Selenium Geo-Availability in stream sediments in selected communities in the Kintampo area of the Bono East region of Ghana.

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Abstract

Selenium is a necessary trace element naturally found in rocks, soil, water and some food crops that contributes to human development. Due to its role in maintaining normal functions of the human body and the health problems associated with its deficiency and toxicity, it is referred to as the 'double-edged sword element'. A total of 43 stream sediment samples were collected using a Global Positioning System receiver to navigate predetermined locations. Selenium concentration in the samples was assessed using inductively coupled plasma/optical mass spectrometry technique and pH measured with a pH meter. The pollution status of Selenium was determined by calculating the degree of contamination, pollution load and geo-accumulation indices. Stream sediments were underlain by sedimentary rocks with lithologies such as sandstone, mudstone, shale and phyllite. Out of the 43 samples analyzed, 35 (81%) were deficient in selenium. Selenium levels ranged from <0.2 mg/kg to 0.4 mg/kg with a geometric mean of 0.11 mg/kg reflecting the global background value in sedimentary rocks. The study found almost the entire area to be deficient in selenium. The low selenium geo-availability may adversely affect its bioavailability in food crops with profound public health implications for inhabitants of the study area who derive dietary selenium through the consumption of these crops. Consequently, our findings call for further research into the link between Se content of food crops grown in the study context, human blood selenium levels and health outcomes in the population to facilitate the potential implementation of remedial public health interventions.

Keywords: Selenium geo-availability, Stream sediments, Sandstone, Ghana, Kintampo.

Introduction

Selenium (Se) is a naturally occurring mineral that, in minute quantities, is important to human and animal health but may be harmful in excess or if deficient (Council, 1983). Selenium has one of the narrowest ranges between dietary deficiency (<40 μg/day) and toxic levels (>400 μg/day) of all elements. Health trends relative to Se exposure have a connection with the amount of Se in soils derived from the underlying rocks. Geology primarily exercises a fundamental influence over the Se concentration in soils on which crops and animals that make up the human food chain are produced. As a result of various geological materials and processes, the Se status of populations, animals, and crops varies remarkably across the world. It is not all rocks in the sedimentary environment that have high Se content. There are some sedimentary lithologies that are Se-deficient due to environmental and geochemical processes. This suggests that health outcomes depend not only on the total Se content of rocks and soils, but also on the quantity of bioavailable Se to be ingested into plants and animals [1].

Selenium is commonly referred to as a 'double-edged sword' for its dual toxic and health-beneficial character. Selenium present in soils determines its concentration in plant foods that eventually affect human health depending on dose. Selenium can cause diseases when deficient or when in excess. For instance, Se deficiency disorders can result in infertility and weak immune system whilst selenium toxicity leads to liver and heart diseases [2].

The health of soils is a primary precursor to the health of the inhabitants of any community since the source of essential elements for human development particularly Se is dietary (Health, 2018). Moreover, dietary Se intake to be greatly influenced by food Se content, which in turn is dependent on the bioavailability of Se in soil. This implies that knowledge of the Se-status of soils is vital as adequate concentration of this trace element contributes to the physiological development of humankind [3].

Most rocks that weather into agricultural soils are sedimentary rocks. The shale component of sedimentary rocks which contain the highest Se concentration in an area is about 58 percent. Globally, it is understood that selenium concentration occurs in order of importance: Shales> sandstones>limestones, and then>phosphorite rocks [4]. However, without any external influence on metal ions mobility, the soils developed from the underlying rocks may have strong relations in terms of the Se content of the geological parent materials after weathering [5]. This presupposes that the Se content of soil is not only controlled by the geological parent material but also a function of other factors such as pH and organic matter content. Evidence of the influence of organic matter on soil Se content has been reported in several studies carried out in low selenium environments [6].

Despite yawning evidence of the effect of selenium on human health, there is little or no knowledge of soil selenium content and spatial variations in its concentration in the study area [7]. Consequently, an understanding of the extent and spatial variability of soil selenium concentration is crucial to the planning and implementation of nutritional health interventions in the study context [8]. In this study, we quantified and mapped the levels of concentration and spatial distribution of soil selenium in the study area using stream sediment samples [9].

Methods and Materials

Location physiographical and geological settings

Location: The study was carried out in the Kintampo North Municipality and Kintampo South District located in the Bono East Region of Ghana [10]. The area is characterized by a forest-savannah type of vegetation as it marks the transitional zone between the northern grassland and southern forest regions of the country [11]. These two districts cover an area of about 7,162 square km with a resident population of 159,701. Kintampo Municipality is approximately 426 km driving distance via the N6 highway from Accra through Kumasi [12].

Physiographical setting

The study area is located at an altitude of 334 meters above sea level [13]. According to the Köppen-Geiger climate classification, it has a tropical type of climate. The area receives much less rainfall between January and April whilst the main rainy season is from May to October with an average rainfall of 1,250 mm per annum [14]. The area has a mean monthly temperature range of 18-38°C. Besides, the area's vegetation cover is made up of shrubs, croplands and trees. Farming is the main occupation of the populace.

Geologic and regolith setting

Palaeozoic sedimentary rocks consisting of Kintampo massifs, thick layers of sandstones, siltstones, shales and new tertiary sedimentary rocks underlie the study area. Typically, the rock units are well cemented or recrystallized in these areas. The characteristics of rocks in the north-western and south-eastern parts of the municipality also consist of massive and thin-bedded quartz, arenite or sandstones. Shales and mudstones are also common in the study area. The south-western part of the municipality is also underlain by phyllite, schist and tuff with derivatives such as tuff-phyllite.

Weathered materials with varying thicknesses of regolith overlie the consolidated sedimentary formations. In general, lithology types, structural features, nature of topography, vegetation cover, erosion, climate and local environmental activities impact on regolith thickness. The thickness of the regolith in Kintampo Municipality varies from 4 to 20 meters in some parts of the Voltaian Basin [15].

Sample collection, processing and analysis

A total of 43 stream sediment samples were collected by traversing to predetermined sampling sites along streams using a Global Positioning System (GPS) receiver. Sediments samples of silt and clay fractions were taken at a depth of 10 cm at each location, mainly in the active stream channel where the water level was low or on the bank where the water level was high. Though the sampling locations were predetermined, our decision to sample sediments from a specific site was dependent on evidence that there was no anthropogenic pollution at the site. At the respective sampling sites, 1 kg of sediment sample was collected into a designated clean plastic bag. For each of the samples, field data such as sample ID, actual location coordinates, sampling environment, drainage geology, type and colour of bed material, average stream velocity and local relief were recorded. The field samples were labeled and sent to Kintampo Health Research Centre (KHRC) Laboratory where pH measurements and further processing to reduce the sample size were done [16].

At the laboratory, the moist stream sediment samples were placed in an oven tray set at a temperature of 80°C-100°C to extract the moisture. Care was taken to avoid sample contamination and mix-ups. As part of the procedure, the field sample weights were taken and recorded. This was followed by weighing the sample trays. These two activities preceded the sample drying process. The field samples were spread on a clean plastic mat for air-drying for 12 hours at an average temperature of 26°C. The air dried samples were then transferred onto already weighed trays and heated for 8 hours in an oven set at 100°C. In the open air, the oven-dried samples were allowed to cool for sieving. The cooled oven dried samples were sieved first through a 1mm mesh and later through a 150 μm mesh. This was done to obtain very fine uniform particle sizes that ensure bigger surface area for reagent penetration. A subsample of 300 g was obtained using a riffle splitter. These samples were relabeled using unique identification numbers and transported to the ALS-Chemex Laboratory in Kumasi, Ghana for geochemical analysis. The ICP-MS geochemical analytical technique was used to analyze the trace elements, including selenium (Se) [17].

Since other environmental conditions contribute to the release of Se and also impact on its concentration in the environment, the pH and other physical properties of the samples were investigated. For instance, the water from the sediment samples was individually collected and centrifuged for 10 minutes at 3,500 rpm. For the attainment of better pH and precise gravity measurements, the centrifuged water was further filtered to remove some more dirt to make the water clearer. A calibrated Jenway pH meter was used for pH measurement and specific gravity strips were inserted into the cleared and filtered water to measure the specific gravity [18].

Quality control and quality assurance

Standard samples (Reference Material) were analysed and determined prior to sample analysis. The analytical quality was also monitored to ensure the consistency of the laboratory data. This was done by adding five (5) duplicate samples to monitor the precision of the duplicate pairs of the trace element analytical results. All five (5) duplicate field samples were incorporated into a single batch of samples sent to the laboratory. Wilcoxon signed rank test was used to analyse the similarities between the measured concentrations of the duplicates [19].

Results

The area is generally characterized by sandstones, siltstones, mudstones, shales, and phyllite. The texture of these rocks varies from coarse to fine grains. The shales and phyllite are fine textured whilst sandstones are generally coarse textured. The fine textured rocks with low porosity have a higher tendency to hold Se than the coarse textured rocks which are permeable and allow Se to leach out easily. The characteristics of weathered materials from different rocks provide varying levels of Se due to differences in their lithology [20].

The results for enrichment factor and pollution load indices computed for selenium concentration in stream sediment samples in the study area are presented in (Table 1).

Table 1. *Concentration and enrichment of Se in stream sediment samples at different geological locations in Kintampo Area of Ghana.*

Sample ID Se (ppm)	Location EF		Se ppm)	EF
UTM-E UTM-N				
KCS_001	1º35.924	8º06.333	0.1	0.25
KCS_002	1º29.790	8º06.533	0.1	0.25
KCS_003	1º43.748	8º00.618	0.1	0.25
KCS_004	1º31.098	8º04.719	0.1	0.25
KCS_005	1º29.949	8º08.651	0.1	0.25
KCS_006	1º33.754	8º07.264	0.1	0.25
KCS_007	1º 49.699	7º 58.364	0.1	0.25
KCS_008	1º 51.908	7º 51.242	0.1	0.25
KCS_009	1º 47.490	7º 46.938	0.1	0.25
KCS_010	1º 40.138	7º 48.590	0.1	0.25
KCS_011	2º 07.280	8º 07.476	0.1	0.25
KCS_012	2º 07.793	8º 06.934	0.1	0.25
KCS_013	1º 41.438	8º 10.018	0.1	0.25
KCS_014	1º34.282	8º34.981	0.1	0.25
KCS_015	1º 35.203	8º12.734	0.1	0.25
KCS_016	1º 35.212	8º 23.981	0.1	0.25
KCS_017	1º34.282	8º34.981	0.1	0.25
KCS_018	1º51.908	7º51.242	0.1	0.25
KCS_019	1º29.949	8º08.651	0.1	0.25
KLS_001	1º47.746	8º04.989	0.1	0.25
KLS_002	1º55.056	8º07.804	0.1	0.25
KLS_003	1º58.126	8º06.035	0.1	0.25
KLS_004	1º 54.753	8º 03.295	0.1	0.25
KLS_005	1º50.626	8º04.869	0.1	0.25
KLS_006	1º50.626	8º04.869	0.1	0.25
KSS_001	1º41.960	8º04.921	0.1	0.25
KSS_002	1º39.389	8º09.449	0.1	0.25
KSS_003	1º.43.706	8º12.589	0.1	0.25
KSS_004	1º43.421	8º11.055	0.1	0.25
KSS_005	1º34.646	8º19.228	0.1	0.25
KSS_006	1º34.243	8º19.091	0.1	0.25
KSS_007	1º 29.249	7º 56.505	0.1	0.25
KSS_008	1º 29.169	7º 56.047	0.1	0.25
KSS_009	1º39.028	7º 56.430	0.1	0.25
KSS_010	1º 39.027	7º 57.930	0.1	0.25
KSS_011	1º27.832	8º26.356	0.1	0.25
KSS_012	1º 32.387	7º53.367	0.1	0.25
KSS_013	1º 25.172	7º57.053	0.2	0.5
KSS_014	1º 34.976	8º03.851	0.1	0.25
KSS_015	1º 34.678	8º 03.916	0.1	0.25
KSS_016	1º42.869	8º02.991	0.4	1
KSS_017	1º24.521	8º.41.621	0.2	0.5
KSS_018	1º 39.028	7º 56.430	0.2	0.5

The Se results obtained in the analyzed samples were transformed using statistical measures that assessed the magnitude of the spatial clustering of Se around a specific geographical point (community). Each observation provided an indication of the magnitude of significant spatial clustering of similar values around that observation and the sum of LISA was assumed to be proportional to the global spatial association indicator for all observations [21]. This represents a geo-spatial map showing high and low significant and non-significant clusters and outliers of selenium concentration in the study area. In particular, a high outlier of selenium concentration was found at a location around the Kintampo Township (Dwenewoho/Habitat). With few isolated areas recording above the background value of Se in soils (0.09mg / kg) and a global baseline value of 0.4 mg / kg, most of the area showed Se deficiency (Table 2).

Table 2. *Summary statistics of selenium in the study area by district.*

Area	Element	Minimum	Maximum	Mean	Standard Deviation	No of Samples
	(mg / kg)	(mg / kg)	(mg / kg)	(mg / kg)	(mg / kg)	
Study Area	Se	0.1	0.4	0.11	0.071	43
Kintampo Municipal	Se	0.1	0.4	0.11	0.55	10
Kintampo South	Se	0.1	0.2	0.11	0.3	33

Furthermore, shows summary statistics of selenium concentration in the study area by district. It appears that 9.3% of the data with Se values greater than the detection limits were not too high on their own and did not impact the mean values. Likewise, the quality of the analysis using field duplicate pairs of stream sediment samples and reference materials is shown in (Table 3).

Table 3. *Quality assurance assessment performed on the field duplicate sample pairs to assess precision of the analytical data.*

Sample ID	Selenium (ppm)	Duplicate	Selenium (ppm)	MEAN	SD	CV	P value
KCS008	0.1	KCS018	0.1	0.1	0	0	
KCS005	0.1	KCS019	0.1	0.1	0	0	
KCS014	0.1	KCS017	0.1	0.1	0	0	0.32
KLS005	0.1	KCS006	0.1	0.1	0	0	
KSS009	0.1	KSS018	0.2	0.15	0.071	0.47	

Moreover, factors such as soil porosity, precipitation, pH level, and organic matter content could significantly explain the observed Se deficiency in the study context. For instance, the sandy soils produced by the underlying sedimentary rocks in the study area have a higher permeability and so their Se retention ability is seriously inhibited. Consequently, the little Se that is able to adsorb to the surface environment easily leaches out in the rainy season. Better still, it has been documented that intense leaching and erosion of soil micronutrients is widespread in the humid temperate and tropical regions of the world where torrential rains are commonplace. Accordingly, we believe that the perennial torrential rains experienced in the study context during the wet season have effectively contributed to the area's soil Se deficiency (Table 4).

Table 4. *Quality assurance analysis using reference materials to evaluate accuracy of the analytical data.*

Reference Material ID		Se CRM Value mg/kg	Se Measured CRM mg/kg	Recovery Rate
EMOG-17	value	5.8	7.2	83
MRGeo08	value	1.2	1.5	80
OREAS 905	value	2.6	2.8	93
OREAS 920	value	0.6	0.6	100
Blank	value	0.4	0.4	100

Discussion

In this study, we investigated soil selenium content in the Kintampo area of Ghana using stream sediment samples. The Se geo-availability analysis showed a general deficiency in the study area.

This probably owes to the fact that the parent sedimentary rocks (predominantly sandstone) that underlie the area are deficient in Se and so soils derived from them have little Se content. Thus, our observation is in line with established evidence of a strong relationship between Se concentration in geological parent materials and soils produced from them [22].

The observed Se paucity in the study area could also be due to low soil pH levels. This is because evidence suggests that acidic soils with low pH values have lower Se content than alkaline soils which have higher pH values.

In the current analysis, the mean pH of the studied samples was 6.4. This suffices to conclude that the rather acidic situation in the study area impedes Se release into soils. Furthermore, low organic matter content of sandy soils, characteristic of the study area could be a contributory factor to the low levels of Se concentration as observed in this study.

This is premised on the fact that organic matter improves soil water holding capacity which helps in the reduction of micronutrient depletion through percolation and soil erosion attributable to surface runoff.

Besides, inadequate organic matter in soils within the study context suggests that Se can hardly adsorb to organic materials in the surface environment and so the soils remain Se-deficient [23].

On the contrary, a study in the west coast of Ghana found a relatively higher soil Se concentration than the current study found in the middle belt of the country.

The authors reported a mean Se concentration of 0.18 mg/kg compared to our finding of a mean value of 0.11 mg/kg. Certainly, the observed spatial disparities in soil Se concentration in the respective study settings are to be expected as the geological and ecological conditions along the west coast differ from those that pertain in the middle belt of the country.

Despite this, the values recorded in both studies are far lower than the mean global value of 0.4 mg/kg. This portends a general soil Se deficiency in the country with dire implications for plant Se bioavailability and public health [24].

Though there is a dearth of studies on soil Se content in Sub-Saharan African countries, a smattering evidence from Nigeria suggest that most countries in the West African subcontinent could be soil Se deficient. This is because prior findings from coastal Ghana and the results of the current study parallel the generally low soil Se levels documented in the Kogi state of Nigeria [25].

Certainly, the congruence of the findings of this study with those of prior studies using similar methods shows that the analytical quality of the current study is robust and so the quality of our findings is undoubted. This owes to the fact that virtually all the five field duplicate samples used for our quality checks yielded similar results. Although one duplicate sample (KSS0018) produced an Se content of 0.2 ppm, which is somewhat higher than the Se concentration of 0.1 ppm detected in the main sample (KSS009), we believe that the difference is not significant to undermine the overall quality of our results [26].

All in all, it is obvious from our findings that the population in the study area could be predisposed to Se-deficiency-related non-communicable diseases and a rapid breakdown of immunity due to infectious diseases [27]. This is because soil Se content determines its bioavailability to plants from which humans and animals derive nutritional Se [28]. Accordingly, the blood Se content of most of the inhabitants of the study area could be lower than the minimum level required for their wellbeing because they may be consuming food crops grown in Se deficient soils [29].

Conclusions

This analysis successfully gauged the Se content of soils in the study area using robust physico-chemical analysis methods. Our analysis showed a general deficiency of soil Se in the study area, portending that the underlying parent rocks from which the soils derive are fundamentally Se-deficient. To that end, there is the need for further research into the nexus between the Se content of food crops grown in the study area, human blood Se levels and health outcomes in the population to facilitate the potential execution of remedial public health
9 interventions. The authors confirm that the summary of data supporting the findings of this study is available within the article. Detailed data are available from the corresponding author upon request.

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