SPATIAL VARIABILITY AND GEOSTATISTICAL ANALYSIS OF HEAVY METALS IN THE MINING AREAS OF BAGEGA, ZAMFARA STATE, NIGERIA

By

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ABSTRACT

Heavy metal occur naturally, its uses have led to wide distribution in the environment rising concerns over their potential effect on human health. Analysing the spatial distribution of heavy metal in Bagega, Zamfara State is necessary because of the recent outbreak poisoning that impacted mostly women and children due to illegal mining activities; the analysis will help the planners especially the health sector for identification of clustering and or "hot spots". Spatial variability of heavy metals (Pb, Cr, Mn, Cd, Ni) from the soil depth of 0-15cm in Bagega, Zamfara State was geostatistically examined, employing GIS technique. The results of semivariogram analysis of Cr, Mn and Ni exhibited strongly spatial autocorrelations. This was controlled by intrinsic factors of parent material, relief and soil type. Pb and Cr were greatly affected by extrinsic factors of mining or anthropogenic activities. Kriging method was also employed to estimate the unobserved points and their spatial distribution. Resultant maps indicate the clustering of Cr and Cd in the farmland areas, and Pb and Ni clustered at the central part of the area while Mn concentrated at the southwestern part. The trends of variability among the heavy metals in the study area indicate that Ni varies more than any other element in the area followed by Cd and Cr. The study recommends further studies on mapping the concentration of heavy metals using more soil depth to adequately compare the level of concentration of the heavy metals across the soil profile. Also, studies should be conducted on mapping areas that are vulnerable to pollution using fuzzy models.

Key words: Geostatistics, GIS, Heavy Metals, Kriging, Spatial Variation

INTRODUCTION

Heavy metals are naturally occurring elements that have high atomic weight and density at least 5 times greater than that of water (Fergusson, 1990). Their multiple industrial, domestic, agricultural, medical and technological applications have led to their wide distribution in the environment, raising concerns over their potential effects on human health and the environment. In this regard, Bradl (2002) reported that human exposure has risen dramatically recently as a result of an exponential increase of their use in several industrial, agricultural, domestic and technological applications. Their toxicity depends on several factors including the dose, route of exposure, and chemical species, as well as the age, gender, genetics, and nutritional status of exposed individuals.

He, Yang and Stoffella (2005) indicated that reported sources of heavy metals in the environment include industrial, agricultural, pharmaceutical, domestic effluents, and atmospheric sources. Environmental pollution is very prominent in point source areas such as mining, foundries and smelters, and other metal-based industrial operations (Fergusson, 1990; Bradl, 2002; He *et al*., 2005). Although heavy metals are naturally occurring elements that are found throughout the earth's crust, Shallari, Schwartz, Hasko and Morel (1998) and He *et al*. (2005) reported that most environmental contamination and human exposure result from anthropogenic activities such as mining and smelting operations, industrial production and use, and domestic and agricultural use of metals and metal-containing compounds. Investigation of heavy metal contamination of environment is very essential since slight changes in their concentration above acceptable limit, whether due to natural or anthropogenic factors, can result in serious environmental and health problems.

Consequent upon the incidence of lead poisoning in 2010 in Zamfara State, Nigeria, interest in assessing the levels of these heavy metals in key affected locations has tremendously increased, with several studies conducted, including Nuhu (2012), Abdu and Yusuf (2013), Rasheed (2014) and Oladipo, Njinga, Elele and Salisu (2014), among others. These reported cases in Nigeria, and many elsewhere, have strengthened the point that the environmental implication of heavy metal contamination does not only elicit concern in cosmopolitan areas, but also in remote and rural areas where anthropogenic activities such as mining and agriculture are taking place (Nuhu, 2012).

Bagega, a village in Zamfara State, Nigeria, has experienced an outbreak of Lead (Pb), Cadmium (Cd), Chromium (Cr), Manganese (Mn), and Nickel (Ni) poisoning that impacted mostly women and children, due to toxic releases of these metals to soil, water and air (Lar, Tsuwang and Mangs, 2013; Majiya, Abdulmumin, Sallau, Hussaini and Mohammed, 2015). Consequent upon this, several attempts have been made in assessing the concentration of heavy metals in the area, though without documenting their spatial distribution or mapping the concentration. These studies include that of Majiya *et al*. (2015), who assessed the concentration of heavy metals in water, and noted that all water sources in Bagega contain high amount of such. In the same vein, Lar *et al*, (2013) studied lead and mercury contamination associated with artisanal gold mining in Anka and Bagega, Zamfara State, and reported that the level of the elements were above WHO standard, especially when children bloods were tested for the presence of lead. Tsuwang, Ajigo and Lar (2014) analysed concentration of Pb, Hg and As, using geoaccumulation index (IGEO) and enrichment factor (EF) as basis for the work. The IGEO gives a quantitative extent of accumulation of the metals with respect to the quality of medium analysed, while the enrichment factor was used to differentiate between metals originating from anthropogenic activities and those from natural processes. The result of this important work indicated that the soils in the study area are significantly contaminated.

Yet, none of the above study attempted to analyse the distribution of the heavy metal in the area. Spatial distribution and source identification of heavy metals in soils are essential for identification of vulnerable areas. While this is usually achieved by interpolation, it no doubt helps in the identification of hot 'spots' or concentration. In this regard, Goovaerts (1997) also indicated that the key focus of the method of geostatistics is to facilitate the use of stochastic theory of spatial correlation for both interpolation and apportioning uncertainty. The aim of this study is to analyse and map the spatial distribution of heavy metals in Bagega by assessing the spatial concentration of heavy metals in the area, determining their spatial variability, and examining the spatial distribution of the heavy metals in the study area.

STUDY AREA

Bagega lies between Latitudes 11^0 32′ and 12^0 29′ North of the equator and Longitudes 5^0 40′ and 6^0 18′ East of the Prime Meridian. It is bordered in the North East by Talatan Mafara, South and South East by Maru, West by Bukkuyyum, North by Bakura (Fig.1). It has a total land area of 3,265 km^2 from which agricultural land takes the highest percent. Bagega has a population of 7,323 according to the 2006 population census (NPC, 2006).

Throughout the year in the study area, average maximum temperature is 36^0C, while average daily minimum is 21^0C. The mean annual rainfall in the study area varies slightly from the northern to the southern parts of the state. While Gummi, the local government in which Bagega is situated records an average of 579mm of rainfall, Talatan Mafara at the northeast records 798mm, Kauran-Namoda records 990mm and Moriki records 1020 mm (Physical Setting of Zamfara, 2003). Two major soil types, ferruginous tropical soils and lithosols, dominate Zamfara state. The ferruginous tropical soils are found in the northern and central parts of the state, particularly around Gumi, Bukuyyum, Anka and Bakura (Physical Setting of Zamfara, 2003).

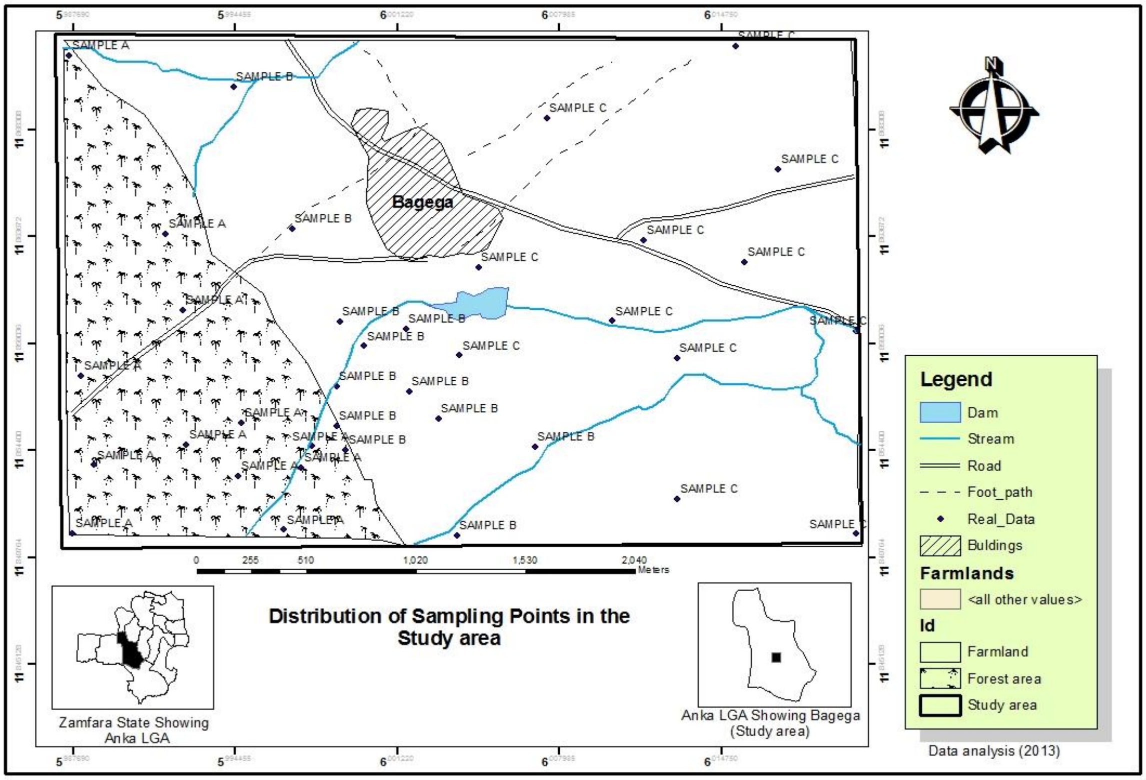

Figure 1: Study area and sampling points

The vegetation of the area consists of Sudan and northern Guinea savannah. The Sudan savannah occurs in the western, northern and eastern parts of the state. Like in the other parts of the country, it is structurally characterized by woodland where grasses occur. Geologically, the state is characterized by very old igneous rocks and metamorphic rocks, formed during the pre-Cambrian era. The two key rock types found are granites and meta-sediments. The granites (including undifferentiated granites), gneiss and migmatites are more resistant to erosion, but when weathered they result into poor soils (Physical Setting of Zamfara, 2003).

MATERIALS AND METHODS

Procedure for Sampling

Three sets of samples were collected from the top (0-15cm) horizon. This is because the heavy metals pollution is believed to be mainly on the top soil. At the mining processing area, samples were collected using stratified random sampling techniques. This was done because the mining processing environment is expected to be the most polluted area. Thus, the contaminated soil of the mining environment was divided into three sections where samples were collected. The sections include: Mining Processing Area (MPA), Surrounding Farmlands (SF) and Residential Exterior (RE). Twelve (12) samples were collected from each section, making the total of Thirty six (36) samples in the area with their respective coordinates (Latitudes and Longitudes) using Garmin GPS Etrax 76scx. Polythene bags were used in transporting the samples to the Standard laboratory for analysis.

Procedure for Laboratory Analysis

The soil samples collected were air-dried at room temperature and lightly ground with agate mortar and pestle and then passed through 2mm sieve before analysis. Atomic Absorption Spectrophotometer (Alpha 4 Digital Model), equipped with a digital read out and a deuterium background correction system, was used for analysis. The concentration of the heavy metals in (Mg/kg) were determined for Lead (Pb), Cadmium (Cd), Chromium (Cr), Manganese (Mn), and Nickel (Ni).

Data Analysis

From the laboratory results, the distribution of Lead (Pb), Cadmium (Cd), Chromium (Cr), Manganese (Mn), and Nickel were characterized using descriptive statistics: graphs, standard deviation (SD) and coefficient of variation (CV) for each set of data using the Statistical Package for Social Sciences (SPSS).

Geostatistical Methods

Kriging method was used in analysisng the spatial distribution of the selected elements. It is an interpolation method applied widely to elucidate spatial distribution of many parameters including metallic elements. Kriging interpolation refers to a group of spatial interpolation methods for assigning a value of a random field to an unsampled location based on the measured values in random fields at nearby locations (Xie, Ye and Wong, 2001).

The need for spatial variability analysis in geostatistics aims at providing quantitative descriptions of natural variables distributed in space and time (Journel and Huijbregts, 1978; Isaaks and

Srivastava, 1989). Based on the regionalized variable theory, geostatistical method assumes that variables in an area exhibit both random and spatially structured properties. The semivariogram is calculated to quantify the spatial structure (Burgess and Webster, 1980).

The spatial variability analysis in this study was used to describe the geospatial distribution of the heavy metals in the area. The geospatial data were compiled, merged, loaded, and spatial interpolation was performed with geostatistics extension in the Arc GIS (10.1 version). Geostatistical extension uses the technique of semivariogram (or variogram) to measure the spatial variability of a regionalized variable and provides the input parameters for spatial interpolation of Kriging (Webster and Oliver, 1993). The equation of semivariogram is expressed as follows (Webster and Oliver, 1993):

$$\boldsymbol{\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2}$$

Where $\boldsymbol{\gamma(h)}$ is the experimental semivariogram value at lag $\boldsymbol{z(x_i)}$ and $\boldsymbol{z(x_i + h)}$ respectively. The $N(h)$ is the number of pairs of observations at the distance, h. Usually, semivariance value increases with sampling distance approaching plateau referred to as 'sill.'

RESULTS AND DISCUSSION

Concentration of Heavy Metals in Bagega

The recorded mean concentration of Cr in soil of the study area was found to be 0.399mg/kg, 0.39mg/kg and 0.26mg/kg, for mining processing environment, farmlands and residential exterior respectively (Table 1) these values are below the Hungarian threshold limit 75mg/kg. The results were compared with European Standard (Hungarian) in view of such standards being absent in Nigerian standards. The highest mean value of 0.15mg/kg was found at the mining processing environment, while the lowest mean value of 0.13 mg/kg was recorded at the residential exterior. This indicates that Cr concentration is high in the mining area and may be accumulating if mining activities continue. While Cr is an element found naturally in rocks, soils, plants and animals, anthropogenic predisposing activities are increasing concentration of the element across the landscape globally (Argonne Nat. Lab, 2005).

Table 1: The mean concentration of heavy metals in the study area

Sites	Cd	Cr	Mn	Ni	Pb
Mining processing environment	**0.15**	**0.4**	**0.86**	**0.12**	**0.14**
Standard deviation	0.09	0.21	0.41	0.07	0.05
Coefficient of variation.	0.58	0.53	0.48	0.59	0.36
Farmlands	**0.14**	**0.39**	**0.56**	**0.15**	**0.12**
Standard Deviation	0.05	0.19	0.32	0.08	0.06
Coefficient of var.	0.35	0.49	0.57	0.52	0.51
Residential Exterior	**0.13**	**0.26**	**0.8**	**0.14**	**0.2**
Standard Deviation	0.09	0.17	0.27	0.1	0.05
Coefficient of var.	0.68	0.66	0.34	0.7	0.25

Sources: Data analysis (2015)

Manganese was detected in the soils of the study area at an average concentration of 0.86mg/kg, 0.56mg/kg and 0.80mg/kg for mining processing environment, farmlands and residential exterior respectively. Elevated concentration of this element was found in the current mining processing environment (MPE) and the old mining areas (RE). This shows that Manganese might have been there due to the breakdown of the original parent rock in both the current and old mining processing unit. Manganese has been reported to be found in elevated levels in most soils since it is one of the major elements in the earth crust (Dara, 1993).

The mean levels of Cd recorded in this study have the highest mean concentration 0.15 mg/kg was recorded in the mining processing environment, followed by the farmlands at the lowest concentration of 0.13 mg/kg recorded at the residential exterior. Cadmium generally is an associate of gold and its ore as it can be seen in its highest concentration in the mining processing environment. This site being the place where mine wastes of gold ore origin are deposited may definitely show higher concentration of Cd, because the element remains the byproduct of mining and smelting of gold, lead and zinc. This further suggests that trace amount of Cadmium may be present in the mining of gold ore which has been identified as the source of contamination (Udiba *et al*., 2012). However, it may occur naturally in soils as a result of the weathering of parent rocks. It has a relatively low crustal abundance. The cadmium concentration found in this study was far below the permissible limit. Standard threshold limit for this element in the soil according to Hungarian threshold is (1mg/kg) and FEPA (3-6ppm).

The recorded level of Ni indicated an average concentration of 0.12mg/kg, 0.15mg/kg and 0.14mg/kg for mining processing environment, farmlands and residential exterior respectively. The result is below the threshold limits (using Hungarian limit of 40mg/kg). The highest concentration was recorded in the farmlands while the lowest was found at the mining processing environment. This shows that Nickel may not be the result of the new mining activities but possibly attributable to the influence of the old mining activities that were conducted within the residential compound.

This also indicates that the surrounding farmlands may serve as spill points for mine waste that flew as dust from the old mining processing environment and causing high level of concentration of nickel in the area. Nickel is one of many trace metals widely distributed in the environment, being released from both natural and anthropogenic sources. It has been reported to be present in the air, water, soil and biological material. Natural sources of soil nickel level include wind-blown dust, derived from the weathering of rocks and soil, volcanic emission, forest fires and vegetation (Cempel and Nikel, 2006).

From Table 1, it can be seen that there was a significant decrease in the soil lead (Pb) levels. The result shows that 0.14mg/kg, 0.12mg/kg and 0.20mg/kg for the mining processing environment, farmlands and residential exterior respectively. The mean concentration of Pb was found to be higher in the residential exterior than either the mining processing environment or farmlands. This may not be surprising, as heavy metals pollution can continue to persist long after mining operation has ceased, and also the intensive farming activities accompanied with application of inorganic fertilizer and manure which have been the dominant activity in the residential exterior may have contributed to the high Pb. It was established that phosphate fertilizer are among the other sources of Pb that may cause pollution in agricultural soil (Yusuf, Abdu and Tanimu, 2007).

Exposure to Lead over prolonged periods may lead to chronic poisoning. Lead is one of the limited classes of elements that can be described as pure toxic (Udiba *et al*, 2012). Most other elements, though toxic at high concentrations, are actually required nutrient at low levels. There is no exposure level below which lead appears to be toxic between the three areas studied when using the Hungarian threshold limits (100mg/kg).

Geostatistical Analysis

It is essential to fit different methods and parameters repeatedly for determining the theoretical model in order to obtain the theoretical variation function for simulating that distance has impacted on data point. It is required to determine the fitting degree between the theoretical variation function and the experimental variation function for inspecting the validity of the model (Sun, Li and Mao, 2012).

Table 2 shows several theoretical models used for best fitting of the heavy metals in the semi-variance selected. The results show that, for Ni and Mn the Tetrasphere model may be theoretical model of the semi-variance; the J-Bessel may be for Pb and Cd, while and the Rational Quad model for Cr. The ratios of soil nugget values of the elements were as follows:

Table 2: Semivariogram Models of Soil Heavy Metal

Parameter	Model	Nugget	Sill	Range	Lag	Nugget Ratio (%)	RMS
Ni	Tetrasphe	0.0007	0.0038	0.02	0.0021	19	0.089
Pb	J-Bessel	0.00032	0.00071	0.025	0.0021	45	0.057
Mn	Tetrasphe	0	0.129	0.00612	0.00061	0	0.344
Cr	Rational Quad	0.003	0.0362	0.011	0.001	8	0.195
Cd	J-Bessel	0.00078	0.0022	0.0391	0.003	35	0.098

Data analysis (2015)

Pb, Cr, Mn, Cd and Ni have spatial dependence of 45%, 8%, 0%, 35%, and 19%, respectively. Spatial correlations were controlled by the structural factors and random factors. Structural factors include parent material, soil type, climate, and soil-forming factors, while random factors were farming, management practices, cropping systems, land use patterns, pollution and other human activities (Sun *et al*, 2012). Therefore the spatial dependence has been classified as strongly, moderately and weakly spatially dependent if the nugget to sill ration falls within <25, 25-75, and >75% respectively (Cambardella *et al*, 1994).

This indicated that Cr, Mn and Ni in the study area are strongly spatial dependent which were probably affected by structural factors like parent materials, soil type or geology. While Pb and Cd are moderately spatially dependent, which maybe as the result of activities within the mining sites which could be transporting the materials by miners or water and winds to other location.

Spatial Distribution of Heavy Metals in Bagega

The spatial distribution and trend of the heavy metals were produced using Kriging interpolation technique as shown in Figure 2 to 6. The analysis in Fig. 2 shows that in the north, east, northeast, and the centre of the study area, the lead level was found to be very high than in the rest of the area. Elsewhere, the concentration of Pb was moderate to low. Highest concentration was found in the old mining environment, water body and the surrounding village of Bagega, this is likely to show that even the water maybe contaminated with heavy metal as the result of high concentration around the water area and this is in agreement with the study of Adewuyi and Opasina (2011) which exceeded FEPA and WHO guidelines. Even though UNEP, (2011) lamented that Pb is relatively immobile in soils due to its tendency to adsorb to particles such as clay, iron and manganese oxides. However, human exposure to soils contaminated with lead can lead to ingestion and inhalation of dust particles contaminated with lead which in turn can lead to potentially serious health consequences due to lead intoxication.

The spatial distribution of Cr in the area (Fig. 3) shows more concentration in the northwestern part of the area especially around farmlands, and less in the residential areas. The highest concentration in the mining processing environment might be due to break down of metal rich parent rock which release different heavy metals and the indiscriminate disposal of waste containing Cr at the mining processing environment. But the concentration of the element in the surrounding farmlands could be attributed to the influence of water flow that transports waste from the mining processing environment to the surrounding farms. Sabine and Wendy (2009) reaffirmed that Cr is found in rocks, animals, plants, and soil and can be a liquid, solid, or gas. Chromium compounds bind to soil and are not likely to migrate to ground water but, they are very persistent in sediments in water.

The spatial distribution of Mn in Fig. 4 shows a higher concentration at the southwest, centre, southeast and northeast. The decreasing values were found in the north and extreme south of the areas. This may be attributed to the influence of current and old mining activities in the southwest and northeast of the region. Therefore Mn concentration showed irregular distribution within the study area which is probably according to Olivia and Espinosa (2007) concluded that enrichment was attributed to natural sources.

The distribution of Cadmium (Fig. 5) shows higher concentrations in the mining areas, followed by the surrounding farmlands and least in the residential areas. The enhanced levels of Cd in the mining areas may be related to the current mining operations that are taking place within the area. Therefore, mining activities have more influence in the concentration of Cadmium than the old mining sites. Also, the concentration in the surrounding farmlands was possibly as a result of mining waste blown from the mining processing environment. The concentration at the farm site maybe attributed with the use of chemical fertilizer and it also occur in soils and rocks. While the concentration this element around the residential areas may affect the health of the inhabitant because Cadmium are known human carcinogens, it causes severe damage to the lungs (Sabine and Wendy, 2009).

The spatial distribution of Nickel (Fig. 6) shows higher values in the surrounding farmlands, with decreasing distribution from the farmlands to the North and Southwest of the region. The higher concentrations in the area may be attributed to the runoffs of mine waste in solution containing Nickel from the current mining processing environment into the surrounding farmlands and to the dam site. The village does not have other means of drinking water for other household work other than the river which is also used for the “illegal” gold mining. This resulting into the mobilization of metals and other chemical compounds related to water-bodies (Raymond and Felix, 2011).

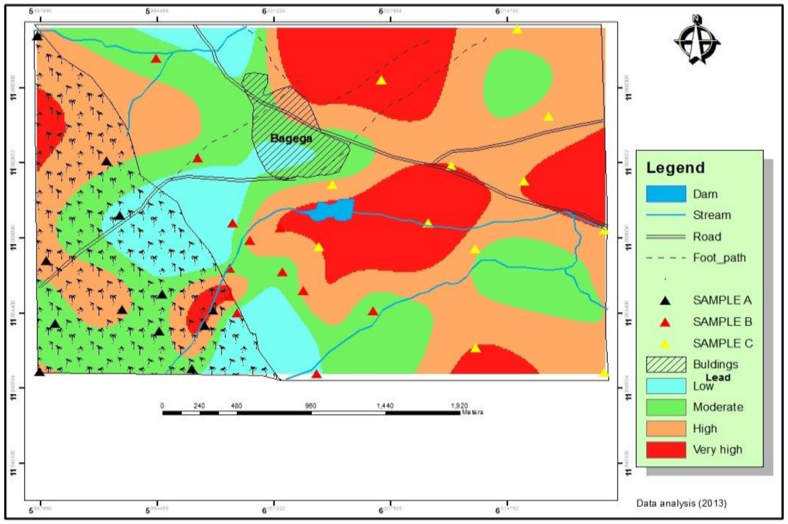

Figure 2: Lead (Pb) Distribution

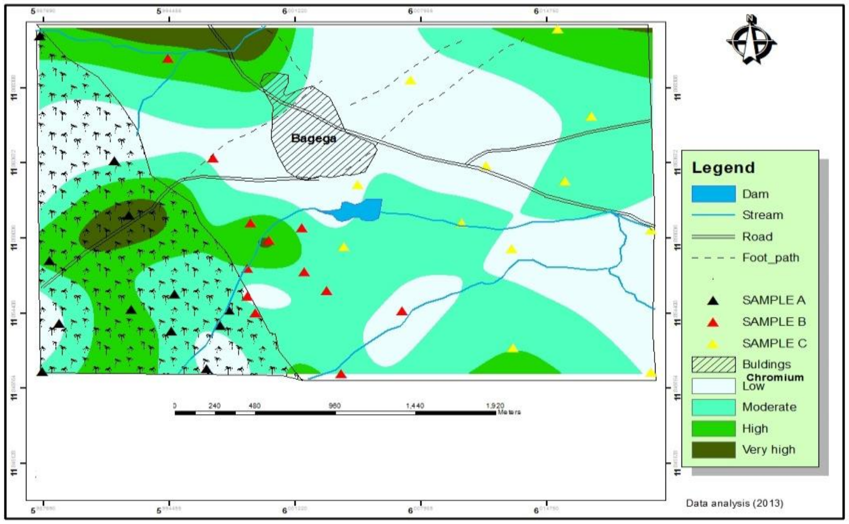

Figure 3: Chromium (Cr) distribution

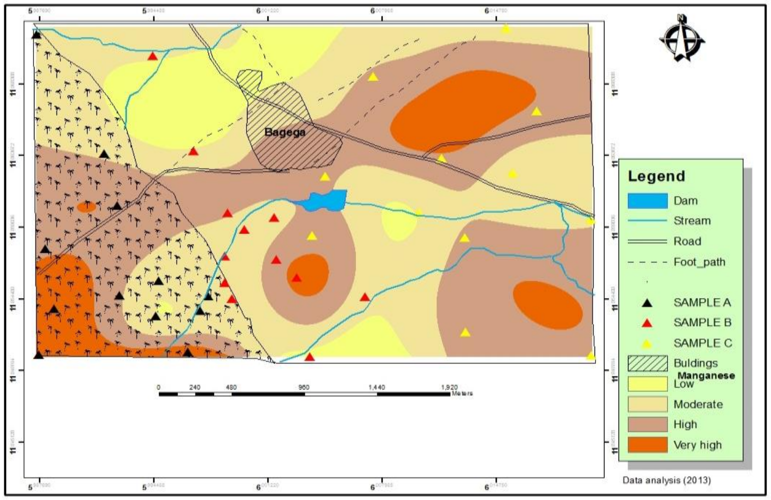

Figure 4: Manganese (Mn) Distribution

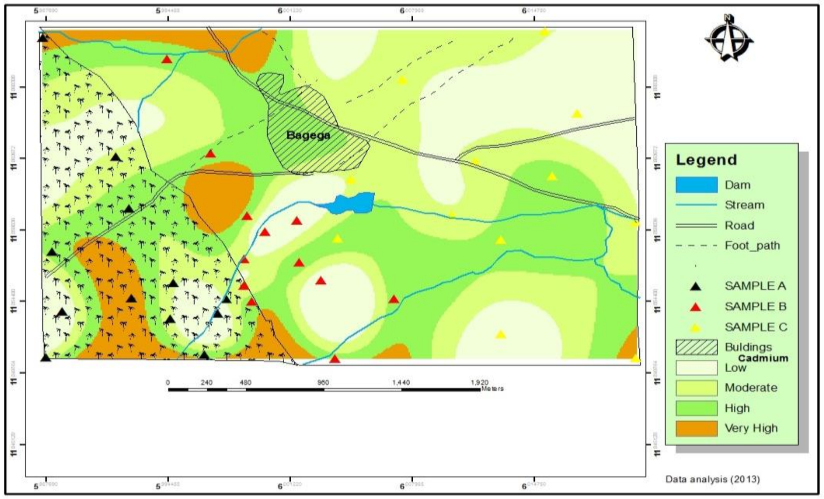

Figure 5: Cadmium (Cd) Distribution

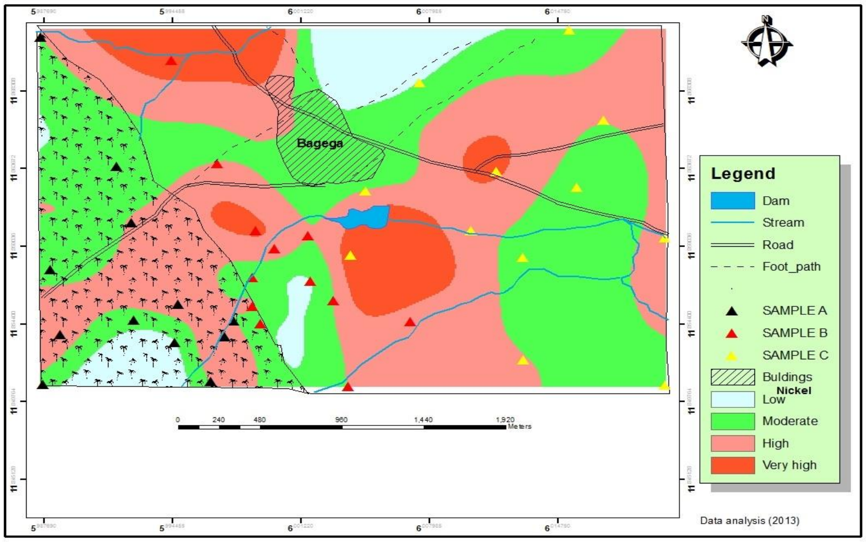

Figure 6: Nickel (Ni) Distribution

CONCLUSION

The levels, sources, distribution and spatial variability of heavy metals in soil around Bagega shows elevated concentration of Cr and Mn in the mining and residential areas. The concentrations of Cd, Ni and Pb on the other hand were low. The concentrations of Cr, Mn and Ni exhibited strongly spatial autocorrelations indicating that spatial variability of these metals may have been affected by factors such as parent material and soil type, Pb and Cd are moderately spatially autocorrelated which are probably affected as the result of human impact.

The general spatial distribution of the elements shows that Cr and Cd have similar characteristic, which is that of being more clustered in the farmland areas. While Pb and Ni are generally clustered at the central part of the area, Mn is seen to be clustered at the southwestern part of the study area. The variability among the heavy metals in the study area indicat that Ni varies more than any other element followed by Cd and Cr. The study recommends further studies at mapping the concentration of the elements at deeper soil levels to compare the level of concentration of the heavy metals across the profile in the study area. Additionally, studies should be conducted mapping areas that are vulnerable to pollution using fuzzy model.

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