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Linking geology to the prevalence of non-communicable diseases: a case study of the Voltaian sedimentary basin, Ghana

Emmanuel Arhin, Raymond Webrah Kazapoe and Fulera Salami
Department of Earth Science, C.K. Tedam University of Technology and Applied Sciences, Navrongo, Ghana

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Abstract

Purpose – The purpose of this study was to define and outline areas prone to disease causing elements by analyzing the spatial distribution and concentration of toxic and essential elements in a section of the Voltaian sedimentary basin.

Design/methodology/approach – A total of 2,668 soil samples were analysed by the inductively coupled plasma mass spectrometry technique and were re-appraised by comparing with baseline values of elements accepted globally to be in soils. The concentrations of arsenic (As), chromium (Cr), iron (Fe) and magnesium (Mg) were evaluated. Factor analysis, hierarchical cluster analysis and principal component analysis multivariate techniques were used to identify the source patterns of the elements in the soils. The Getis-Ord Gi method was used to generate the optimised maps for these selected elements. These maps spatially defined and outlined high value clusters which imply potential pollution or areas with high background values (hotspots), whereas the low value clusters imply areas with low background values (cold-spots).

Findings – The multivariate analysis supports a dominant geogenic source of these heavy elements with obvious influences from variably metamorphosed mafic–ultramafic rocks known to have contributed to the deposition of sediments in the basin. The hotspots for As were located around Nalerigu and to the east of Nawchugu. A Cr hotspot was located to the east of Nawchugu with Cr cold-spots located within Nalerigu and Yunyuo. Fe hotspots were observed to the south of Nalerigu and the east of Nawchugu with Fe cold-spots around Yunyuo, Bongo-Da and Nagbo. The spatial maps demonstrated the presence of toxic and deficient areas of all the selected elements used in the investigation. Therefore, it suggested the likely health implications depending on the exposed elements, their pathways and recommended the usefulness of using the results displayed in the spatial maps to guide in devising appropriate remediation techniques.

Originality/value – This paper fulfils an identified need to study the distribution of elements and the possible effects it may have on the health and livelihoods of those residing in these areas.

Keywords Geological process, Toxicity, Deficiency, Geological materials, Trace elements, Environmental health

Paper type Research paper

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1. Introduction

Geologic materials including rocks and soils contain not only essential elements but also toxic elements; their effect may be detrimental to humans and the natural environment depending on the extent of exposures to these toxic elements and their available concentrations (Grandjean, 2016). The link which exists between geologic materials and various processes has been demonstrated in ancient times to be capable of causing diseases – an example is seen in the mining and employment of lead in ancient Rome. Large tonnages were mined annually with the metal used in plumbing, architecture, as well as fruit and vegetable preservation. The metal was however later identified to have an impact on health including high incidences of sterility, stillbirths and mental incompetence (Alloway *et al.*, 2005). Hippocrates also noted that under certain circumstances water which interacted with soils containing iron, copper, silver, sulphur, and so on were "bad for every purpose" (Alloway *et al.*, 2005).

The distribution and relative abundances of the various elements are dependent on the underlying geology directly impacted by the various geological settings (determined by sediment deposition, igneous emplacements or metamorphism among others), as well as various geogenic/geochemical processes and anthropogenic processes such as weathering, acid mine drainage, mineral dissolution or precipitation (Kazapoe and Arhin, 2019). The breakdown of minerals during weathering from rocks release both toxic and essential elements into soils where food crops are cultivated for human consumption. Vegetation including food crops by virtue of the root systems play an important role in transporting the released minerals/elements to the environment that sustains life. The translocated minerals and elements hydraulically are moved to the preferred zones of the plant where the trace elements concentrate in the tissues that act as intermediate receptors or pools. The receptors in this sense as food crops, fish and drinking water then plays the roles as pathways or conduits through which the toxic and essential elements find their way to man and animals (Kabata-Pendias and Pendias, 2001).

Majority of Ghanaians consume crops cultivated in their environment and rely on groundwater which closely interacts with the underlying rock for various household activities (Ayoob and Gupta, 2006). These allow for the indirect transfer of the elements in the host rocks/soils to the consumer. This act exposes people to both the benefits and the adverse effects originating from the environment. The impacts of the exposed elements tend to be slow and sometimes undetectable by clinical diagnosis as trace amounts of the elements often are taken up into the human system. There are some elements that are bio-accessible in humans. Others if ingested, inhaled or topically absorbed by dermal contact will be excreted out through some organs thus may not bioaccumulate. The bio-accessible elements may however bio-accumulate to a trigger point and cause harm to the exposed person. Knowledge of their presence in the environment contributes to devising methodologies for remediation against any adverse health on the population. The creation of spatial–temporal distribution of elements could aid in pre-empting the likely diseases which are developed because of exposures to hotspots or cold-spots of disease-causing elements in an area. In addition, the sources, the sinks or receptors and chemical species causing the diseases can also be identified and outlined for remediation processes.

This study attempts to link geology to some non-communicable diseases (NCD) associated with the natural environment as a way of educating people and hence equipping them to take measures to prevent these diseases, addressing the sustainable developing goal of good health for all a reality.

As most people in the area rely on their diet for the essential micronutrient's supplements, excesses or depletion of elements in soils could be used as a guide to determine the health outcomes in the area. There is a school of thought that argues that good health and well-being require the provision access to health facilities. Conversely, if deficiencies of essential elements and enhancements of toxic elements find their way into humans through the different pathways, then the fight for good health and well-being for all may become a challenging task as the affected patients will still meddle with the source species that made them unwell (Xiu, 1996; Kabata-Pendias and Pendias, 2001), and sometimes causes death (Hodgson, 2004; Lovell *et al.*, 2014). Many NCDs reported in hospitals and in some mining communities are indications of potential problems of excess or deficiency of elements in the human system. Hence an element geoavailability map of an area can be used as an indication of possible disease patterns particularly for NCDs in an area.

Previous studies conducted in various parts of Ghana have established the presence of potentially toxic elements (PTEs) as well as deficiencies of some essential elements in the surface soils; they however failed to link these as disease-causing agents (Apambire *et al.*, 1997; Apambire, 2001; Yidana *et al.*, 2012; Affam *et al.*, 2012; Arhin *et al.*, 2016). As such, this study presents the spatial distributions and concentrations of toxic and essential elements in the study area in an attempt to identify those which are disease causing and also define and outline specific areas prone to the outbreak of resultant diseases.

2. Study area

The study area is situated directly south of Gambaga and just southeast of the northern contact zone of the Voltaian sedimentary Basin with the Birimian Bole–Navrongo Belt in the northern region of Ghana (Figure 1). The area is underlain by the Neoproterozoic Voltaian sedimentary rocks, consisting of arenaceous and argillaceous rocks. The rock units include sandstones, shales, mudstones and some conglomerates (Junner and Service, 1937; Apambire *et al.*, 1997; Apambire, 2001; Yidana *et al.*, 2012; Affam *et al.*, 2012). Some of these rocks were deposited as molasses during uplift of the Dahomeyide orogen located to the southeast of the study area while others contain zircons suggesting Amazonian sources supported by inferences from paleo-depositional trends (Carney *et al.*, 2010).

The inhabitants of the study area have farming and quarrying as their main occupation. The farmers grow crops such as millet and groundnuts and keep livestock also. Much like most parts of Africa, the people and animals in the study area rely on the food grown in the area as the main part of their diet (Ghana Statistical Service, 2012).

3. Methods

3.1 Sample collection and laboratory analysis

A total of 2,668 soil samples collected from the Gambaga area (Figure 1) for geochemical studies were re-appraised for some elements whose exposure to humans are known to cause serious health challenges. The elements re-appraised were arsenic (As), barium (Ba), potassium (K), zinc (Zn), cobalt (Co), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), magnesium (Mg), and iron (Fe) of which some are essential and others have toxic consequences on human health.

Predetermined sampling locations were planned on a 1/50,000 scale of the study area to assess soil geochemistry. A total of 1 kg composite samples were collected from 30 cm nominal diameter holes, dug to depths of 30 cm after the humus layer had been scrapped and discarded. The samples were sieved to $<106\,\mu m$ fraction. The sieved samples were subsequently bagged in double plastic bags and readied for geochemical analysis at a commercial laboratory. XRF analytical technique was used after the sieved samples were moulded into press pellets. Elements analysed were As, Ba, K, Zn, Co, Cr, Cu, Mn, Ni, Pb, Mg, and Fe. Out of the 12 elements, 4 elements were selected for exploratory studies so as to

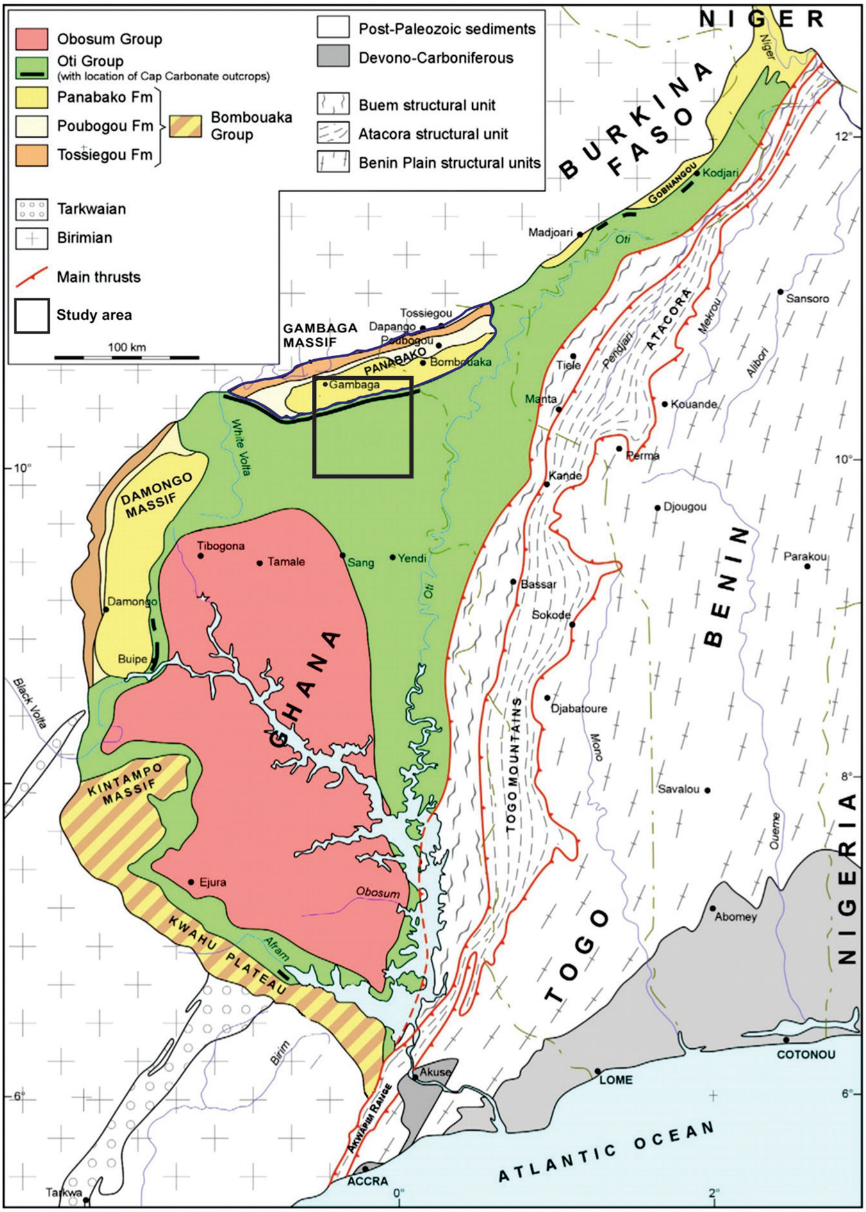

Figure 1.
Location and geology map of Ghana

Source: Abu *et al.* (2020)

know the impacts on human exposure relative to human health. The selected elements were made up of two PTEs (As, Cr) and two essential elements (Mg, Fe).

3.2 Quality assurance and quality control analysis

The analytical quality of the data was ensured by inserting certified reference materials (CRM) at every 50th sample. These samples were inserted in the batches of samples sent to the laboratory. In addition to the CRM insertions, blank samples were inserted at every 100th sample, whereas the field duplicate samples were also inserted at every 40th sample. The reference samples inserted showed good reproducibility in all elements except one where there were issues with the reference elements, Fe and Cr. The non-reproducibility of Fe and Cr was attributed to their concentrations which were close to detection limits and thus had issues with calibration. Other elements that had significantly high values showed good reproducibility in all elements. The per cent precision measured from the field duplicates showed marginal variations when compared. The major elements showed small average variations of 1.0%–5.5% between duplicate sample pairs, with MgO and Na_2O displaying values of 20.8% and 49.6%, respectively. This variation is mainly because of the value range of Na_2O (0.01–2.07) where the instrument detection limit seems to be very erratic on the Na_2O detector. The errors recorded in the CRM are marginal, thus increasing the confidence of the analytical quality from the laboratory. The analysis of recovery rates for some selected trace elements example Cr, As and Pb showed no significant variation between reference and measured CRM values.

3.3 Geochemical data analysis and interpretation

A multivariate statistical approach was applied to sort through the sources of elemental enrichments in the soil and identify associations and similarities between the various elements. This was done by employing the principal component analysis (PCA), factor analysis (FA) and hierarchical cluster analysis methods. During the performance of the FA, the number of measured element variables were reduced from 12 to 10 by selecting only those elements with a communality of extraction higher than 0.5 (50%) or common variances/0.5 (Bern *et al.*, 2019). The use of this approach in this context has been effectively used with similar intents (Jiang *et al.*, 2017; Rasool *et al.*, 2016; Kazapoe and Arhin, 2019; Lermi and Sunkari, 2020). Prior to this, the concentration data were subjected to log transformations after the data normalities for the elements were examined using the one-sample Kolmogorov–Smirnov test (the K–S test of normality) and the Shapiro–Wilk tests. The descriptive statistics for Co, Mg, Fe, Cr, Pb, and As is presented in Table 1. The summarized information in Table 1 guided the comparison of the measured averages with globally accepted background averages for the various elements (Figure 2).

The optimised hotspot analysis based on the Getis-Ord Gi* method was performed on the transformed data using the ArcGIS (ver. 10.6) software. The Getis-Ord Gi* functions by considering individual samples within the context of neighbouring sampling points. A sample with a high value may not be a statistically significant hotspot, as it has to be surrounded by other samples with high values as well, and the averages of the neighbourhood area need to be significantly higher than the global average value for the whole data in the study area. Therefore, a hotspot point represents its neighbouring area, instead of a single point. This feature is useful in geochemistry when the sample number is large, as we are interested in spatial patterns covering an area. The most important feature of the optimised hotspot analysis is that the statistical significance is automatically adjusted for multiple testing and spatial dependences by the false discovery rate (FDR) correction method.

The application of the FDR method ensures that false high value clusters do not contaminate the results. The high value clusters imply potential pollution or areas with high background values, while the low value clusters imply areas with low background values (Figures 4-7).

4. Results and discussion

The availability of individual trace elements in soils determine if plants and animals will receive sufficient amounts of an element to meet their nutritional requirements, or whether the element uptake by living things could be detrimental to health. In the event of excess potentially harmful elements in soils, the impact on human health may be exacerbated because most Ghanaians consume locally cultivated food and drink from groundwater excavated locally. Similarly, in the case where the soils are depleted in essential elements complicated health issues will be realized (Arhin *et al.*, 2019). In both situations any individual exposed to these things will be influenced, making relevant the observations by Kaplan (2016) that "we are what we eat and drink".

Correlations between metals Cu, Fe, Cr, Mn and Ni (with the exception of As, Ba and K_2O) were significant at the $p < 0.01$ probability level, while Cr is only correlated with Fe (Table 2). Two major clusters have been indicated (Figure 3) with Cluster 1 consisting of Ba, Mn and Cr while cluster 2 consists of Ni, Fe, K_2O, Pb, As and Cu. Mn and Cr are commonly enriched in mafic rocks indicating that the Cluster 1 elemental association are from mafic suites of source rocks for the sandstones. The elemental association in cluster 2 are elements

Table 1.
Summary statistics of elements in soil samples

Elements and their respective average crustal abundances	As 20	Ba	Cr 130	Cu 80	Fe	MgO	Mn	Ni 50	Pb 450
Maximum	22.68	361.20	1997.39	104.82	6.90	2.59	144.21	33.27	61.70
Minimum	2.22	12.60	152.27	4.00	0.55	0.01	6.10	1.80	2.70
Mean	10.28	61.18	448.63	5.41	1.57	0.23	27.56	3.70	8.86
Median	10.17	51.40	395.93	4.00	1.42	0.19	23.80	2.00	8.00
SD	2.60	37.64	223.79	4.10	0.62	0.18	14.31	3.72	4.92
Skewness	0.27	3.25	2.05	10.67	2.00	3.78	2.66	3.61	2.54
Kurtosis	0.51	13.82	6.28	209.92	6.79	27.86	11.36	17.09	14.90

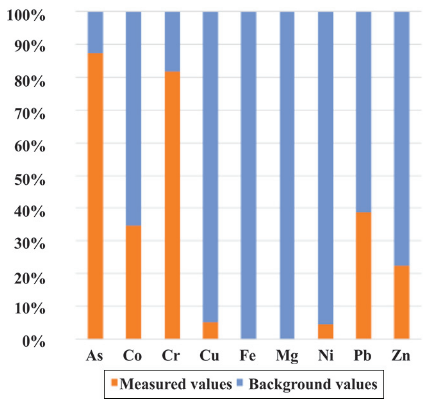

Figure 2.
Concentration levels disparities between measured and background concentrations of some potentially harmful elements to assess risk of exposure

that are well known largely within mafic and ultramafic rocks except for K_2O and its weathered clay products. Furthermore, the As association with this suite of elements indicates that it may be sourced from metamorphosed mafic–ultramafic suite of rocks, this would appear to support the widely held assertion that the sandstones from the area are partly derived from clastic sediments of the Paleoproterozoic Birimian basement metasedimentary rocks which underlies the Volta basin (Anani, 1999; Couëffé and Vecoli, 2011; Anani *et al.*, 2017; Abu *et al.*, 2020). PCA was carried out using SPSS version 20.0; the eigenvalues and rotated sum of squares loadings are shown in Table 3. The first three principal components (PCs) accounts for 72.96% of the total variance. PC1 accounted for the 50.29% of the total variance, PC2 loadings accounted for 11.81%, whereas PC3 loadings accounted for 10.86% of the total variance (Table 3). FA using R – Mode FA generated the

Elements and their respective average crustal abundances	As	Ba	K	Cr	Cu	Fe	Mn	Mg	Ni	Pb
As	1.000	0.114	0.083	0.224	−0.024	0.225	0.046	0.025	0.028	0.185
Ba		1.000	0.001	−0.079	0.018	0.062	0.181	−0.006	0.144	0.170
K			1.000	0.305	0.245	0.250	0.287	0.352	0.296	0.288
Cr				1.000	0.257	*0.540*	0.400	0.363	0.368	0.337
Cu					1.000	0.326	*0.508*	0.407	*0.576*	0.308
Fe						1.000	*0.718*	0.420	*0.606*	0.426
Mn							1.000	0.471	*0.819*	*0.526*
Mg								1.000	*0.605*	0.246
Ni									1.000	0.487
Pb										1.000

Notes: $p < 0.05$; $p < 0.01$

Table 2. Coefficients of correlation of elemental concentrations in the study area

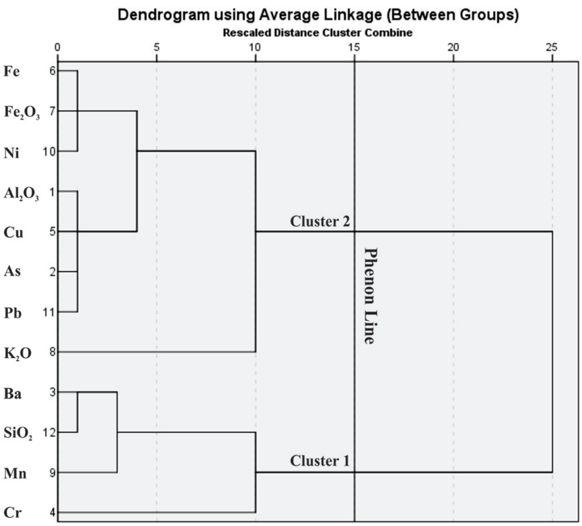

Figure 3. Dendrogram showing elements linkages and possible natural loadings in the samples

rotated components (Table 4) showing the various elemental components of the PC. PC1 contains Al_2O_3, Cr, Cu, Fe, Mn, Ni and K_2O, with PC2 and PC3 consisting of As, Cr and Ba, respectively (Table 3). PC1 accounts for 50.29% of the total variance. The constitution of elements within this first component (Table 4) collaborates that of the elemental association in cluster 1 (Figure 3) and hence points to lithological control of those elements present in the samples.

From Figures 4 and 5 the average measured concentrations of As and Cr were greater than their crustal background concentrations in the soils. The implication therefore is that human exposure to the potentially harmful elements may have adverse health consequence. Kabata-Pendias and Pendias (2001) recognised arsenic minerals and compounds as soluble minerals which have restricted movement in certain types of soils. As is able to adsorb to hydroxides, clays and organic matter. Hence, in an environment underlain by arenaceous (sandstones) and argillaceous (mudstones) rocks such as the study area, then the movement of As will be mixed forming a miscellany of different spatial patterns. The physical and chemical properties of the underlying rocks will lead to different types of soils which will either facilitate or hinder the movement of As. Although As plays a role in the normal

Table 3. Total variance explained for elements in the soil samples in the study area. Extraction method: Principal component analysis

Component	Initial eigenvalues Total	Initial eigenvalues (%) of Variance	Initial eigenvalues Cumulative (%)	Rotation sums of squared loadings Total	Rotation sums of squared loadings (%) of Variance	Rotation sums of squared loadings Cumulative (%)
1	5.029	50.291	50.291	4.857	48.571	48.571
2	1.181	11.811	62.102	1.310	13.104	61.676
3	1.086	10.862	72.964	1.129	11.288	72.964
4	0.810	8.103	81.067			
5	0.611	6.110	87.177			
6	0.561	5.605	92.783			
7	0.245	2.452	95.235			
8	0.200	2.002	97.238			
9	0.166	1.660	98.898			
10	0.110	1.102	100.000			

Table 4. Rotated component matrix for elements in the soil samples in the study area

Rotated component matrix	Component 1	Component 2	Component 3
Al_2O_3	*0.902*	0.014	0.164
As	−0.073	*0.892*	0.163
Ba	0.202	0.131	*0.860*
Cr	*0.503*	*0.521*	−0.443
Cu	*0.724*	−0.114	−0.085
Fe	*0.782*	0.432	−0.050
K_2O	*0.538*	0.102	−0.194
Mn	*0.885*	0.080	0.187
Ni	*0.870*	0.025	0.205
SiO_2	−0.882	−0.100	−0.121

Note: Extraction method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization

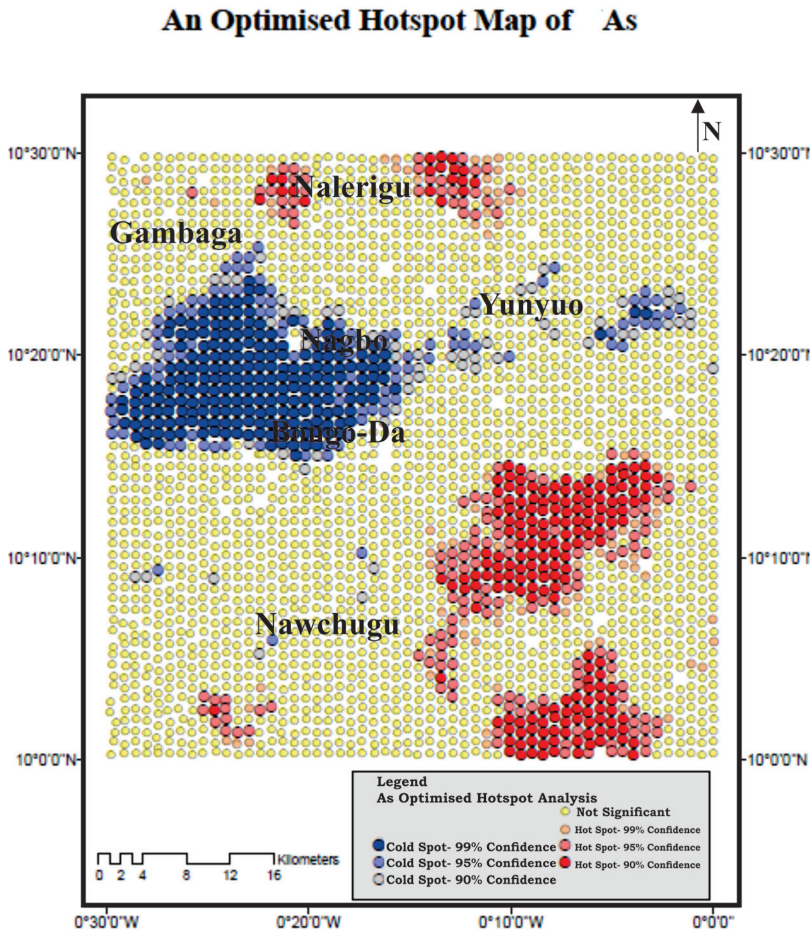

Figure 4. Optimised hotspots and colds-pots map for arsenic (As) in soils

physiological and biological functions of plants, it is generally not considered to be a significant element in the normal function of plants (Carbonell *et al.*, 1998). Arsenic levels ranging from 5–20 ppm (dry weight basis) can be toxic to plants in leaf and show symptoms including necrosis, wilting, reduced growth and root discolorations (Kabata-Pendias and Pendias, 2001). However, it is still unlikely that the phytotoxic As levels will result in the possible poisoning of consumers because plants will cease to grow if roots have absorbed too much As. Likewise fruits and seeds will not have elevated levels (Adams and Ohene-Yankyera, 2014). Toxicities in animals is also possible as animals may come into contact with soils containing elevated levels of As and this could lead to the accumulation of arsenic in the organs (Ventura-Lima *et al.*, 2011). As the main occupation in the study area is subsistence crop farming and livestock rearing (Ghana Statistical Service, 2012), it makes the consumption of various parts of livestock including their organs very high. Trace concentrations of As in animal organs after consumption may also bio-accumulate as they are bioavailable and will have possible health risks (Adams and Ohene-Yankyera, 2014).

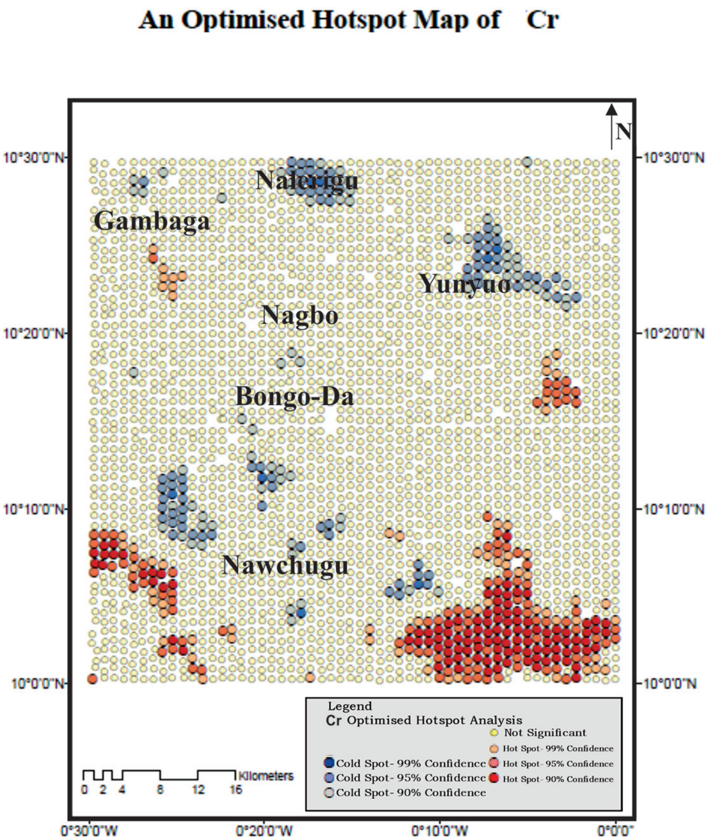

Figure 5.
Optimised hotspots and cold-spots map for chromium (Cr) in soils

Most parts of the study area showed insignificant concentrations of As with hotspots clustered around Nalerigu and to the east of Nawchugu (Figure 3), which is good for the population living there due to the carcinogenic nature of As. It has been observed to be non-destructive in the environment and also soluble in water. This means in water, As can bio-accumulate in fish and shellfish and when consumed could cause heart diseases (hypertension-related cardiovascular disease), cancer, stroke (cerebrovascular diseases), chronic lower respiratory diseases, and diabetes (Carbonell *et al.*, 1998). As little or no As is found in most areas it is possible that the As-related diseases may not occur in those areas. Further to this area, there are some areas mapped as cold-spot areas. These areas are patchily distributed and are spatially recognized to occur at the middle section of the study area. These areas contain As in soils with concentrations well below the worldwide baseline. It however does not denote the absence of As in the soils. Considering the bioaccumulation feature of As, its solubility in water and duration of exposure, it is possible to anticipate the occurrence of As-related diseases here. The only difference between the cold-spots and hotspots in terms of As-related diseases is that the impact may not be widespread in areas mapped as cold-spots. The hotspots areas are patchily and spatially distributed (Figure 4).

Cr levels in sandy soils generally are low but the average concentrations of measured Cr in the study area far exceeded the worldwide background concentrations in soils. The worldwide Cr concentration level is 54 ppm, but as seen in Table 1, the mean measured Cr in the soil samples is 449 ppm. The measured Cr concentration values range from 152 to 1,997 ppm. Like As, Cr concentrations are more in clayey and fine textured soils but tend to be low in sandy soils and organic soils (Kabata-Pendias and Pendias, 2001). The climate of the study area is savannah and does not support thick vegetation growth, meaning soils rich in organic matter may be uncommon (Dickson and Benneh, 1995). However, Cr^{3+} may be more available in sandy soils due to its low cation exchange capacity (Moon, 2005). Chromium is an essential trace element for mammals but there is no evidence that it is essential for plants although there are some reports of growth stimulation by Cr^{3+} for plants (Stearns, 2000). In another instance, Cr^{6+} is toxic to both plants and animals (Nriagu and Nieboer, 1988). Phytotoxicity occurs at leaf levels of 5–30 ppm (dry weight basis) and there is some evidence of toxicity to livestock grazing on plants high in Cr (Gad, 1989). Since total Cr was measured in this study, it is not possible to tell the type of Cr-specie present in the area. Therefore, there is an urgent need to conduct further speciation investigations to avert an anticipated medical geology problem from direct inhalation of Cr and indirect ingesting through the consumption of livestock grazing on plants high in Cr content. Inhalation of Cr compounds can lead to respiratory tract irritations and could cause pulmonary sensitization, increase the risk of lung, nasal, and sinus cancer and results in severe dermatitis and usually painless skin ulcers. The spatial pattern recognition for hotspots and cold-spots for Cr (Figure 5) are sporadically distributed. The hotspots appear to cluster at the southern parts. From Figure 5, Cr hotspot was significantly clustered to the east of Nawchugu with cold-spots located in Nalerigu and Yunyuo. Most areas in the study have insignificant Cr in soils or generally deficient in Cr. This means Cr intake will be inadequate because the sources of essential elements supplements in this area are often through diet. About 80% of the area is deficient in Cr but numerous studies have shown that a strong association exists between chromium deficiency, high blood insulin, and elevated blood cholesterol levels (Simonoff, 1984; Anderson, 1993; Wilson and Gondy, 1995). So, in these areas of Cr-deficiencies (Figure 5), NCD such as heart attack, diabetes (particularly the adult onset type), hypoglycaemia, fatigue, mood swings (depression and anxiety), depressed sperm formation, loss of sugar in the urine, high blood cholesterol, and atherosclerosis are anticipated to occur in the study area (Wilson and Gondy, 1995. These health outcomes can affect many people because Cr deficiency in the soil is widespread in the study area.

Fe and Mg are essential elements; a deficiency of these elements may therefore cause certain health challenges. There was a vast difference between the measured averages of Fe and Mg compared with globally accepted values of Fe and Mg (Figure 2) in soils within the area. The optimized hotspot analysis showed some areas contained insignificant Fe and Mg contents in the samples (i.e. measurements below detection limit), some areas depicted low and high clusters of these elements and there are high and low cluster areas also (Figures 6 and 7). Contrastingly, the average of the measured values of Fe and Mg in all the analysed samples when compared with the global average concentrations of Fe and Mg in soils show an apparent of Fe and Mg in the area.

Fe is known for its essentiality for the well-being of people (Cairo *et al.*, 2006). It is generally well-known for the correct functioning of haemoglobin in human blood and thus prevents anaemia. Many people strive to have more Fe in their diet in order not to suffer from anaemic conditions. But like many of the micro-essential elements, some optimum amounts are required for human and animal well-being. An excess or a deficiency of Fe in human physiological functions can cause adverse health effects. The spatial patterns of Fe concentrations (Figure 6) are scattered with hotspots clustered to the south of Nalerigu and the east of Nawchugu and cold-spots around Yunyuo, Bong-Da and Nagbo. This suggests

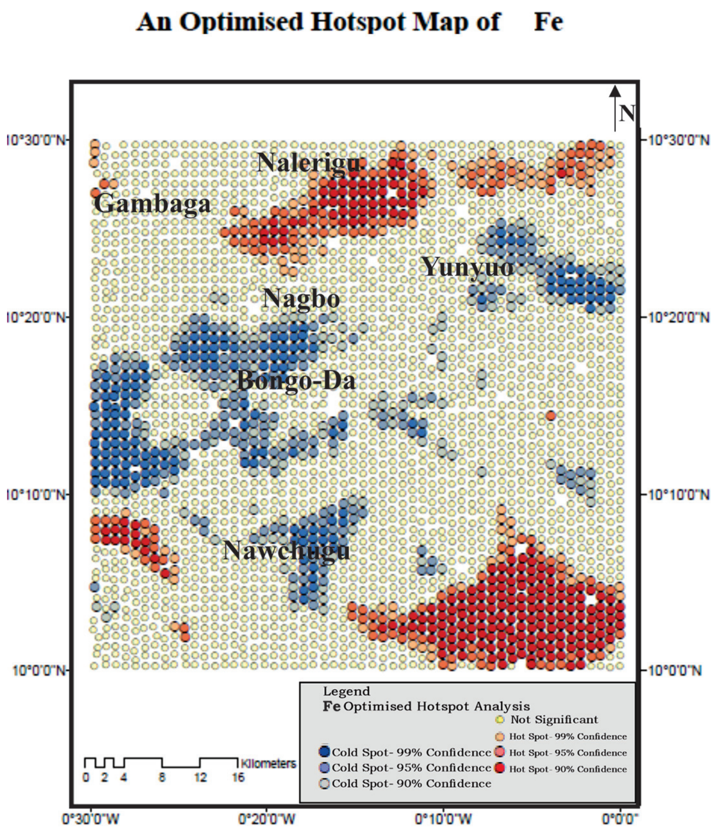

Figure 6.
Optimised hotspots and cold-spots map for iron (Fe) in soils

that the anticipated disease patterns in the area will generally vary with the possibility of anaemic conditions prevailing in Fe-deficiency communities and Fe-overload-diseases predominating in Fe-excess areas. Clinical diagnosis has identified that excess Fe in vital organs increase the risk of liver disease (cirrhosis, cancer), heart attack or heart failure, diabetes mellitus, osteoarthritis, osteoporosis, metabolic syndrome, hypothyroidism, hypogonadism, numerous symptoms and in some cases premature death (Huang, 2003).

Magnesium which is generally unknown to many when compared to Fe, plays an important role in over 300 enzymatic reactions within the body including the metabolism of food, synthesis of fatty acids and proteins, and the transmission of nerve impulses (Dean, 2007). As seen in Figure 7, most parts of the study area are deficient in Mg compared to Mg-excess hotspot terrains. Based on this revelation, it is likely that the population in the communities recognized to have low or insignificant concentrations of Mg in soil may have deficient amounts of Mg in their diet as the abundance of the elements in soils are transferred to the plants through the root systems. This implies that crops grown for consumption in the Mg-deficient or cold-spot areas may have low uptake of Mg from the soils into the cultivated food crops. Similarly, grazing animals will have insufficient Mg for their wellbeing if the source of Mg intake is only from the local vegetation. The health implications of either excess or depleted Mg concentrations have not yet been mapped out

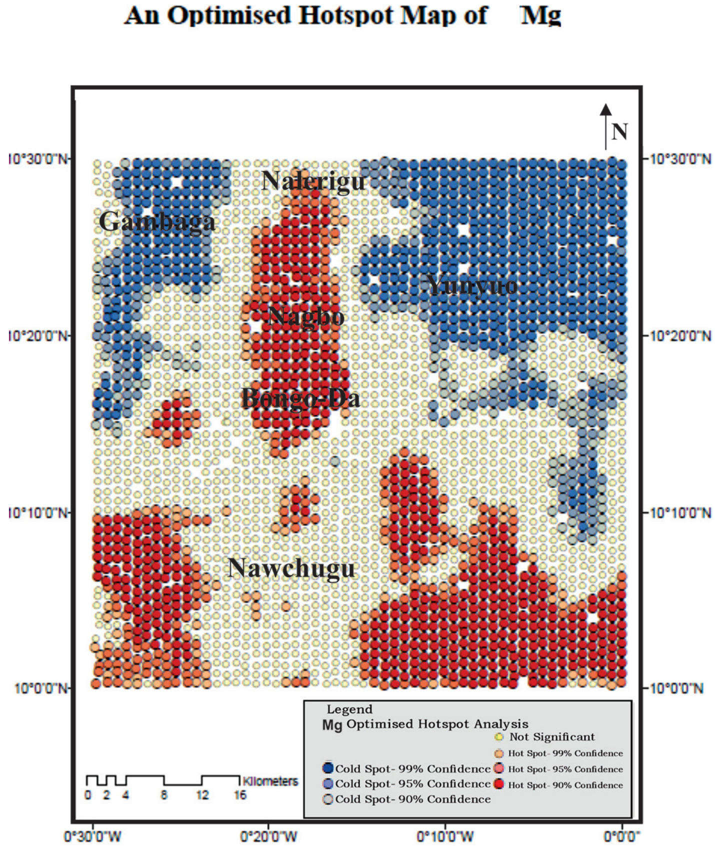

Figure 7.
Optimised hotspots and cold-spots map for magnesium (Mg) in soils

from the epidemiological data available in Ghana but published records shows that Mg-deficiency in humans can affect heart health, blood pressure, cancer, chronic pain, digestion problems and diabetes. These diseases seem predominant in the national health records in many of the developing countries including Ghana because we eat what we grow. So the health benefits of key vitamins and minerals such as Mg in soils that are exposed to humans and animals for their well-being must be monitored in order to control the effect on the human well-being.

5. Conclusions

The varying levels in elemental concentrations in soils may find their way into the locally cultivated food and in drinking water sourced from groundwater which may influence the concentration levels of these media. The continuous consumption of locally cultivated foods and drinking of water depleted in essential elements and enriched in toxic elements may cause environmentally related diseases. The multivariate analysis employed supports a dominant geogenic source of these heavy elements with obvious influences from variably metamorphosed mafic-ultramafic rocks known to have contributed to the deposition of sediments in the basin. The methodology employed also successfully delineated hotspots for

As around Nalerigu and to the east of Nawchugu. Cr hotspot was located to the east of Nawchugu with Cr cold-spots located within Nalerigu and Yunyuo. Fe hotspots were observed to the south of Nalerigu and the east of Nawchugu with Fe cold-spots around Yunyuo, Bongo-Da and Nagbo. The spatial maps demonstrated the presence of toxic and deficient areas of all the selected elements used in the investigation. Therefore, it suggested the likely health implications depending on the exposed elements, their pathways, and recommended the usefulness of using the results displayed in the spatial maps to guide in devising appropriate remediation techniques. The disease patterns may probably have direct correlations with the elements concentration levels in the soils. The study finds the hotspots and cold-spots of disease-causing elements to be useful as the sources and pathways of the elements can be identified for remediation. Such information can help to ensure that appropriate environmental policies are developed to address the likely health issues head on. This kind of study will also facilitate a deeper understanding of non-communicable disease epidemics and would enable proper handling of such diseases, similar to what is seen with communicable diseases. This is because the toxicities and deficiencies of essential elements such as Fe and Mg and toxicities of As and Cr can affect millions of people outlined in the spatial maps developed from the reappraised geochemical data. Disease pattern maps can be developed from the appraised data for disease prevention work.

In conclusion access to health care to all is good but being able to prevent outbreaks of NCD is best in achieve Sustainable development goal 3 on good health and well-being.

The authors recommend the development of spatial maps that display hotspots and cold-spots of disease-related-elements in similar areas which also considers a comparison with epidemiological data, to guide in devising mitigation and prevention strategies against the elements-causing disease impacts on Public Health.

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Corresponding author

Raymond Webrah Kazapoe can be contacted at: rkazapoe@yahoo.com