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Research Article

Economic Potentials of Migmatites Around Nabardo Area, Bauchi Northeastern Nigeria

Johnson Kayode Ayeni[*]

Department of Geology, Lead City University, Ibadan, Nigeria

Abstract

This study investigates the Nabardo area, northeastern Nigeria for the economical potentials of the migmatites. Field evidence suggests that the study area has undergone an episode of metamorphism and deformations as depicted by the structural features like preferred orientation of the mineralogical and lithologic units. At least two deformational episodes (D1 and D2) which produced S1 and S2 planar fabrics. It was also observed from the field measurements, that the main structural trend within the study area is NNE/SSW. Representative rock samples were divides into several groups. From these groups, selected samples were studied under thin section and analyzed for XRF geochemistry. The petrographic study under thin section reveals the presence of felsic magma with identification of mineral suites of K- feldspar, biotite, quartz and accessory minerals like Zircon and garnet, indicating high grade of metamorphism. Geochemistry data plotted on major tectonic discrimination diagrams gives tholeiite and calc alkaline nature for the protolith of the selected samples. Based on the geochemical plots and REE signatures, fractional crystallization alone cannot account for these migmatites but rather partial melting and metamorphic differentiation are the major source of these migmatites. They are formed by partial melting of mafic rich protolith that were formed during the Pan-African orogeny. Using the first and second order classification of Sawyer, as a guide for morphological classification of the migmatites in the study area, the migmatites are grouped into metatexites, diatexites and nebulites. Results obtained from the geochemistry using concentration map inferred mineralization potential of Nickel (Ni), Chromium (Cr), Zinc (Zn) and industrial minerals.

Keywords

Nabardo, Migmatites, Nickel (Ni), Chromium (Cr), Zinc (Zn)

1. Introduction

The area of investigation is typical of the Precambrian to lower Paleozoic rocks of northern Nigeria with a type locality in Bauchi state. This region is underlained by migmatites, gneisses and metasediments of Precambrian age which have been intruded by a series of granitic rocks of late to lower palaeozoic age. The oldest rocks are represented by a series of older metasediments and gneisses believed to be of Birrimian age and older. These rocks have been variably metamorphosed and granitised through at least two tectonic - metamorphic cycles so that they have been largely converted to migmatites and granite - gneiss. Younger metasediments, believed to be upper Proterozoic in age, were deposited on this granitised basement and filled along with it during the pan - Africa

[*]Correspondence: Johnson Kayode Ayeni (ayeni.johnson@lcu.edu.ng)

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orogeny. They are of low metamorphic grade and are now represented as synclinal trough among older rocks in northern Nigeria. Intrusive into both the basement and the younger super crustal cover is a series of basic, intermediate and acid plutonic rocks known as the Older Granites. The youngest rocks in the area belong to a suit of volcanic rocks intruded into Older Granite bodies during Lower Palaeozoic epirogenic uplift following the Pan - African orogen (c.600 million years) as deduced from the radiometric data discussed by Rahaman [9]. However, Ogezi [4] has, on the basis of Rb/Sr isochron age of 1050 + 64 Ma obtained from the Maru phyllite, suggested the evolution of Kibaran event that predated the Pan African event in Nigeria. These palaeozoic and Precambrian rocks can be divided into four major groups; the basement complex (senso strict), younger metasediments, the older granite series and the younger volcanic rocks. Evidence of Pan- African reworking have been seen in petrographic studies displaying medium to upper-amphibolite-facies metamorphism. The migmatite-gneiss complex has ages ranging from Pan-African to Eburnean. Lithologically, similar rocks in other parts of Nigeria especially in the northeast and southeast, have given only the Pan-African age Tubosun [10]. Mehnert [11] (employs migmatite terminology based on their macroscopic appearance. Hasalov á[12] uses two major deformation events recorded in this gneiss-migmatite complex.

Migmatites typically contain components such as quartz, feldspar, and mica, along with darker mafic minerals in the melanosome. Varieties include banded orthogneiss, diatexites, nebulites, and pegmatites often found associated with younger granitic intrusions. Their formation commonly occurs in Pan-African aged basement complexes, particularly noted in regions like northern Nigeria (Bauchi State, Nabardo area area), where migmatitic terrains are accessible.

Migmatites form a significant part of the Basement Complex in northern Nigeria. They are characterized by partial melting and deformation, resulting in complex lithological and structural features with potential to host valuable mineral deposits. Despite their extensive distribution, the economic significance of migmatites in this region remains underexplored. Recent studies focused on the Nabardo area have revealed morphologies typically classified as banded orthogneiss, diatexites, pegmatite ridges, and nebulite, with geochemical signals of associated rare earth elements (REEs).

2. Geology of the Study Area

The study area is located on latitudes 10^0 9’00” N & 9^0 12’00” N and longitudes $9^0$23’00” E & $9^0$26’00” E (Figure 5). It covers an area of approximately 42.55km^2 with an average elevation of 900m above sea level. The study area which is part of Sheet 148, Toro SE is entirely typical of the Nigerian Basement Complex and is underlain by the following rock units. *Migmatitic Gneiss, Granite gneiss, mica schist and porphyritic granite.*

2.1. Migmatite Gneiss

The migmatites / gneisses in this group, Oyawoye [7], recognized two major types of gneisses which include: the biotite gneiss and the banded gneiss. He also grouped the migmatites into two types, namely; the lit-par-lit gneiss and the migmatitic gneiss. In the lit- par-lit gneiss, according to the author, the paleosome (a granulite or high-grade schist of the ancient metasediment) occurs with quartz-feldspar veins and dykes in parallel orientation. In the migmatitic gneiss, the paleosome also is quartz-microcline veins but, the melanosome which is biotite or banded gneiss, is dissected into irregular blocks. On the basis of petrography, Oyawoye [7] suggested that the gneisses and migmatites originated through silica-potash metasomatism. Areas of the Jos-Bauchi transect has revealed several occurrences of granulite facies rocks within high-temperature amphibolites facies rocks and anatexites. It exposes high-grade metamorphic rocks of contrasted character depending on their distance from Neoproterozoic monzonitic plutons. In this area a medium to high pressure and temperature amphibolite and granulite facies have been recognized in different localities with the formation of orthopyroxene-bearing tonalitic-dioritic leucosomes, garnet-bearing and the emplacement of charnockitic-monzonitic plutons (Ferre) [14].

The Migmatite gneiss which is a member of the migmatite - gneiss complex constitutes the largest lithological unit mapped within the study area. It is a heterogeneous rock with different lithological components and occupies about half (45%) of the study area. They consist of felsic components which are pegmatitic, aplitic and granitic in composition and mafic components that are basic in composition. Texturally, they are medium to coarse grained and occurs as low-lying to gentle upland in most of the exposures. The migmatite (Figure 1) gneiss is characterized by a variety of structures and textures. The well-foliated gneissic portion and the mafic component constitute the paleosome while the granitic and felsic component constitute the neosomes. The previous assume a general trend of NW/SE with few exceptions in NE/SW direction. It is pertinent to know also that almost E-W structures were also observed which forms relics of the older structure believed to have been affected by the eburnean (possibly) orogenic event. They are generally elongated along the strike of foliation for several meters. They are generally grey in colour and composed of feldspar, quartz and mafic minerals. Biotite and hornblende are the main mafic minerals and where their content is sufficiently abundant; the rock assumes a dark-grey colour. The foliation is marked by alternating bands of felsic and mafic materials ranging from millimetric to centimetric in widths. The felsic components comprise of quartzo-feldspathic materials, usually medium to coarse grained. They are layered with the mafic component band which is very dark, fine to medium grained and probably of amphibole/biotite composition. The fine-grained granites were observed as intrusive bodies into the gneisses as part of the lithological components together with pegmatites (and quartzo-feldspathics) which occur mainly as veins; some are large and extensive within some of the encountered outcrops.

Figure 1. A low lying exposure of migmatite at N10^0 09'19.2", E009^0 23'44.3", 646m showing the gneissic and amphibolite portion as A and B respectively around Nabardo area.

2.2. Granite Gneiss

This unit outcrops mainly at the north central and southeastern portion of the mapped area occupying about 40% of the landmass. It shares boundary mainly with the migmatite gneiss and porphyritic granite. It occurs as low-lying and gentle uplands of varying sizes. The rock is medium to coarse grained, light grey to pinkish in colour due to abundance of orthoclase feldspar. The exposures show a weak foliation of light and dark materials. The foliation is marked by continuous mineralogical bandings on a millimetric to centimetric scale. The light colored bands varying in widths from about 0.5cm to 2.5cm and are rich in quartz and feldspars while the dark colored bands of about 0.4cm-1.8cm wide are rich in biotite and other ferromagnesian minerals. Some of the bands are wavy and discontinuous. The general trend (strike of foliation) is NW/SE. Mineralogically; the granite gneiss is composed of alkali feldspar, quartz, plagioclase, biotite and some other mafic minerals.

2.3. Mica Schist

About 5% of the study area is covered by mica schist outcropping mainly at the western flank of the mapped area. Most of the exposures occur as a low-lying, highly weathered rock some being exposed along the stream channel while others are seen with lots of quartz rubbles surrounding it. The mica schist generally trends in a NW - SE direction, dipping mostly westwards. The schist foliation is defined by its schistocity (Figure 2) which is demonstrated by the parallel alignment of platy mineral grains. The texture is mostly fine grained but, in some cases, fine to medium. The minerals present which can be seen megascopically are muscovite, biotite and quartz. The color varies from light grey to dark grey.

Figure 2. *At location 5 showing a well foliated, weathered schist with a trend of 150^0 at $N10^0$ 10' 27", $E009^0$ 23'12.1", 657m, Nabardo area.*

2.4. Porphyritic Granite

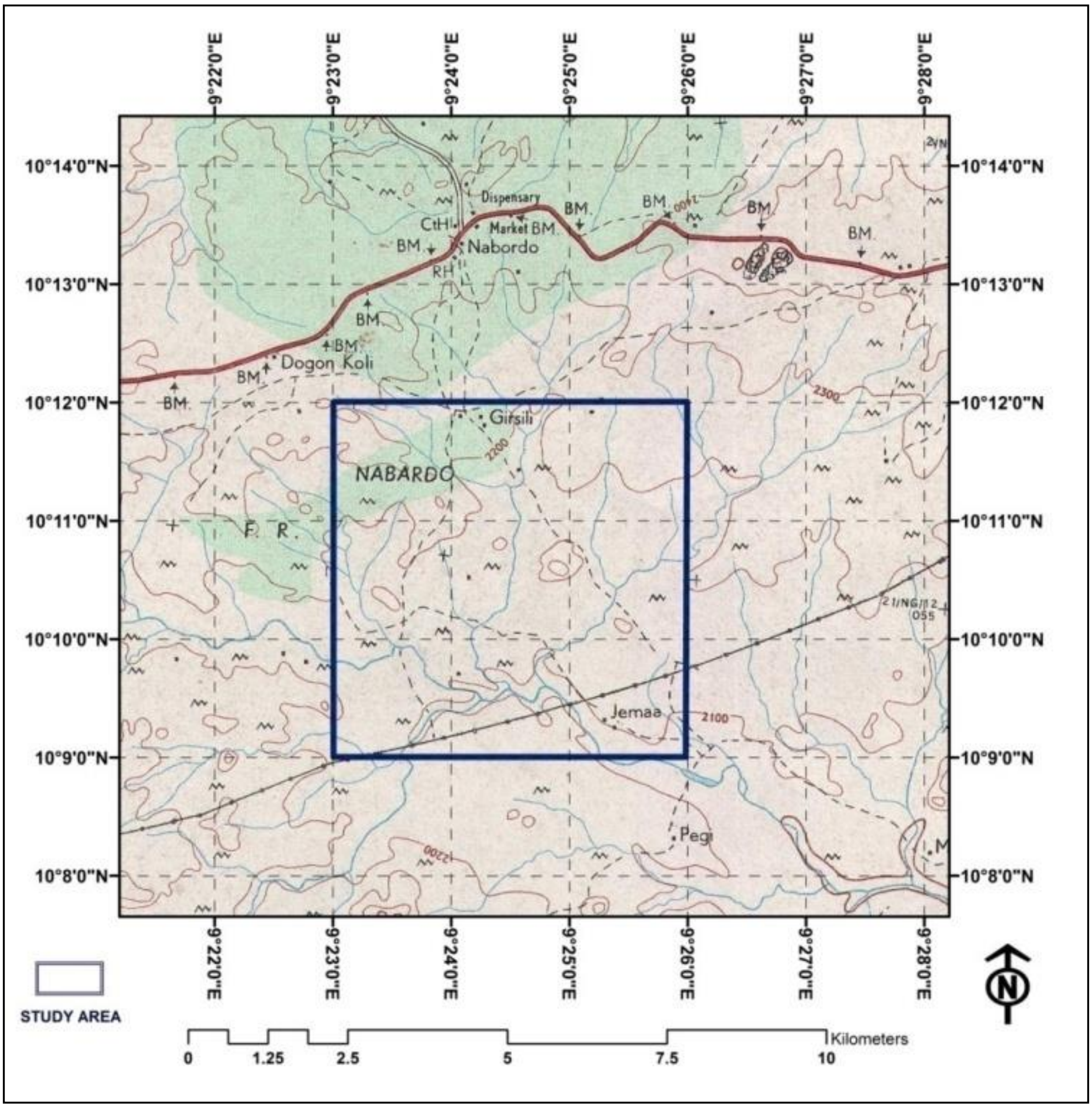

Figure 3. *Location map of Nabardo and its environs drawn from ArcMap 10.3.*

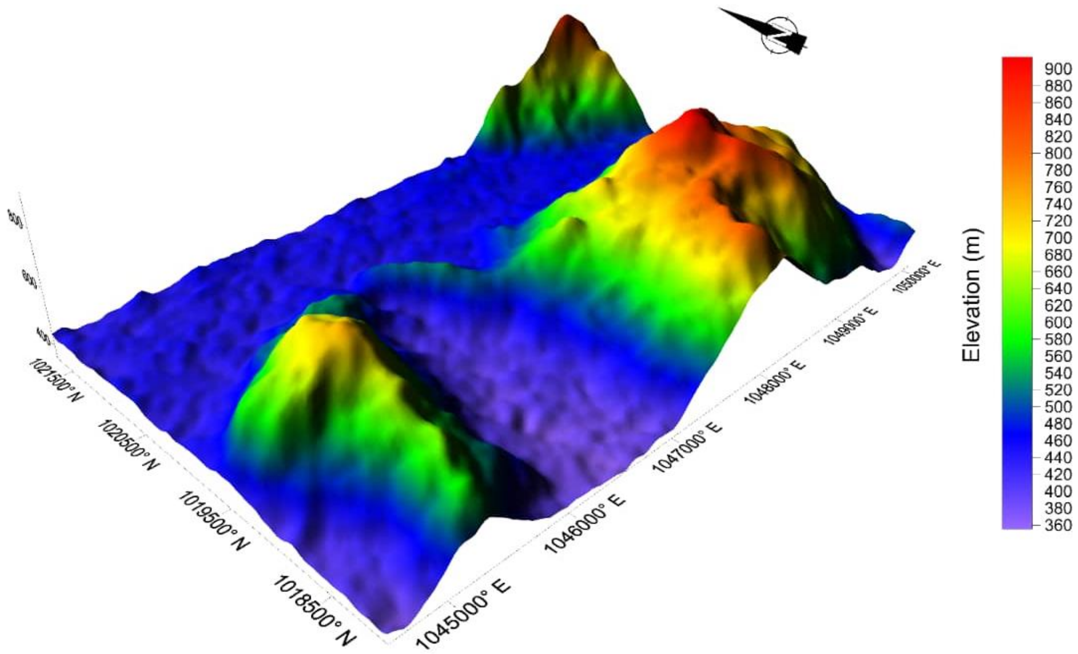

Figure 4. Digital Elevation model of the study area.

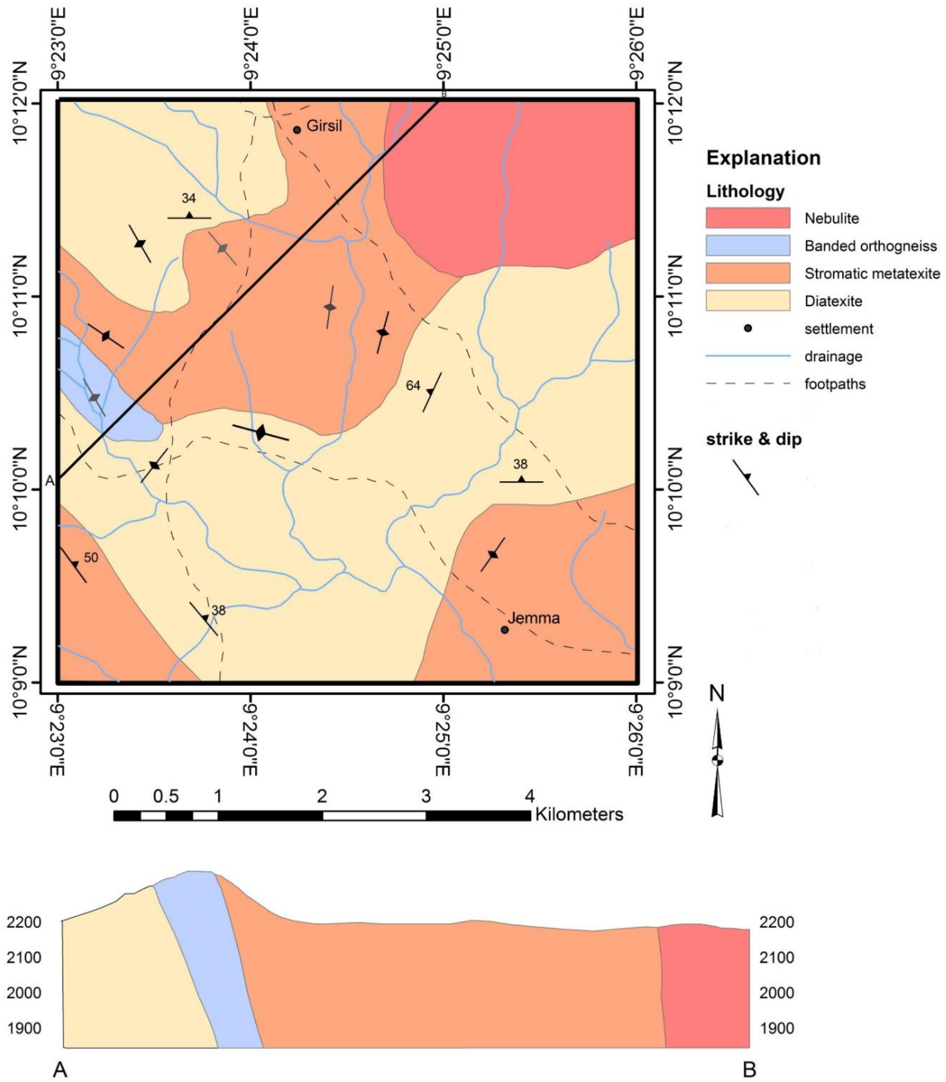

Figure 5. Geological map of the study area.

This unit outcrops at the extreme northeastern axis of the study area occurring prominently as hilly and bouldery outcrops. However, flat lying - low lying were observed in some other localities. It is coarse to porphyritic texture and leucocratic/light in colour. They are fractured and well jointed. The rock composed mainly of whitish feldspar (plagioclase) phenocrysts, Quartz and Biotite forming the interlocking ground mass/matrix of the rock. The feldspar phenocrysts are randomly distributed (no preferred orientation) in most outcrops mapped and are densely populated or concentrated than the ground mass/matrix of the rock. The feldspar phenocrysts are mainly whitish type; the shapes vary from angular to oval-spherical, while the elongated ones are rectangular and are mostly common. The sizes varied, they range from 1.5cm-3cm by 5cm-8cm, and are randomly distributed. They constitute about 30- 40% by volume of most of the porphyritic granite outcrops. The rocks were established as migmatites and gneiss.

With respect to field observation, petrographic study and fabrics, the lithologies encountered were further subdivided into categories: *Metatexite- Diatexite and Nebulite.*

3. Geochemical Characteristics

The use of geochemistry in geological mapping/investigation cannot be overemphasized as it concerns the quantities, distribution and circulation of chemical elements in the natural domains like soil, water, atmosphere, vegetation and rocks. In continuation of the research work within the study area, some rock samples were selected for geochemical studies after carrying out a detailed field mapping. The samples selected were fresh representative rocks that cover the geology of the whole study area. The selected rock samples were sent to National Geoscience Research Laboratories of Nigerian Geological Survey Agency for detailed analysis into major oxides and trace element. The geochemical analysis through XRF indicated high silica (SiO_2) and aluminum oxide content (Al_2O_3), typical of metasedimentary sources. Based on the geochemical plots and REE signatures fractional crystallization alone cannot account for these migmatites but rather partial melting together with fractional crystallization are the major source of these migmatites. They are formed by partial melting of gabbroic protolith that crystallized from a mantle derived magma that was contaminated by crustal materials at a convergent plate boundary during the Pan-African orogeny.

4. Mineralization Potential of the Study Area

Mineral deposits are of various types and can be grouped according to their geological environment or origin into the following: *magmatic, hydrothermal, sedimentary, metamorphic and residual* mineral deposits. *Magmatic* deposits are those formed by igneous processes. They occur mainly as disseminations, layered bodies or massive ores in igneous rocks and formed by processes of crystal settling, dissemination, liquid immiscibility and crystallization fractionation in magma. *Hydrothermal* deposits are formed by hot, ore bearing fluids from various sources, including magmatic, connate seawater and meteoric water. They are usually emplaced in pre-existing rock as lodes veins. *Metamorphic* deposits are products of recrystallization of existing minerals or formation of new minerals due to the effects of increase in temperature and or pressure. *Residual* deposits accumulate at or near the earth's surface by chemical weathering, leaching and concentration of useful materials through secondary enrichment.

In interpreting element's concentration in earth's sampled materials and considering its significance in a study area, a basis of comparison is required. The average crustal abundance of elements in the earth serves that purpose in this study since our sampling media is a rock sample.

The distribution maps of the selected elements are herein presented in the Table 1 below:

Table 1. *Summary of the basic statistics for rock geochemical data in the study area.*

Elements (ppm)	**Zn**	**Ni**	**Cr**	**Co**	**Mn**	**V**
Min	6.42	8.85	10.26	2.43	42.01	23.134
Max	132.2301	654.45	601.46	26.6	878.49	130.4056
N	30	30	30	30	30	30
Average	55.92217	62.80874	96.26926	13.715	496.484	69.534
median	74.39	33.477	92.30	12.98	472.65	68.255
Std dev	45.5167	125.3678	116.0681	7.41076	273.3736	32.60255
Average Crustal Abundance	70	84	102	25	950	120

4.1. Zinc - Zn

Zinc is a ubiquitous element occurring in many rocks in Earth's crust and as a trace constituent in the oceans and the atmosphere. Zinc is commonly found in mineral deposits along with other base metals, such as copper and lead. Sphalerite, a zinc sulfide mineral, is the primary ore mineral for zinc and has been source for most of the world's production.

Most zinc is used to galvanise other metals, such as iron, to prevent rusting. Galvanised steel is used for car bodies, street lamp posts, safety barriers and suspension bridges. Large quantities of zinc are used to produce die-castings, which are important in the automobile, electrical and hardware industries. Zinc is also used in alloys such as brass, nickel silver and aluminum solder.

Zinc oxide is widely used in the manufacture of very many products such as paints, rubber, cosmetics, pharmaceuticals, plastics, inks, soaps, batteries, textiles and electrical equipment. Zinc sulfide is used in making luminous paints, fluorescent lights and x-ray screens.

Zinc is widely distributed within the area of study (Figure 6) and the values range from 6.42 ppm - 132.23 ppm with a mean value of 55.922 ppm. In comparing the median value (74.39 ppm) with the average crustal abundance (70ppm), the abundance of zinc is considered to be relatively high. From the concentration map, areas with values above the crustal abundance are underlained by the metatexites and diatexites. Though, the high values could have been as a result of anthropogenic effect or zinc released from decayed leaves in the study area might be the source of high zinc values rather than mineralization. Further exploration is however suggested here.

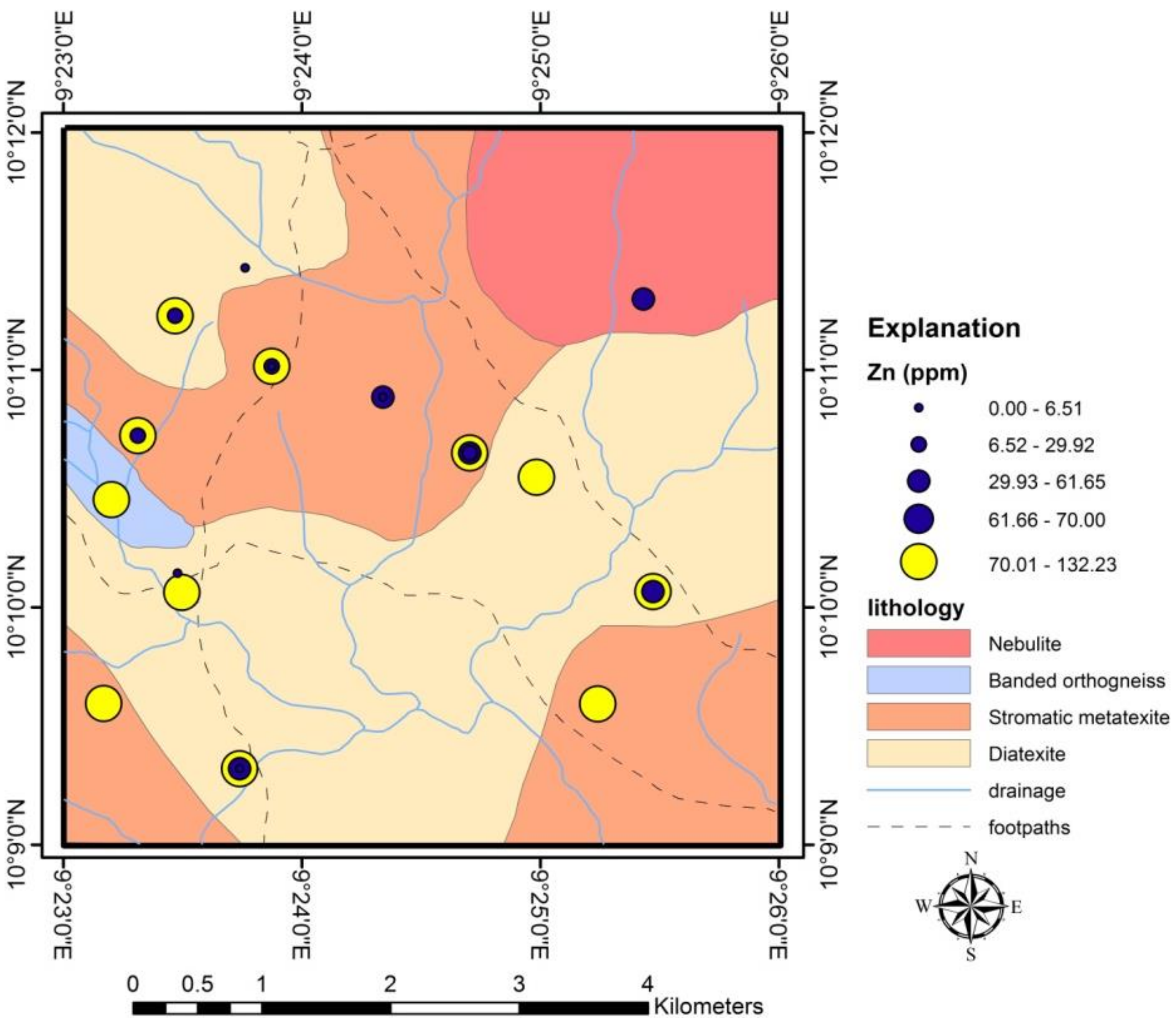

Figure 6. Point symbol map of zinc superimposed on the geology.

4.2. Nickel - Ni

Nickel (Ni) is a ferro-alloy metal used mainly in the production of stainless steel. It resists corrosion and its found useful as plating material to protect other metals. Geologically, nickel is most commonly found within ultramafic and mafic igneous rocks or their metamorphic equivalent and show a close affinity with chromium (Cr) in the mode of occurrence. However, unlike chromium, nickel occurs in mineral deposits predominantly as nickel sulfides such as pentlandite {(Fe, Ni_9)S)$_8$} and heazlewoodite (NiS_2), but rarely as an oxide, and even rarer still as native metal or Ni-Fe alloy Krishnarao, [2]. So, it can be stated unequivocally that the occurrence of native nickel in mineral deposit is extremely rare. Garnierite, a Ni-bearing iron silicate containing about 1-2% Ni is found in lateritic nickel deposits. Nickel mineralization occurs within the Precambian Basement Complex of north central Nigeria which is composed of mostly Archean migmatite- gneiss complex, Proterozoic schist belts and Pan African Older Granite intruded by minor meta- ultramafic bodies and pegmatite dikes [1, 8].

Nickel was detected in almost all the samples analyzed with values ranging from 8.85 ppm - 654.45 ppm with a mean value of 62.8 ppm. In comparing the median value (33.477 ppm) with the average crustal abundance (84 ppm), the abundance of nickel is considered to be relatively low. Though from the concentration map (Figure 7), few isolated values are higher than the crustal abundance which suggest further exploration.

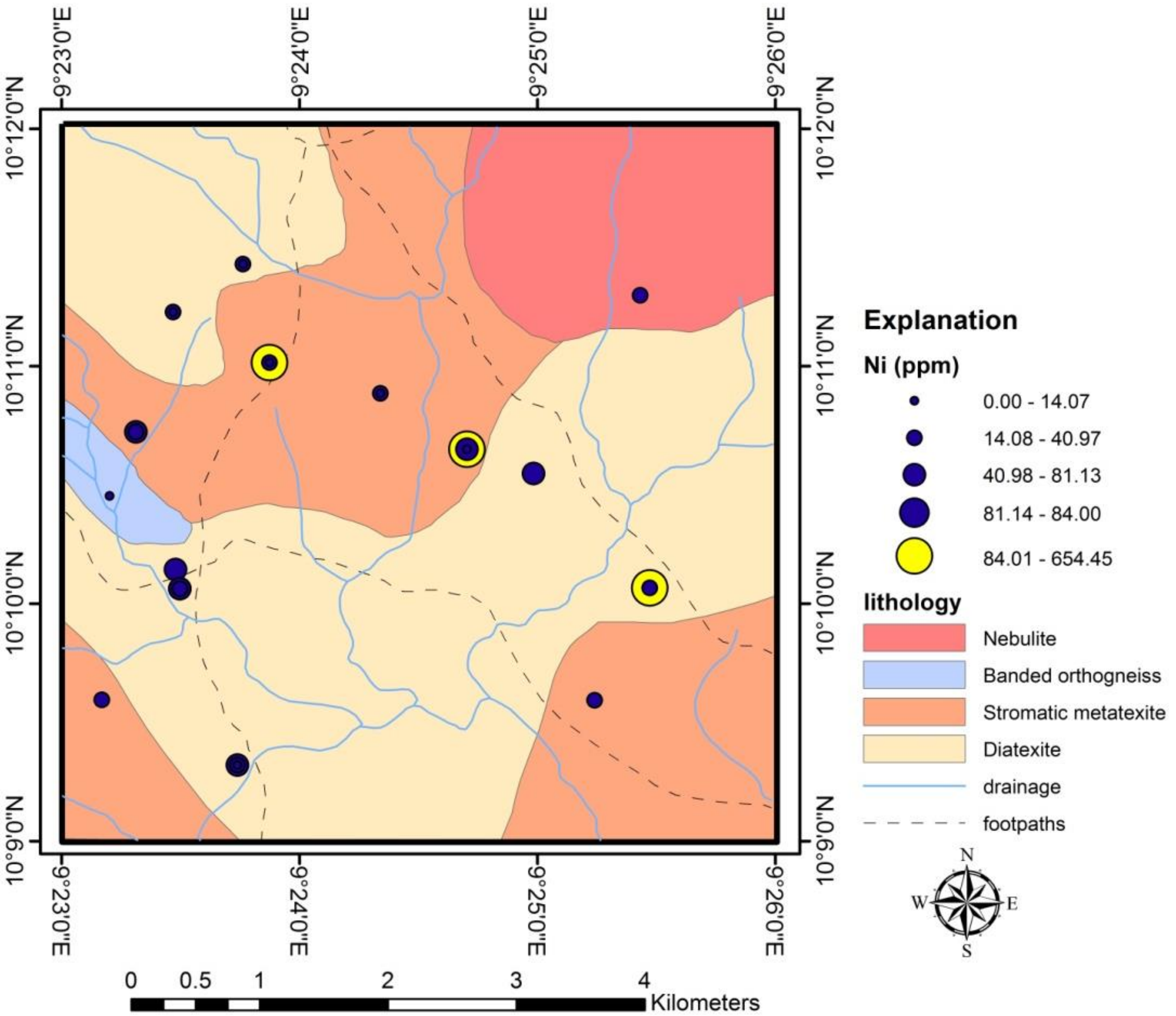

Figure 7. *Point symbol map of Nickel superimposed on the geology.*

4.3. Chromium - Cr

Chromium (Cr) is a ferro-alloy widely used in the production of stainless steel and for plaiting of other metals. Chromite ($FeCr_2O_4$), the principal ore of chromium is found mostly within mafic and ultramafic intrusive bodies (dunite, peridotite, and pyroxenite) or their metamorphosed equivalents (serpentine, talc schist). Mineralization is usually in form of dissemination, lenses or layers and pod of chromites (> 90% chromite rock) within the host, usually layered intrusive complexes.

In Nigeria, occurrences of disseminated chromite have been reported in the serpentinite talc schist bodies intercalated within the Proterozoic schist belts of northwestern Nigeria, [3, 5, 6, 13].

In the study area, Chromium was detected in almost all the samples analyzed with values ranging from 10.26 ppm - 601.46 ppm with a mean value of 96.269 ppm. In comparing the background value (92.30 ppm) with the average crustal abundance (102 ppm), the abundance of chromium is considered to be relatively low. The concentration map (Figure 8) shows some isolated values higher than the average crustal abundance being underlained by both metatexites and diatexites. Chromium mineralization is very unlikely in this area. The few anomalous values of Cr may be due to co-precipitation of Cr with manganese hydroxide or Fe-oxide. Further investigation by surface drilling may lead to the discovery of more viable subsurface mineralization.

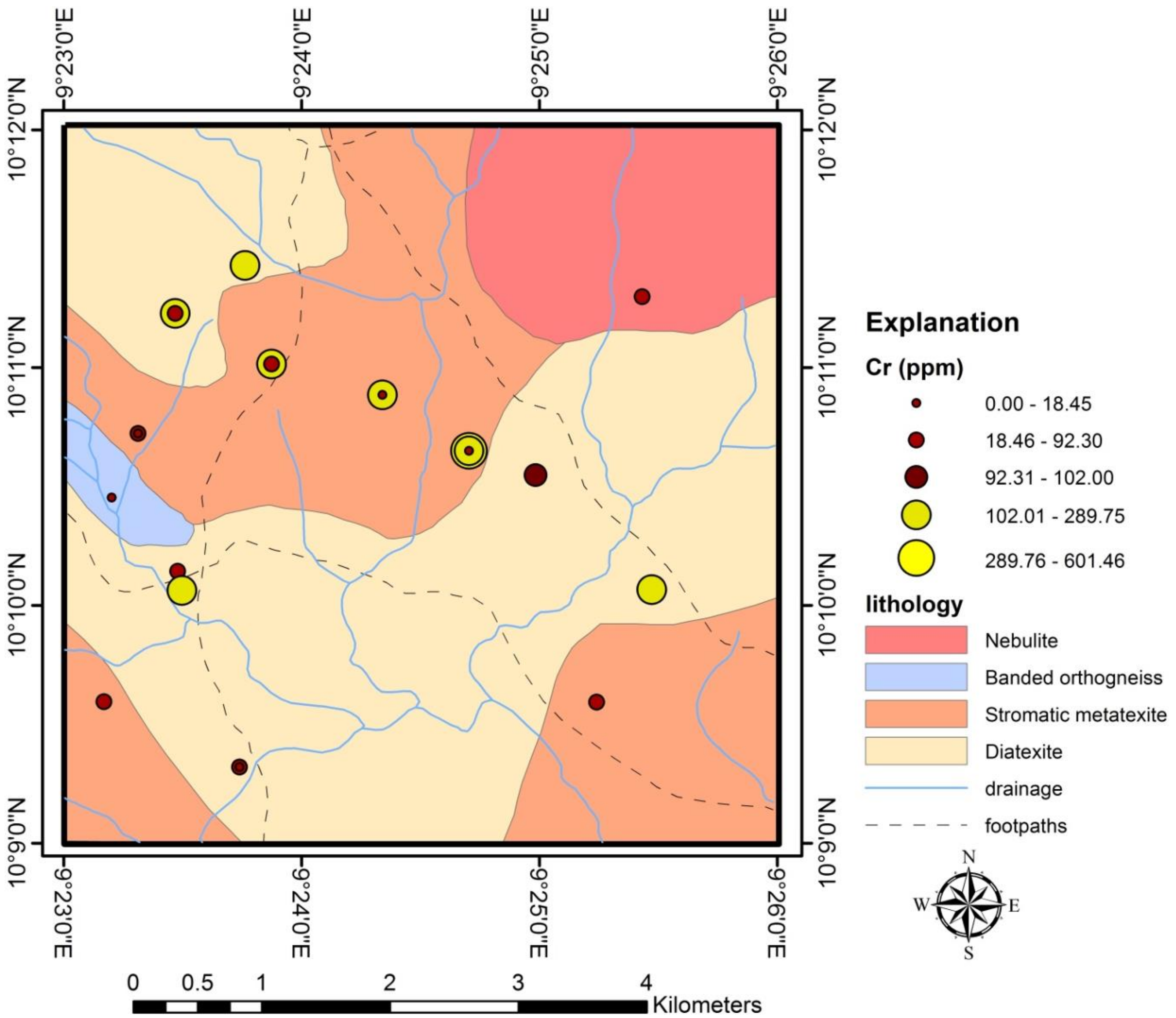

Figure 8. Point symbol map of Chromium superimposed on the geology.

4.4. Cobalt - Co

Cobalt concentrations range between 2.43 ppm - 26.6 ppm with a mean value of 13.715 ppm. In comparing the background value (12.98 ppm) with the average crustal abundance (25 ppm), the abundance of cobalt is considered to be relatively low. The concentration map (Figure 9) shows only one isolated value higher than the average crustal abundance being underlained by metatexite. The anomalous value is thus insignificant and may be due to co precipitation of cobalt with Mn- and or Fe-oxides.

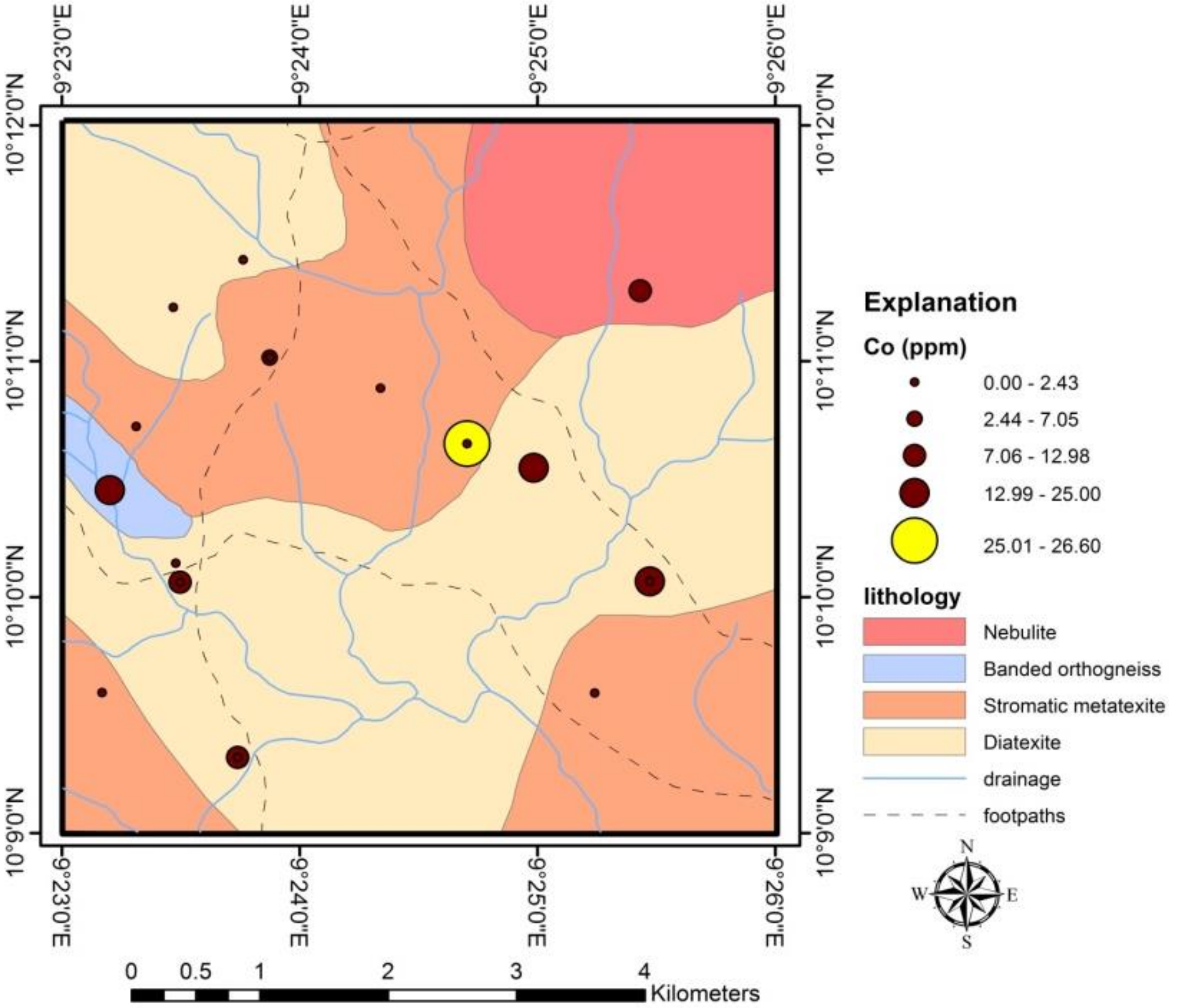

Figure 9. Point symbol map of Cobalt superimposed on the geology.

4.5. Manganese - Mn

Manganese concentrations range between 42.01 ppm - 878.49 ppm with a mean value of 496.484 ppm. In comparing the background value (472.65 ppm) with the average crustal abundance (950 ppm), the abundance of manganese is considered to be relatively low. The concentration map shows no value higher than the average crustal abundance.

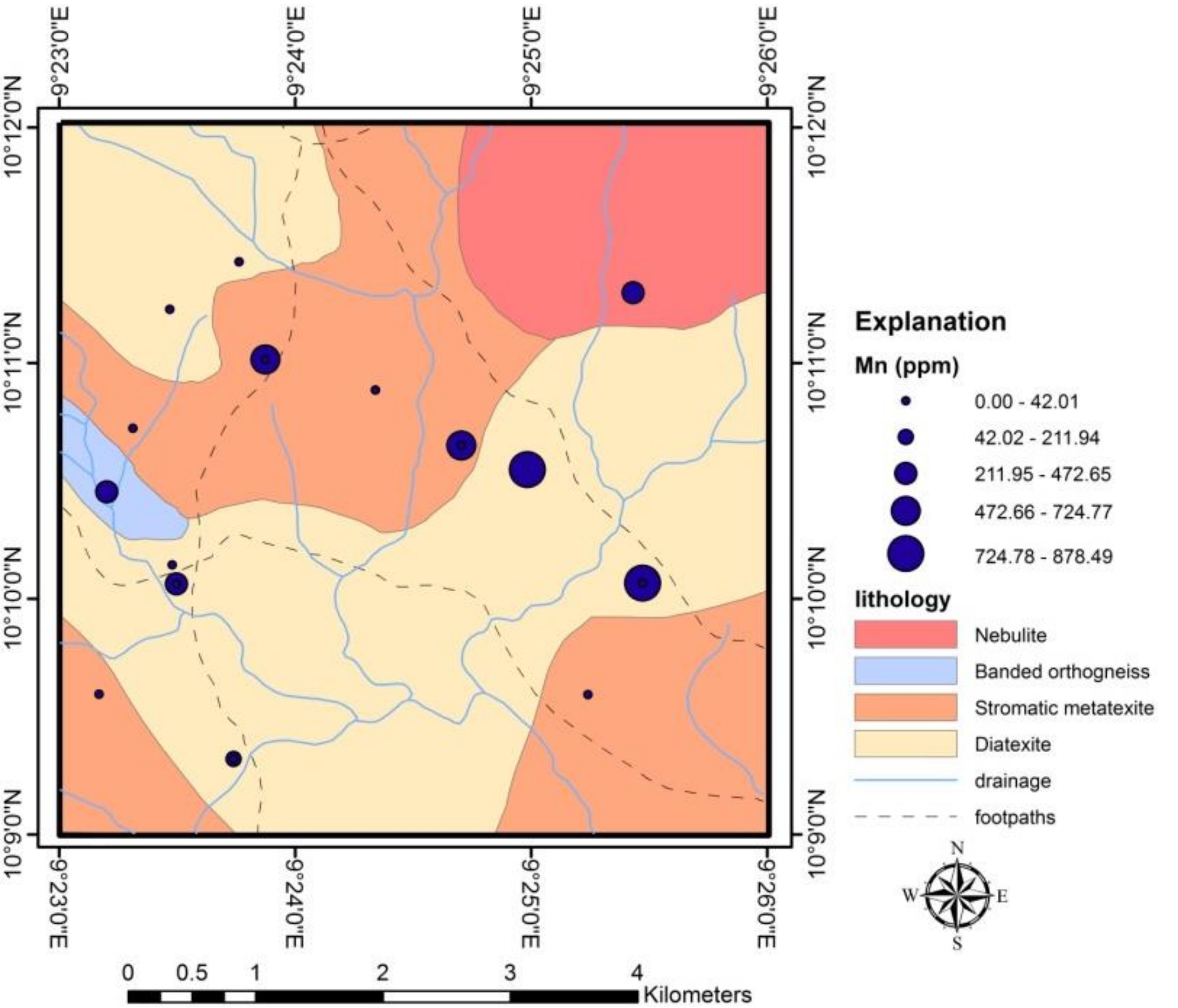

Figure 10. *Point symbol map of manganese superimposed on the geology.*

4.6. Vanadium - V

Vanadium concentrations range between 23.134 ppm - 130.4 ppm with a mean value of 68.255 ppm. In comparing the background value (69.534 ppm) with the average crustal abundance (120 ppm), the abundance of cobalt is considered to be relatively low. The concentration map (Figure 11) shows only one isolated value higher than the average crustal abundance being underlained by diatexite. This obviously is no indication of any mineralization.

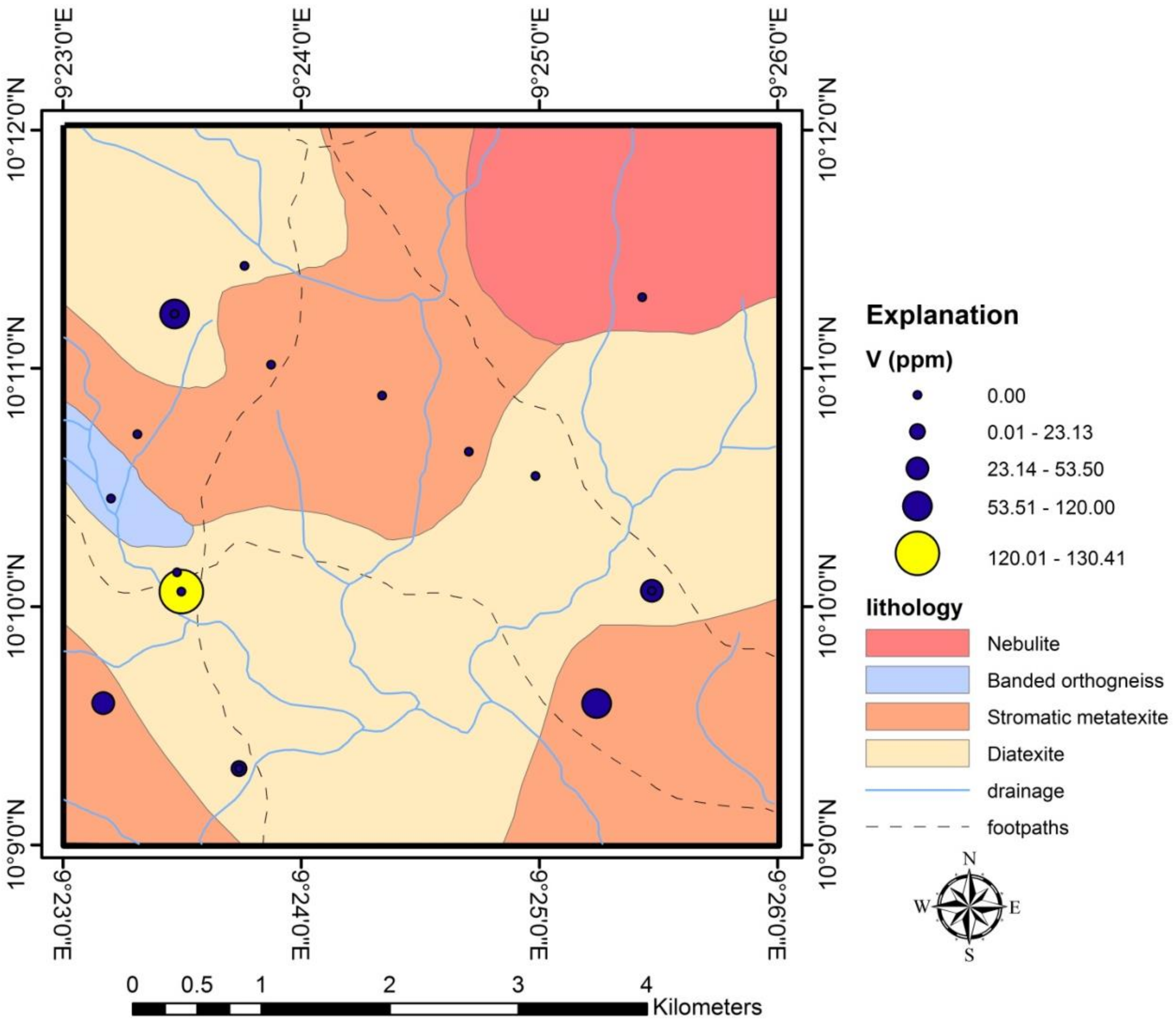

Figure 11. *Point symbol map of vanadium superimposed on the geology.*

5. Conclusion

The geologic condition and mode of occurrence of the migmatites in the Nabardo area have been studied. The geological mapping, field relationship studies revealed that the Precambian Basement rocks in Nabardo area consist of migmatites. The geological setting, distribution, composition, structures and possible economic potentials of the migmatites were also examined. The concentration maps revealed possible economic potential of mineralization of Zinc, Chromium and Nickel. Further exploration is also recommended to where anomalous were encountered within the tenement of the study area.

Abbreviations

D1, D2	Deformation Events
S1 and S2	Planar Structural Fabrics

Author Contributions

Johnson Kayode Ayeni: Conceptualization, Data curation, Methodology, Resources

Conflicts of Interest

The author declares no conflict of interest.

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