GEOCHEMICAL ANALYSIS OF STREAM SEDIMENTS IN PART OF GIDA KWANO CAMPUS, FUT, MINNA (ZUNGERU SHEET 163SE)

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ABSTRACT

This geochemical study analyzes ten stream sediment samples from the Gidan Kwano area in Minna (Zungeru Sheet 163SE), located in North-Central Nigeria, to evaluate the region's geological history, mineral potential, and environmental characteristics. Geological mapping identified three distinct rock units: granite, granitoid, and diorite. Using X-ray fluorescence (XRF) analysis, the study determined the distribution and abundance of major oxides and trace elements to establish an exploration baseline. Statistical evaluations of average elemental concentrations revealed distinct patterns of enrichment and depletion. Notably, the area shows significant enrichment in trace elements, including cobalt (148.5 ppm), cadmium (7.8 ppm), molybdenum (6.8 ppm), tungsten (5 ppm), and gold (0.08 ppm). These elevated concentrations indicate strong potential for localized mineralization, making the region a promising site for further investigation and artisanal-scale mineral exploration. In terms of major oxides, the sediment composition is dominated by high levels of silica (SiO_2) and iron oxide (Fe_2O_3), reflecting a highly siliceous and iron-rich provenance. Conversely, low concentrations of calcium oxide (CaO), magnesium oxide (MgO), titanium oxide (TiO_2), and alumina (Al_2O_3) indicate minimal input from carbonate or feldspar-rich source rocks. Furthermore, elevated levels of phosphorus pentoxide (P_2O_5) and sulfur trioxide (SO_3) suggest either localized mineralization or anthropogenic influences. Ultimately, the geochemical data demonstrate that these stream sediments are shaped by a combination of natural weathering and economic mineralization, providing critical insights into trace element mobility for future exploration.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Stream sediments are integral components of fluvial systems, formed through a variety of geological processes that involve the erosion and transportation of rock fragments and minerals by flowing water. The processes of stream sediment formation can be categorized into physical, chemical, and biological weathering (Caracciolo, 2020). Physical processes of stream sediment formation include abrasion, which occurs when rock fragments are carried by water and collide with each other, breaking them into smaller particles (Allen, 2012). Minerals within the rocks may undergo dissolution or alteration when exposed to water, resulting in the release of ions and the formation of secondary minerals (Putnis & Ruiz-Agudo, 2013). Biological weathering of stream sediment involves the action of organisms such as plant roots, fungi, and bacteria, which break down rock fragments and minerals through processes like root wedging and organic acid production, contributing to the physical and chemical alteration of sediments (Nayak et al., 2023).

High enrichment factors for certain heavy metals in stream sediment can indicate significant inputs from anthropogenic activities, mining operations, or urban runoff (Sutherland, 2000). To establish these thresholds accurately, regional baseline grids rely on large-scale sampling cells across the North-Central province (Lapworth et al., 2012), providing a structural framework for localized drainage analysis. In Nigeria, studies on enrichment factors have focused on areas with known anthropogenic activities such as mining, oil exploration, and industrialization (Amadi et al., 2012; Waziri, 2014; Owhoeke et al., 2023).

As stream sediments are transported downstream by the flow of water, they undergo sorting and deposition based on their size, shape, and density. Graded bedding, cross-bedding, and channel bar deposits are common features observed in stream sedimentary environments (Bjørlykke, 2015). The depositional processes within streams are influenced by flow dynamics, sediment dynamics, sediment supply, and channel morphology. Human activities such as agriculture, mining, and urbanization can also contribute to the formation of stream sediment by increasing erosion rates and altering water flow in stream channels, resulting in channel aggradation and downstream impacts on aquatic ecosystems (Vietz & Finlayson, 2017). Understanding the processes that govern the formation of stream sediments is important for studying the geological history of an area, managing mineral resources, and mitigating environmental impacts (Caracciolo, 2020).

Nigerian researchers such as Biswas et al. (2020) in their study of upland regions have highlighted the significance of physical weathering processes in the formation of stream sediments. Erosion of granite and gneissic rock through mechanical weathering contributes to the supply of coarse-grained sediments that characterize many river systems. The impact of intense rainfall events and steep topography in triggering mass wasting processes underscores the dynamic nature of sediment production in Nigeria's upland terrains. Studies of the weathering of basement rocks in Nigeria have shed light on the role of chemical weathering in sediment formation (Adepoju et al., 2022). The alteration of minerals such as feldspar and quartz under tropical weathering conditions produces clay minerals and soluble ions that contribute to the composition of stream sediments in Nigeria (Ayodele, 2016).

Furthermore, researchers have explored the influence of biological weathering agents on stream sediment formation within tropical ecosystems (Nayak et al., 2023). The activities of plants, roots, termites, and microbial communities play a crucial role in the breakdown of rocks and the release of nutrients and organic matter into streams. Sediment transport dynamics in Nigerian rivers highlight complex patterns of sediment deposition and erosion in response to varying flow regimes. The seasonal variability of rainfall and discharge rates influences sediment transport capacity and the distribution of deposits along river channels (Lawal & Omosanya, 2023).

The enrichment factor of stream sediments is a widely used method in geochemistry to assess the degree of contamination or enrichment of metals in sediment samples compared to baseline levels. The enrichment factor is calculated by comparing the concentration of a particular metal in a sediment sample to a reference or immobile element, normalized to a background value to determine if the metal is enriched, depleted, or at background level (Waziri, 2014). Studies have shown that stream sediments serve as effective indicators of metal contamination. High enrichment factors for certain heavy metals in stream sediment can indicate significant inputs from anthropogenic activities, mining operations, or urban runoff (Sutherland, 2000). In Nigeria, studies on enrichment factors have focused on areas with known anthropogenic activities such as mining, oil exploration, and industrialization (Amadi et al., 2012; Waziri, 2014; Owhoeke et al., 2023).

1.2 Statement of the Research Problem

The stream sediments within the vicinity of the Federal University of Technology, Minna (Gidan Kwano campus) are of high geochemical interest due to their potential for mineral exploration and environmental baseline assessment. However, there is a lack of comprehensive, systematic studies on the trace element geochemistry of these sediments and the environmental implications of the metals they contain, particularly in relation to identifying sources, distribution, and potential impacts. This research addresses these gaps to enhance the understanding of stream sediment enrichment in relation to economic minerals.

1.3 Significance of the Study

This research contributes to the baseline geochemical knowledge of stream sediments in the Gidan Kwano area of Niger State. By analyzing the geochemistry of stream sediments on campus, areas with potential for localized mineral deposits can be targeted to guide future exploration.
Additionally, this work provides valuable information about environmental management, tracking the natural baseline or potential anthropogenic dispersion of trace elements, which is essential for sustainable development and environmental health risk monitoring in the university ecosystem.

1.4 Aim and Objectives of the Study

The principal aim of this research project is to evaluate the economic mineral potential and environmental baseline of the stream sediments within the vicinity of the Federal University of Technology, Minna. The specific objectives are:

- Conduct geological field mapping of part of the Federal University of Technology, Minna on a scale of 1:12,500.
- Collect stream sediment samples systematically along active channel stretches using a hand trowel.

- Carry out geochemical analysis using X-ray Fluorescence (XRF) spectrometry to unravel the elemental composition of the sediments.
- Evaluate the economic potential and enrichment parameters of the stream sediments using the analytical results.

1.5 Scope of Work and Limitation

The scope of this research project is limited to geochemical information of part of Federal University Technology Minna campus (Gidan kwano) is to evaluate the economic mineral composition of the stream sediment using X-ray Fluorescence (X-RF) technique and obtain the enrichment factor of the elemental composition of the stream sediment. The area mapped on a scale of 1:12500 detailed geochemical sampling was carried out using geological compass clinometers, hand trowel, and Global Positioning System (GPS). The mapping exercise involved labelling of the fresh stream sediment sample collected from different locations and outcrops and the location of each points on the stream where the sediments were collected, is located in the field using the topographic map and aid in obtaining the geochemical data of the area.

1.6. Study Area

The rocks in the study area belong to the part of the central portion of the Nigerian basement complex. Area comprises of metasediment rocks which have undergone deformation. These rocks is believed to have been intruded by granitic rocks of Pan-African age. Granitic rocks dominate the rock types in the area and vary in texture and composition; there is small presence of pegmatite intrusion. The study area is located between 9º 32’ 00’’ N and 9º 34’00’’N latitude and 6º26’ 00’’ N and 6º 28’ 00’’ E longitude. Most of the outcrops found are mainly granitic rock type. It is within the North-central portion of the Nigeria basement complex (Figure 1.1).

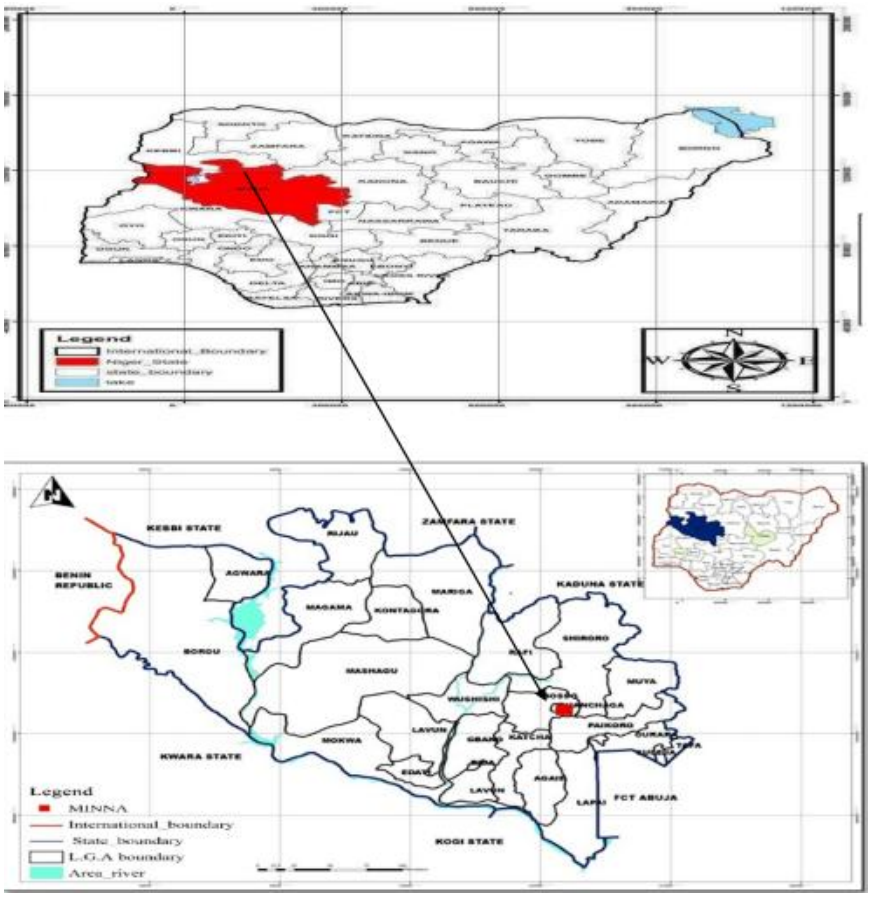


Figure 1.1: Map of Nigeria and Niger state highlighting the study area (Oguh Collins, 2020)

1.6.1 Location, Extent and Accessibility

The study area lies within the vicinity of Federal University of Technology, Minna campus (Gidan kwano) is situated in Chanchaga Local Government area of Niger State. It is bounded within latitude 9º 32’ 00”N and 9º 34’ 00”N and 6º 26’00”E and 6º 28’ 00”E.

The mapped area is on a scale of 1:12500 and has area extent of 3km by 3km. The mapped area is accessible through a major road (Minna-Bida Road) traversing the area from North to south and also accessible through minor road (Figure i.2) within developed area of the school. Also because of the school building and farmlands in the area, there are numerous footpaths. It was difficult for me to access the entire area as it is still bushy, nonetheless with the footpaths.

TOPOGRAPHICAL MAP OF PART OF ZUNGERU SHEET 163 SE

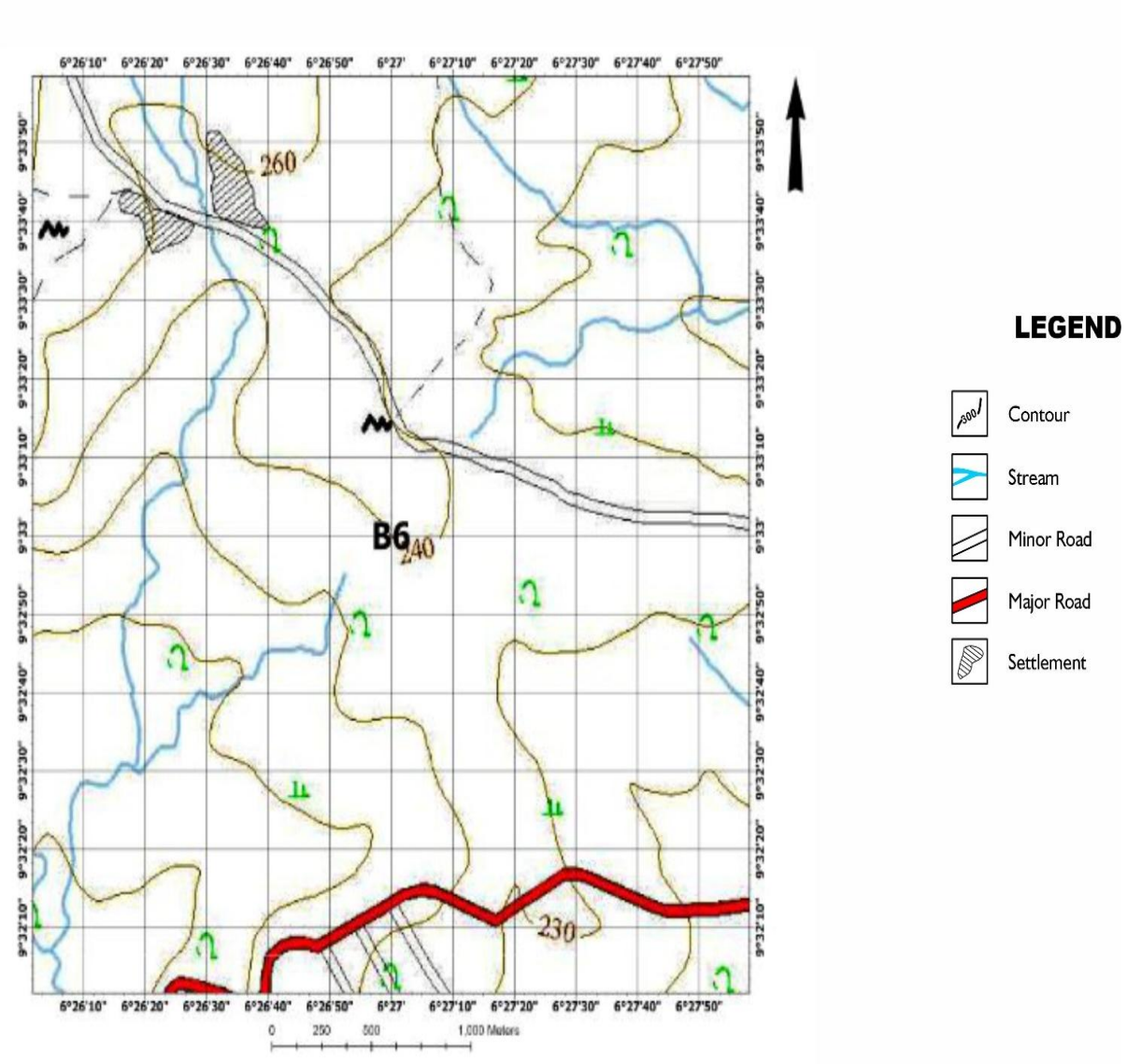


Figure 1.2: Topographical map of the study area

1.6.2 Relief and Drainage

The study area is made up of long extensive ridges as well as plain lands. The ridge was either steeply or mapped elevated, and are randomly located throughout the entire area. The ridges are composed of granitic rock having being weathered mechanically and biologically, this gives rise to displaced joints, boulders and faults

1.6.3 Climate and Vegetation

The mapped area received a total annual rainfall of about 1,200mm-1,334mm and and spread over the month of April to October. The highest amount of rainfall is recorded in August and temperature rarely falls below 22ºC. The average annual temperature is between 33ºC to 40ºC in March and lowest in August at about 25ºC (Edoga and Suzzy, 2008).

The Vegetation of area is characterized by patches of woodland long grasses in river valleys and long extensive ridges, the transition type and forest zone in the guinea south and the savannah type in the north.

1.6.4 Land Use

The area mapped is the permanent site where the university in resettles, where high builds (Senate building, ICT, Engineering, Environmental, Agriculture, and School of physical science) and some portion of the campus is mused in cultivation by the School of Agric and Agricultural extension (SAAT) practical. Some other part of the study area is also used as farmland for cultivating yam, rice, and maize by people from the neighboring village

1.6.5 Geology of the Study Area

Minna, Niger State is located between Lat. 9° 24’ N to 9° 48’ N and Long. 6° 25’ E to 6° 45’ E, which occupies major central segment of the Nigeria Basement Complex. Minna environs is made of meta-igneous rocks and meta-sedimentary of polyphase deformation with metamorphism.

The Study area is underlain by granite, granitoid and diorite, which is believed to be part of the Precambrian Basement Complex suite. The granite is more prominent than the granite-gneiss and schist, and it trends N-S in the northern and southern parts of the area. The Federal University of Technology, Minna belongs to the Pan-African Province, which is characterized by late Proterozoic to early Paleozoic orogenic events that resulted from the collision of the West African Craton and the Congo Craton. The Pan-African Province is further subdivided into several domains, such as the Ibadan, the Ife, the Egbe-Isanlu, the Zungeru, and the Bauchi domains. The area around Bosso Dam is located in the Zungeru domain, which is composed of migmatitic gneisses, schists, amphibolites, and granites.

The granitic rock of the area differs in the texture and composition. The schist of the area occurs as a plane laying narrow southwest-northeast belt at the central part of mina with small quartzite ridge parallel to it. The gneiss presents as small suites at the northern -southern part of the area forming a contact with the granite, (Alabi, 2011).

CHAPTER TWO: LITERATURE REVIEW

2.1 Geology of Nigeria

Nigeria lies approximately between latitudes 40N and 150N and Longitudes 20E and 150E, within the Pan African mobile belt in between the West African and Congo cratons. Oyawoye (1972), previously studied the general geology and geochronology of the basement rocks of Nigeria. In a regional scale, the geology is divided into two parts; the crystalline rocks and the sedimentary Basins (Figure 2.1).

The geology of Nigeria is made up of three major litho-petrological components, namely, the Basement Complex (Pan-African and older (Precambrian)> +600 million years), Younger Granites (Jurassic: 200 – 145 million years), and Sedimentary Basins (Cretaceous to Recent {< 145 million years}). The crystalline rocks in Nigeria are distributed in a circular area in the north central, a triangular area in the west that runs into the Benin Republic, and a rectangular area broken into three parts by sedimentary rocks on the eastern border of Nigeria with Cameroun Republic. The crystalline rocks are divided into three main groups: Basement complex, younger granites and Tertiary to Recent volcanic. The Precambrian rocks of Nigeria, collectively known as the basement complex, occupy nearly half the total area of the country. The other half is covered by the Cretaceous and younger sedimentary rocks. The Basement complex, which is Precambrian in age, is made up of Migmatite-Gneiss Complexes, the older metasediments, the younger metasediments and the Pan African Granitoids. The Younger Granites comprise several Jurassic magmatic ring complexes centered around Jos and other parts of north-central Nigeria.

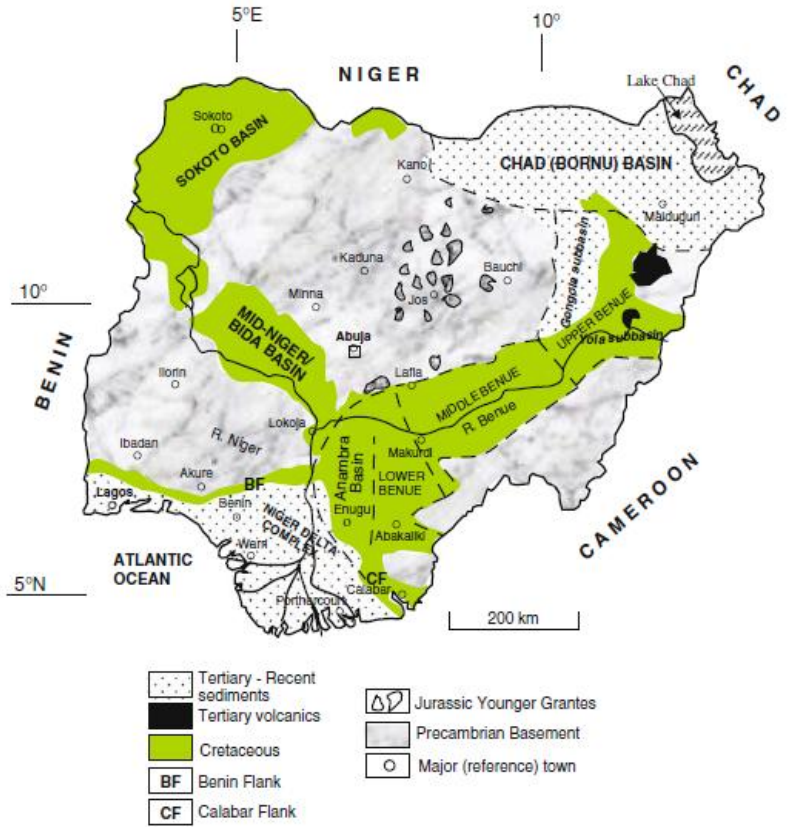


Figure 2.1: Geological sketch of Nigeria Showing the major geological components; Basement, Younger Granites and Sedimentary Basins, Obaje (2009)

2.1.1 The Basement Complex

The Nigerian basement complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Craton and south of the Tuareg Shield (Black, 1980). Basement complex rocks are subdivided into migmatite-gneiss complexes; the older metasediments; the younger metasediments; the Pan-African Granitoids; the younger granites. It is overlain by Cretaceous and younger sediments.

Within the basement complex of Nigeria four major petro-lithological units are distinguishable (Dada, 2006), namely:

1. The Migmatite – Gneiss Complex (MGC)

2. The Schist Belt (metasedimentary and metavolcanic rocks)

3. The Older Granites (Pan African granitoids)

4. Undeformed Acid and Basic Dykes

2.1.1.1 The Migmatite-Gneiss Complex

The Migmatite – Gneiss Complex is generally considered as the basement complex sensustricto (Rahaman, 1988; Dada, 2006) and it is the most widespread of the component units in the Nigerian basement. It is the commonest rock type in the Nigerian Basement complex. It comprises two main types of gneisses: the biotite gneiss and the banded gneiss. Very widespread, the biotitic gneisses are normally fine-grained with strong foliation caused by the parallel arrangement of alternating dark and light minerals. The banded gneisses show alternating light-colored and dark bands and exhibit intricate folding of their bands. The Migmatite gneiss complex is the oldest basement rock, and is believed to be of sedimentary origin but was later profoundly altered into metamorphic and granite conditions. Oyawoye (1965) recognized the following rock types as part of the MGC: banded gneisses, augen gneisses and pegmatites. Recent petrological division of the MGC includes: A grey foliated biotite acid or biotite hornblende quartz feldspathic gneiss of tonalitic to granodioritic composition, which is also known as the "grey gneiss" (Rahaman, 1981). Mafic and ultramafic components which when present, often outcrop as discontinuous boudinaged lenses or concordant sheets of amphibolites with minor amounts of biotite-rich ultramafic. Except where it constitutes the palaeosome to the migmatite, these are present in grossly subordinate amounts to the grey gneisses. Felsic components are a varied group of rocks consisting essentially of pegmatites, aplite, quartz-oligoclase veins, finegrained granite gneiss, porphyritic granites etc. The three components may or may not be present together on a single outcrop. The migmatite-gneiss complexes are Archean (Dada, 1989; Bruguier et al., 1994). Another important type of migmatite common in the Basement complex is the Agmatite, in which schistose or gneissic rocks (palaeosome) are dissected into irregular blocks by quartzo-feldspathic dykes and pegmatites (metasome) (Oyawoye, 1970).

2.1.1.2 The Meta-sediments

The Older Meta-sediments were also among the earliest rocks on the Nigerian Basement Complex. Initially of sedimentary origin, with a more extensive distribution, the older meta-sediments underwent prolong, repeated metamorphism; and now occur as quartzite (ancient sandstones), marble (ancient

limestone's), and other calcareous and relics of highly altered clayey sediments and igneous rocks. Most parts of the Basement complex are underlain by belts of roughly north-south trending, slightly metamorphosed ancient Precambrian sedimentary and volcanic rocks known as the younger meta-sediments. The major rock types are ancient shaly rocks which are now referred to as quartz- biotite-muscovite schist. These change laterally into coarse grained feldspar bearing micaceous schists. Schists with graphite, phyllites and chlorite are common. Ferruginous quartzites and tale schists also occur. The Younger Metasediments contain most of the gold deposits in Nigeria in the northwest around Maru and Anka, and at Zuru; near Kaduna, and also at llesha in southwestern Nigeria

2.1.1.3 The Older Granites (Pan African Granitoids)

The term "Pan African granitoids" cover a group of rocks that include biotite and biotite-muscovite granites, syenites, charnokites, diorites, monzonites (Bauchite), serpentines, anorthosites, etc. previously called "Older Granites" as a name introduced by Falconer (1911) to distinguish this rock type based on morphology and texture from Jurassic, anorogenic, peralkaline "Younger Granites" in north central Nigeria. There is enormous variety in the granite composition of these rocks. The Older Granites, e.g. the coarse-grained biotite-hornblende granites, have concordant foliation with the MGC or schists (Oyawoye 1965) though they vary in composition, texture and color. They are widespread throughout the Basement Complex and occur as large circular masses within the schists and the older migmatite-gneiss complexes. The Older Granites vary extensively in composition. The younger granite complexes in Nigeria are found mainly on the Jos Plateau, forming a distinctive group of intrusive and volcanic rocks that are bounded by ring dykes or ring faults. Other occurrences approximate a north-south belt towards the middle Benue in the south where the ages are younger and towards Niger Republic in the north where the younger granites are older.

2.1.1.4 Undeformed Acid and Basic Dykes

The undeformed acid and basic dykes are late to post-tectonic Pan African. They crosscut the Migmatite-Gneiss Complex, the Schist Belts and the Older Granites. The undeformed acid and basic dykes include: • Felsic dykes that are associated with Pan African granitoids on the terrain such as the muscovite, tourmaline and beryl bearing pegmatites, microgranites, aplites and syenite dykes (Dada, 2006) • Basic dykes that are generally regarded as the youngest units in the Nigerian basement such as dolerite and the less common basaltic, felsite and lamprophyric dykes. The age of the felsite dykes has been put at between 580 and 535 Ma from Rb-Sr studies on whole rocks (Matheis and Caen-Vachette, 1983; Dada, 2006), while the basic dykes have a much lower suggested age of ca. 500 Ma (Grant, 1970). The structural and geochronological importances of this suite of rocks, which have been put to immense chronological use elsewhere (Dada, 2006) are often 14 overlooked in Nigeria. When they cross-cut basement, they could be used to infer relative age of metamorphic structures and rock suites and could also suggest the existence of older basement windows in the Nigerian schist belts, apart from the immense guide they provide in sampling for isotope geochemistry, analysis and interpretation (Dada, 2006).

2.1.2 Younger Granites

The younger granite complexes in Nigeria are found mainly on the Jos Plateau, forming a distinctive group of intrusive and volcanic rocks that are bounded by ring dykes or ring faults. Other occurrences

approximate a north-south belt towards the middle Benue in the south where the ages are younger and towards Niger Republic in the north where the younger granites are older. Falconer (1911) was the first to define the Younger Granites, where he described them as crosscutting alkali granites containing riebeckite or biotite, characteriesed by chilled margins against their country rocks. The Nigerian Younger Granites are part only of a much larger igneous province extending far to the north in Niger Republic (Black and Girod 1970). The emplacement of Younger Granite is completely unrelated to orogenic activity. Their age is Jurassic.Anorogenic; the Older Granites are orogenic. The Younger Granites intrude the basement discordantly to form highly steeped hills; basement complex rocks are generally flat/low lying and lowly steeped occur generally as ring dykes and cone sheets, sometimes with outer and inner rings. The Younger Granites are generally peralkaline (high amounts of Na and K: feldspars are albitic, pertitic, Kfeldspars; sodic amphiboles like arfvedsonites and riebeckites, alkaline pyroxenes like aegerines are very common. The Younger Granites of Nigeria are known to be rich in tin and niobium mineralization.

2.2 Geology of Niger State

Niger state is located within the middle belt of Nigeria, which stretched within latitude 7° 51'N to 11° 04'N and longitude 4° 40'E to 7° 30'E, with most of the sedimentary consist of loosely cemented sandstones of different grain sizes siltstones, clay and shale, which are often by lateritic or ironstone concentration, particular in upland areas. The boundary ranges of rock trends NW/SW direction, with Basement rocks trending towards north and sedimentary formations towards south consist of a suite of migmatites. Precambrian granites and schist gneiss (Oyawoye, 1972). Figure 2.2 is a map of Niger state showing its lithologies.

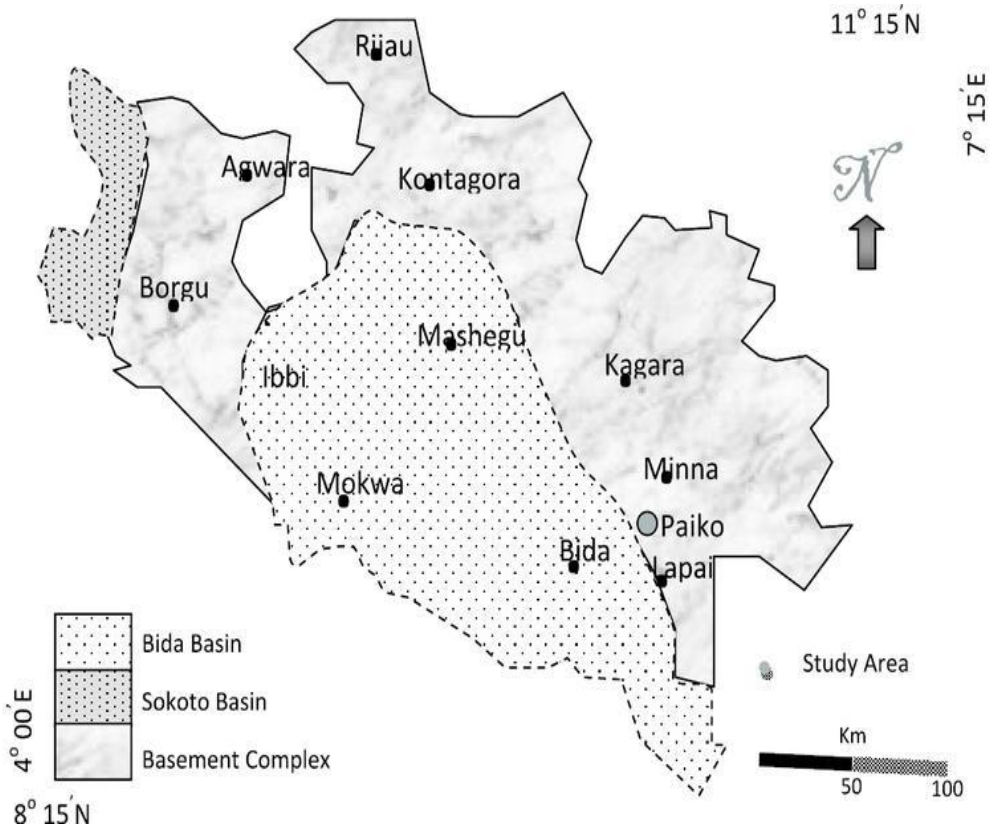


Figure 2.2: Geological map of Niger State basement complex and sedimentary basins (Amadi et al., 2012)

CHAPTER THREE: MATERIALS AND METHODS

3.1 Materials

Topographical base map, Geological GPS, a compass clinometer, hand trowel, field note, pencil, masking tape, marker pen, meter rule, hand lens, camera and a sample bag were among the tools used for the mapping activity. The laboratory tools used is the XRF Spectrometer.

- **Compass/Clinometer**: This is an instrument that indicates directions, typical by means of freely turning needle pointing to magnetic north (**Plate I**).



Plate I: A Typical compass clinometer used on the field

- **Geological Global Positioning System (G.P.S):** This instrument is used in measuring the coordinates (Longitude and Latitude) of any Location or point and the elevation of that point above Sea Level (Plate II). It functions in global positioning, Navigation, communicator, compass, Altitude, Referencing, Planning of traverse, Etc.



Plate II: Global Positioning System

- **Hand trowel**: The flat-bladed hand tool (Figure3.1) is used in scoping the stream sediment samples in each of the locations within the stream.



Figure 3.1: A typical hand-trowel used on the field

- **Field notebook, pencils, masking tape, marker pens**: These are used for documentation of observation of outcrops, for general field work and for labeling of the stream sediment samples.
- **Topographic (Base) Map:** This is the map of the area on which we can locate every of our position through the use of the G.P.S. coordinates. These contain details of the area at an approximate scale. It is used for location of oneself on the field at any given point in time and contains sufficient contours of the different elevation depicting ridges, hills, valleys, cliffs (high and low), roads, footpaths, rivers and river channels, bridges and settlements.
- **Field camera**: Is the only back up memory in addition to the notebook. It is very important to take photographs of all interesting features ensuring a scale is used in each instance. Photographs are important for descriptive purposes especially during report writing and for making presentations

3.2 Methods

- The process is divided into three phases: desk study, field work, and laboratory analysis in order to accomplish the goals of the research.

3.2.1 Desk study

Desk study of the research involved obtaining literature linked to this study, which served as the foundation for its development. The main actions at this stage are listed below:

- Review of previous work: There was a review of all past work done in the area which include: Thesis, journals and map from related sources.
- Compilation of materials needed for the work. These includes: The topographical map of Zungeru sheet 163SE was used as the source for the 1:12500 scale base map for the stream sediment mapping.

- Reconnaissance survey: the study area was visited to compare and verify the knowledge learned from desk research with what was actually there.

3.2.2 Field work

Following the reconnaissance survey, a thorough field investigation was conducted in the research area. The activities that was carried out include the geological mapping; description of stream sediment samples on the field; stream sediment sampling.

3.2.2.1 Stream Sediment Sampling

The topographical map, Zungeru, sheet 163SE, was used to extract a base map at the scale of 1:12500 for the field mapping. Stream sediments were collected along meandering stream channel on the field, at the Gidan kwano campus of FUT, Minna. Active stream sediments were collected along the stream channel of ten area using a hand trowel, and a clean polythene bag. They were sampled mostly at the depth of 10cm due to change in horizon with depth, the sediments collected consist of mud soil and dark colored mineral. Clean polyhthen bags were used in storing the stream sediment samplings. The sample bags were carefully labelled with permanent makers to avoid mix up. The samples collected were sundried for 48 hours and large grains were handpicked from the dried samples which were sieved to obtain finer grain sizes and resulting samples were weighed and packaged in a polythene zip lock, labelled and transferred to the NGSA laboratory at Kaduna state, Nigeria for geochemical analysis.

3.2.3 Laboratory analysis

Ten (10) stream sediment samples were chosen and sent for chemical analyses using the XRF technique at National Geological Survey Agency at Kaduna, Nigeria.

3.2.3.1 Stream sediment sample preparation

A composite sample was made by combining samples that were gathered from the field. It was thoroughly mixed to achieve a representative composition. The composite sample was spread on a clean, flat surface to dry. Once dried the sample was sieved to achieve a uniform particle size.

3.2.3.2 Stream sediment sample analysis

A small, representative sub-sample from the crushed sediment was used for XRF analysis. The XRF instrument was calibrated to certify reference material with known elemental compositions. The calibration establishes relationship between the Instruments responses and concentration of specific element. The sample is then placed on a sample pellet die. The sample was then pressed into a pellet to form a solid sample for the analysis. The analysis then start by inserting the prepared sample into the XRF device. The sample is exposed to X-ray from the instrument, which causes the sample's atom tom release distinctive X-rays. The X-rays emitted by the sample were then detected and quantified by the instrument.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Geology

From the result obtain from field observation at outcrop and hand specimen, various lithologies and structures have been studied and classified accordingly. Igneous rocks dominantly makes up the study area (Futminna, Gidan kwano campus, part of zungeru sheet 163SE), which must have formed a continuous ridge. Three main lithological units, including granite, granitoid and diorite, were identified as a result of the field mapping (Figure 4.1).

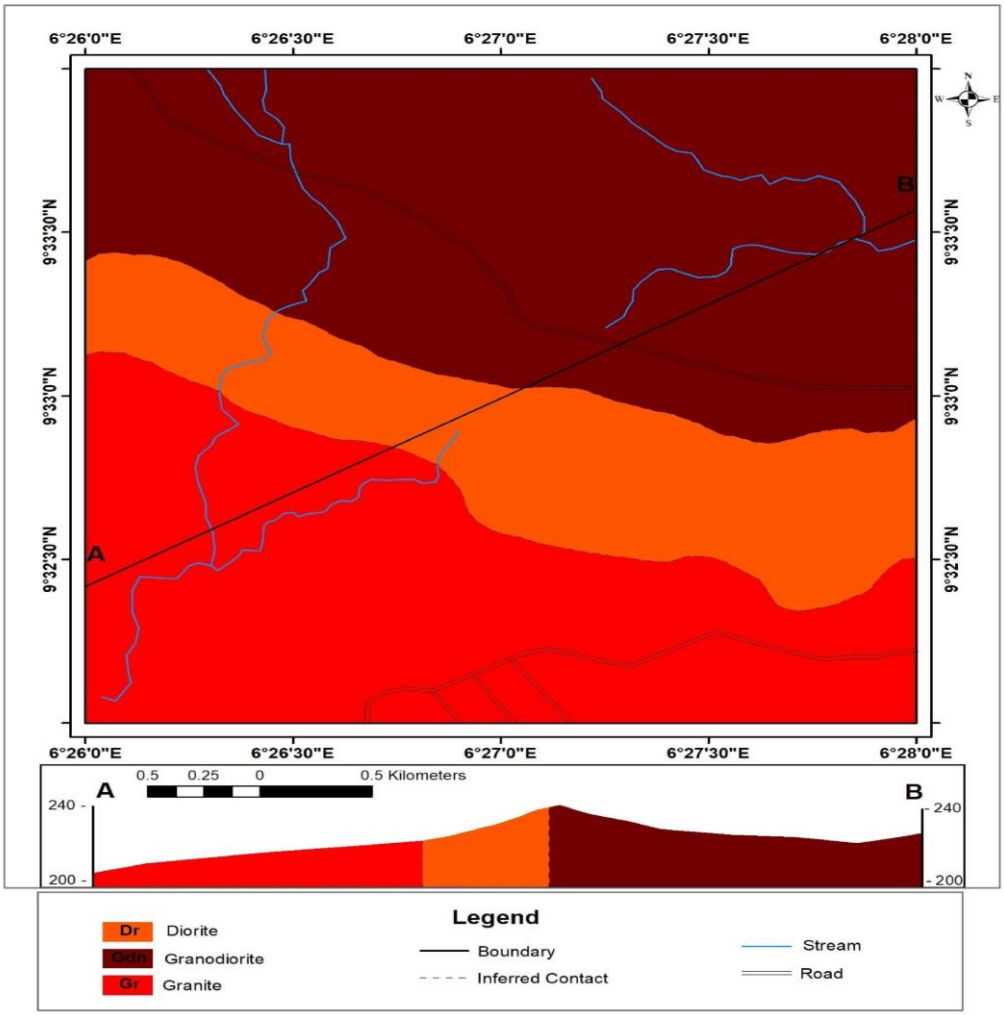


Figure 4.1 Geologic map of the study area (Daodu *et al*, 2024)

4.1.1 Granite

From the field observation, the granites found within the study area are quite extensive in size (Plate IV). Texturally they are medium grained, dark and grey in color, and composed of quartz, feldspar, hornblende and biotite (mica) when studied on hand specimen. Some of the granites are well exposed due to weathering activities (Chemical and biological weathering). Granite is the most prevalent rock in the study region, the granite rocks of older granites suite makes up 80 percent of all rock there. They are mostly exposed near the river channel and occupying low lying flat-rugged vicinity. The veins are typically observed to be extensive ranging from 1 centimeter to 10 centimeter as joint set and joint density where they occur.



Plate III: Granitic rock

4.1.2 Granitoid

I also encountered granitoid rocks, which were similar to granite but showed more variability in terms of texture and mineral proportions. The granitoids in the field ranged from coarse to medium grain size, with colors varying from light gray to pink. In some specimens, orthoclase feldspar dominated, contributing to the pinkish hue, while others had more quartz and plagioclase feldspar, giving them a lighter, grayish appearance. Mafic minerals, including hornblende and biotite, were also present in granitoid samples, adding darker spots to the otherwise light-colored rock. These granitoid rocks appeared more granular in texture compared to the granite, likely due to the increased presence of mafic minerals. This composition suggested that granitoids play a significant role in contributing sand-sized particles to the stream sediment, especially in areas where physical weathering has occurred.

The granitoid provide a valuable source of economic minerals, including feldspar, mica and occasionally rare metals like tin and tungsten, which are important foe local mining activities, the weathering of these granitoids contributes significantly to the geochemistry of the stream sediment in the study area (Zungeru sheet 163SE).

4.1.3 Diorite

Diorite stood out during my fieldwork due to its darker appearance and distinctive “salt-and-pepper” texture (light and dark minerals). In hand specimens, the diorite was medium to coarse-grained, with the intermingling of light-colored plagioclase feldspar and dark minerals like hornblende and biotite creating a striking contrast. Unlike the granite and granitoids, quartz was absent or only present in very small amounts, making diorite a more basic rock. The presence of hornblende and biotite gave the rock a darker tone, which was a useful field indicator for distinguishing it from the lighter granitoids. The

composition of diorite suggested it contributes more to the fine-grained, clay-rich fraction of the stream sediments, particularly due to the higher weathering rate of its mafic minerals.

Diorite is a potential source of construction materials due to its durability and aesthetic appeal. Additionally, understanding its distribution and geochemistry is crucial for environmental monitoring, as dioritic rocks can influence the geochemical characteristics of surrounding soils and stream sediments. The weathering of diorite can release trace elements into the environment, which may have implications for soil fertility and groundwater quality in the region.

Diorite a key component of the region's geological framework. Its study not only provides insights into the tectonic and magmatic processes that have shaped the Nigerian Basement Complex but also has broader implications for environmental and economic considerations.

4.2 Field relation

The structural features observed in the study area are majorly in direction of structural deformation of the outcrops in the study area such as fault and joints.

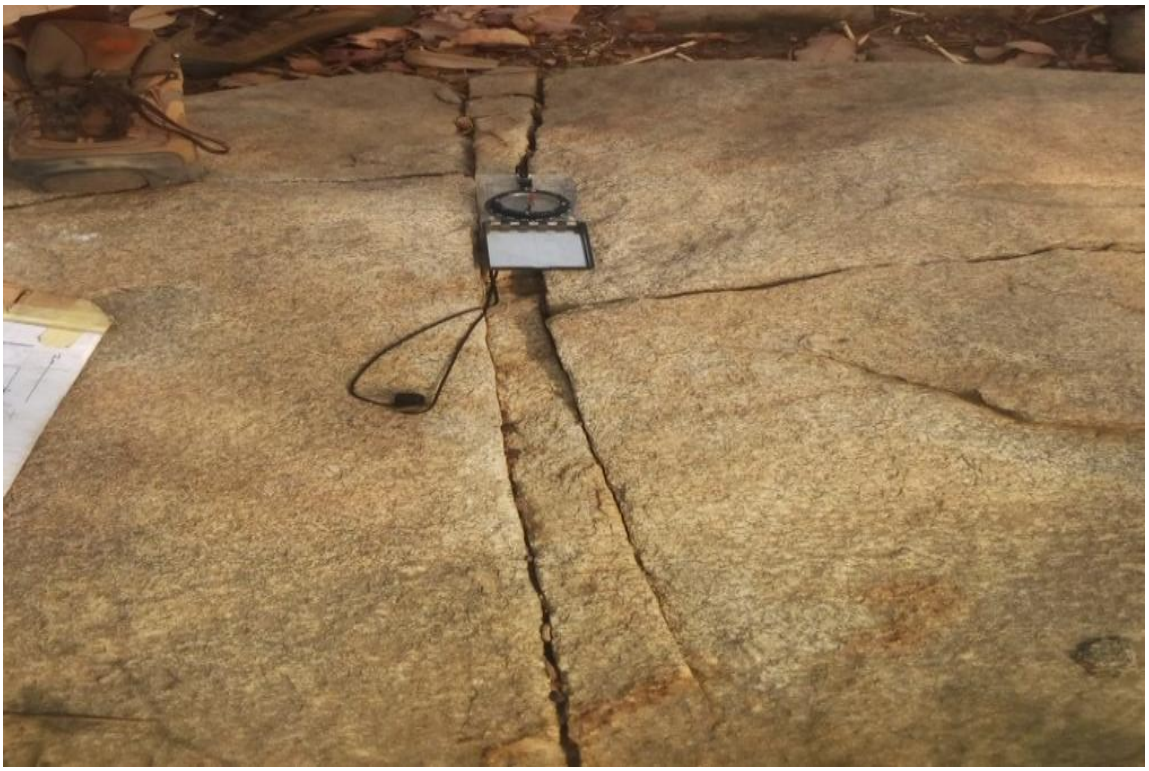


Plate IV: Fracture (Joint) on a granitic rock

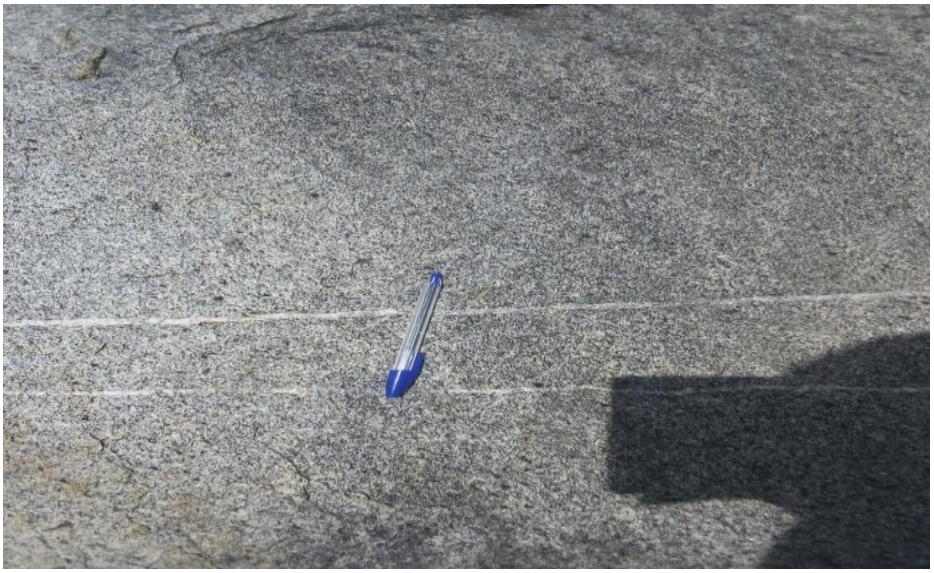


Plate V: Granitic rock showing quartz vein at location



Plate VI: pegmatite vein in the study area, part of futminna, gidan kwano campus, (zungeru sheet 163SE)



Plate VII: A vein trending 280^{o}NW, along a river channel at location

4.3 Laboratory results

The geochemical results obtained through X-ray fluorescence (XRF) spectrometry analysis are detailed in the following sections. This data represents the outcome of the laboratory examination of the stream sediment samples and provides comprehensive insights into the elemental composition. The results, derived from precise XRF spectrometric techniques, offer a thorough overview of the concentrations of various major and trace elements present in the sediment samples, contributing significantly to the geochemical understanding of the area under study.

4.4 Stream sediment geochemistry

A set of Ten (10) stream sediment samples were carefully prepared for the geochemical analyses. Each of these samples passed through analysis to determine both major elements and trace elements present. The major oxides that were analyzed, and presented in weight percentage, Includes SiO_2, Fe_2O_3, CaO, MgO, TiO_2, Al_2O_3, MnO, K_2O, P_2O_5, SO_3, Na_2O, and LIO. The trace elements, which are expressed in parts per million (ppm), includes Nickel (Ni), Chromium (Cr), zinc (Zn), Tungsten (W), Cobalt (Co), Rubidium (Rb), Copper (Cu), Niobium (Nb), Cadmium (Cd), Tin (Sn), Lead (Pb), Molybdenum (Mo), Vanadium (V), Gold (Au), Silver (Ag).

4.4.1 Major oxide geochemistry for stream sediments

The result of major oxide composition for the analysed stream sediment sample for the study area (part of Zungeru sheet 163SE), are presented in Table 4.1 and 4.2. The data was obtained through XRF analysis of then stream sediment samples obtained from the study area.

The table 4.2 shows the results of this work along with the compared crustal averages by Wedepohl (1995), Rudnick and Gao (2003).

In these tables, the silica (SiO_2) content ranged from 60.2 to 81.4 weight percent (%), with an average concentration of 74.37 weight percent (%). Rudnick and Gao (2003) suggests that the crustal abundance of SiO_2 is 66.6% and Wedepohl (1995) suggests 61.5 weight percent (%). The average concentration of SiO_2 in the samples is higher compared to the crustal abundance which might indicate significant contribution from quartz rich rock such as granite, which tends to enrich silica as other elements are leached away.

Iron oxide (Fe_2O_3) content ranged from 7.01 to 27.6 weight percent (%) with an average concentration of 11.872 weight percent (%). Iron oxide (Fe_2O_3) is relatively elevated in the stream sediments compared to the average crustal composition, which has Fe_2O_3 around 5.04 weight % (Rudnick and gag, 2003) to 6.28 weight % (Wedepohl, 1995). This is indicative of mafic sources or from chemical weathering of iron rich minerals from parent rocks.

Calcium oxide (CaO) content ranged from 0.04 to 3.16 weigh percent with an average concentration of 0.875 weight percent (%). This is lower than the typical crustal abundance value which is around 3.59% (Rudnick and Gao, 2003). This suggests lack of calcareous material or the lack of minerals like plagioclase feldspar (which contains calcium). The low concentration could also reflect high degree of chemical weathering, as calcium tends to be leached out easily in warm and humid environments.

The Magnesium oxide (MgO) content ranged from 0.91 to 3.21 weight percent (%), with an average concentration of 2.032 weight percent (%). The magnesium oxide (MgO) align closely with the average crustal values, which is about 2.48 weight % (Rudnick and Gao, 2003) to 1.56 weight % (Wedepohl, 1995). MgO in the sediments typically comes from mafic minerals such as olivine, pyroxene, or biotite, indicating that the stream sediments may contain contributions from basaltic or ultramafic rocks.

Titanium oxide (TiO_2) content ranged from 0.4 to 0.81 weight percent with an average concentration of 0.644 weight percent. The titanium oxide (TIO2) in the stream sediment sample is relatively close to the crustal average around 0.64 weight % (Wedepohl, 1995) to 0.7 weight % (Gao and Rudnick, 2003). TiO_2 is commonly associated with mineral like ilmenite and rutile. This suggests that the stream sediment samples have minor contribution from heavy minerals and are not overly enriched or depleted in titanium bearing phases, likely derived from mafic igneous rocks.

Aluminum oxide (Al_2O_3), also known as corundum content ranged from 5.1 to 10.5 weight percent with an average concentration of 7.629 weight percent (%). The aluminum oxide (Al_2O_3) is lower than the average crustal value which is around 7.76 weight % (Wedepohl, 1995) to 15.4 (Rudnick and Gao, 2003). Al_2O_3 is typically found in feldspars, so a lower than average Al_2O_3 concentration might indicate a reduced presence of these minerals. This could point to the significant quartz (SiO_2) enrichment.

MnO content ranged from 0.04 to 0.61 weight percent (%), with an average concentration of 0.25 weight percent (%). The manganese oxide (MnO) concentrations are slightly lower compared to the average crustal value, 0.33 weight % (Rudnick and Gao, 2003) to 0.48% (Wedepohl, 1995). Manganese is typically found in trace amount in sediments, often concentrated in oxide phases or associated with iron minerals. The depletion in manganese oxide (MnO) may indicate lack of geochemical condition that favor manganese enrichment.

K_2O content ranged from 0.53 to 2.61 weight percent %, with an average concentration of 1.188 weight percent. Potassium oxide (K_2O) is slightly lower than crustal average 1.38% (Wedepohl, 1995) to 2.8% (Rudnick and Gao, 2003) suggesting a lesser contribution from potassium feldspar or micas (such as muscovite or biotite). This may reflect a sediment source poor in felsic or heavy weathering, which tends to leach K_2O.

P_2O_5 content ranged from 0.17 to 0.51 weight percent with an average concentration of 0.248 weight percent. P_2O_5 in the stream sediment sample is slightly above the average crustal value of 0.1 weight % (Rudnick and Gao, 2003) to 0.15 weight % (Wedepohl, 1995). P_2O_5 is typically found in apatite, a common accessory mineral in igneous and metamorphic rocks. This indicates the stream sediment of the study area (Zungeru sheet 163SE) may have normal input of phosphatic material, possibly from weathered igneous rock.

SO_3 content ranged from 0.22 to 0.62 weight percent with an average concentration of 0.388 weight percent. This concentration is relatively minor but can be significant if local sulfur mineralization or input from anthropogenic sources (e.g., pollution)

Sodium oxide (Na_2O) is low compared to the crustal average of 3.1 weight % (Rudnick and Gao, 2003) to 3.9 weight % (Wedepohl, 1995). Na_2O is often found in plagioclase feldspar, its low concentration suggests either a source with minimal plagioclase or heavy weathering, which tends to leach sodium out of sediments.

Lithium oxide (LI_2O) content ranged from 1.01 to 1.76 weight percent (%), with an average concentration of 1.287 weight percent (%). The Lithium oxide (LIO) in the stream sediments is somewhat elevated. Lithium tends to be enriched in clay minerals and can indicate contributions from felsic rocks.

Table 4.1: Concentration of major oxides in stream sediments (weight percent)

Oxide	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10	MIN	MAX	MEAN
SiO_2	80.4	79.4	70.5	60.2	69.4	81.4	72.2	75.4	79.4	75.4	60.2	81.4	74.37
Fe_2O_3	7.01	9.8	12.6	27.6	13.0	7.01	8.9	10.3	8.7	13.8	7.01	27.6	11.87
CaO	0.04	0.04	3.16	0.3	0.8	0.04	0.6	2.4	1.33	0.04	0.04	3.16	0.88
MgO	2.6	2.51	3.21	0.92	0.91	2.64	1.81	1.61	1.6	2.51	0.91	3.21	2.03
TiO_2	ND	ND	ND	0.42	0.81	ND	0.81	0.78	0.4	ND	0.4	0.81	0.64
Al_2O_3	8.42	5.71	6.93	8.21	10.5	8.4	10.5	6.81	5.1	5.71	5.1	10.5	7.63
MnO	0.04	0.04	0.55	0.61	0.22	0.04	0.31	0.33	0.32	0.04	0.04	0.61	0.25
K2O	0.53	0.71	1.47	0.9	1.91	0.54	2.61	1.22	1.28	0.71	0.53	2.61	1.19
P_2O_5	0.23	0.21	0.26	0.51	0.17	0.24	0.19	0.21	0.25	0.21	0.17	0.51	0.25
SO_3	0.34	0.45	0.3	0.22	0.31	0.36	0.62	0.52	0.31	0.45	0.22	0.62	0.39
Na_2O	0.55	0.41	0.8	0.61	0.93	0.51	0.13	0.21	0.92	0.41	0.13	0.93	0.55
LiO	1.01	1.76	1.23	1.21	1.21	1.42	1.24	1.41	1.11	1.27	1.01	1.76	1.29

Table 4.2: Summary of XRF data for major elements (weight percent %) in stream sediment samples from Gidan kwano campus compared with published crustal abundances

Oxide (Wt %)	Mean Conc.	Wedepohl (1995)	Status vs 1995	Rudnick & Gao (2003)	Status vs 2003
SiO_2	74.37	61.5	High	66.6	High
Fe_2O_3	11.872	6.28	High	5.04	High
CaO	0.875	1.74	Low	3.59	Low
MgO	2.032	1.56	High	2.48	Low
TiO_2	0.644	0.64	Low	0.7	Low
Al_2O_3	7.629	7.76	Low	15.4	Low
MnO	0.25	0.48	Low	0.33	Low
K_2O	1.188	1.38	Low	2.8	Low
P_2O_5	0.248	0.15	High	0.1	High
Na_2O	0.548	3.9	Low	3.1	Low
SO_3	0.388	0.065	High	0.065	High
LiO	1.287	0.0075	High	0.0043	High

Figure 4.2, 4.3 and 4.4 are plots showing the mean concentration of major oxides contained in the stream sediment samples obtained in bar chart, pie chart and line graph respectively. The mean concentration is plotted against the major oxides.

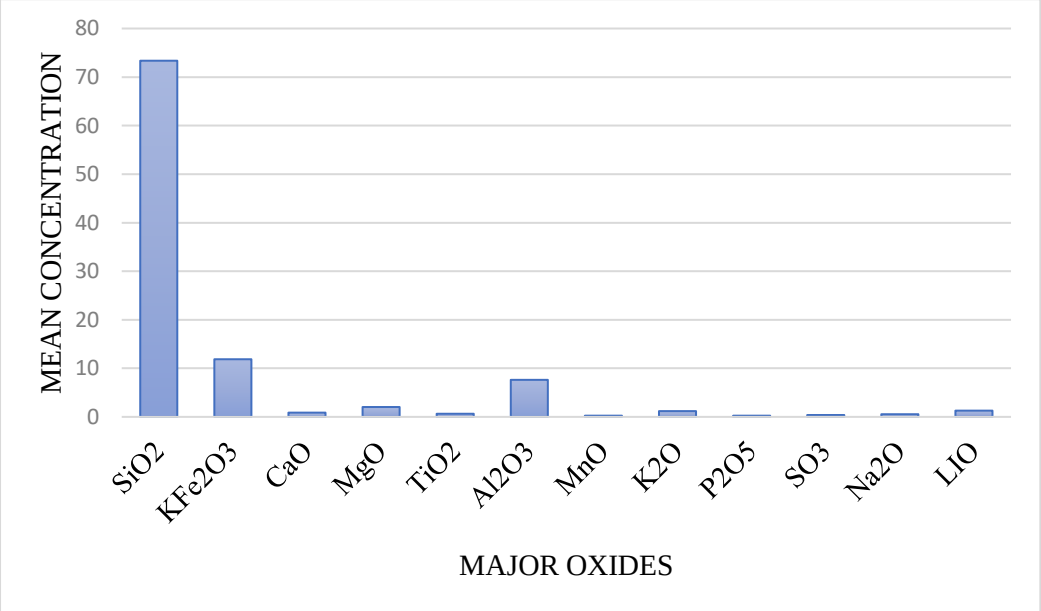


Figure 4.2: Mean concentration of major oxides in stream sediments (Bar chart)

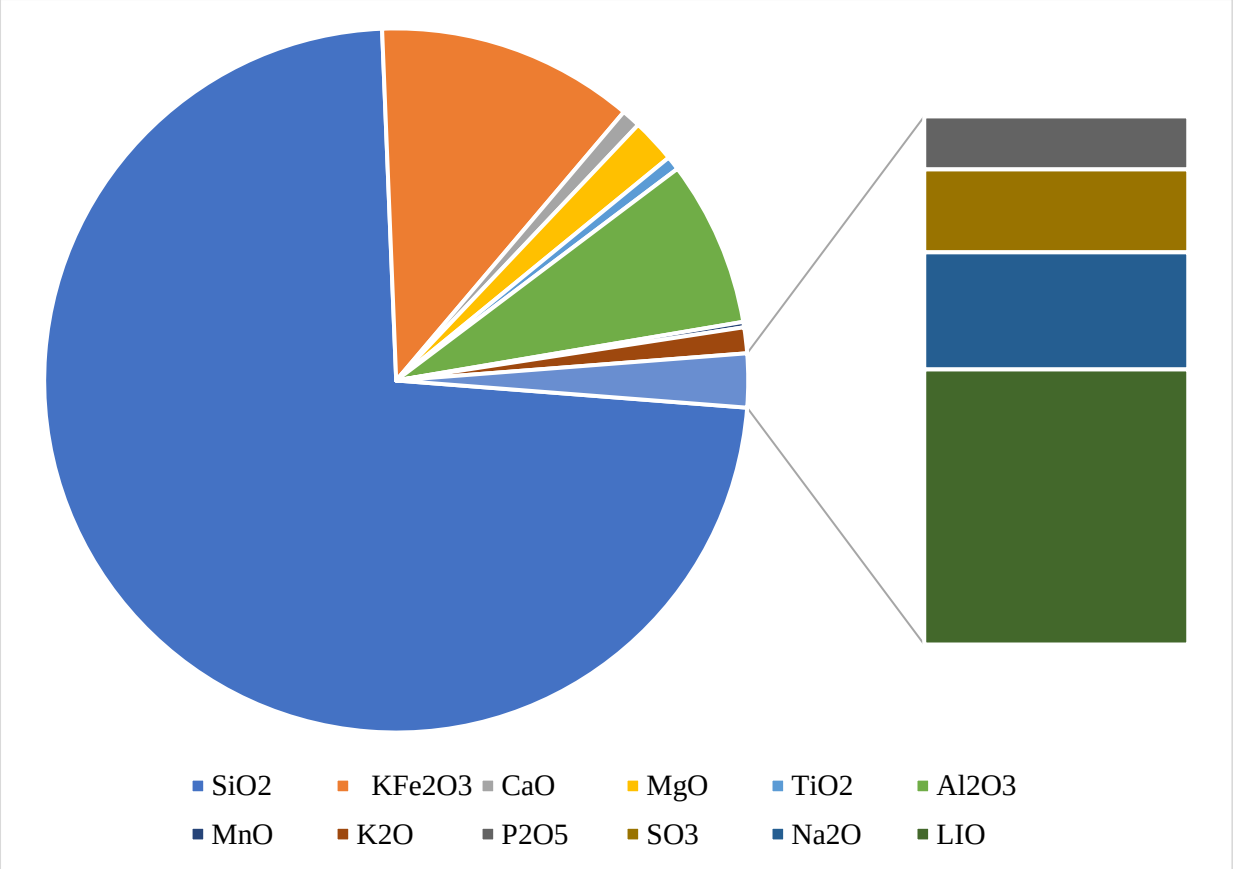


Figure 4.3: Mean concentration of major oxide in stream sediments (Pie chart)

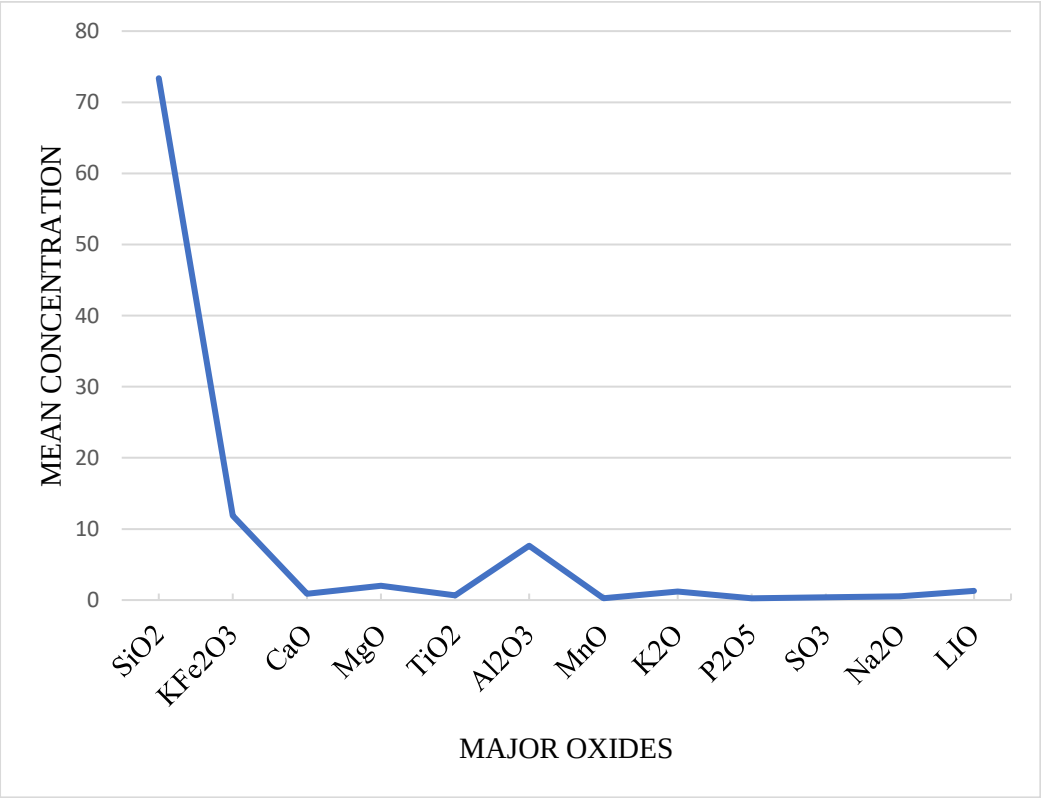


Figure 4.4: Mean concentration of major oxide in stream sediment (Line graph)

4.4.2 Trace elements geochemistry for stream sediments

Table 4.3 and 4.4 shows the results of the trace element analysis for sediment samples from stream sediments of the study area, Part of Zungeru sheet 164SE. based on the average concentrations of detected trace elements, can be interpreted in comparison with the average crustal values provided by *Rudnick and Gao (2003)* and *Wedepohl (1995)***.**

The concentration of Nickel (Ni) ranges 29 ppm to 79ppm, with an average concentration of 43.6ppm. The concentration of nickel in the sediment is slightly lower than the average crustal value but still close to the expected range, indicating moderate mobility of Ni or limited contribution from Ni-rich sources such as ultramafic rocks.

The concentration of Chromium (Cr) within the range of 58ppm to 144ppm, with an average of 110.375ppm. Chromium (Cr) is enriched compared to the average crustal values. This could suggest contributions from mafic or ultramafic rocks, which are typically Cr-rich. It may also reflect low mobility of Cr in the sediment.

The Zinc (Zn) concentration ranges within 28ppm to 83ppm, with an average of 58.8ppm. Zinc (Zn) content is slightly lower than the average crustal values, indicating possible depletion due to weathering or transport processes. Zinc's moderate mobility under acidic conditions could contribute to its lower concentration.

Tungsten (W) concentration ranges from 1ppm to 8ppm, and average 5ppm. The concentration of Tungsten shows significant enrichment compared to average crustal values. This suggests that there are local sources of W-rich minerals, possibly from granitic or hydrothermal deposits in the vicinity. W is generally considered to be immobile, which supports its accumulation in the sediment.

Co is highly enriched in the sediment, the concentration ranges from 123ppm to 180ppm, with an average concentration of 148.5ppm. This high concentration suggests that Co has low mobility, allowing it to accumulate rather than being leached away.

Rubidium (Rb) exhibits substantial depletion when compared to average crustal values. The concentration of rubidium in the sediment ranges 15ppm to 62ppm, with an average concentration of 45.5ppm. This depletion may reflect limited contributions from Rb-rich felsic sources or leaching processes that remove Rb from the sediment during weathering.

The concentration of copper (Cu) ranges from 15ppm to 38ppm, and average at 28ppm. copper (Cu) concentration is consistent with crustal values, indicating a balanced input from source rocks. This suggests that the sediment has retained the Cu content without significant leaching, reflecting a stable source in the region.

Niobium is typically immobile in sediment systems, indicating that the observed concentration is likely due to local geological conditions. The concentration of niobium ranges from 4ppm to 35ppm, with an average concentration of 14.1ppm. Niobium (Nb) is slightly enriched relative to average crustal values, which suggests the presence of nearby felsic sources.

The concentration of Cd is significantly higher than average crustal values, indicating potential local sources, possibly from anthropogenic activities or sulfide mineralization. Cd is highly mobile in acidic environments, suggesting that it has been readily available for accumulation in the sediments.

Tin (Sn) concentration ranges from 1ppm t0 6ppm, with an average concentration of 2.9ppm. Tin (Sn) is slightly enriched compared to average crustal values, reflecting contributions from Sn-rich minerals, such as cassiterite. Tin generally exhibits low mobility, supporting its retention in the sediment.

The lead (Pb) concentration ranges from 13ppm to 39ppm, with an average concentration 29.1667ppm. Lead is notably high when compared to the crustal average by Rudnick and Gao (2003), Wedepohl (1995), indicating potential input from lead-bearing sulfide ores or anthropogenic sources. Given Pb's relatively low mobility under the conditions of sediment transport, its concentration suggests localized accumulation.

Molybdenum (Mo) shows significant enrichment compared to average crustal values. The concentration of Molybdenum ranges from 4ppm to 10ppm, withan average concentration of 6.777778ppm, indicating proximity to Mo-rich mineral sources. Molybdenum mobility is variable, but its elevated concentration suggests retention within the sediment.

The concentration of vanadium (V) ranges from 36ppm to 76ppm, with an average concentration of 60.5ppm. Vanadium (V) is depleted relative to average crustal values, possibly reflecting low input from source rocks or the effects of weathering processes that leach vanadium from sediments.

The Gold (Au) concentration ranges from 0.043ppm to 0.098ppm, with an average concentration of 0.077667ppm, suggesting proximity to gold-bearing sources, possibly from local alluvial deposits or quartz veins. Gold's immobility contributes to its accumulation in the sediment.

The silver (Ag) concentration ranges from 0.001ppm to 0.019ppm, with an average concentration of 0.019ppm, Ag is depleted compared to average crustal values, indicating low input from Ag-rich sources or increased mobility that leads to leaching from the sediment.

Table 4.3: Concentration of trace elements in stream sediments (ppm)

S/N	Ni	Cr	Zn	W	Co	Rb	Cu	Nb	Cd	Sn	Pb	Mo	V	Au	Ag
SS1	29	127	29	ND	180	15	15	35	5	1	39	7	36	ND	ND
SS2	45	136	42	ND	125	51	32	18	ND	4	13	ND	42	0.066	0.033
SS3	40	112	58	1	143	62	28	10	12	6	33	10	67	ND	ND
SS4	41	123	41	ND	164	59	32	7	9	2	30	7	76	0.095	ND
SS5	44	ND	79	ND	155	47	29	4	ND	4	ND	6	65	ND	0.001
SS6	43	121	59	8	144	43	24	ND	ND	3	ND	9	64	0.084	ND
SS7	50	58	64	4	169	60	38	8	4	2	ND	5	56	0.08	0.023
SS8	52	62	78	7	123	47	33	23	ND	1	31	8	75	0.043	0.026
SS9	79	ND	83	5	131	45	28	9	9	4	ND	5	63	0.098	0.022
SS10	40	144	55	5	151	26	21	13	ND	2	29	4	61	ND	0.009
MIN	29	58	29	1	123	15	15	4	4	1	13	4	36	0.043	0.001
MAX	79	144	83	8	180	62	38	35	12	6	39	10	76	0.098	0.033
MEAN	43.6	110.375	58.8	5	148.5	45.5	28	14.11111	7.8	2.9	29.1667	6.777778	60.5	0.077667	0.019

Table 4.4: Summary of XRF data for trace elements (ppm) in stream sediments from the study area (Zungeru sheet 163SE) compared with published crustal abundances. Modified after Rudnick and Gao (2003), and Wedepohl (1995).

Element	Average concentration	Crustal Abundance of Chemical Element			
		Wedepohl (1995)	Status	Rudnick & Gao (2003)	Status
Ni	43.6	75.00	Low	65.00	Low
Cr	110.375	126.00	Low	92.00	High
Zn	58.8	65.00	Low	67.00	Low
W	5	24.00	Low	1.00	High
Co	148.5	1.00	High	24.0	High
Rb	45.5	25.00	High	1.00	High
Cu	28	1.09	High	1.00	High
Nb	14.11111	1.00	High	1.00	High
Cd	7.8	1.10	High	28.00	Low
Sn	2.9	15.00	Low	1.00	High
Pb	29.1667	1.10	High	1.00	High
Mo	6.777778	98.00	Low	1.00	High
V	60.5	0.025	High	17.00	High
Au	0.077667	0.07	Low	1.10	Low
Ag	0.019	0.1	Low	0.1	Low

Figure 4.5, 4.6 and 4.7 are plots showing the mean concentration (ppm) of trace elements contained in the stream sediment samples obtained in bar chart, pie chart and line graph respectively.

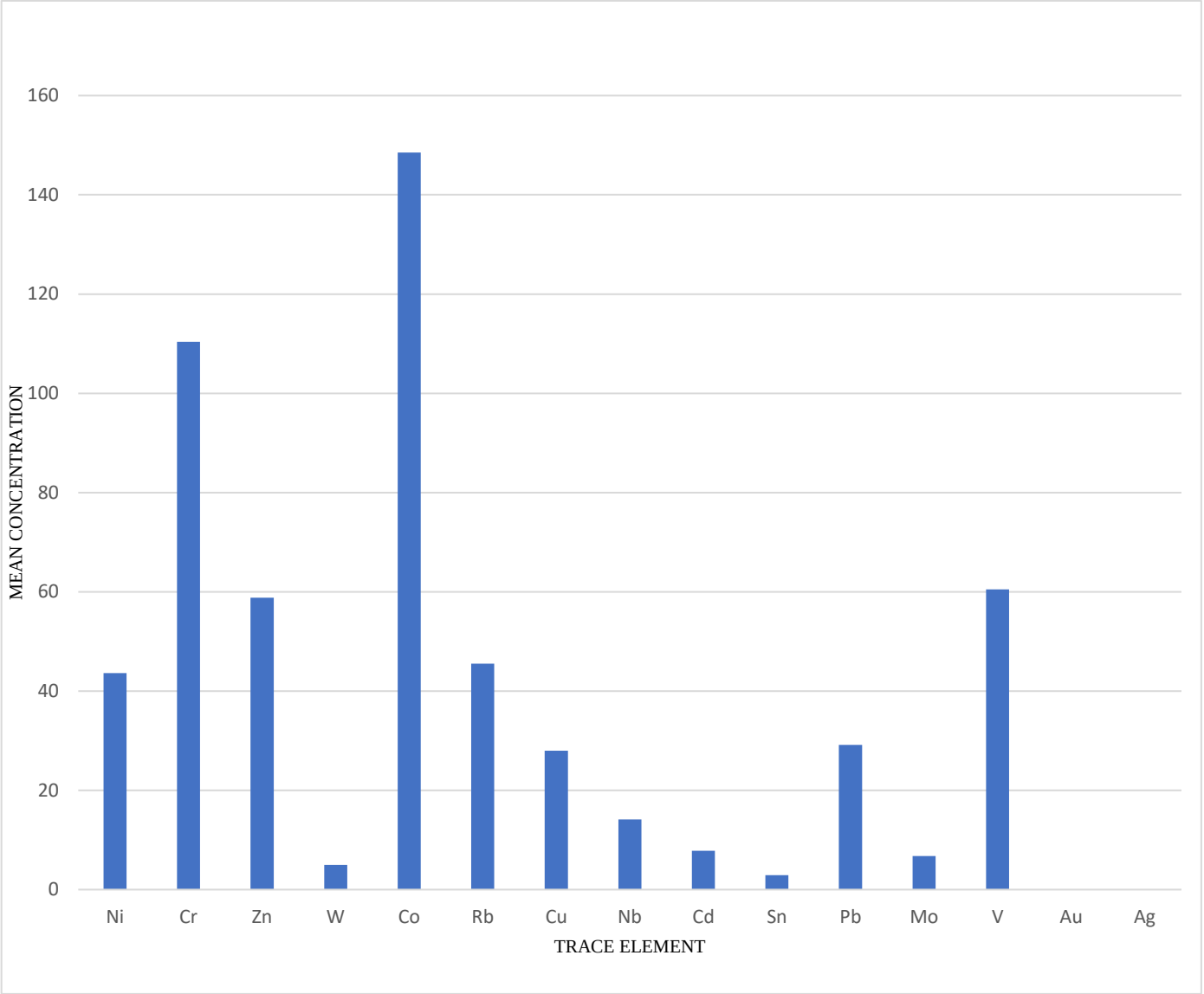


Figure 4.5: Mean concentration of trace elements in stream sediments (Bar chart)

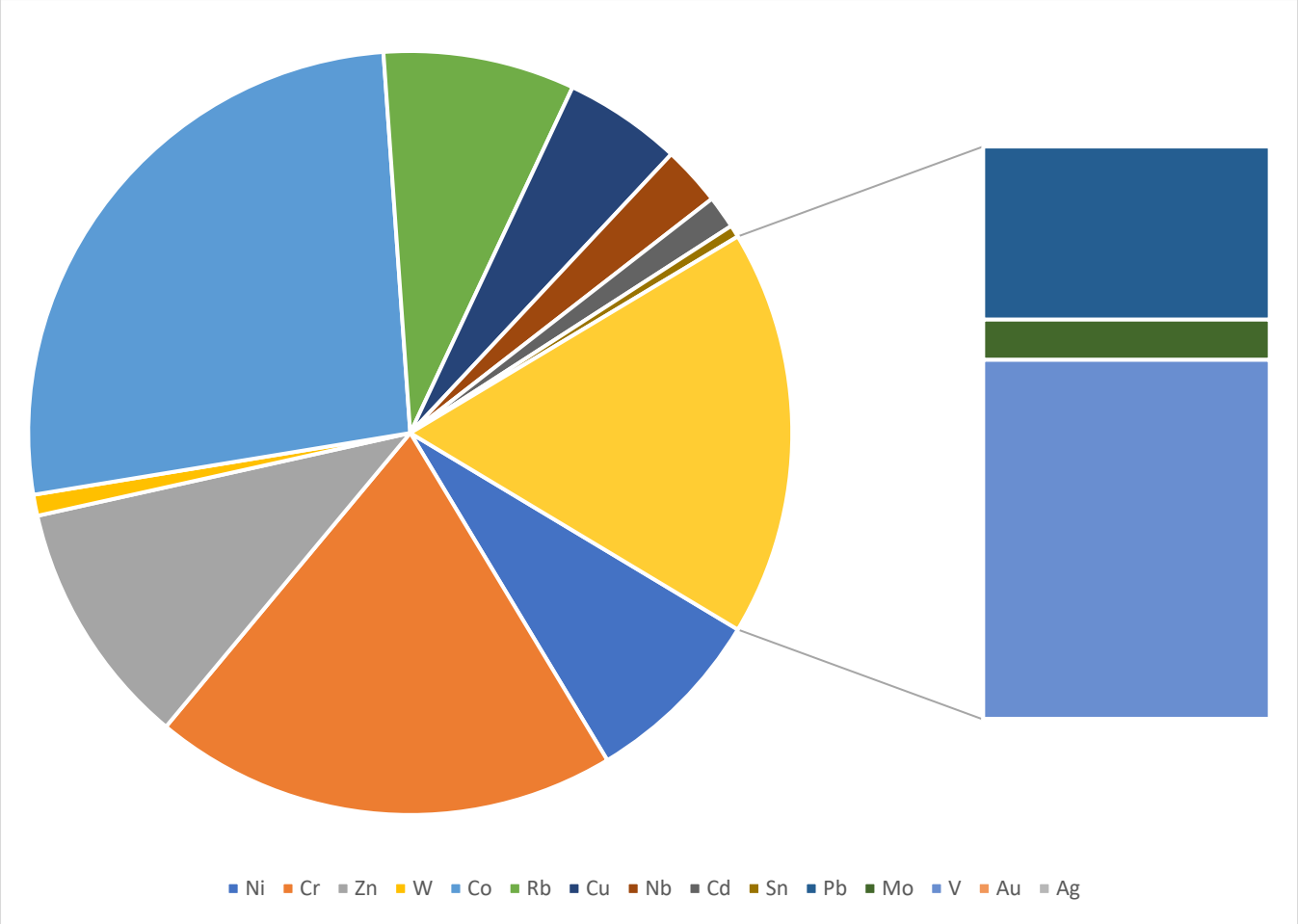


Figure 4.6: Mean concentration of trace elements in stream sediment (Pie chart)

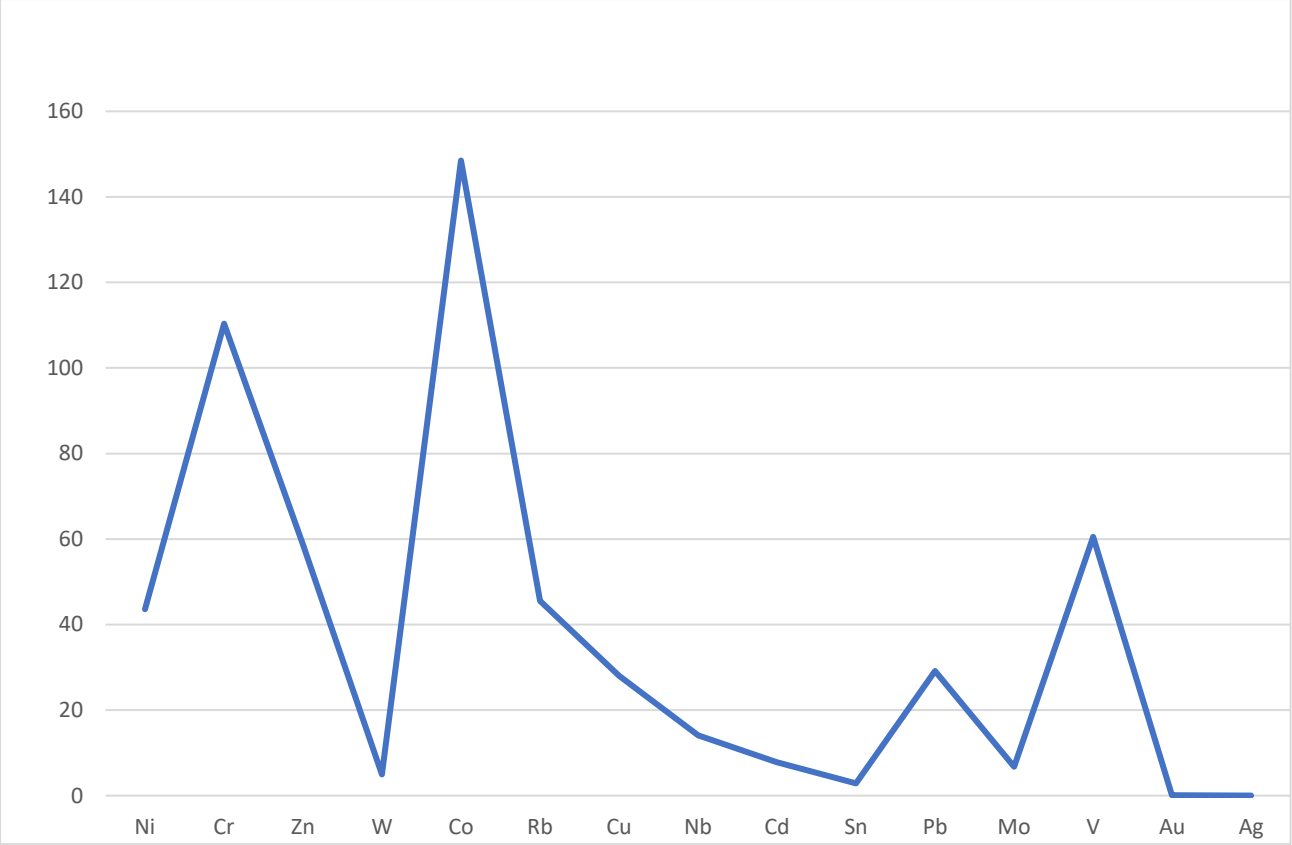


Figure 4.7: Mean concentration of trace elements in stream sediment (Line graph)

4.4.3 Element Enrichment Factor (EFF)

The enrichment ratio, as described by Rudnick and Gao (2003), is referred to as the relative concentration of an element in the Earth's crust compared to its average concentration in the whole Earth. This concept is often used in the context of understanding the distribution of the elements and their abundance in the Earth's.

The crust of the earth is composed of various elements, and their distribution can vary significantly depending on geological processes and history. Some elements are more abundant in the Earth's crust than in the overall composition of the Earth, while others may be less common.

The enrichment ratio (ER0 for an element can be derived using the formulae below:

$$ER(Cn) = \frac{(\text{Cn crustal concentration})}{(Bn\ average\ Earth\ concentration)} \quad \text{.....Equation 1}$$

Where:

- Cn crustal concentration: Represents the concentration or abundance of the element X in the Earth's crust.
- Bn average Earth concentration: Represent the average concentration of the element X in the entire Earth (Including the crust, mantle, and core).

A value of ER (Cn) greater than 1 indicates that the element Cn is enriched in the Earth's crust compared to its overall average in the entire planet. Conversely, a value of ER (Cn) less than 1 suggests that the element Cn is less abundant in the crust when compared to its average in the whole Earth.

The concept of enrichment ratio helps geologists and other researchers to understand the relative importance of specific elements in the Earth's crust and provides insight into processes such magmatic processes, crustal differentiation and geochemical evolution over the geologic time scales. It also adds to our understanding of the formation and composition of the rocks and minerals that makes up the Earth's crust.

The enrichment ratios of the trace element for the stream sediments are summarized in Table 4.5. The evaluation of these elements was carried out using following the methodology of Sunderland (2000), who explains the enrichment ratio (ER) in the following manner:

ER <2 Depletion to minimal enrichment

ER 2-5 Moderate enrichment

ER 5 – 20 significant enrichment

ER 20 – 40 Very high enrichment

ER>40 extremely high enrichment

Table 4.5: Background value and enrichment factor of sample analysed (modified after Sutherland 2000)

Element	Average Concentration (Cn)	Background Concentration (Bn) Rudnick & Gao (2003)	ER= Cn/Bn	Status
Ni	43.6	65.00	0.67	Depleted
Cr	110.375	92.00	1.20	Depleted
Zn	58.8	67.00	0.88	Depleted
W	5	1.00	5	Significant enrichment
Co	148.5	24.00	6.19	Significant enrichment
Rb	45.5	50.00	0.91	Depleted
Cu	28	28.00	1	Depleted
Nb	14.11	5.00	1.90	Depleted
Cd	7.8	1.00	7.8	Significant enrichment
Sn	2.9	1.00	2.9	Moderate enrichment
Pb	29.1667	17.00	1.72	Depleted
Mo	6.777778	1.10	6.16	Significant enrichment
V	60.5	97.00	0.62	Depleted
Au	0.077667	0.004	19.42	Significant enrichment
Ag	0.019	0.05	0.38	Depleted

It can be deduced from (Table 4.3) that the sediment sample from the study area are depleted in Ni, Cr, Zn, Rb, Cu, Nb, Zn, Pb, Ag, Sn, Nb and Mo, moderately enriched in Sn. The stream sediment samples however, are significantly enriched with Co, W, Cd, Mo, and very highly enriched in Au.

4.4.3.1 Significantly enriched elements

- **Cobalt (Co) –148.5ppm (Enrichment ratio ER: 6.19):** The concentration of cobalt ranges between 29ppm and 79ppm, with a mean value of 43.6ppm. The falls within the range of "significant enrichment" (Sunderland, 2000). The enrichment of of cobalt may suggest local geological sources rich in Co–bearing minerals, such anthropogenic sources like mining or industrial activities.

- **Cadmium (Cd) –7.8ppm (Enrichment ratio, ER: 7.8):** The concentration of cadmium (Cd) ranges from 4ppm to 12ppm, with average value of 7.8ppm. Cadmium (Cd) is significantly enriched which compared to the crustal average of 1.00ppm (Rudnick and Gao, 2003). This indicates possible anthropogenic contamination, as cadmium is often linked to industrial waste, metal smelting, and mining operations. It could pose significant environmental risks due to cadmium's toxicity.

Cadmium (Cd) is significantly enriched when compared to the crustal average of 1.00 ppm (Rudnick & Gao, 2003). This indicates possible anthropogenic contamination, as cadmium is often linked to industrial waste, metal smelting, and mining operations. This accumulation dynamic mirrors hazardous trace element profiles observed downstream across the local Chanchaga drainage channels (Alhassan & Amadi, 2024), where elevated urban runoffs alter baseline sediment matrices. It could pose significant environmental risks due to cadmium's toxicity.

- **Gold (Au) – approximately 0.08ppm (Enrichment ratio, ER: 19.42):** The Gold (Au) concentration is significantly enriched relative to the average crustal value of 0.004ppm (Rudnick and Gao, 2003). This could suggest the presence of placer deposits in the area, which might have economic significance.

- **Molybdenum (Mo) – approximately 6.78ppm (Enrichment ratio, ER: 6.16):** Elevated Molybdenum (Mo) level might be lined to natural occurrences in molybdenite–bearing mineralization or anthropogenic contamination input from mining or metalworking industries.

4.4.3.2 Moderately enriched elements

- **Tin (Sn) – approximately 43.6ppm (Enrichment ratio, ER: 0.67):** The moderately enriched tin (Sn) content in stream sediment suggests that there is a local or nearby source of tin-rich minerals, most likely cassiterite (SnO_2), which is the primary ore of tin. This enrichment typically indicates the presence of granitic or pegmatitic rocks in the drainage basin, as these rock types are commonly associated with tin mineralization. The moderate enrichment could also point to specific geological processes such as the erosion and weathering of these Sn-bearing rocks, with tin subsequently being transported and deposited in the stream sediment.

Since tin is relatively immobile under neutral pH conditions and tends to remain in the solid phase rather than being dissolved and transported in the water column, its moderate enrichment in the sediment indicates that Sn has likely been deposited close to its source. This low mobility implies that the tin-bearing rocks or mineralization zones are not far upstream from where the sediments were collected, suggesting proximity to tin deposits or areas of mineralization.

4.4.4.1 Depleted elements

- **Nickel (Ni) – approximately 43.6ppm (Enrichment ratio, ER: 2.9):** Nickel depletion could indicate a geological environment dominated by felsic rocks such as granites, which typically has lower concentration of elsic compared to mafic or ultramafic rocks. This depletion suggests that source rock contributing to the sediments are not rich in Ni-bearing minerals such as olivine and pyroxene commonly found in mafic rocks.

- **Chromium (Cr) – approximately 110.375ppm (Enrichment ratio, ER: 1.20):** Chromium depletion could suggests that the region the lack of mafic or ultramafic sources or chromite-bearing rocks, which are typically enriched in Cr. This could also suggests absence of industrial activities such as metal processing, chrome plating, or leather tanning, which are major source of chrome pollution.

- **Lead (Pb) – approximately 29.1667ppm (Enrichment ratio, ER: 1.72):** Lead (Pb) slight depletion in sediment suggests the contributing source rock, such as felsic might be poor in lead bearing minerals such as galena (PbS). This implies a geologic setting where Pb-bearing mineralization is absent or insignificant. Since Pb is often associated with anthropogenic pollution from sources such as paint and batteries.

- **Niobium (Nb) – approximately 14.11ppm (Enrichment ratio, ER: 1.90):** Niobium (Nb) depletion points to sediment source that lack significant amount of Nb-bearing minerals, such as columbite-tantalite, which are usually found in granite pegmatites. They may suggest the absence of Nb-rich rock type in the sediment or low concentration of these elements in the lower crust.

- **Rubidium (Rb) – approximately 45.5ppm (Enrichment ratio, ER: 0.91):** The Rb concentration is depleted compared to the crustal abundance by Rudnick and Gao (2003).This may indicate that the stream sediments are derived from rocks with low Rb content

- **Zinc (Zn) – approximately 58.8ppm (Enrichment ratio, ER: 0.88):** Although slightly below the crustal average, Zn is relatively stable. It suggests mineral enrichment or contamination, with potential source being natural weathering or mild anthropogenic inputs.

- **Vanadium (V) – approximately 60.5ppm (Enrichment ratio, ER: 0.62):** The depletion of V suggests minimal influence from sources or anthropogenic contributions.

- **Silver (Ag) – approximately 0.019ppm (Enrichment ratio, ER: 0.05):** Silver (Ag) is depleted compared to the crustal abundance. This could indicate limited silver-bearing mineralization in the area or absence of significant anthropogenic contamination (such as from electronics or silver mining)

The Trace Element Enrichment Map of the Study Area (Figure 4.8) reveals important spatial trends for Cobalt (Co) and Niobium (Nb) in the stream sediments. Cobalt (Co) shows significant enrichment in specific localized zones. These cobalt-rich areas could be of interest for further exploration, particularly for assessing the potential for cobalt mineralization, which is economically significant for various industries. The map highlights distinct geochemical behaviors of Co and Nb, providing insight into their distribution and potential provenance.

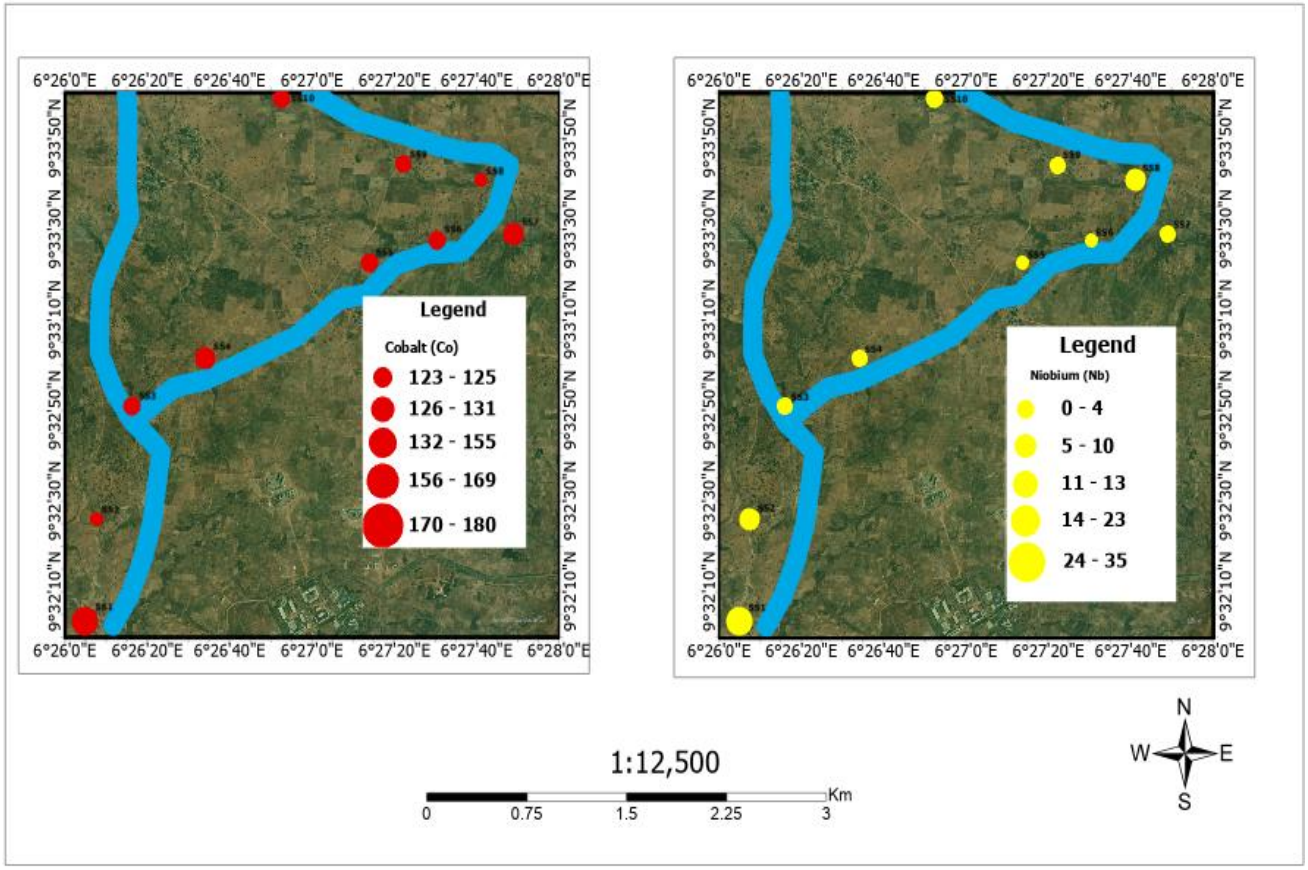


Figure 4.8: Enrichment map of Cobalt (Co) and Niobium (Nb).

4.4.4 Trace Element Mobility

Trace elements contained in stream sediments can exhibit varying degrees of mobility based on their chemical properties of the mobile phase, size, shape, density of the clastic grain in stream, and environmental conditions. Trace elements are categorized into three main group based on their mobility; highly mobile, moderately mobile, and immobile elements.

Nickel (Ni) is considered moderately mobile in acidic and reducing environments. Its depletion suggests it has been leached away due to chemical weathering processes, particularly if the stream sediment is in an acidic or low-pH environment. This indicates Ni has been transported away from its source.

Chromium (Cr) is relatively immobile, especially in oxidizing conditions. Its depletion in the stream sediment likely indicates that the environment may have favored its mobilization (such as under acidic conditions), causing it to be leached and transported away.

Zinc (Zn) is moderately mobile in acidic environments. Its depletion suggests that weathering has enhanced its mobility, allowing it to be removed from the sediment through leaching and transported downstream or out of the sediment.

Tungsten (W) is typically immobile under most environmental conditions. Its significant enrichment suggests that W has not been transported far and remains in the sediment, indicating limited mobility.

Cobalt (Co) is relatively immobile in neutral to alkaline environments but can be mobile in acidic conditions. However, its significant enrichment here suggests that it has remained in the stream sediment, implying low mobility in the prevailing environmental conditions.

Rubidium (Rb) is considered moderately mobile, especially in acidic environments. Its depletion points to leaching and transportation away from the sediment, indicating that it has been removed from the local environment due to its mobility.

Copper (Cu) is generally immobile in neutral to alkaline conditions but becomes mobile in acidic environments. Its depletion suggests that Cu has been leached out and transported away, driven by its increased mobility under acidic conditions.

Niobium (Nb) is highly immobile in most environmental conditions, particularly in neutral or alkaline settings. Its depletion suggests either the absence of Nb in the source or that some environmental factor has increased its mobility (e.g., acidic conditions), causing it to be transported away.

Cadmium (Cd) is highly mobile in acidic and oxidizing environments. Despite this, its significant enrichment implies that the local conditions may have limited its mobility, leading to its accumulation in the sediment rather than being transported away.

Tin (Sn) is generally immobile in natural environments. Its moderate enrichment suggests that Sn has not been significantly transported from its source, indicating low mobility in the current sediment environment.

Lead (Pb) is typically immobile under most natural conditions, but it can become more mobile in acidic or reducing environments. Its depletion suggests that it may have been mobilized and transported away from the stream sediment.

Molybdenum (Mo) is mobile in alkaline and reducing environments. Its significant enrichment suggests that the local conditions have prevented its mobility, allowing it to accumulate in the stream sediment.

Vanadium (V) is generally immobile in oxidizing and neutral conditions but can be mobile in acidic or reducing environments. Its depletion indicates that V has been mobilized, likely under acidic conditions, and transported away from the sediment.

Gold (Au) is highly immobile in most environmental conditions. Its significant enrichment suggests that it has not undergone transport, confirming its very low mobility and close proximity to its source.

Silver (Ag) is moderately mobile in acidic and reducing environments. Its depleted status implies that it has been extensively leached and transported out of the sediment, likely due to enhanced mobility in the prevailing environmental conditions.

Nickel (Ni), Chromium (Cr), Zinc (Zn), Rubidium (Rb), Copper (Cu), Lead (Pb), Vanadium (V), and Silver (Ag) tends to be highly mobile (more likely to be leached and transported). Cadmium (Cd) and

Cobalt (Co) are moderately mobile elements (under certain conditions), while Tungsten (W), Tin (Sn), Molybdenum (Mo) and Gold are immobile elements (remain close to their source).

This resulting pattern suggests that elements like Nickel (Ni), Chromium (Cr), Zinc (Zn), Rubidium (Rb), Copper (Cu), Lead (Pb), Vanadium (V), and Silver (Ag) have been mobilized and transported away due to environmental conditions that favour their mobility (acidic or reducing environments). In contrast, elements like Tungsten (W), Tin (Sn), and Gold (Au), which are generally immobile, have remained in the stream sediment, indicating that they have not been significantly transported from their provenance.

The Trace Element Enrichment Map of the Study Area (Figure 4.7) reveals important spatial trends for Cobalt (Co) and Niobium (Nb) in the stream sediments. Cobalt (Co) shows significant enrichment in specific localized zones. The enrichment of cobalt suggests limited mobility in the stream, allowing it to accumulate near its source. These cobalt-rich areas could be of interest for further exploration, particularly for assessing the potential for cobalt mineralization, which is economically significant for various industries.

In contrast, Niobium (Nb) is depicted as depleted across most of the study area.

The widespread depletion of niobium indicates either its low natural abundance in the source rocks or higher mobility, which may result in its leaching and removal during weathering and sediment transport processes. The depletion pattern suggests that the region may lack significant felsic or alkaline igneous rock sources, which are typically rich in niobium-bearing minerals.

Overall, the map highlights distinct geochemical behaviors of Co and Nb, providing insight into their distribution and potential provenance. Cobalt's enrichment points to localized mineralization, while niobium's depletion reflects its lower concentration or greater mobility within the study area.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study area, Futminna, Gidan Kwano campus, Niger state (part of Zungeru sheet 163SE) is made up of igneous rocks, the majority of which have formed continuous ridge. The main lithological unit which includes granite, granitoid and diorite, which were identified after the study in hand specimen of which granitoid and granite dominates. (Zungeru sheet 163SE).

The geochemical analysis of the stream sediments reveals a mixture of depleted and enriched trace elements, indicating diverse geological sources and geochemical processes. Elements such as Tungsten (W), Cobalt (Co), Cadmium (Cd), Molybdenum (Mo), and Gold (Au) are significantly enriched, suggesting proximity to mineralized zones or hydrothermal systems. Conversely, elements like Nickel (Ni), Chromium (Cr), Zinc (Zn), Rubidium (Rb), Copper (Cu), and Vanadium (V) are depleted, indicating either low source contributions or their greater mobility and leaching during weathering.

The major oxide composition, with high Silica (SiO_2) and Iron oxide (Fe_2O_3), points to the dominance of quartz and iron-bearing minerals in the sediments. Low levels of Calcium oxide (CaO), Magnesium oxide (MgO) (variable), and Alumina (Al_2O_3) suggest limited contributions from carbonate or feldspathic sources, reflecting the prevalence of siliceous material in the sediment.

Elevated levels of Phosphorus pentoxide (P_2O_5) and Sulfur trioxide (SO_3) could indicate inputs from phosphatic or sulfide mineralization, with the latter possibly linked to anthropogenic activities. The low concentrations of Potassium oxide (K_2O) and Sodium oxide (Na_2O) suggest minimal input from feldspar-rich rocks or extensive leaching of alkali elements during transport.

5.2 Recommendation

Based on the geochemical analysis of the stream sediments, it is recommended that further exploration be conducted in areas showing significant enrichment of trace elements such as Tungsten (W), Cobalt (Co), Cadmium (Cd), Molybdenum (Mo), and Gold (Au). These enrichments indicate the potential for localized mineralization, making these zones promising targets for detailed geological mapping and potential mineral resource evaluation, especially for metals with economic importance such as tungsten, cobalt, and gold.

Given the depletion of key trace elements like Nickel (Ni), Chromium (Cr), Zinc (Zn), and Copper (Cu), which are typically sourced from mafic or ultramafic rocks, it is recommended that future studies investigate the upstream geology to better understand the factors contributing to this depletion. This may include assessing the role of weathering, sediment transport, and potential leaching of these elements in the area.

The high concentrations of Silica (SiO_2) and Iron oxide (Fe_2O_3) in the sediments suggest that the area is influenced by siliceous and iron-rich rock formations. It is recommended that sediment provenance studies be expanded to trace the specific lithological sources contributing to these oxides. Additionally, the high levels of Sulfur trioxide (SO_3) and Phosphorus pentoxide (P_2O_5) warrant further investigation to determine whether these are of natural origin or linked to anthropogenic activities such as mining or industrial discharge.

Lastly, environmental monitoring should be considered, particularly in regions with significant enrichment of elements like *Cadmium (Cd)***,** due to its potential environmental and health impacts. Regular water and sediment quality assessments can help track the influence of these elements on the local ecosystem and inform mitigation strategies if necessary.

Data Availability

The primary geochemical and mineralogical datasets generated and analyzed during the current study—including raw X-ray fluorescence (XRF) major oxide weight percentages, trace element concentrations (ppm), and localized enrichment mapping coordinates—are fully included within this manuscript (Table 4.1, Table 4.2, Table 4.3, and Table 4.5). Additional background validation values and baseline master-cell monitoring fields are derived from open-access crustal abundance frameworks published by Rudnick and Gao (2003) and Wedepohl (1995). Any further technical queries regarding the geological field mapping files or raw laboratory outputs can be requested directly from the corresponding author.

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