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MULTI-ELEMENT ASSOCIATION AND REGIONAL GEOCHEMISTRY OF REGOLITHS IN TASHAN JATAU AREA, NORTHWESTERN NIGERIA: IMPLICATIONS FOR GOLD EXPLORATION

B. O. OMANG, E. A. ASINYA, H. F. EFFIOM, G. T. KAVE, P. E. OKO AND M. I. MORPHY

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ABSTRACT

Soil geochemical surveys are widely used in the early stages of gold exploration, especially in areas with poor outcrops and thick overburden. Fifty-one (51) soil samples were collected in duplicate with the aim of analyzing them geochemically and determining the gold grade through panning and weighing methods. The geochemical results were subjected to multivariate statistical treatment through Factor analysis and Pearson correlation matrix. Four factors were generated from the PCA. These are Factor 1: Cu-Sr-Nb-Ba-La-W-Pb-Zr, suggesting sulfide mineralization that is related to granitic rock while Factor 2 has Au with a low to negative correlation with Mo and Nb suggesting a second phase of intrusion-related activity which must have emplaced gold in this area. Factor 3 is made up of W-Pb suggesting a second sulfide mineralization distinct from the first. While Factor 4 gives a single element factor, Hg. Single-elementt maps were constructed to show the element dispersion in the catchment. In general gold concentrations in this study is erratic and attain a high of 0.67ppm and 0.90g/t. The study delineates the northwestern part of the catchment to be the most prolific in terms of gold potential and shows that the granitic batholiths are the most primary gold-hosting lithology.

KEYWORDS: Tashan Jatau, Metasedimentary, Babban Gona, Geochemical, Gold exploration,

1. INTRODUCTION

Trace elements composition in soil geochemical surveys has been useful in constraining not only the metal enrichments in the soils (Naseem et al., 2002; Tijani et al., 2006; Grunsky et al., 2014) but can help in expressing the spatial relationship between the different elements in the catchment area especially when built into a GIS platform (Embui et al., 2013; Omang et al., 2014). This approach has been used for gold exploration across the world. Lin et al. (2014) used an integrated method of geochemistry and a multivariate statistical approach to improve the interpretation of geochemical patterns over an arid desert terrain. Sadeghi et al. (2014) successfully employed the use of statistics in processing soil geochemical data and interpretation for bedrock mapping and gold exploration in the Giyani greenstone belt. Martins-Ferreira et al. (2017) also used geochemistry and multivariate statistics to explore gold in the Almas gold province of central Brazil. The problem though is that the heterogeneous

B. O. Omang, Department of Geology, University of Calabar, Cross River State, Nigeria
E. A. Asinya, Department of Geology, University of Calabar, Cross River State, Nigeria
H. F. Effiom, Department of Geology, University of Calabar, Cross River State, Nigeria
G. T. Kave, Department of Geology, University of Calabar, Cross River State, Nigeria
P. E. Oko, Department of Environmental Resources Management, University of Calabar, Cross River, Nigeria
M. I. Morphy, Department of Geology, University of Calabar, Cross River State, Nigeria

distribution of gold in panned samples can be erratic for different reasons (Plant and Hale.,1994; Ali et al., 2006) thereby reducing the region's prospectivity (Bellehumeur et al., 1993; Bellehumeur et al., 1994), this is more so as centuries of mineral exploration have depleted surface anomalies in mineralized regions (Martin-Ferreira et al., 2017). However, the need to explore deep-seated deposits, especially in the tropics where extensive regolith cover has hampered exploration activities. Gold concentration estimated through the panning and weighing technique can help during gold exploration, especially in areas with poor outcrops (Embui et al., 2013; Omang et al., 2014). However, this study looks at gold grade variations and other elemental distributions on the drainage on a regional scale as well as studies. Over the years geochemical surveys have become an integral part of mineral exploration, especially in the search for different metallic deposits of Cu, Pb, Zn, Au, etc. Stream sediment geochemical surveys remain a very important sampling medium in mineral exploration where relief allows the development of distinct drainage systems (Fletcher et al., 2003; Grunsky, 2010, 2014). This method of exploration depends on sediments that are generated from the weathering of rocks and are dispersed in stream channels thereby making it best suited for the study of immobile and semi-mobile elements such as Ti, Cr, Mn, Sn, W, and Ba.

Due to dispersing energy and dilution of sediments from other barren sources, natural concentrations of heavy metals as a result of weathering processes of mineral deposits can be relatively high in stream sediments adjacent to the deposit but diminish with increasing distance downstream (Fletcher et al., 2003). Furthermore, the spatial display of stream sediment geochemical data, as well as statistical treatment of the data, can reveal element associations that are relevant to primary exploration in the region, as well as useful in speculating on the source region lithology, geological processes, and the nature of primary (rock-hosted) mineralization, if any is present (e.g., Plant and Hale, 1994; Key et al., 2004; Grunsky, 2010; Omang et al. 2014).

2. GEOLOGICAL SETTINGS

2.1. REGIONAL GEOLOGY AND STRUCTURE

African and South American continents have been of significant interest in terms of the understanding of global tectonics specifically with the continental drift hypothesis (Torquato and Cordani, 1981; Dada et al., 1998, 2008; Dantas et al., 2004). Nigeria's Proterozoic province is sandwiched between the Hoggar Massif in the north and the Borberema province in the south (Fig. 1) both of which are made up of metasediment and crystalline basement rocks. The Kushaka schist belt which is part of Nigeria's basement rocks covers a belt of about 50 km wide and stretches from the Minna area up to the Tsohon Birnin Gwari area of northwestern Nigeria (Fig.2). The rocks are embedded in a series of isoclinal fold structures that are trending NNE and have a pronounced foliation parallel to the folds' axial planes (Truswell and Cope, 1963). Many granitic plutons intrude the metasedimentary succession (schist, phyllites, banded iron formations), and the whole series is cut and displaced by the Kalagai Fault (Fig.2). This area host gold mineralization as well as other minerals such as rare earth metal and pegmatites. The regional and local controls of most of the mineralization in this area are primarily structures e.g., gold (Akande et al., 1988; Garba, 2000, 2002, 2013). The role of fractures in mineralization is dual as they serve as channel ways for the mineralizing solution and as loci of deposition of mineralization. Regional features are of fundamental importance in the selection of targets for mineral exploration, while localized features such as contact zones and shear zones are responsible for the localization of the ore deposits.

This area is part of the basement complex of northwestern Nigeria of Neoproterozoic to early Phanerozoic age separating the West Africa and Congo craton. This vast terrain consists of reactivated older crust in which Archaean (ca 2700 Ma) and Paleoproterozoic (ca 2000 Ma) isotopic ages have been recorded (Ajibade et al., 2008; Obaje 2009). The Pan African event (600 150 Ma) was the latest reactivation that affected the whole region (Turner, 1983; Fitches et al., 1985; Wright et al., 1985).

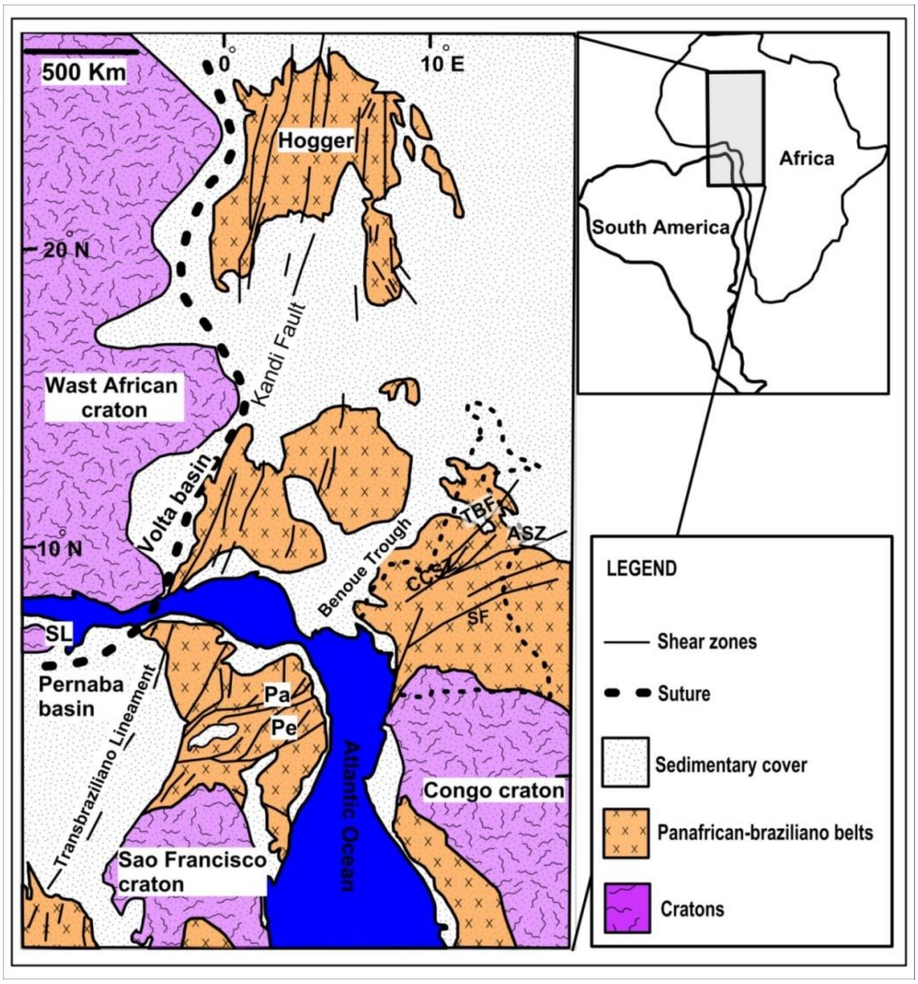

Figure 1: Late-Precambrian reconstruction of Africa and NE Brazil Borborema province (Modified after Nganko et al., 2003). ASZ: Adamawa shear zone; SF: Sanaga fault; SL: Luis craton; Pa: Patos shear zone; Pe: Pemambuco shear zone; TBF: Tcholliré-Banyo fault.

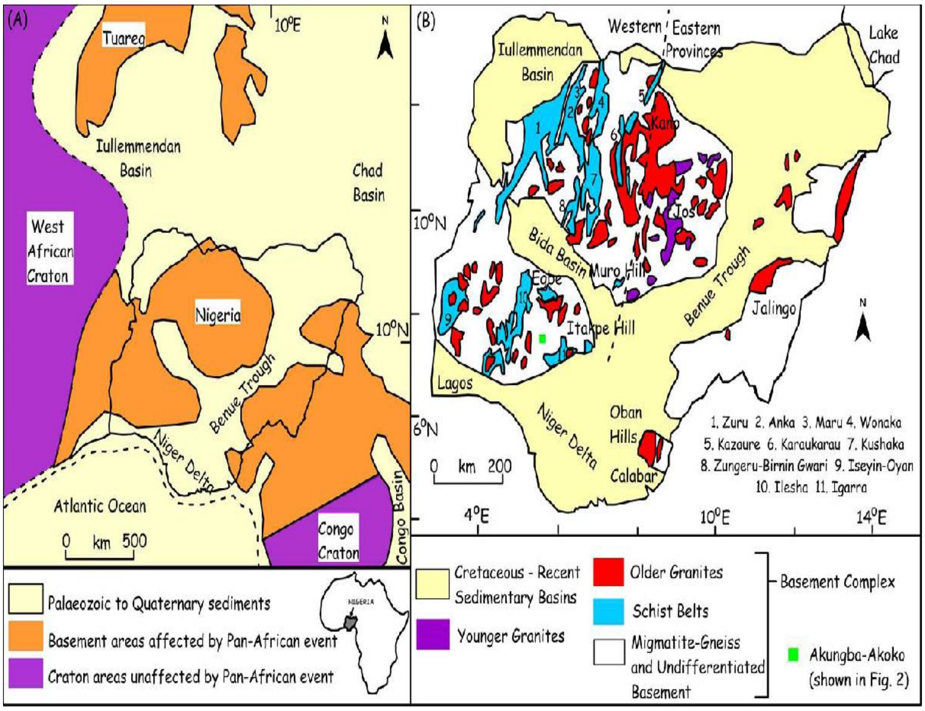

Figure 2: Location of Nigerian schist belts on the eastern margin of the West African craton modified after Turner (1983) b) Regional geologic map of Nigeria showing the Kushaka shist belt (7)

As a result, the landscape is known as the Pan African shield. Pan-African region and the West African craton, in which a subduction zone dips eastward beneath the Pan- African region. The continental collision occurred around 660 Ma, which is regarded as the basement sensu stricto, and most radiometric ages are in the range 600 + 150 Ma, dating the imprints of the subsequent crustal thickening in the Nigerian region (Turner, 1983). As the last manifestation of the Pan-African orogeny, extrusion of post-tectonic alkaline to calc-alkaline volcanic and brittle deformation occurred between 650 and 500 Ma (McCurry and Wright 1977).

2.2. Local Geology

Longitude $6^{o}0'\ 0''$E and $6^{o}12'0''$E, and latitude $10^{o}0'0''$N and $10^{o}8'0''$N with 300.4 metres as the highest elevation and 177.9 as the lowest point (Fig. 3) occupies the central portion of the Nigerian basement complex. The Tashan Jatau area comprises metasedimentary and meta-igneous rocks which have undergone polyphase deformation and metamorphism. These rocks have been intruded by granitic rocks of Pan-African age. Porphyritic granites, undifferentiated schist with phyllites and gneiss, migmatites, granitic gneiss and mylonite are the five lithostratigraphic units recognized in this area (Fig. 4). The undifferentiated schist with phyllites and gneiss, occurs, as a flat laying narrow southwest-northeast belt at the central part of Tashan Jatau with the gneiss occurring as small suites at the northern and southern part of the area forming contact with the granite. Feldspathic-rich pegmatite is bounded to the east, with an average width of 65meters and 100 meters long, the pegmatite hosts tourmaline. Granitic rocks, which vary in texture and composition, are the most common rock types in the area.

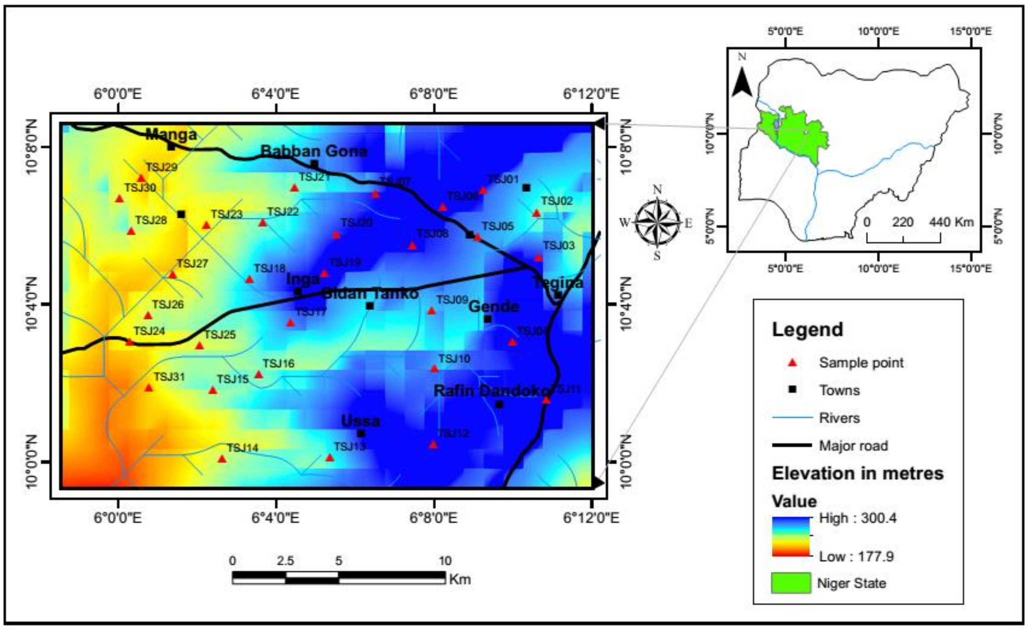

Figure 3: Map of study area showing its elevations and samples collection points

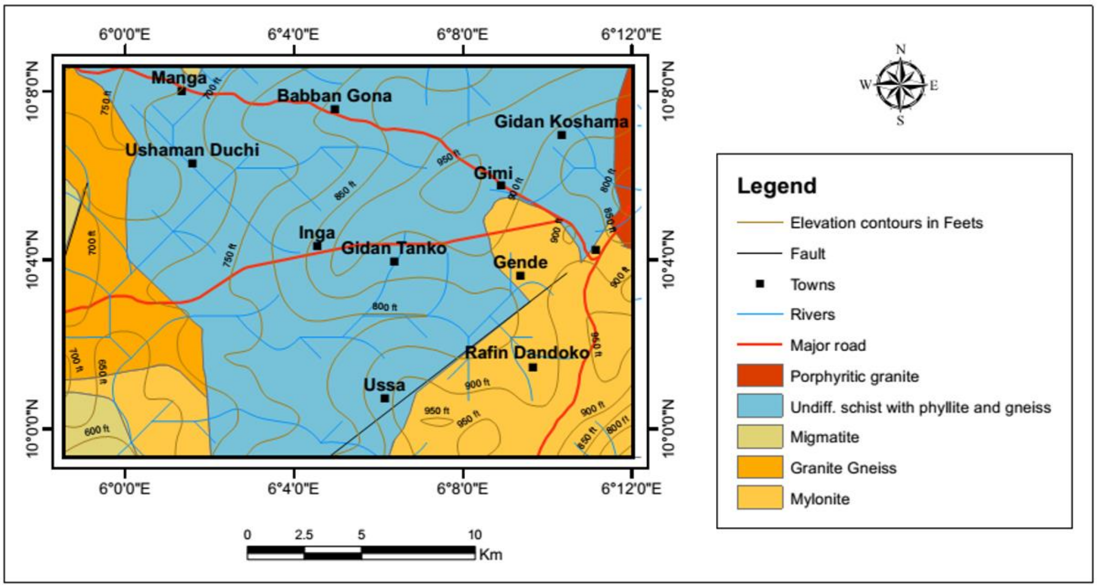

Figure 4: Geology map of the study area

MATERIALS AND METHOD

Fifty-one (51) homogenized soil samples were taken from hand-dug pits, trenches, and excavated areas where semi-mechanized mining and artisanal mining activities are ongoing (Fig. 5). These pits and trenches are mostly 3-4 metres dip, 1-2 metres in width and 4-5 metres long. Sample collection followed a non-grid system (Fig. 3). Three samples of approximately 10g were collected in duplicate from the top 5 cm at the apices of a roughly equilateral triangle with sides 1m long. One portion was panned, dried and gold grains were picked from the heavy mineral concentrates under a binocular microscope while the other portion was mixed and stored in a clearly labelled self-sealing plastic bag, and then shipped to the Bureau veritas commodities laboratory in Vancouver Canada for Inductively coupled mass spectrometry (ICP-MS) analyses. 15g of the homogenized samples were digested in aqua regia and analyzed for low to ultra-low elements by ICP-MS. The results of 20 suites of major and trace elements were subjected to a multivariant statistical approach to produce different element association and concentration maps.

The second sample is equally panned and weighed to determine the gold grade variations for the catchment. Standard procedures adopted for this study are as recorded in Embui et al. (2013) and Omang et al. (2014).

Figure 5: Panning of soils to concentrate gold grains (a-d). Pits and trenches where samples are taken sometimes up to 3m (a & d); employment of rudimentary tools (b & c) by indigenes to pan for gold using a shaking table.

4. RESULTS AND DISCUSSIONS

Panning and weighing techniques gave gold grade ranges of 0.01g/t to 0.9g/t as shown in the spatial map (Fig. 6a). Gold grades that range between 0.51-0.9g/t are concentrated more in the northwestern part of the study comprising Mariga and Unguwar Maidabo. Conversely, gold concentration determined by the geochemical method has a maximum of 0.67(ppm) with a sporadic high occurrence in the northwestern part of the study area comprising Mariga, and the central part of the study comprising Babban Gona. The spatial distribution between gold grade determined by panning and weighing coincides with that determined geochemically (Fig. 6a&b). Chalcophile elements Cu, Pb, and Zn have their highest concentrations of 55ppm, 54 ppm, and 532 ppm respectively (Table 1). Pearson correlation matrix (Table 2) was used to calculate the element's inter-relationship which shows a high positive correlation between Sr-Ba-La-Ce-Zr. The r-value for La-Ce is 0.97 higher than the r-value of 0.90 for Sr-Ba. Gold has a weak to negative correlation with Nb and Mo. Four (4) factors generated from the PCA (Table 3) are:

Factor 1: Cu-Sr-Nb-Ba-La-W-Pb-Zr
Factor 2: Au-Nb-Mo
Factor 3: W-Pb-Sb
Factor 4: Hg

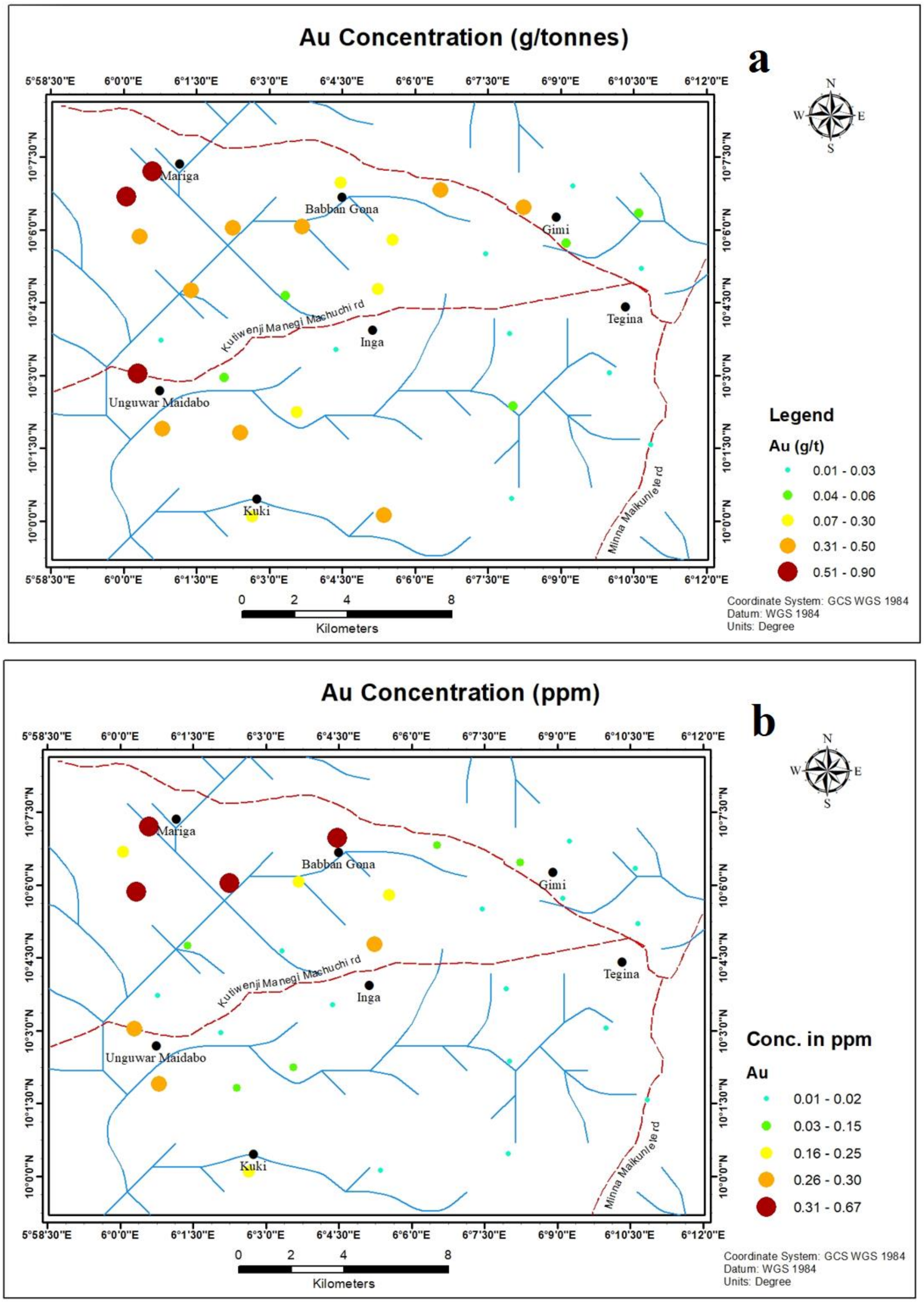

Figure 6: Graduated symbol plots for (Au)(g/t) and(b) Au (ppm) superimposed on the drainage map of Tashan Jatau

Table 1: Summary of the descriptive statistic of Au and associated elements determined by geochemical analysis of 51 soil samples from the Tashan Jatau area of northwestern Nigeria

Parameter	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Au	0.00	75.00	11.65	18.69
Cu	5.00	55.00	32.94	12.19
Zn	28.00	532.00	69.90	67.96
As	5.00	67.00	11.69	13.10
Hg	0.01	2.26	0.41	0.57
Sr	17.00	364.00	87.90	80.54
Y	20.00	89.00	48.18	15.79
Nb	18.00	54.00	40.35	8.35
Mo	1.00	5.00	2.49	1.05
Ag	0.10	0.50	0.11	0.06
Cd	1.00	1.00	1.00	0.00
Sn	5.00	5.00	5.00	0.00
Sb	5.00	12.00	5.16	0.99
Ba	294.00	2052.00	651.04	373.62
La	10.00	110.00	37.59	25.94
Ce	27.00	263.00	121.24	62.40
W	1.00	9.00	2.00	1.94
Pb	5.00	34.00	17.94	7.63
Bi	1.00	1.00	1.00	0.00
Zr	278.00	1451.00	765.24	319.90

Table 2: Pearson correlation matrix (r) for various elements determined by geochemical analysis from the Tashan Jatau area

	Au	**Cu**	**Zn**	**As**	**Hg**	**Sr**	**Nb**	**Mo**	**Ag**	**Sb**	**Ba**	**La**	**Ce**	**W**	**Pb**	**Zr**
Au	1.00															
Cu	-0.17	1.00														
Zn	-0.14	0.34	1.00													
As	0.13	0.02	-0.02	1.00												
Hg	0.32	0.18	-0.11	0.06	1.00											
Sr	0.22	0.44	0.08	0.29	0.17	1.00										
Nb	-0.20	**0.76**	0.29	-0.07	0.17	0.30	1.00									
Mo	-0.48	0.31	0.23	-0.25	-0.09	-0.18	0.49	1.00								
Ag	0.01	-0.08	0.02	0.11	-0.04	-0.02	-0.16	-0.07	1.00							
Sb	-0.06	-0.23	-0.06	0.07	-0.04	-0.07	0.01	-0.21	0.12	1.00						
Ba	0.17	0.34	0.05	0.15	0.07	**0.90**	0.17	-0.16	-0.08	-0.07	1.00					
La	0.09	**0.63**	0.23	0.27	0.21	**0.87**	**0.58**	0.07	-0.04	-0.12	**0.72**	1.00				
Ce	0.12	**0.70**	0.19	0.25	0.27	**0.85**	**0.65**	0.09	-0.11	-0.19	**0.71**	**0.97**	1.00			
W	0.02	**-0.54**	-0.15	0.03	-0.12	-0.30	-0.45	-0.25	0.30	0.48	-0.24	-0.48	**-0.54**	1.00		
Pb	-0.10	0.26	0.36	0.07	0.07	0.41	0.32	0.04	0.10	0.22	0.38	0.48	0.43	0.11	1.00	
Zr	0.27	**0.50**	0.18	0.22	0.39	**0.74**	**0.54**	-0.05	-0.14	-0.17	**0.59**	**0.81**	**0.87**	-0.40	0.42	1.00

Table 3: Extraction Method: Principal component analysis

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Communality
Au	0.100	**0.638**	0.391	0.244	0.629
Cu	**0.740**	-0.418	0.004	0.084	0.729
Zn	0.288	-0.360	-0.379	-0.051	0.358
As	0.209	0.435	-0.102	-0.171	0.273
Hg	0.289	0.223	0.296	**0.763**	0.803
Sr	**0.850**	0.388	-0.055	-0.223	0.927
Nb	**0.672**	**-0.516**	-0.121	0.319	0.834
Mo	0.114	**-0.812**	-0.076	0.042	0.680
Ag	-0.138	0.196	-0.422	-0.006	0.236
Sb	-0.200	0.264	**-0.635**	0.324	0.618
Ba	**0.728**	0.364	-0.054	-0.337	0.780
La	**0.951**	0.090	-0.080	-0.080	0.925
Ce	**0.982**	0.047	0.023	-0.017	0.966
W	**-0.561**	0.378	**-0.525**	0.154	0.757
Pb	**0.485**	0.075	**-0.655**	0.125	0.685
Zr	**0.873**	0.186	0.081	0.162	0.829
Variance	5.723	2.461	1.720	1.124	11.029
% Var	35.800	15.400	10.800	7.000	68.900

Factor 1 is made up of incompatible elements correlating strongly with chalcophile elements reflecting a lithologic control possibly of granitic rock containing sulfide through hydrothermal veining. This accounts for 38.5% of the total variance of the data set. Factor 2 is made up of Au correlating weakly with Nb and Mo suggestive of gold from a different episode of hydrothermal alteration and constitutes 15.4% of the data variability. Factor 3 shows a weak correlation between W, Sb, and Pb and constitutes about 10.8% of the data variability while factor 4 has a single element factor with Hg forming 7% of the data variability.

The spatial distribution of the elements in factors is given in figures 7 to 13 drawn to scale and superimposed on the GIS platform.

The results of this study returned high gold grades from the panning and weighing method (up to 0.9g/t) than from the geochemical analysis (0.67ppm) as depicted in Table 1. This is attributable to nugget effects considering that the size fraction analyzed geochemically does not contain gold grains larger than 100µm size fraction. The problems of sporadic and erratic gold grades values in different size fractions are a major challenge in stream sediment studies applied to gold exploration (Bellehumeur et al. 1993). Fletcher et al. (2003) was able to demonstrate that gold values are highest in the gravel size fraction and decreases with decreasing grain size down to the -54μm fraction in the Sungali Kuli area of Malaysia Similarly, Embui et al. (2013) show that the spatial displays of gold generated by panning and weighing and those derived geochemically differ, making the ≥100 µm fraction less suitable to be used for gold prospecting in the Vaimba-Lidi drainage system of Eastern Cameroon.

The occurrence of high field strength elements in these associations (Factor 1) is also ascribed to contributions from minerals such as celestite, monazite, zircon, and stibnite, which are most abundant in granitic rocks. The intermediate loading of Cu and Pb in Factor 1 is assumed to be influenced by the hydrothermal protolith contributed by the intruding pegmatites in the shear zones (Martins-Ferriera et al. 2017). This may be responsible for the chalcocite inclusions in the system which raises the possibility that the gold may be associated with relatively deep-seated igneous hydrothermal processes (Chapman *et al.*, 2011), This further supports an intrusion-related mineralization model for the gold mineralization in this study. It is important also to recall that the Tashan Jatau area is mainly a volcano-sedimentary rock terrain containing quartzite which late granitic plutons have intruded.

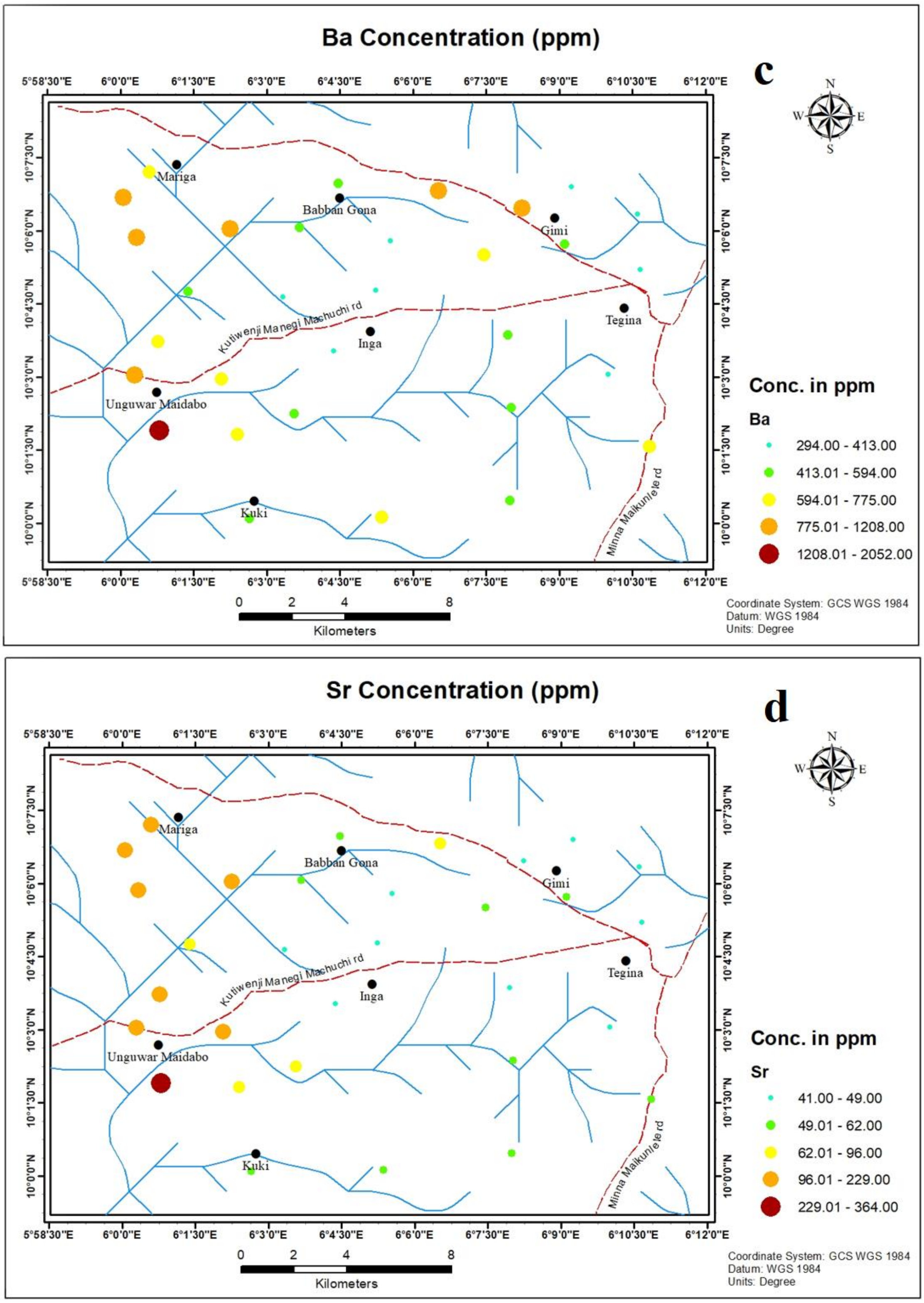

Figure 7: Graduated symbol plots for (c) Ba and(d) Sr (ppm) superimposed on the drainage map of Tashan Jatau

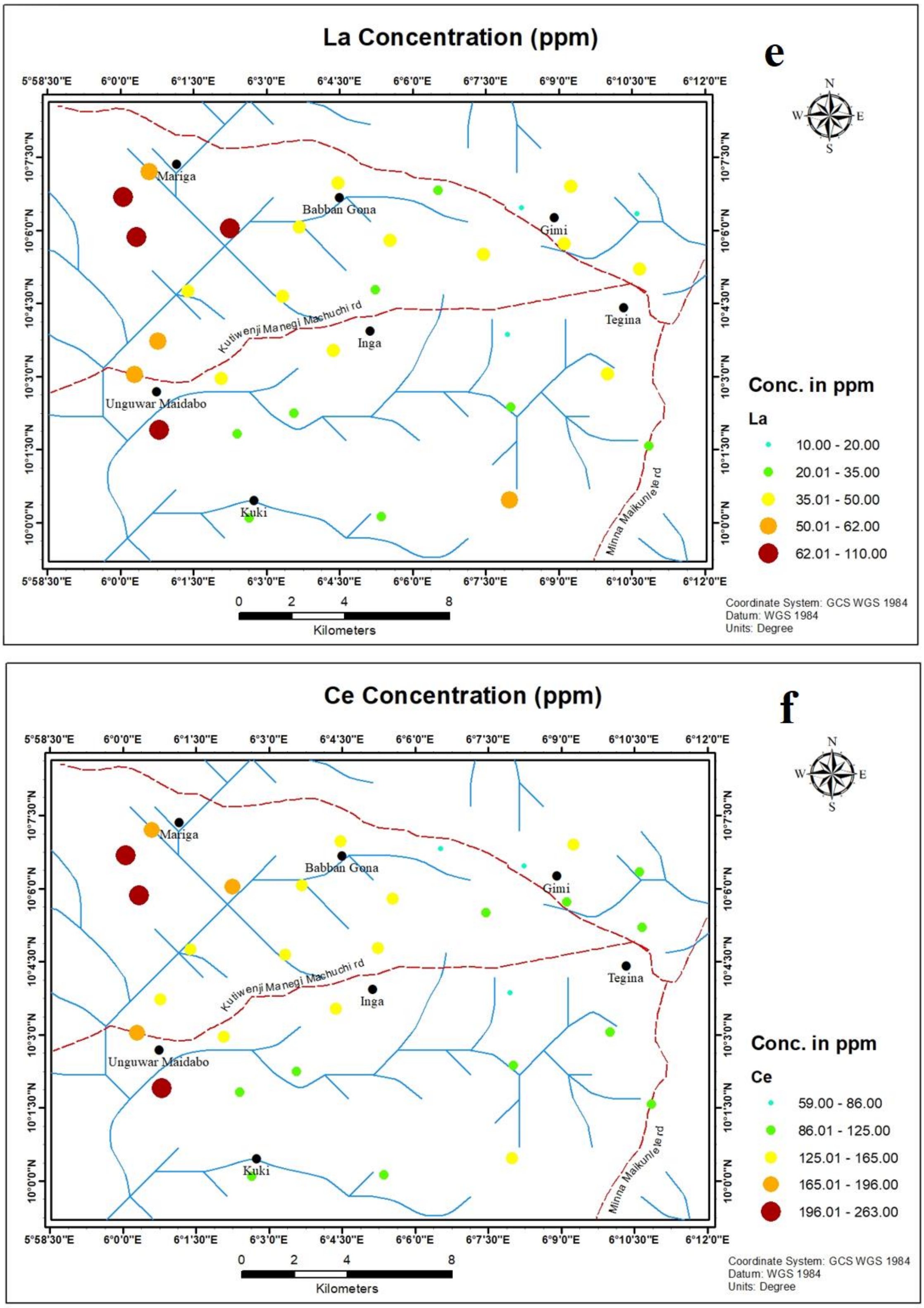

Figure 8: Graduated symbol plots for (e) La and (f) Ce (ppm) superimposed on the drainage map of Tashan Jatau

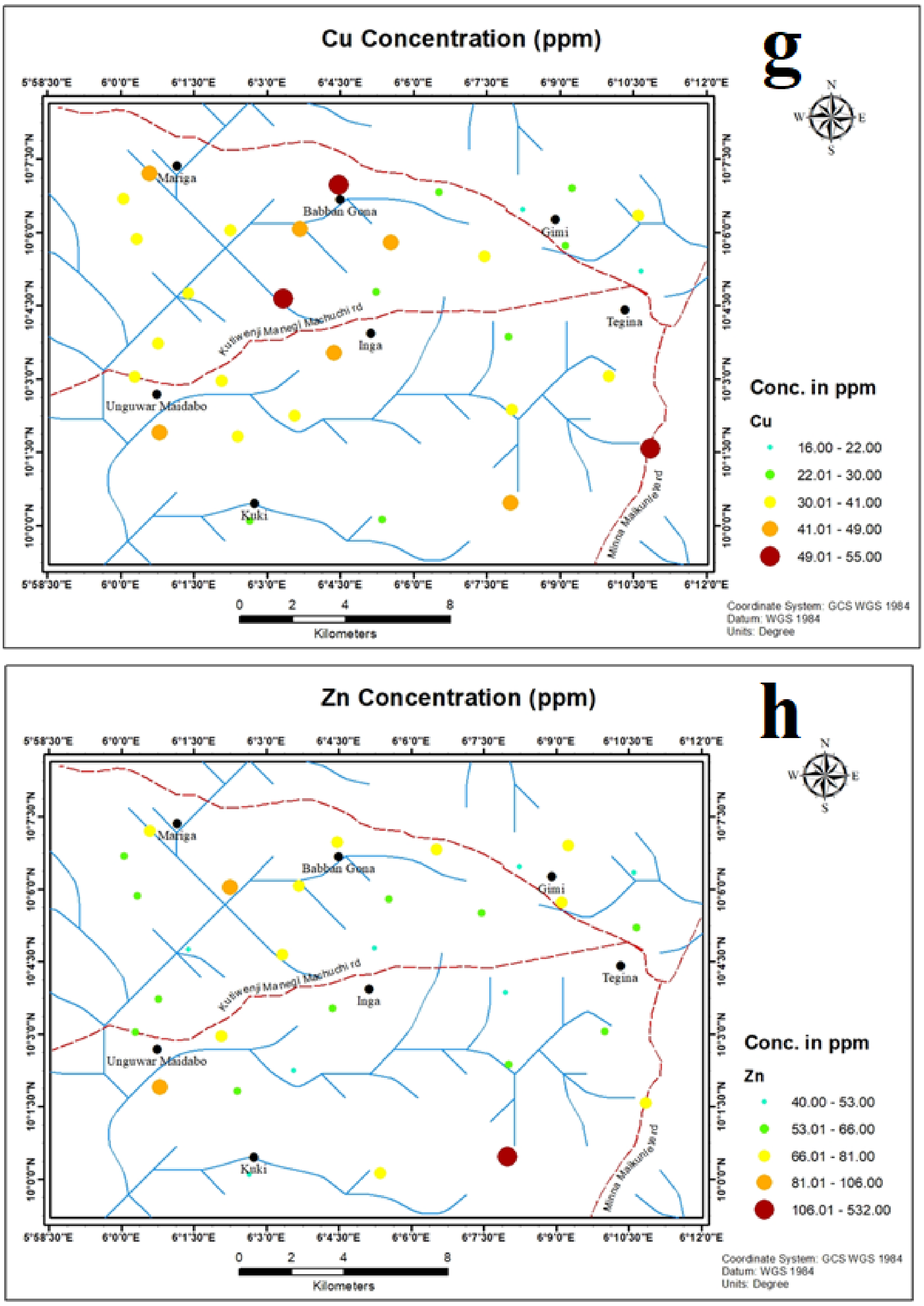

Figure 9: Graduated symbol plots for (g) Cu and(h) Zn (ppm) superimposed on the drainage map of Tashan Jatau

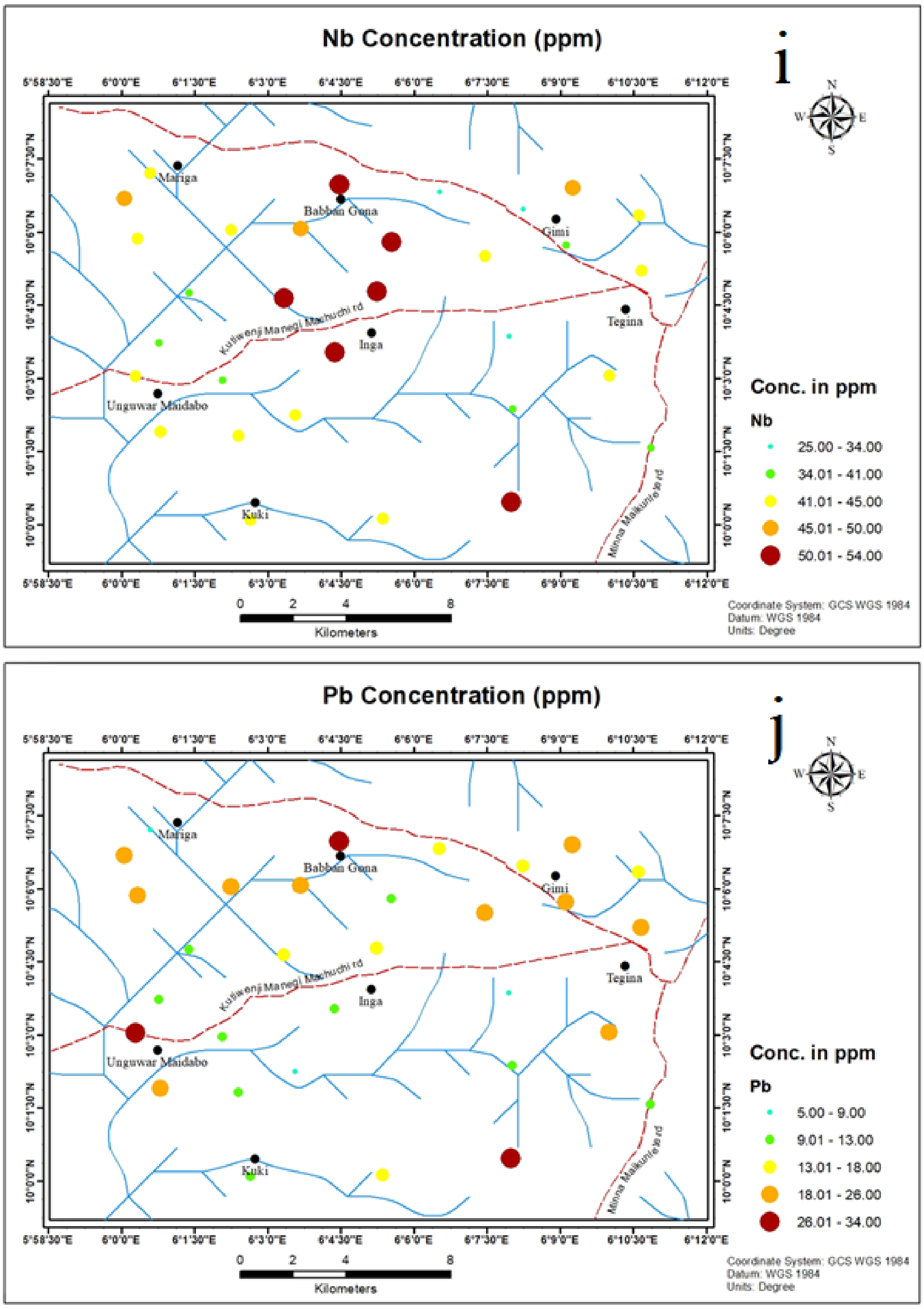

Figure 10: Graduated symbol plots for (i) Nb and (j) Pb (ppm) superimposed on the drainage map of Tashan Jatau

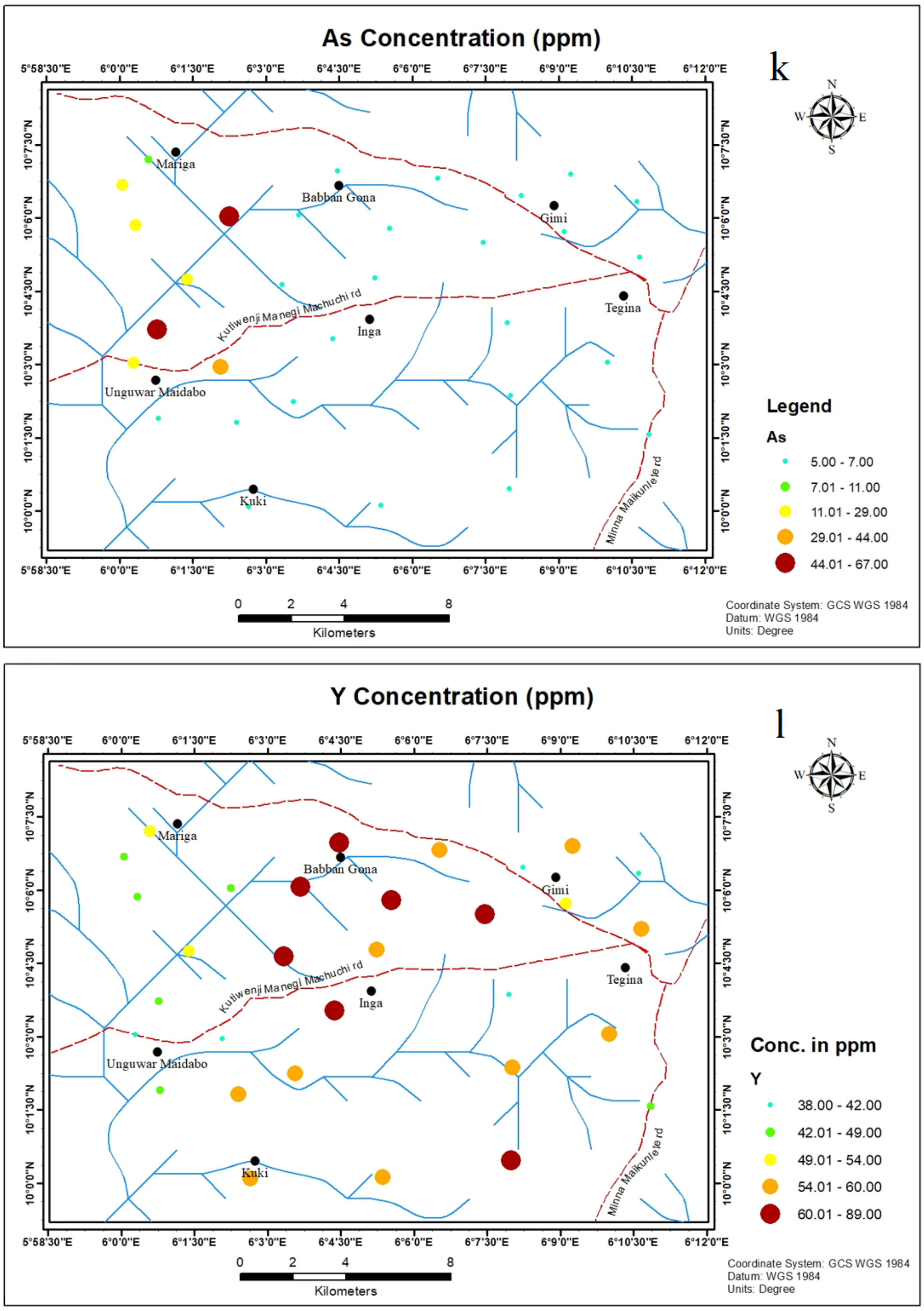

Figure 11: Graduated symbol plots for (k)As and(l) Y (ppm) superimposed on the drainage map of Tashan Jatau

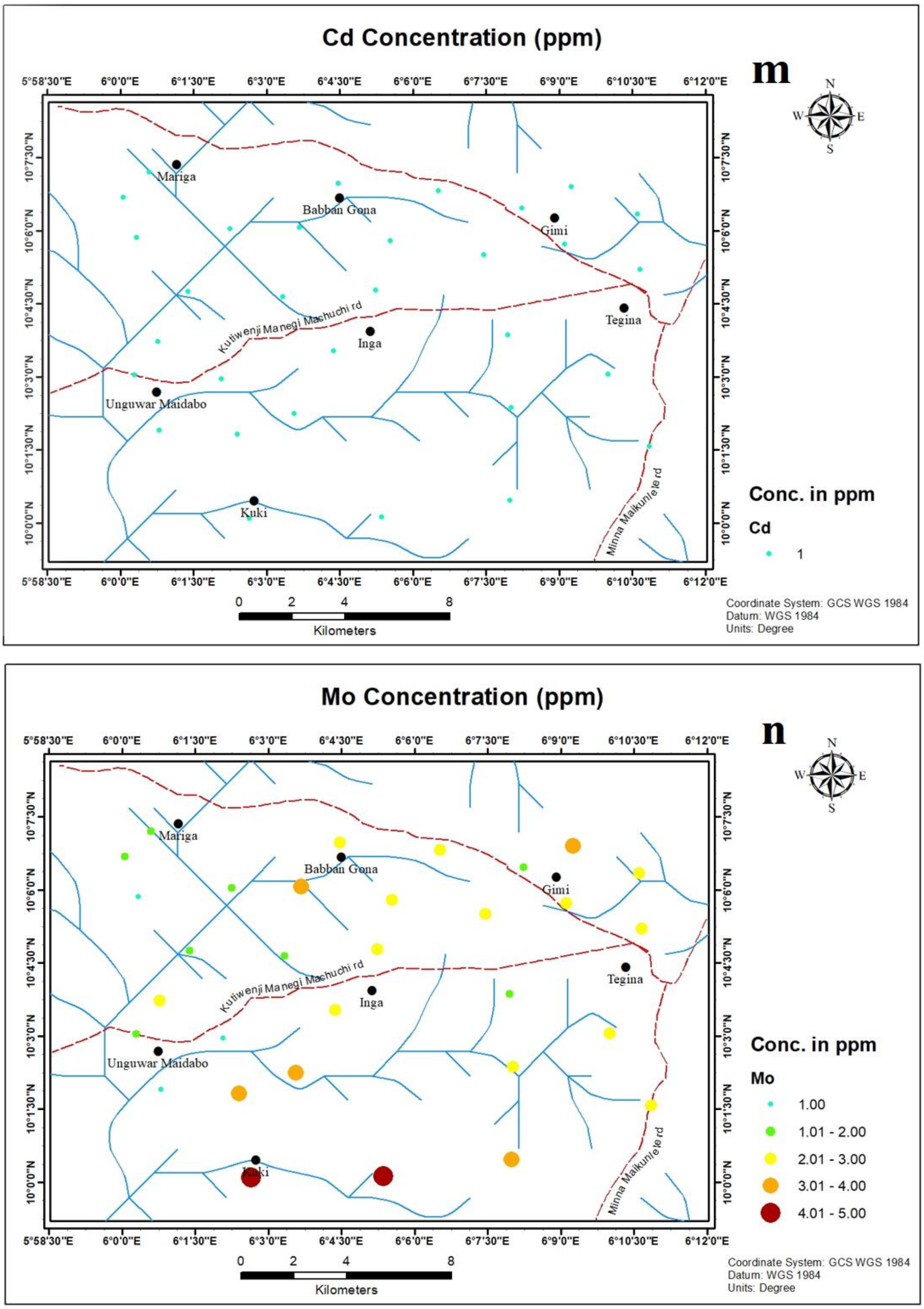

Figure 12: Graduated symbol plots for (m)Cd and(n) Mo (ppm) superimposed on the drainage map of Tashan Jatau

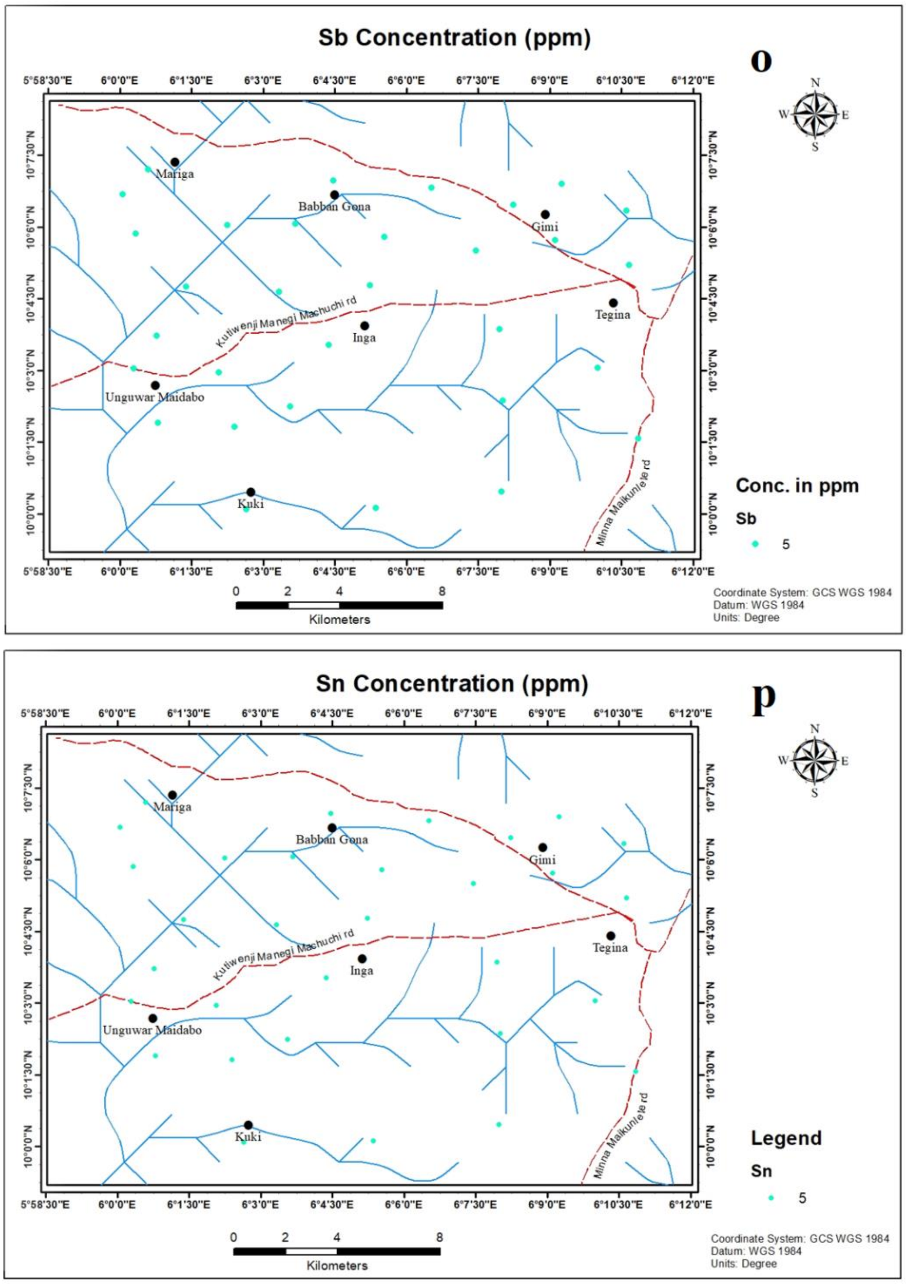

Figure 13: Graduated symbol plots for (o) Sb and(p) Sn (ppm) superimposed on the drainage map of Tashan Jatau

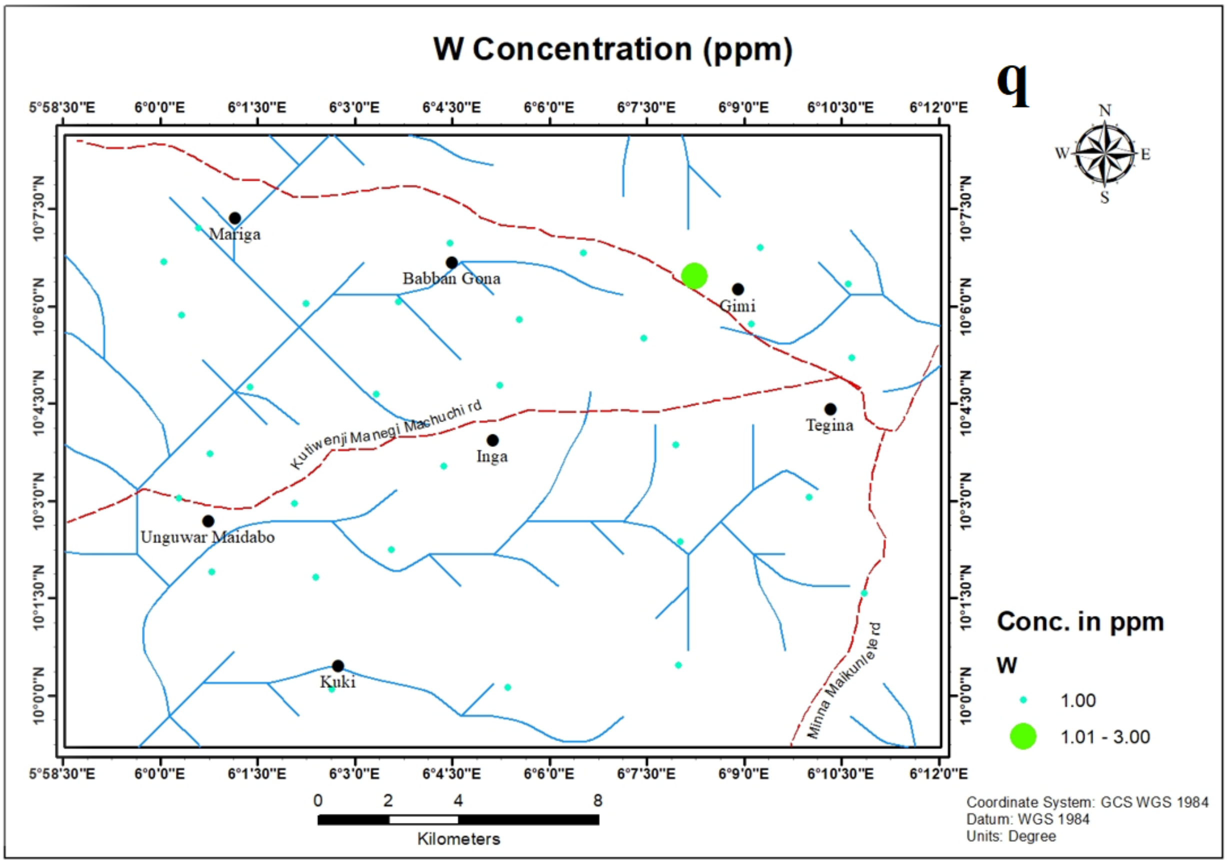

Figure 14: Graduated symbol plots for (q) W (ppm) superimposed on the drainage map of Tashan Jatau

Other lithotypes include schists, granite gneiss, and phyllites. From an exploration point of view, the emplacement of these granitic bodies could have resulted in the remobilization of the Au. Factor 2 shows that Au did not correlate with any of the elements except for a weak to negative correlation with Nb and Mo which account for 15.4% of the data set and constitute the major fingerprints in terms of gold exploration for this study. Inter-intrusion and intra-intrusion variations in mineral chemistry can be interpreted to reflect petrogenetic processes through assimilation and fractional crystallization during granitoid evolution must have emplaced the gold. Although magmatic equilibration among rock-forming minerals is disturbed by sub-solidus hydrothermal processes, this could well be the prospective target for intrusion-related gold systems in this study (Yang and Lentz. 2005). This model, therefore, suggests that the granitoid emplacement, sulfide deposition, and gold mineralization are not contemporaneous (Embui et al. 2013), meaning that the exploration strategy to be employed in the region must recognize the different episode of hydrothermal veining that has contributed to the Au emplacement and should be focused more in the northwestern part of the study, particularly in the Unguwar Maidabo, Mariga and Baban Gona areas.

CONCLUSIONS

The research suggested that the gold grades derived by panning and by geochemical method return relatively high values for gold and are almost with little influence of nugget effects and concentrated almost in the same area in the study. The lithologic paragenesis as presented in the factors can be said to be barren in terms of gold mineralization and does not in any way contribute to the gold emplacement in the catchment area, rather a completely different episode of magmatic emplacement may have emplaced the gold in the study area. In terms of gold exploration, granitic batholiths should be targeted because it holds the most important promise for gold emplacement. Any exploration programme in this area must therefore target this granitic batholith which holds the key to the primary gold mineralization potentials in the study area.

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