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Emerging potentially toxic elements (strontium and vanadium) in Ghana's pedological studies: Understanding the levels, distributions and potential health implications. A preliminary review

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ABSTRACT

Soils constitute an important location for the transfer and retention of pollutants in the environment. The contents of pollutants in soils are increasing due to geo-natural and anthropogenic factors. This study sought to highlight the emergence, levels, distribution, trends, and possible health implications associated with two potentially toxic elements (PTEs) (vanadium and strontium) which are now gaining attention in pedological studies in Ghana. The study discussed concentrations of Sr reaching 951 mg/kg and 954 mg/kg, and 665 mg/kg in northeastern and southeastern Ghana respectively. These were well above the average crustal average for Sr (375 mg/kg). The average concentration of V in the northeastern part of Ghana increased from 72 mg/kg to 78 mg/kg from 2012 to 2017. In southeastern Ghana, V results ranged between 71 mg/kg and 375 mg/kg which indicates that 65% of the samples exceeded the average crustal value of 135 mg/kg. In southern Ghana, positive correlations between Sr and V with PTEs and elements with systematic toxicity; Sr, Zn and Zr ($R^2 = 0.0448$ and $R^2 = 0.1944$), Pb and V ($R^2 = 0.9201$). In southwestern Ghana, results of V and Sr respectively ranged from 0–622 mg/kg and 0–556 mg/kg with 67% and 53% of the soil samples exceeding average crustal values. This suggests that other areas of Ghana may harbor similar elevated concentrations of V and Sr, and these may be posing hidden environmental and health impacts.

1. Introduction

Soils form an integral part in supporting agriculture, plants, and the natural climate. It stores about 75% of the terrestrial organic carbon (Kassa et al., 2017). However, it is heavily impacted by geogenic and anthropogenic factors. Similarly, Kazapoe and Arhin (2019) outlined that understanding the elemental concentration, sources, patterns, and distribution of soil is essential for solving toxicities related to humans, animals, and plants which are significantly influenced by geogenic and anthropogenic processes and activities including mining, the geochemistry of parent or underlying materials, weathering processes, lithology, and geopedological processes.

Antwi-Agyei et al. (2009) and Azevedo-Silva et al. (2016) revealed that predominant amongst the anthropogenic factors that impact soil quality, mining is a major activity that affects the chemical and physical characteristics of soil resulting from the disposal of mining waste including tailings and polluted wastewater into the natural environment. In Ghana, extensive studies and reviews including Antwi-Agyei et al. (2009), Nude et al. (2011), Bempah and Ewusi (2016), Petelka et al. (2019), Darko et al. (2019), and Kazapoe et al. (2019) have been conducted to ascertain the levels of heavy metal and potentially toxic elements including arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn), nickle (Ni), copper (Cu), and mercury (Hg). Therefore, the sources, trends, and distributions, environmental and health implications of these elements have been well-established in Ghana. Although strontium (Sr) and vanadium (V) have not been widely studied in the country, some recent studies (Hayford et al., 2009, Foli et al., 2012, Essel, 2017, Nuamah et al., 2019) have reported high levels of Sr and V in soils within some areas of Ghana. Additionally, these elements also pose deleterious health and environmental impacts which have not been considered in studies in the country. Therefore, this study seeks to highlight the levels and distributions of Sr and V in some parts of Ghana, possible environmental and health impacts associated with Sr and V which may arise in areas with high concentrations, and recommends areas that can be considered in scientific research to expand the knowledge-scope of Sr and V in the pedology of Ghana and beyond. This study will also serve as a basis to create

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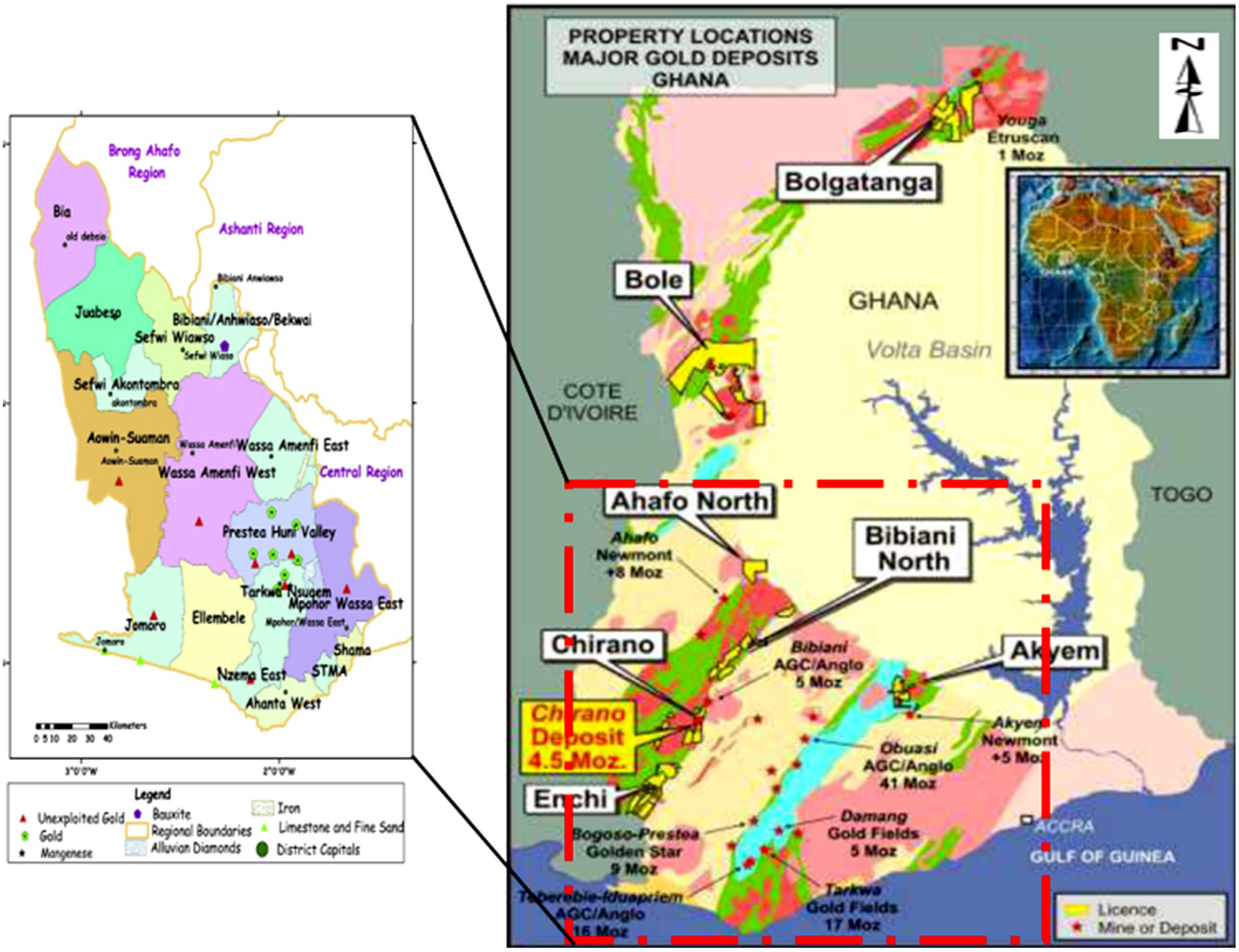

Fig. 1. Distribution of some mining sites in Ghana (modified from (Arah, 2015, Owusu-Nimo et al., 2018)).

awareness for detailed studies of these elements in other environmental media; surface and groundwater resources, food crops, and vegetation across the country.

2. Methods

2.1. Study area description

Ghana (longitudes 0º 05′ 04″ E and 3º 14′ 12″ W and latitudes 5° 5′ 39″ N and 10° 54′ 38″ N) is located to the north and south with Burkina Faso and the Gulf of Guinea, and Togo and Cote d'Ivoire to the east and west respectively. Ghana is endowed with enormous precious resources (Fig. 1) including gold, bauxite, diamond, crude oil, salt, manganese, copper, iron ore, limestone, and nickel (Owusu-Nimo et al., 2018). The geology of Ghana is primarily made up of the Paleoproterozoic Birimian domain to the west, the Voltaian sedimentary units in the central part of the country, the Pan African mobile belt straddling the southeastern part of the country with the coastal sedimentary basins occupying the southern boundary of the country Kesse (1985).

2.2. Sourcing information

The study considers the emergence of Sr and V in soils in mining areas within Ghana and the possible environmental and health implications. The main keywords searched were impacts of mining on soils in Ghana, Sr in soils in Ghana, V in soils within mining areas of Ghana, environmental and health impacts of Sr and V in Microsoft Academic, Google Scholar and Google browser, BASE, Baidu Scholar, Semantic Scholar, Science.gov, and CORE. Also, Sr and V results on 2884 soil samples from southwestern Ghana (Fig. 2); the Wassa Amenfi East, West, and Central, and the Prestea-Huni Valley Districts were obtained from repository data attached to a study by Arhin et al. (2019). V and Sr levels in soil samples presented by Kazapoe and Arhin (2019) were analyzed using the Panalytical Axios-Advanced Wavelength Dispersive X-ray Fluorescence (WDXRF) spectrometer.

3. Results and Discussion

3.1. Previous studies

Foli et al. (2012) in the Upper East Region (Paga, Navrongo, Chuchuliga, and Sandema) of Ghana described Sr to be above its average crustal abundance as the concentrations ranged from 27.6 mg/kg to 951 mg/kg (avg. 448 mg/kg) whereas V was between 41 mg/kg and 120 mg/kg (avg. 72 mg/kg). The study showed that though V was below the average crustal value (135 mg/kg), 58% of the samples exceeded the average crustal abundance (375 mg/kg) for Sr. Similarly, in the same region (Bolgatanga, Bongo, Navrango, Paga, and Sandema), Essel (2017) discussed that Sr ranged between 165 mg/kg and 954 mg/kg (avg. 522 mg/kg) and V ranged from 45 mg/kg to 126 mg/kg (avg. 78 mg/kg). The study showed that 64% and 4% of the samples were above acceptable limits for strontium and vanadium respectively. Sr is enriched in granitic rocks, and as the area is mostly

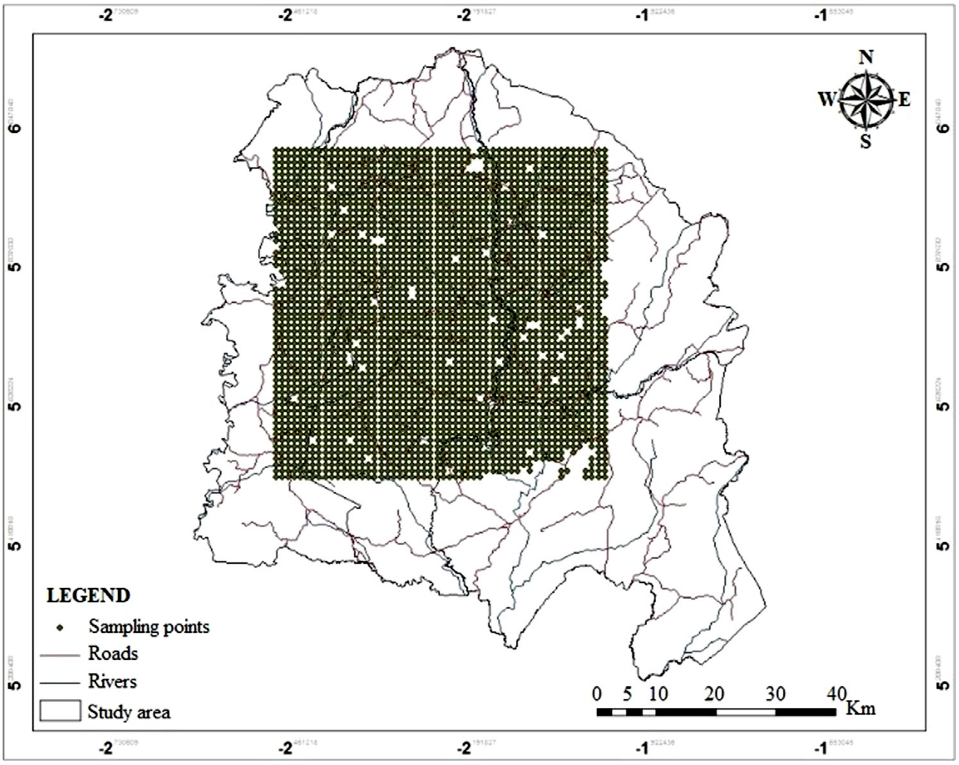

Fig. 2. Sampling locations.

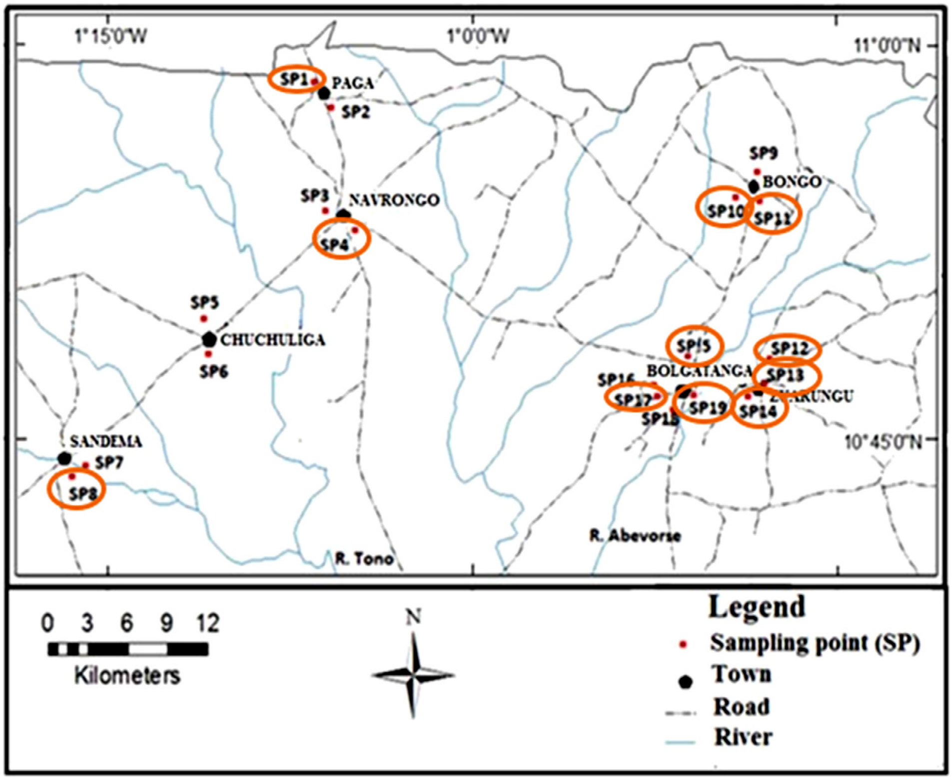

Fig. 3. Sr results in northeastern Ghana; high areas circled in red (modified from Foli et al. (2012))

underlain by granitoids it is expected that Sr may be high. However, the exceedance of Sr and V concentrations as presented by Essel (2017) compared to Foli et al. (2012) and the variation in concentrations in soil sampling points within the same areas (Fig. 3) suggest the presence of some anthropogenic sources and/or geogenic factors contributing to the rise in Sr and V in recent times. For instance, SP1 and SP2 (Fig. 3) are located within the same geological areas, however, only SP1 was above average crustal abundance for Sr. Hayford et al. (2009) also found elevated levels of V in soils around the Tarkwa-Prestea area. The concentration ranged between 121 μg/g (121 mg/kg) and 188.40 μg/g (188.40 mg/kg). Due to this, traces of V were found in cassava and plantain grown in the area (Hayford et al., 2009).

In a geochemistry study of minor and trace elements in soils of the Akuse area of Southeastern Ghana, Nuamah et al. (2019) presented V results from 71 mg/kg to 375 mg/kg (avg. 162 mg/kg) and Sr (171–665 mg/kg) with a mean concentration of 337 mg/kg. Based on the findings of Nuamah et al. (2019), 32% and 65% of the samples exceeded the average crustal values of 375 mg/kg and 135 mg/kg presented by Taylor (1964) for Sr and V respectively. Essel (2017) further showed positive correlations between Sr and V with PTEs and elements with systematic toxicity; Sr, Zn and Zr (R^2 = 0.0448 and R^2 = 0.1944), Pb and V (R^2 = 0.9201). A scatter plot presentation revealed correlations between V and Cr, and Pb, and Sr Zr, Zn, and Cd. This suggests that Sr and V may be present in areas dominated by agricultural, industrial, and mining activities. Factor analysis by Nuamah et al. (2019) presented V and Sr in the first and second components with significant loadings of 0.85 and 0.50 respectively. The study further described V as "associated with parent materials and therefore had natural sources, thus, the weathering of parent materials and subsequent pedogenesis due to the alluvial deposits" whereas Sr "had anthropogenic sources (probably from over use of chemical fertilizers and pesticides, industrial and discharges, animal wastes, sewage irrigation, etc)". Similar to this, Aubert and Pinta (1977) mentioned that the characteristics of parent rocks are closely related to the level of vanadium present in soils. The high levels of Sr and V could be attributed to the high mobility rates of these elements in the weathering environment, lithological characteristics, and anthropogenic activities.

3.2. Current study

Sr and V respectively obtained results ranging between 0 mg/kg and 662 mg/kg (CV% of 79%), and 0 mg/kg and 556 mg/kg (CV% of 67%). The study showed that 53% and 67% of the soil samples exceeded the average crustal abundance of 375 mg/kg and 135 mg/kg for Sr and V as indicated by Taylor (1964). The Sr results were similar to studies by Foli et al. (2012) (27–951 mg/kg) and Essel (2017) (165–954 mg/kg) in northeastern Ghana, and Nuamah et al. (2019) (171–665 mg/kg) in southeastern Ghana. Though the levels of V were low in northeastern Ghana and above crustal abundance in southeastern Ghana, results obtained in southwestern Ghana were much higher. These findings were similar to Reyes et al. (2019) in Taltal, northern Chile where V fell within 58.00-663 mg/kg. The study showed that 89% of the results of V exceeded the 1.10 mg/kg recommendation by Crommentuijn et al. (2000). Połedniok and Buhl (2003) indicated that V is predominant in alkaline and argillaceous-based lithology. Therefore, the extremely high V values relate to Kesse (1985) which described the underlying geology of the area to compose granitic intrusions which have alkaline signatures. Similar to the findings of Nuamah et al. (2019) in a study in southeastern Ghana where V and Sr were presented in the first and second factors, with significant loadings of 0.85 and 0.50 respectively, in southwestern Ghana, Arhin et al. (2019), V and Sr were shown in the first and second factors with respective loadings of 0.856 and 0.888 (Supplementary material). This suggests that the levels of V were associated with the geologic-parent materials whereas Sr could be related to anthropogenic factors such as the use of agrochemicals, poor disposal of sewage, and industrial waste. The direct relationship between Sr and Cu suggests the anthropogenic origin of Sr as the European Institute of Copper (European Institute of Copper, 2018) and Masindi and Muedi (2018) revealed that mineral mining, fertilizer application, industrial activities, and waste are predominant factors that elevate the concentration of Cu in the natural environment.

Hotspot areas for Sr were clustered at the mid-eastern of the Wassa Amenfi Central District and stretched through the southern, and northern parts of the Wassa Amenfi East area, and the Prestea-Huni Valley, Wassa Amenfi East, and West Districts (Fig. 4a). Chadwick et al. (2009) described Sr as ubiquitous and present in most rocks and soils. This depicts its presence in the soils within the study areas. Though the hotspot zones for V were sparsely distributed in some parts of the study area, a large concentration was identified in mid-Wassa Amenfi East District stretching towards the southeastern part of the district (Fig. 4b).

3.3. Possible health and environmental impacts associated with Sr and V

According to Aubert and Pinta (1977) and Essel (2017), the levels of V and Sr could pose deleterious health implications. Water-soluble compounds of Sr are a greater threat to human health than water-insoluble ones. Therefore, water-soluble forms of Sr can pollute drinking water. Fortunately, the concentrations in drinking water are usually quite low. People can be exposed to small levels of (radioactive) Sr through inhalation and oral ingestion or dermal contact with contaminated soils. Sr chromate has been discussed to contribute to lung cancer. It could also pose disruptions in bone development in adults as it may be attached to the surface of bones and in children, it creates hard bone mineral which impedes bone growth. The bone marrow, where red blood cells are formed is also damaged by the high levels of Sr Robinson (2017). This reduces the production of red blood cells. Therefore, proper respiration could be disrupted. Radioactive Sr contributes to anemia and oxygen shortage in people exposed to high concentrations. Studies have also associated genetic disruptions in humans which could results in a wide range of cancers (bone, nose, lung, and skin) to Sr. Sr has also been linked to other debilitating health and psychological impacts including severe skin reactions, disturbances in thinking, inflammation of the liver, and seizures (American Bone Health 2020). According to Hahn (Hahn, 1999, Hahn, 2001), strontium has been shown to inhibit sensory irritation after continuous dermal contact. In the environment, Sr is always present in the air as dust. Dust particles that contain Sr are then deposited in surface water, soils, or plant surfaces. In high-available levels, Sr may end up in aquatic lives, water systems, vegetables, livestock, and animals (source: Lenntech https://www.lenntech.com/periodic/elements/sr.htm). Also, the positive relationship established between Sr and Ba (Supplementary material) suggests the possible occurrence of cardiovascular, renal, respiratory, hematological, nervous, endocrine, hepatobiliary, reproductive systems disorders related to high Ba concentrations as discussed by Kravchenko et al. (2014) in the area.

The Agency for Toxic Substances and Disease Registry (Agency for Toxic Substances and Disease Registry (ATSDR) 2004) described vanadium as a naturally occurring element that is widely distributed in the earth's crust. A report by Healthpedian (2021) indicates that though all the V compounds have not been widely described as health hazards, they pose some level of toxicity. Adverse health impacts of V include loss of appetite, nausea, vomiting, abdominal pain, diarrhea, and loose stool, liver and nervous system damages, kidney failure, and disrupted growth (Healthpedian 2021). Other symptoms associated with V toxicity are irritation of mucous membranes and the upper respiratory tract, dizziness, abdominal and intestinal inflammations, headaches, skin rashes, nose and internal bleeding, damage in the cardiovascular system, and behavioral changes (ATSDR, 2012a, Healthpedian 2021, Wong, 2020). Paradoxically, high levels of V can contribute to anemia, high cholesterol, reduction in blood sugar (hypoglycemia) and white blood cells, and fertility and birth challenges. Other studies including Evangelou (2002), Chatterjee (2011), and Tang et al. (2012) have also indicated the accumulation of V in breast tissues which poses a high-risk breast cancer. Inhaling V could result in throat, lung, and nose irritation, bronchitis, and pneumonia. Studies have also revealed an association between V and the development of lung cancer in certain animals (ATSDR, 2012b, Healthpedian 2021).

Additionally, the direct association between Ag and V (Supplementary material) suggests that both Ag and V are deposited into the environment from gold-rich soils via mining activities. This indicates that health implications related to Ag such as kidneys and liver dysfunction, argyria and argyrosis, and skin irritation presented by Lansdown (2006) could occur in Ag hotspot areas. The positive cor-

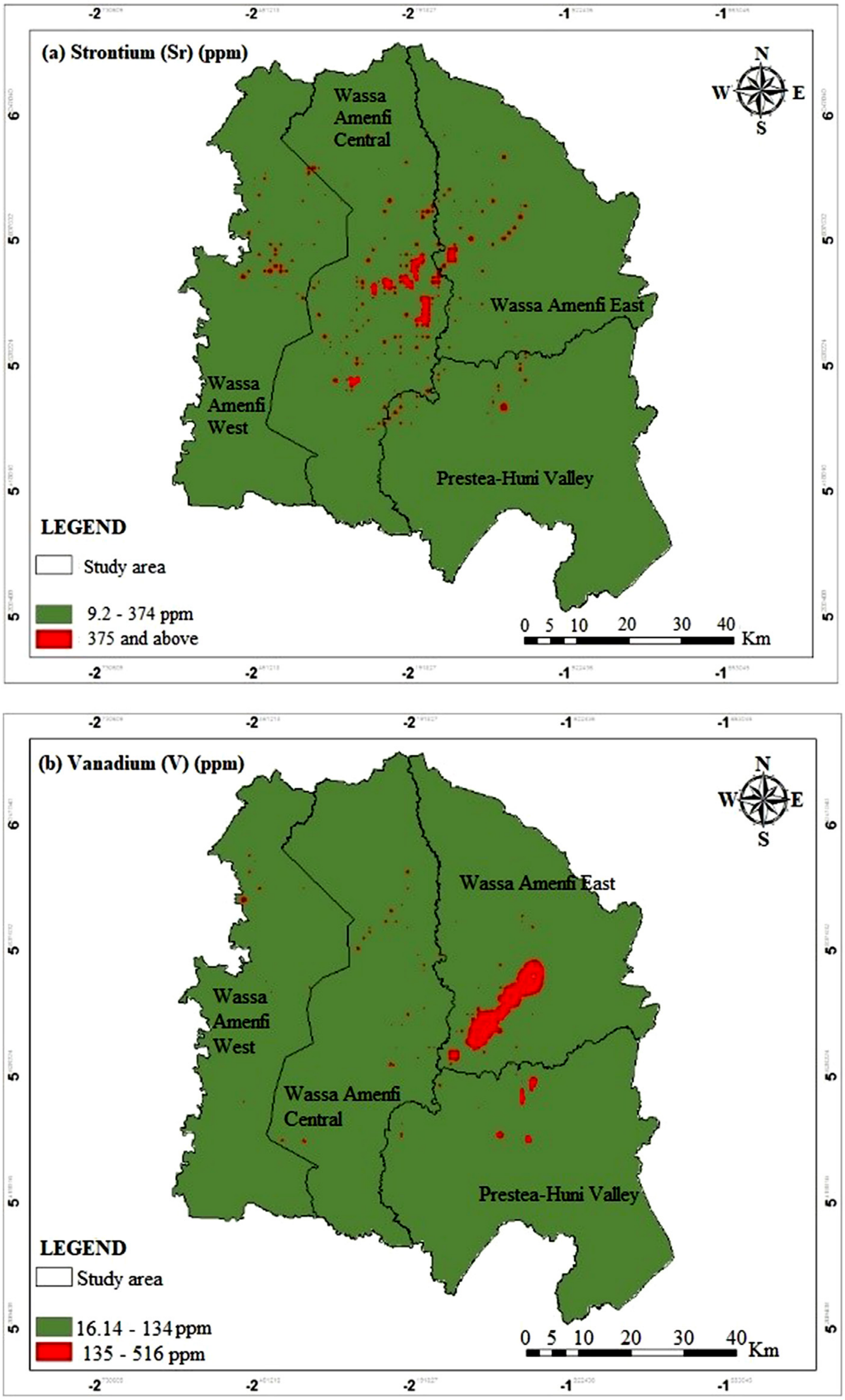

Fig. 4. Spatial description of (a) Sr and (b) V in the Wassa Amenfi and Prestea-Huni Valley areas.

relation presented by Cu and V suggest that long-term dermal contact, consumption of crops, or inhalation of particulate matter could result in health complications linked to high levels of Cu including nose, eye and mouth irritation, jaundice, hypotension, headache, kidney and liver disorders, hematemesis, melena, and cognitive retardation (Klaassen and Amdur, 2013, New Hampshire Department of Environmental Services 2013). Similarly, though Ni has been studied to bioaccumulate in biological systems and the food chain, it showed a direct relation with V, which suggests that interacting with these soils could also cause skin irritation/rashes, and cardiovascular and respiratory tract disorders (Brera and Nicolini, 2005, Cadman, 2018). The deposition and partitioning of V in water and soil are influenced by acidity and the presence of particulates. It can be dissolved in water as dissolved ions or may become absorbed into particulate matter. V bio-accumulates in aquatic animals and plants but does not concentrate in above-ground portions of terrestrial plants (ATSDR, 2012a, ATSDR, 2012b).

4. Conclusion and future studies

The occurrence, sources, levels, fate, and environmental and health impacts of Sr and V have not been extensively studied in Ghana. The studies done have shown elevated concentrations above-average crustal values in some areas. The levels of Sr were high in some areas of the southeastern, northeastern, and southwestern parts of Ghana, whereas V was high in some parts of southwestern and southeastern Ghana. Factor analysis in southwestern and southeastern Ghana has associated V with parent-geologic materials, whereas Sr appears to be associated with anthropogenic activities. Based on these, further studies could be carried out in the following directions:

- Establishing local geochemical background values for Sr and V in Ghana.
- Understanding the major sources of Sr and V in Ghana's environment.
- Determining the specific type(s)/compounds of Sr and V in Ghana's soils.
- Exploring the factors contributing to the rise in V results in the Upper East Region.
- Extensive studies on the levels of V and Sr in all the geological and ecological settings of Ghana.
- Assessing the levels on Sr and V in other environmental media; surface and groundwater systems, vegetation, and air.
- Studying the health and environmental impacts related to the increasing levels of Sr and V in Ghana.
- Developing remediation approaches in reducing the levels of Sr and V in contaminated areas.

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Conflict of interest

No competing interest is declared.

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