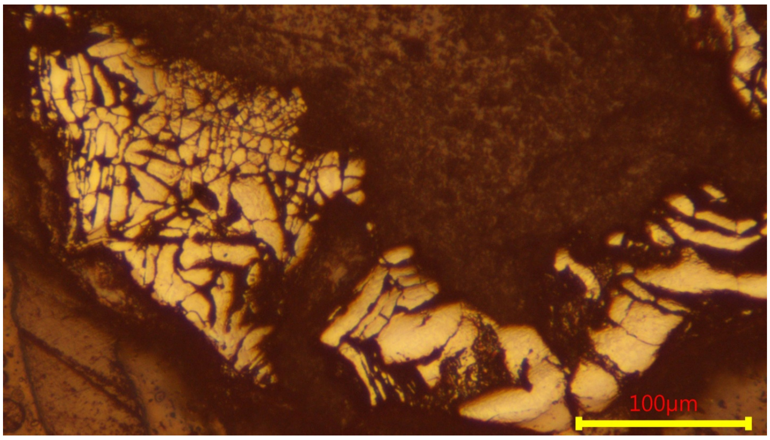


Figure 5. Break apart texture in chromite.

5.2. Statistical Analysis

Basic statistical parameters determined from stream sediment geochemical data are reported in (**Table 1**). The histogram plot and Q-Q plot of raw data show positive skewness and Normality test results strongly suggest that the distribution of the raw data is non-normal (**Table 2**). The raw data were transformed using the natural log transformation method in SPSS software and the normality test result for transformed data appears to be normalized (**Table 3**). Histogram and Q-Q plots for transformed data show no skewness and are nearly symmetric, indicating that the distribution of elements is log-normal. Examples of two sets of histogram plots (**Figure 6** and **Figure 7**) and Q-Q plots for raw data and transformed data are presented (**Figure 8** and **Figure 9**).

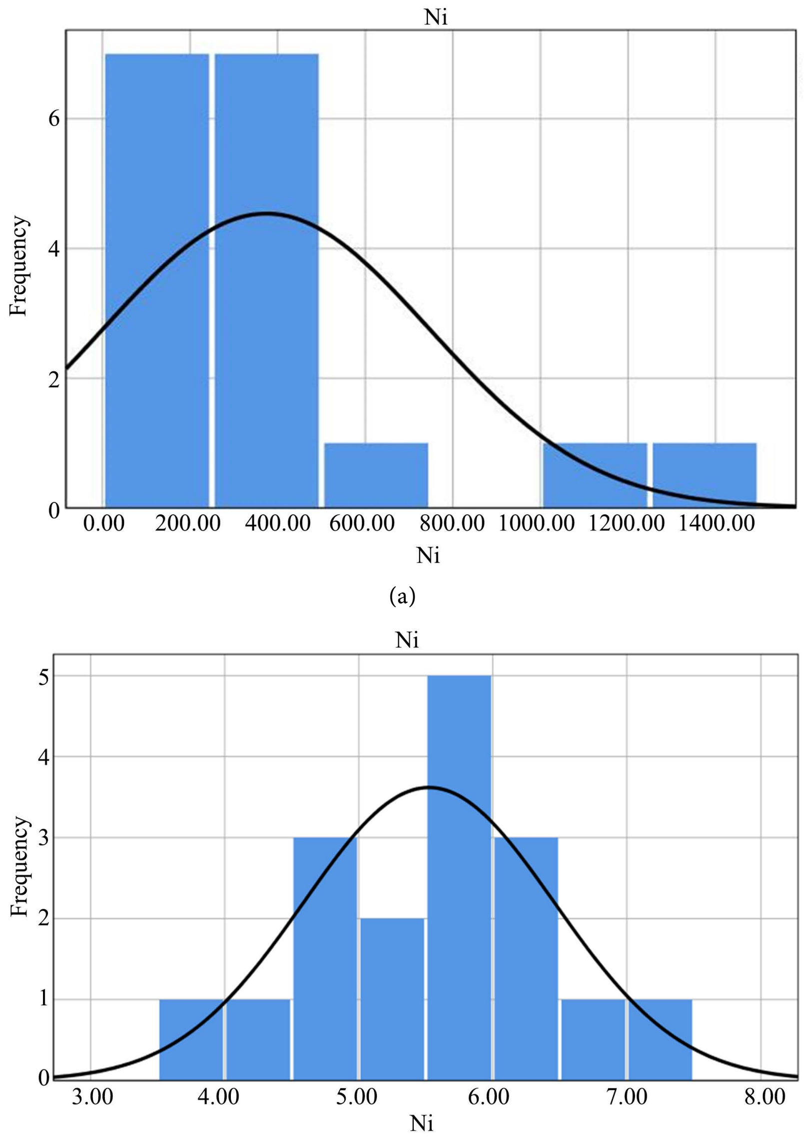


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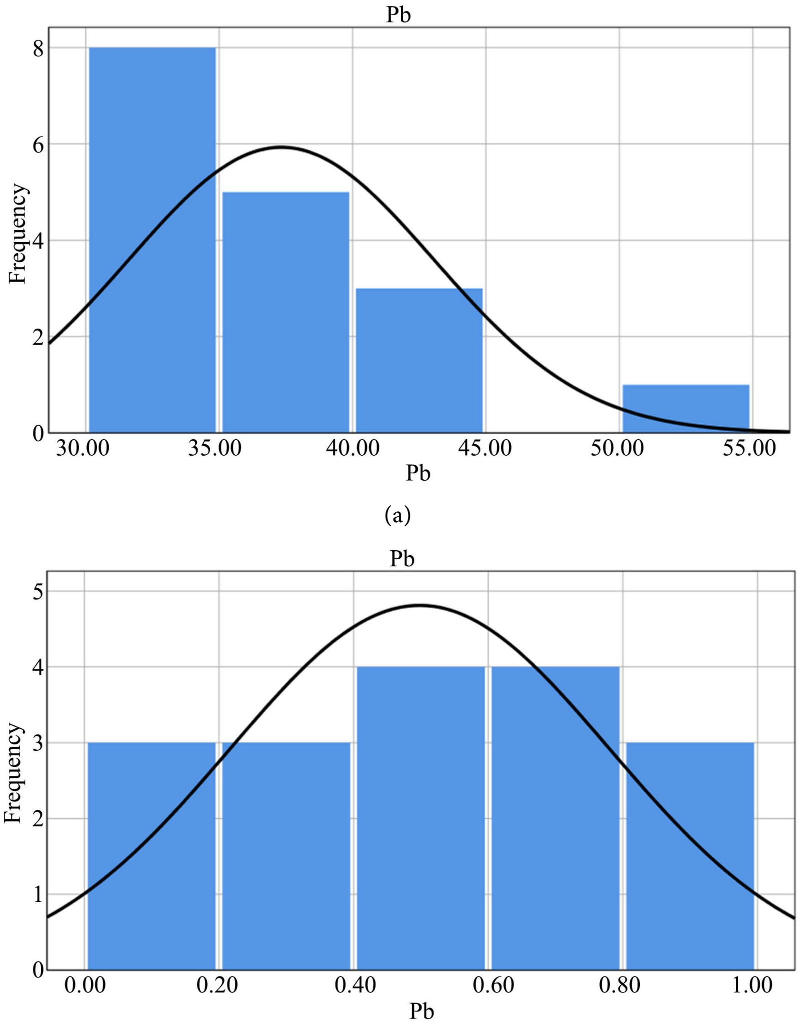
Figure 6. (a) Normal frequency distribution of Ni, and (b) Natural log transformed the distribution of Ni.



(a)

(b)

Figure 7. (a) Normal frequency distribution of Pb, and (b) Natural log transformed frequency distribution of Pb.

Pearson Correlation analysis was performed for natural log-transformed data (**Table 4**). The correlation matrices reveal a wide variation in a correlation coefficient (r), ranging from −0.494 between Pb and As to 0.909 between Cd and Fe. Most of the element pairs show a positive correlation except Pb which expresses a negative to negligible correlation. Ni shows a moderate correlation with Mn, Cr, and As, a weak correlation with Cd, Zn, V, and Fe, and a negligible correlation with Cu and Ti. Pb shows negligible correlation with Ti and Cd. Similarly, other element pairs with positive correlation ranging from strong to weak correlation are Cd-(Fe, Zn, Cu, Ti, Cr, As, V, Mn), Mn-(Cr, Fe, V, Zn, As, Ti, Cu), Cu-(Fe, Zn, Cr, Ti, As, V), Zn-(Fe, Ti, As, Cr, V), Cr-(V, As, Fe, Ti), Ti-(Fe, As, V), V-Fe-As, and Fe-As. This wide variety of paired element associations could probably reflect the heterogeneous nature of the underlying geology, environmental influence, and the presence of mineralization in the study area [4] [9].

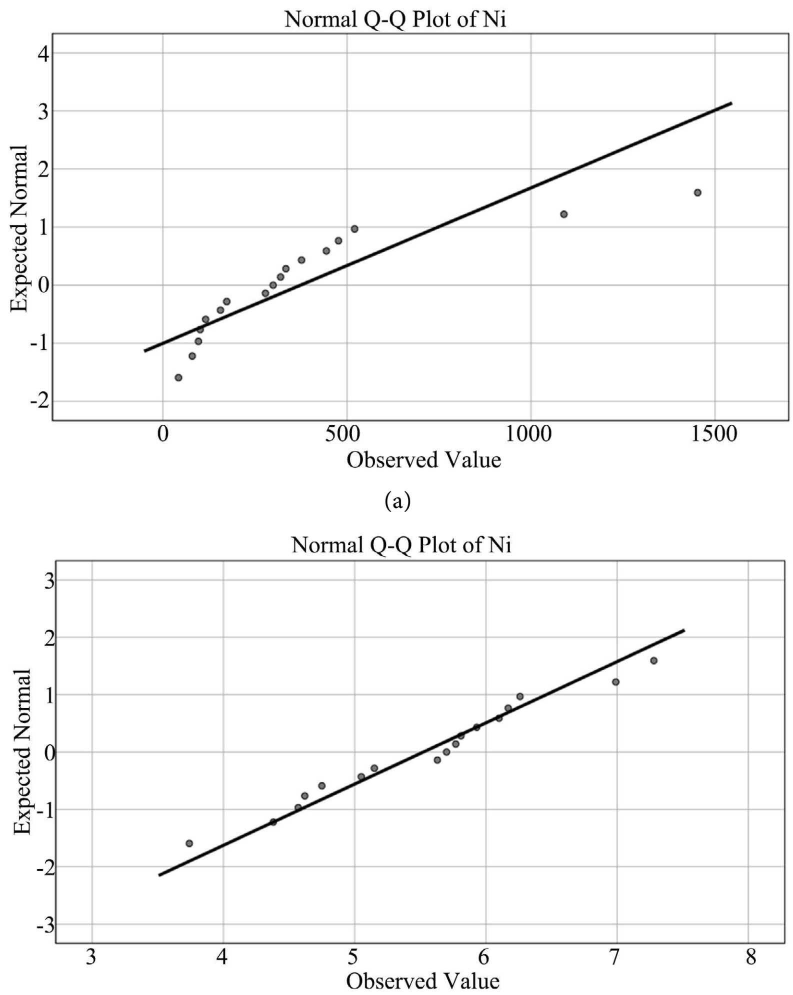
Table 2. Descriptive statistics summary of raw geochemical data of stream sediment samples.

Descriptive Statistics of Raw Data									
Variables	Mean	Std. Error	Std. Deviation	Skewness	Kurtosis	Z-Test		Shapiro-Wilk	
						Skewness	Kurtosis	Statistic	p-value
Ni	373.874	90.620	373.634	2.017	4.080	3.667	3.838	0.758	0.001
Pb	37.330	1.387	5.718	1.670	3.372	3.036	3.172	0.846	0.009
Cd	1.575	0.063	0.260	0.277	−0.706	0.504	−0.664	0.943	0.350
Mn	1213.000	169.022	696.896	0.690	1.338	1.255	1.259	0.910	0.100
Cu	64.154	12.208	50.334	2.217	6.248	4.031	5.878	0.785	0.001
Zn	56.409	6.052	24.955	0.816	−0.073	1.484	−0.069	0.915	0.120
Cr	1172.891	352.242	1452.331	2.070	4.406	3.764	4.145	0.719	0.000
Ti	578.083	61.916	255.286	1.021	0.200	1.856	0.188	0.896	0.058
V	61.139	5.855	24.141	0.924	1.783	1.680	1.677	0.936	0.273
Fe	72065.855	11702.250	48249.612	1.919	4.478	3.489	4.213	0.816	0.003
As	4.823	0.883	3.639	0.615	−0.667	1.118	−0.627	0.914	0.118

Table 3. Descriptive statistics summary of natural log-transformed geochemical data of stream sediment samples.

Descriptive Statistics of Natural Log-Transformed Data									
Variables	Mean	Std. Error	Std. Deviation	Skewness	Kurtosis	Z-Test		Shapiro-Wilk	
						Skewness	Kurtosis	Statistic	p-value
Ni	5.524	0.22732	0.937	0.013	−0.292	0.024	−0.275	0.978	0.931
Pb	0.498	0.06839	0.282	−0.106	−0.656	−0.193	−0.617	0.986	0.993
Cd	0.443	0.04026	0.166	−0.022	−0.666	−0.040	−0.627	0.952	0.490
Mn	0.498	0.06839	0.282	−0.106	−0.656	−0.193	−0.617	0.986	0.993
Cu	3.930	0.16937	0.698	0.118	0.113	0.215	0.106	0.981	0.968
Zn	3.942	0.10676	0.440	−0.010	−0.548	−0.018	−0.516	0.962	0.662
Cr	6.468	0.26747	1.103	0.541	−0.926	0.984	−0.871	0.922	0.158
Ti	6.786	0.1014	0.418	0.343	−0.617	0.624	−0.580	0.966	0.744
V	61.139	5.85513	24.141	0.924	1.783	1.680	1.677	0.936	0.273
Fe	11.016	0.14248	0.587	0.372	−0.017	0.676	−0.016	0.977	0.919
As	1.226	0.22531	0.929	−0.309	−1.425	−0.562	−1.341	0.915	0.119

Factor analysis is a multivariate statistical dimension reduction technique that helps to classify data and examines relationships between variables based on their mutual correlation coefficients. KMO and Bartlett's test result values satisfy that our data is appropriate to proceed further with Factor analysis (**Table 5**).



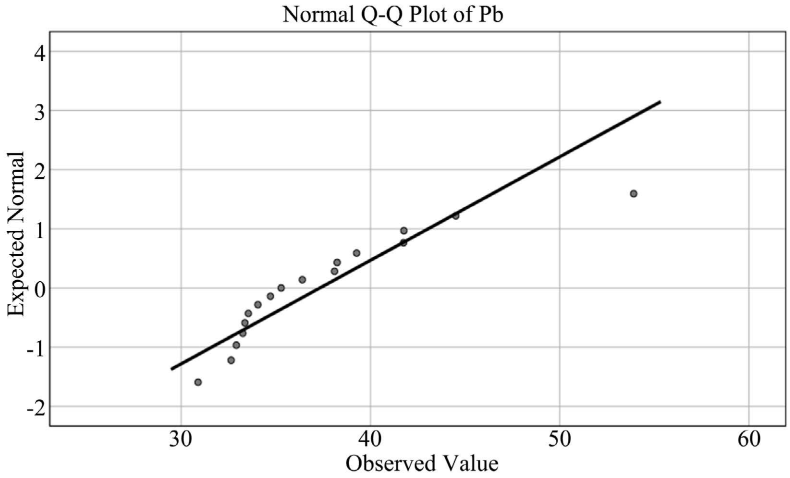
(a)

(b)

Figure 8. (a) Q-Q plot for raw data of Ni, and (b) Q-Q plot for natural log transformed data of Ni.

Table 4. Pearson correlation matrix for natural log-transformed geochemical data of stream sediment sample

Variables	Ni	Pb	Cd	Mn	Cu	Zn	Cr	TiO_2	V	Fe	As
Ni	1	−0.279	0.324	0.565	0.191	0.428	0.650	0.247	0.410	0.390	0.557
Pb	−0.279	1	0.001	−0.069	−0.146	−0.152	−0.127	0.133	−0.090	−0.236	−0.494
Cd	0.324	0.001	1	0.306	0.806	0.878	0.554	0.659	0.344	0.909	0.419
Mn	0.565	−0.069	0.306	1	0.190	0.324	0.461	0.251	0.397	0.430	0.302
Cu	0.191	−0.146	0.806	0.190	1	0.725	0.398	0.388	0.146	0.824	0.307
Zn	0.428	−0.152	0.878	0.324	0.725	1	0.616	0.738	0.371	0.854	0.619
Cr	0.650	−0.127	0.554	0.461	0.398	0.616	1	0.540	0.658	0.611	0.623
TiO_2	0.247	0.133	0.659	0.251	0.388	0.738	0.540	1	0.398	0.618	0.555
V	0.410	−0.090	0.344	0.397	0.146	0.371	0.658	0.398	1	0.547	0.296
Fe	0.390	−0.236	0.909	0.430	0.824	0.854	0.611	0.618	0.547	1	0.485
As	0.557	−0.494	0.419	0.302	0.307	0.619	0.623	0.555	0.296	0.485	1



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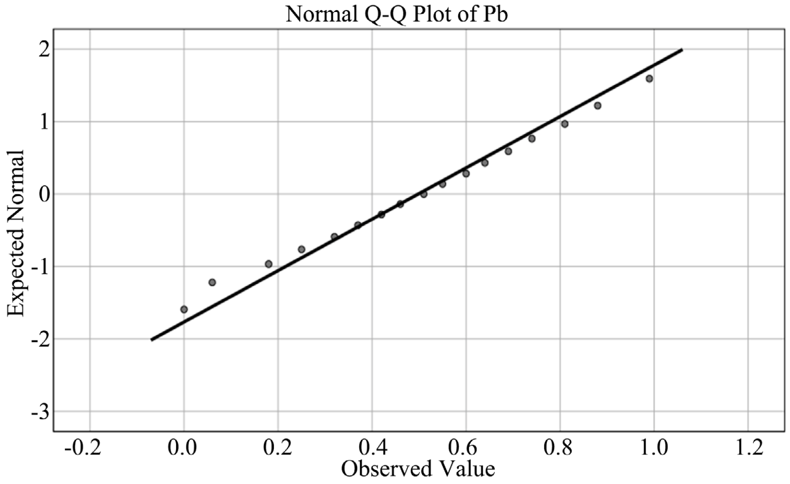


(b)

Figure 9. (a) Q-Q plot for raw data of Pb, and (b) Q-Q plot for natural log transformed data of Pb.

Table 5. KMO and Bartlett's test result for natural log-transformed data.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**0.609**
Bartlett's Test of Sphericity	Approx. Chi-Square	132.508
	df	55
	Sig.	0

Factor analysis was applied to the natural log-transformed stream sediment geochemical data with varimax rotation. The factor analysis yielded three rotated component factors with eigenvalues greater than 1, accounting for 77.15% of the total variance of the dataset (**Table 6**), which was extracted based on a scree plot (**Figure 10**). To improve the clarity of factor variables absolute values lesser than 0.25 are omitted in factor loading values.

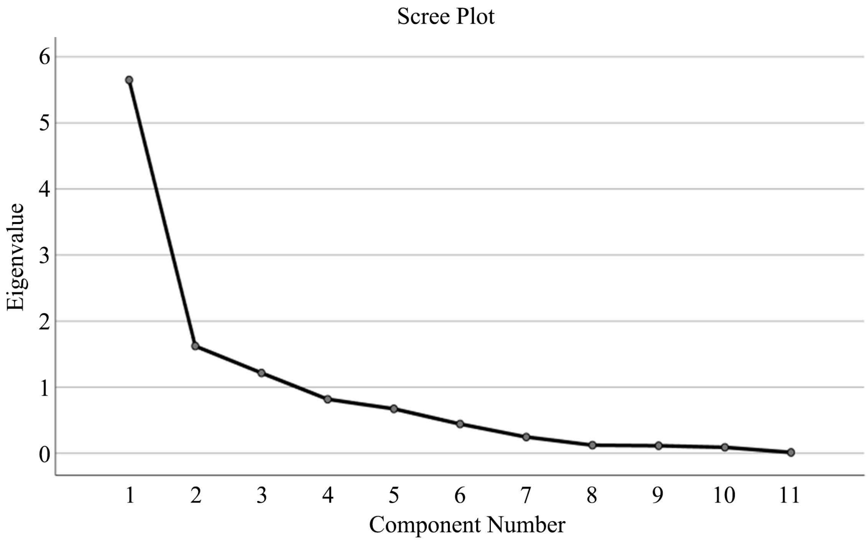


Figure 10. Scree plot of eigenvalues based on factor analysis.

Table 6. Rotated component factor matrix for natural log-transformed stream sediment data.

Rotated Component Matrix				
Variables	**Factor 1**	**Factor 2**	**Factor 3**	**Communality**
Ni		**0.756**	0.380	**0.728**
Pb			**−0.947**	**0.897**
Cd	**0.934**			**0.924**
Mn		**0.732**		**0.551**
Cu	**0.884**			**0.809**
Zn	**0.877**	0.316		**0.898**
Cr	0.428	**0.762**		**0.784**
Ti	**0.688**	0.393		**0.65**
V		**0.752**		**0.616**
Fe	**0.868**	0.350		**0.904**
As	0.390	0.453	**0.607**	**0.725**
Eigen Values	**5.649**	**1.622**	**1.215**	
Total Variance Percentage	**51.357**	**14.357**	**11.047**	
Cumulative Percentage	51.357	66.106	**77.153**	

Factor 1: Cd, Fe, Cu, Zn, Ti, Cr, As

This factor explains 51.357% of the variance and is interpreted as the siderophile and chalcophile association. It represents the enrichment of metals in the stream sediment samples. A strong positive correlation between Fe to Cd, Zn, Cu, and Zn to Cd, Ti, and Cu indicates the scavenging activity of hydrous Fe oxides [4]. Strong positive correlation between Cd to Cu indicates that Cd probably occurs as a substitute for Cu and Ferrous hydroxides are known to adsorb cd [16].

Factor 2: Cr, Ni, V, Mn, As, Ti, Fe, Zn

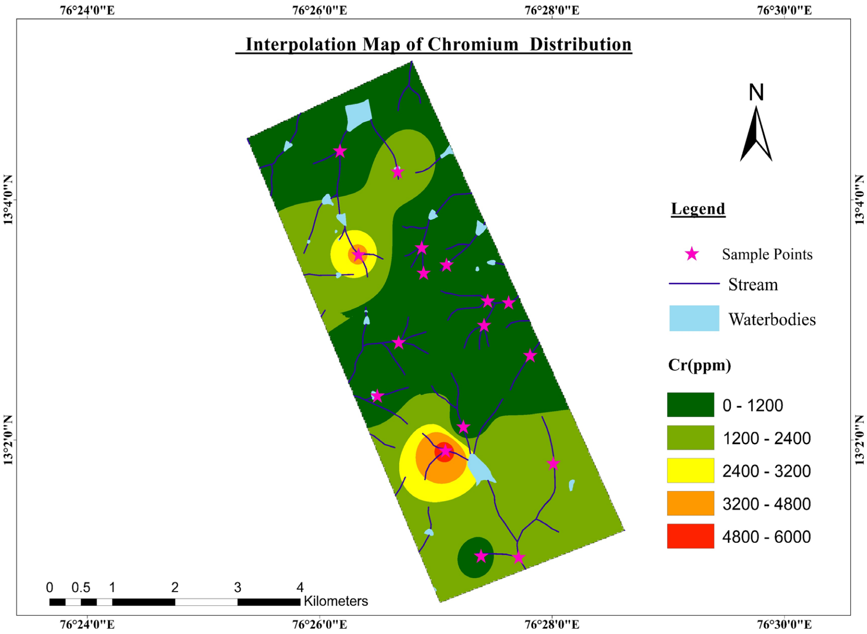
This factor explains 14.749% of the variance. This factor is interpreted as lithogenic elements. These elements are likely derived from the geological composition of the sediments. A good positive correlation between these elements reflects mafic and ultramafic parent rocks in the study area [3] [8]. The association of As with Cr, Ni, Zn, Ti, and Fe probably indicates sulphide mineralization.

Factor 3: Pb, As

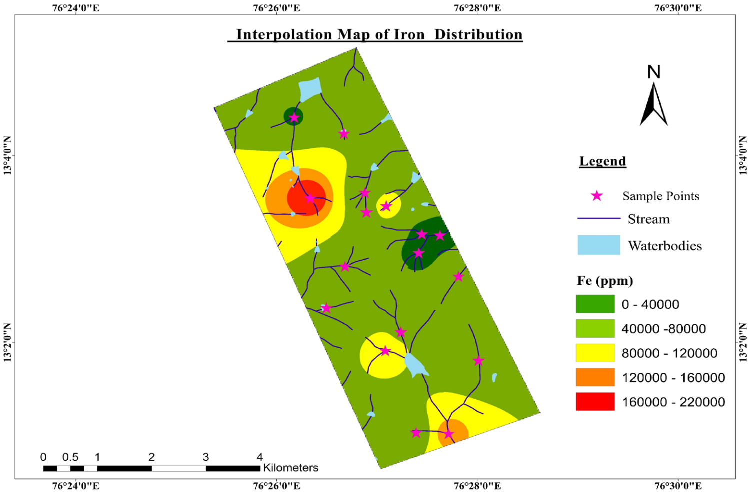
This factor explains 11.047% of the variance and it represents the variation in the lead (strongly negative) and arsenic (moderately positive) levels in the stream sediment samples. These elements may indicate different geochemical processes, possibly related to environmental contamination or pollution.

5.3. Spatial Analysis

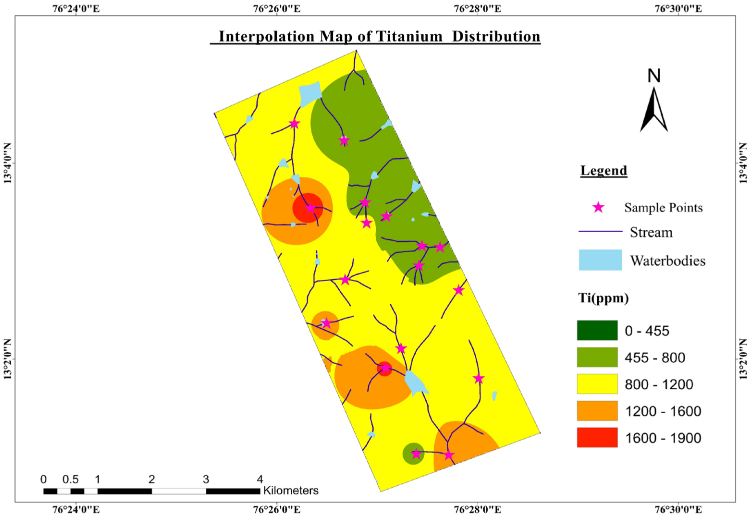
To understand the geochemical distribution and anomalous concentration in stream sediment of the study area for the selected element variables viz.: Fe, Cr, Ti, V, Cu, Ni, Zn, Pb, Mn, Cd, and As, inverse distance weighted (IDW) maps were constructed using the interpolation method in ArcGIS software (**Maps 3-13**). The varied spatial distribution of elements concentration could be seen in IDW maps. The integrated anomalies of Cr, Fe, Ti, V, Cu, Cd, Zn, and As in stream sediments are found close to the source bedrock (mafic and ultramafic) and the dispersion of background concentration could be seen throughout the study area probably due to their less mobility and non-solubility. The Mn and Ni anomalies are occurring in the southern part of streams and Pb concentration is uniformly distributed throughout the study area.



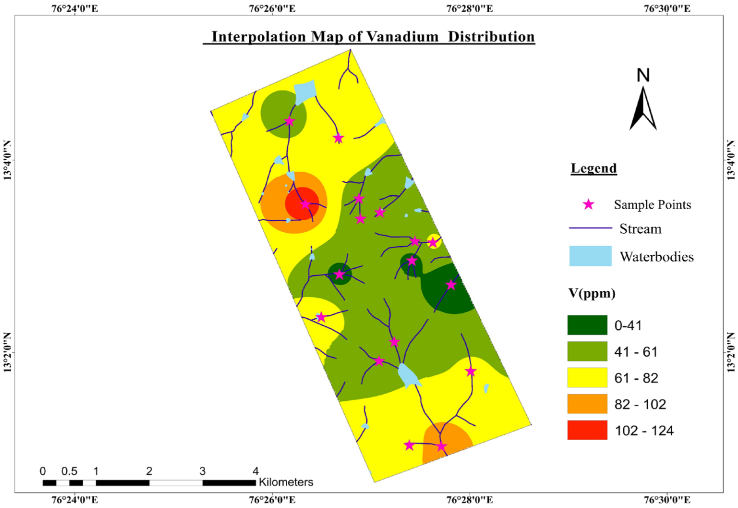
Map 3. IDW interpolation map for Cr distribution in stream sediments of the study area.



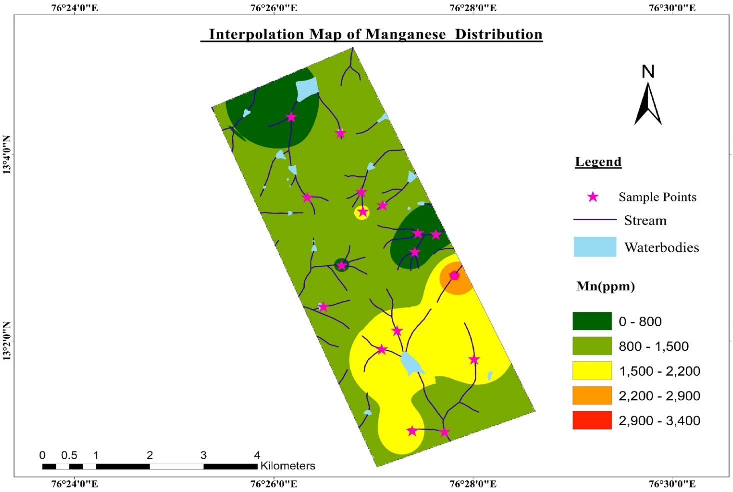
Map 4. IDW interpolation map for Fe distribution in stream sediments of the study area.



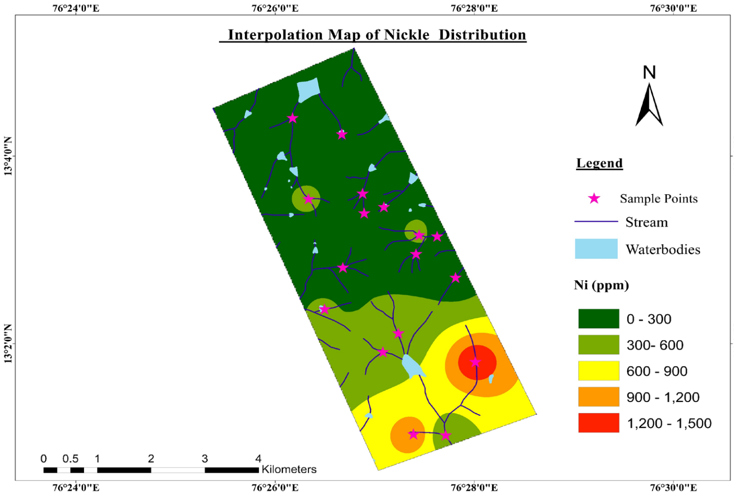
Map 5. IDW interpolation map for Ti distribution in stream sediments of the study area.



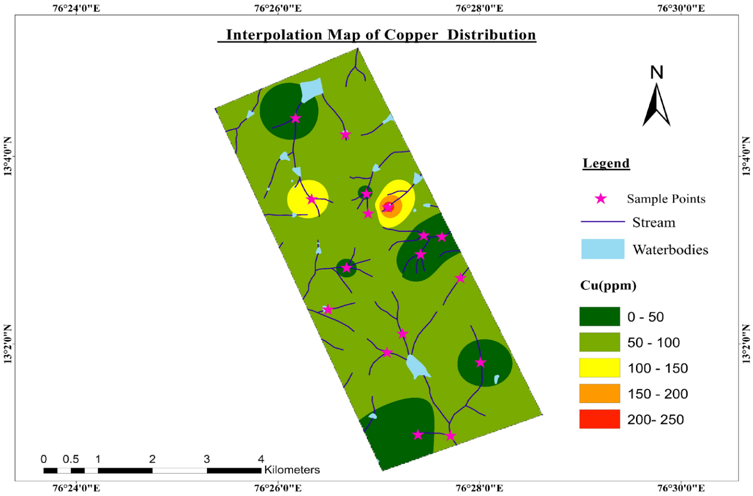
Map 6. DW interpolation map for V distribution in stream sediments of the study area.



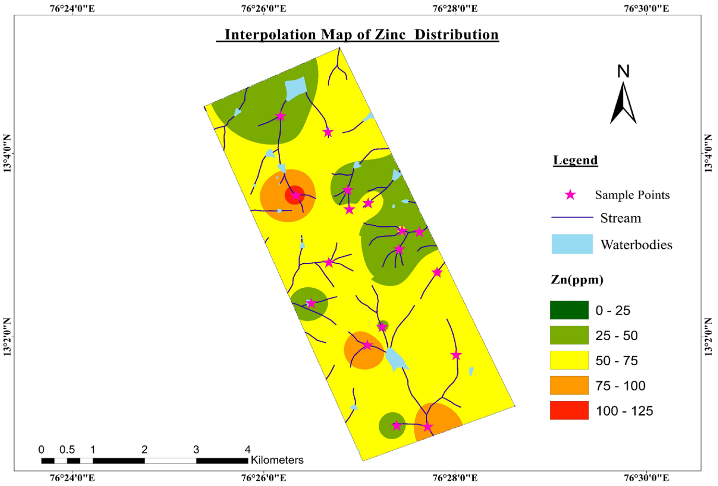
Map 7. IDW interpolation map for Mn distribution in stream sediments of the study area.



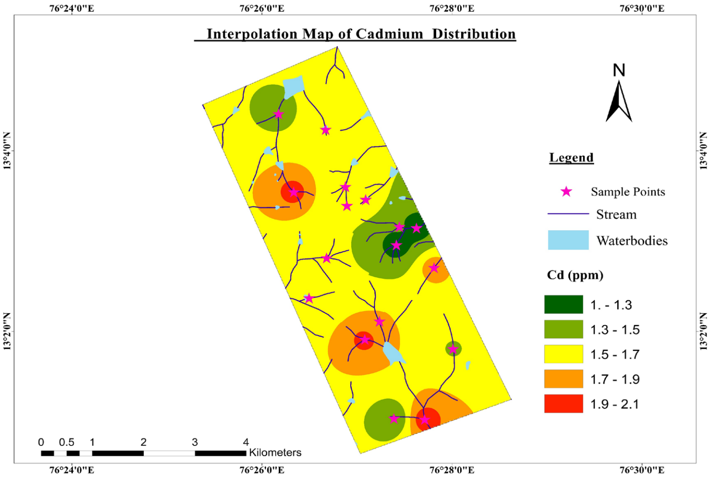
Map 8. DW interpolation map for Ni distribution in stream sediments of the study area.



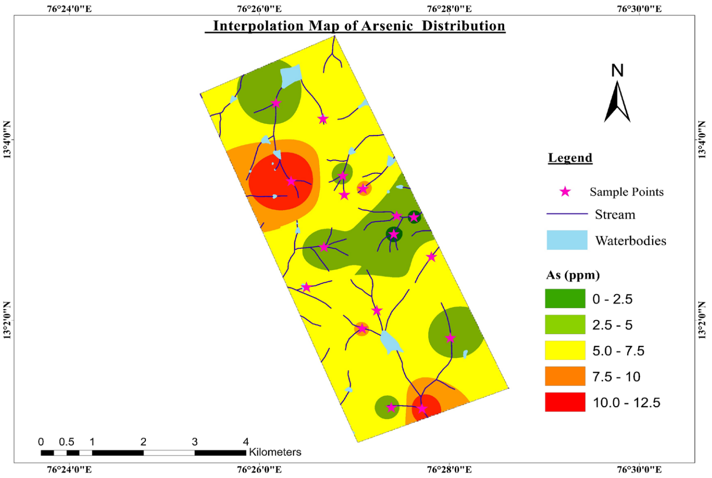
Map 9. IDW interpolation map for Cu distribution in stream sediments of the study area.



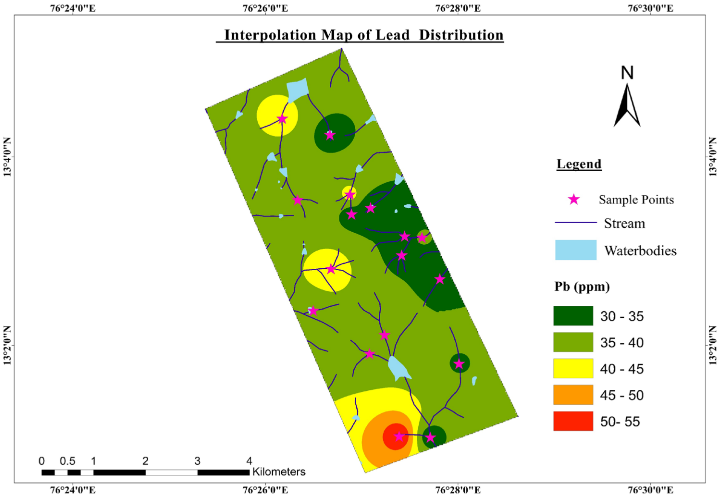
Map 10. IDW interpolation map for Zn distribution in stream sediments of the study area.



Map 11. IDW interpolation map for Cd distribution in stream sediments of the study area.



Map 12. IDW interpolation map for As distribution in stream sediments of the study area.



Map 13. IDW interpolation map for Pb distribution in stream sediments of the study area.

6. Conclusions

In conclusion, this study focused on stream sediment exploration techniques and statistical analysis methods to assess the geochemical characteristics of the Tagadur Ranganathaswamy Gudda and surrounding areas within the Nuggihalli schist belt. The location and physiography of the study area were carefully considered when selecting sample sites, based on a literature study of previous works. The study area exhibited an undulating terrain with radial drainage patterns, and various ore minerals in the bedrock mineral assemblages were noted. The sampling methodology involved discrete sampling at predetermined locations, and both sieved and raw sediment samples were collected for further analysis. The reflected light microscope study of panned heavy mineral concentrates provided insights into the mineralization processes and revealed the ore minerals such as chromite, magnetite, ilmenite, goethite, sphalerite, and sulfide specs indicating varying degrees of oxidation weathering characteristics. Stream sediment geochemical data represents both compositional data and spatial data.

The statistical analyses provided insights into the inter-element relationships, element groups, and underlying geological influences. The stream sediment geochemical data were found to be non-normal and were subsequently transformed using the natural log transformation method to normalize. Pearson correlation analysis revealed various inter-element relationships, with some elements exhibiting strong positive correlations, while others showed negligible or negative correlations indicating the influence of the heterogeneous nature of the geology and potential mineralization in the area. Factor analysis was employed to classify the data and examine the inter-element relationships. Factor analysis yielded three rotated component factors contributing to understanding the geochemical processes and their implications for bedrock mineralization. Factor 1 relates to metal enrichment (Cd, Fe, Cu, Zn, Ti, Cr, As) representing siderophile and chalcophile associations, Factor 2 relates to lithogenic elements (Cr, Ni, V, Mn, As, Ti, Fe, Zn) affiliating underlying geology and Factor 3 relates to the distribution of Pb and certain As implicating secondary dispersion due to environmental factors. The element associations identified in this study are related to the underlying geology (Mafic and Ultramafic rocks) and mineralization.

The spatial analysis was performed using interpolation techniques to identify trends and patterns in the geochemical parameters across the study area. Inverse distance weighting (IDW) maps are indicating the spatial variations and anomalous concentrations of the elements. In oxidizing environments, the distribution of selected trace elements appears to be immobile to low mobile due to the coprecipitation controlled by adsorption with Fe-oxides and Mn-oxides. Anomalies of certain elements are found to be distributed near the source bedrocks, Ultramafic-mafic sequences (Cr-Ni-Fe: Peridotites, Serpentinites, Chromitite, and Fe-Ti-V-Mn: Vanadium Titano magnetite, Gabbro, Pyroxenites) and the other elements Cu, Cd, Zn, Pb and As exhibiting more uniform distribution throughout the study area indicating the associated minor sulfide mineralization in the bedrocks as a magmatically derived fraction or as sporadic remobilized epigenetic concentrations.

Overall, this work contributes to a better understanding of the geochemical processes, underlying geology, potential mineralization, and environmental influences in the Tagadur Ranganathaswamy Gudda area. These findings serve as a valuable resource for future mineral exploration and could provide insights for further studies in geochemical prospecting.

Acknowledgements

We thank KSMCL (Karnataka State Mineral Corporation Limited) for permitting us to carry out fieldwork in their Lease area. We also thank Mr. Sagar D. N. and Mr. Madan G. for assisting during our fieldwork, Mr. Karthik S. is thanked for extending support in geochemical analysis.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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