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Review paper

Environmental cadastre of plant-soil interactions in the uptake and distribution of heavy metals or trace elements

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Especially in high concentrations, heavy metal are potential toxic substances in the environment with untoward impacts on fauna and flora. The metal toxicity is enhanced by chemical associations. The immediate and remote concerns for sustainable growth and development are the identification, control and management of factors which affect plants and soils with concomitant hunger, quality food deprivation, impairment of health in humans and animals. It becomes of major concern for opportunities to create sustainable mechanisms or modalities to eradicate the sources of the issues and challenges.

Keywords: mining operations, environmental monitoring, environmental variability, spatiotemporal variations, environmental management.

INTRODUCTION

The major challenges, issues and opportunities facing the agriculturist, environmentalist, or ecologist for sustainable management of the ecosystem and to combat hunger (Chukwuma 2020a) are the identification of factors which may contribute to growth inhibition or retardation of the fauna and impairment human and animal health (Chukwuma, 1994a; Chukwuma 1995a; Chukwuma 2011; Sethy and Ghosh, 2013; Chukwuma 2016) by mining and mining-related operations as well as other anthropogenic activities and natural occurrences; and to find remedies to resultant problems or issues (Chukwuma 2021). In polluting and derelict mine precincts including smelter sites, the waters become sterile due to the presence of toxic substances and infertile wastes. Certain of these toxic compounds are trace elements which are essential nutrients for higher plants, whereas at certain levels they may reach toxic concentrations. Disparate plant species accumulate several elements, particularly in mining areas via several mechanisms, such as competition and/or adaptive tolerance. Heavy metals constitute potential toxic substances environmental problem; and present untoward impacts on agriculture (Jamil et al., 2014), quality of life and the human environment; and the metal toxicity is inextricably-linked to the chemical associations in soil (Sivapatham et al., 2014). Superimposed on these are the environmental and public health implications of low level Pb exposure in the paediatric population which may culminate in psychometric deficit (Chukwuma, 1997; Chukwuma, 2020b). Cadmium is a persistent and ubiquitous environmental pollutant that is associated with renal dysfunction and different disorders (Adams et al., 2011). Trace element prevalence in plants growing on diverse unpolluted soils depicts widespread variation in defined elements (Kabata-Pendias, 2000); and this is observable in contaminated and polluted sites. Information on toxicity and heavy metal levels in crops is also pertinent to identify adequate, sub- adequate, and marginal intake contents for human and/or animals, so that diseases associated with trace element deficiency can be prevented, controlled or managed.

Issues, challenges and opportunities

The monitoring, evaluation and assessment of the trend and spatial dissemination of both natural and anthropogenic sources of trace elements and heavy metals in our environment are crucial to obtain and maintain database of the proportion of chemical elements and compounds in soils and plants. Baseline data for the occurrence and distribution of heavy metals as contaminants and pollutants are important as criteria for assessment of critical heavy metal contents in agricultural soils. Varied studies of the sources, fluxes and pathways of elements in the surface environment has been the focus of both national and international research communities in response to pollution and health impacts. Rural and agricultural areas have been precincts of interes where there may be incidence and prevalence of the perturbation of heavy metals on ecological and farming systems. Appreciable number of inhabitants is in the urban areas where natural geochemical elemental processes and in-puts undergo significant modifications and variations or completely masked by contamination due to industrial activities and urban development. In several non-industrialised or low middle income countries with non-extant, non-compliant, unenforceable legislation or at its infancy, polluted or contaminated derelict mines or wastelands are used for agricultural purposes (Chukwuma, 1996).

Environmental toxicology is associated with heavy metals or trace elements, the ecological and health impacts of environmental contaminants and pollutants as well as the factors related to weather and climatic conditions. Environmental modification, variation and geographical perspective are pertinent in toxic-element-related issues which interact on the food chain as evident in the Enyigba-Abakaliki lead and zinc mine precinct (Chukwuma 1993a; Chukwuma, 1994a,b). This study tends to explicate or elucidate plant-soil interactions as inextricably-linked to the environment, agriculture and health.

Patterns of uptake and distribution

The forms, variations and distributions of elements are particularly of concern as heavy metals bioaccumulate in the system with severe health risks to humans and animals. Manganese, Mn concentrations in agricultural soils and derelict mine area had an overall mean of 1105.5 mg/kg, with range from 120.7-2628.08 mg/kg (Chukwuma, 1996). Mn from stream sediments in the Abakaliki area was found to be from 20-20000 mg/kg with a mean of 1183 mg/kg (Olade, 1987). Mn is associated with clay in silty and loamy soils. Highest mean Mn contents have been associated with slightly acidic pH, increased bulk density, organic matter content and brown medium textured soils (Chukwuma, 1996). Rice leaves depicted the highest mean of Mn, 930.3 mg/kg; rice grain depicted a mean Mn level of, approximately, a factor of 3 less than in leaves (Chukwuma, 1995b). The uptake of Mn in plant parts may be dependent on soil Mn, acidic pH and slightly high organic matter content (Chukwuma, 1995b). Mn concentrations in plants are negatively associated at increased soil pH and positively associated with soil organic matter (Kukurenda and Lipski, 1982). It indicates that pH has greater influence than organic matter content, and is more indicative of the proportion of soil Mn. Oxisols and ultisols generally have pH values of circa 5 and contain elevated concentrations of soluble and exchangeable Mn. The total soil Mn concentrations may be relatively low due to excessive leaching associated with weathering in the formation of these soils.. The distribution of the diverse Mn formations and variations in soils is predominantly influenced by pH. Increasingly soluble and exchangeable Mn levels are extremely significant in soils in reducing conditions in association with commensurate source of reducible Mn minerals (Rendig and Taylor, 1989). Mn levels in cassava were also lower at decreased pH (Islam et al., 1980; Chukwuma, 1995b). An increased phyto available Mn is associated with pH values not greater than in 5.5,anaerobic condition or restricted aeration emanating flooded, waterlogged or compact soils (Kabata-Pendias and Pendias, 1992; Chukwuma, 1995b). The excoriating impacts of excess Mn on plant shoots are more coerceive than on roots. Both in nutrient and in soil solutions, the soluble Mn levels at which plant toxicity symptoms are commonplace are in the range from 10-20 mg/l (Adams, 1984). The plant Mn contents resulting in untoward growth are highly variable for disparate species. The critical levels pertaining to the minimum tissue concentrations required to produce a 10% decrement in yield of soil-grown plants range from 200 to greater than 1000 mg/kg (Macnicol and Beckett, 1985).

The trace element, Cu is evenly distributed regarding its high binding energy to soil clays and organic matter at slightly acidic pH, with total mean of 22.65 mg/kg, with range of 5.5-68.8 mg/kg (Chukwuma, 1996). Cu in contaminated soils is not effected to increase its concentration to become toxic to plants, animals and humans. Diverse organic substances produce both soluble and insoluble complexes with Cu. Thus the binding capacity of Cu with soils and Cu solubility are highly dependent on the type and quantity of organic matter content of soils. Nigeria is a geological ambient with greater than 106 ha of reduced amount of Cu in soils. Cu absorption rates are observed among the lowest of the essential elements, and expansive differences are detected between species and cultivars within species. Elevated Cu2+ levels are accumulated by green leaves without release to younger leaves and other tissues, such as inflorescence despite the elemental deficiency (Gupta, 1979). The highest Cu contents in shoots normally takes place in phases of intensive growth and at the expense of Cu supply limit. Plants require Cu, but geochemical fortuity, biological content during soil formation, mining, smelting or industrial emissions may cause plant exposure to elevated concentrations to a specific toxic element while other environmental factors are normal. Thus, plants are susceptible to extremely strong, highly specific selection pressure. Cu uptake in rice is exclusively distributed or translocated to the tissues (Chukwuma, 1995b), and Cu distribution in barley leaves is relatively uniform for any phase of plant growth (Scheffer et al., 1978/1979). Cu deficiency reduces the amount of total plant Cu translocated into cereal grains. The highest Cu contents are located in the embryo of cereal grains and in the seed coat. Cu concentration in the embryo ranged from 2-18 mg/kg, from 8-23 mg/kg in the seed coat, and in whole seeds the highest content was 4 mg/kg (dry weight). However, these are disproportionate to the uniform Cu distribution throughout the barley grain (Liu et al., 1974). Cu is an essential nutrient that is variably mobilized in plants with the rate and pattern of mobility being influenced by internal and external factors. Cu content in the plant parts in yam leaves were found to have the highest contents, 12.8 mg/kg, while rice grains had the lowest total mean content, 3.9 mg/kg (Chukwuma, 1995b). Disparate factors may influence the relative slight variations in Cu uptake by the various plants relative to soil Cu. Cu in forage and pasture crops is associated to soil availability of the element, plant species, stage of development and growth, seasonal variations, lime and fertilizer applications. Variably, non-crop species or weeds tend to increase the dietary Cu intake by grazing livestock. Cu phytotoxicity usually inhibits plant growth before its concentration in plant can elevate dietary levels estimated to be at least 20 mg/kg that is detrimental to monogastric animals (Underwood, 1971). Phytoavailability of Cu is inextricably-linked to the speciation of the trace elements rather than total soil contents.

Zn is an essential element with even distribution and elevated concentrations at a derelict mine transect, also, it was determined to have over all mean in rural, urban and derelict mine of 528 mg/kg ranging from 14.9 mg/kg in the rural area to 8921.9 mg/kg at the derelict mine. The lowest Zn mean content was associated with acidic pH, high organic matter content and increased bulk density (Chukwuma, 1996). Zn from stream sediments ranged from 20-2178 mg/kg with a mean of 112 mg/kg (Olade, 1987). The highest mean Zn level, 222.7 mg/kg was determined in cassava leaves, with the broadest range reaching 1005.4 mg/kg at the derelict Pb-Zn mine. The lowest mean Zn concentration, 33.4 mg/kg was detected in both rice leaves and grains (Chukwuma, 1995b). In contrast to Mn and Cu, cassava translocated more Zn to the leaves than yam (Chukwuma, 1995b). With the exclusion of the mineral- enriched derelict mine transect, the broad - leaved tuberous plants, yam and cassava presented the greatest relative uptake of Zn at pH 6.5-7.4.

Nickel, Ni is alsi uniformly distributed, ranging from 7 mg/kg at derelict mine transect to 96.9 mg/kg at a timber log area of red-brown fine soils (Chukwuma, 1996). Ni is associated with „serpentine barren; and its distribution in soil profiles is associated with the organic matter content and clay fractions, and there is inverse relationship of its solubility to pH (Bodek et al., 1988). The highest mean Ni concentration was detected in yam leaves, 8 mg/kg and the lowest in rice leaves, 0.71 mg/kg (Chukwuma, 1995b). Ni content in rice grains was higher than in the rice leaves by a factor of 2. Reduced organic matter content ostensibly influenced the differential degree in Ni uptake more than soil content and pH. Although, plant and pedological factors influence Ni uptake by plants, the most outstanding factor is soil pH. Elevating the soil pH from 4.5 to 6.5 reduced the Ni content of oat grain by a factor proximal to 8 (Morrison et al, 1980). Ni level in plants normally indicates elemental level in the soil, but this is more directly associzted with the soluble and exchangeable forms of Ni (Hutchinson, 1981). The phytoavailability of Ni correlates with the soil Ni content until adsorptive levels in plant tissues are consummated. An expansive array of data on Ni toxicity to field crops emerged from plants growing in non-serpentine and non-contaminated soils ranged from 0.1 to 5 mg/kg (Farago and Cole, 1988). Soil Ni content ranging from 50 to 100 mg/kg suggests Ni toxicity in plants. Phytotoxicity of Ni as in Cu ostensibly provides an effective barrier against Ni toxicity to humans and animals (Underwood, 1971). The easy phytoavailability of Ni was clearly indicated by the significant positive correlation between Ni levels in the plant species and soils (Chukwuma, 1995b; Chukwuma, 1996). Ni content in plants on uncontaminated soils may remarkably vary as it is goverened by both environmental and biological factors. Ni level in surface soils is also indicative of processes of soil formation and pollution (Kabata- Pendias and Pendias, 1992). Total mean of Ni content was higher in rice grains than in rice leaves in rural and urban areas except at a derelict mine transect with slightly higher Ni content in rice leaves (Chukwuma, 1995b). It is suggested that the latter occurrence was due to physiological barriers of other elemental antagonistic effects. During vegetative growth, Ni accumulated principally in soya bean leaves, but during senescence a major fraction was mobilised to seeds (Cataldo et al., 1978). Oat grains accumulated higher Ni than straw, whereas other trace elements accumulated higher in cereal straw (Grupe and Kuntze, 1987). The increased uptake of rice grains compared to rice leaves provides the latitude to augment the burdens in animals and humans who consume rice grain. The phytoavailability of the trace elements is indicative of the corresponding association of Cu, Mn, Ni, and Zn levels in the plant species and soils. This is significantly depicted as mean elemental levels in the plants decreased in the order: Mn>Zn>Cu>Ni, whereas, in the soils, mean elemental levels decreased in the order: Mn>Zn>Ni>Cu (Chukwuma, 1995b).

Pb pollution and deposits due to anthropogenic activities are on or proximal to highways as a result of the combustion of leaded fuel by automobiles, and in localized situations near metal ore deposits, mining, smelting, and other industrial modus operandi. Pb ranged from 5mg/kg in rural area to 4355.8 mg/kg at a derelict mine, with overall total mean concentration of 301.5 mg/kg (Chukwuma, 1996). In stream sediments, Pb varied from 10-99 mg/kg with a mean of 50 mg/kg (Olade, 1987). A significant correlation exists of the Pb level of soils regarding the composition of the bedrock; also, Pb has the least mobility compared to the other heavy metals. The relative decrement for Pb level in natural soil solutions concur with this finding. The characteristic localization of Pb at the vicinity of the soil surface or sub-surface is inextricably associated with the accumulation of surficial organic matter. Highest Pb levels are also encountered in the enriched organic surface horizons of uncultivated soils. Thus, it is imperative to regard organic matter as the critical sink of Pb in polluted soils (Kabata-Pendias and Pendias, 1992). Plant toxicity Pb levels in soils are problematic to evaluate or assess; however, high soil Pb levels are important to produce toxic plant response. Various soil parameters such as alkaline pH and high organic matter content have observedly antagonized Pb uptake; whereas acidic rather than alkaline soil pH levels promote the uptake of Pb by plants (Chukwuma, 1994c). The modifying effect of soil pH is minimal, and it plants growing on calcareous soils may tolerate appreciable Pb level. Merely a tiny proportion of soil Pb is available for uptake by plants. Pb inculcated into soils frequently binds to organic or colloidal materials, or is in a precipitated form, with resultant decrease of Pb uptake into plant roots by soluble ionic mobility. Pb content of plant surface can be influenced by aerial Pb emanating from automobile exhausts as aerosol automobile exhaust particles and water insoluble halogens. The probability of plant uptake from aerial sources is infinitessimal, though. Plants growing in proximity to highways are usually exposed and susceptible to higher concentration of Pb than most other locations. Pb deposition is easily propagated on hairy or rough surface leaves.

Cadmium, Cd a non-essential heavy metal has even distribution at low concentrations in both urban and rural areas with elevated levels at a derelict mine transect (Chukwuma, 1996). Cd mobility in soils is pH dependent with range from <0.001 mg/kg yellow-brown moderately fine soils to 40.5 mg/kg in grey fine soils, and total mean in all soils of 1.57 mg/kg Chukwuma, 1996). Cd from stream sediments ranged from 1-20 mg/kg with a mean of 3.5 mg/kg (Olade, 1987). The major factor determinative of soil Cd level is the chemical composition of the parent rock. Highest mean Cd level was proportional to relatively low soil Cd, slightly mean acidic pH, and mean organic matter content higher than the precinct level (Chukwuma, 1996). Cd level in soil solution is relatively low; and in comparison to other heavy metals, Cd is appreciably mobile under diverse soil conditions (Kabata-Pendias and Pendias, 1992). Cd activity in all soils is markedly effected by pH. However, in acid soils, the organic matter content is mainly the influencing factor in Cd solubility. Soils having markedly disparate organic matter content depicted that the Cd contents in diverse plants are lower when cultivated in soil-enriched organic matter (Street et al., 1977). Also, increased Cd phytoavailability to sewage sludge-treated plants and increased incubation time was associated with the release of Cd organically adsorbed by means of microbial organic matter decomposition (Street et al., 1978). Cd is toxic to plants at relatively low soil and plant levels. Cd accumulates more in the leaves of vegetables than in fruits and seeds; and Cd uptake is decreased if the soil pH is 6 or higher. (Chukwuma, 1994b).

What factors influence elemental uptake from soils and distribution to plants?

The solubility of the metal associated with the solid phase constitutes the major factor that governs elemental uptake or availability from soils to plants. In order for root uptake to take place, an extant soluble species must be adjacent to the root membrane for a finite duration. The form and release rate of the soluble species will have strong impact on the rate and extent of uptake and, probably, mobility and toxicity in the flora, and in the fauna as consumers (Cataldo and Wildung, 1978b). The factors influencing solubility and metal speciation in soils provide expansive geographic variability, such as in the quantity and chemical form of the element entering soil, soil attributes (endogenous metal level, mineralogy, particle size distribution), and soil processes (e.g., mineral weathering, microbial activity), as these impact the kinetics of sorption reactions, metal content in solution as well as the form of soluble and insoluble chemical species. The plant root constitutes the initial barrier for the selective absorption and accumulation of ions present in soil solution. Uptake and kinetic analytic information for nutrient ions and chemically related non-nutrient analogs may indicate that metabolic processes associated with root absorption of nutrients regulate both the affinity and absorption rate of specific non-nutrient ions. Kinetic analysis of Ni, Cd, and Tl uptake by plants depict multi-phasic root absorption mechanisms over an extensive concentration range, and the application of transport processes for the nutrient ions Cu, Zn, and K (Cataldo and Wildung, 1978). Usually, mining populations are exceptionally tolerant to the specific heavy metals or trace elements present in the soils of their original habitats at high concentrations. There is tolerance specificity that may embrace more than one element (Chukwuma, 1993a; Chukwuma 1994a,b). Disparate types of plants accumulate diverse elements from the soils especially in mining transects. Soil parameters such as soil type, bulk density, organic matter content and pH are determinants in the uptake of these heavy metals and trace elements from soils into plants. These have been determined in similar or increased levels of these elements in contaminated soils and crops in mining or old mining areas (Chukwuma, 1994b). Higher plants may exhibit less tolerance of elevated concentrations of heavy metals, but may accumulate trace elements and survive on contaminated soils or stressed environments (Chukwuma, 1996).

Heavy rainfall, washing of plant leaves, leaching, element speciation, and other environmental factors (Lieth and Markert, 1990; Kabata- Pendias and Pendias, 1992) influence trace element uptake by plants, but these may not contribute considerably to the expansive disparity in soil pH, bulk density and trace element availability for cassava and rice leaves in dry and rainy seasons (Chukwuma, 1994a). Heavy precipitation resulted in a significant 70% decrement of Pb level in Alocasis odora growing in proximity to highways after 13 mm of rain (Bingham et al., 1980). It is observed that all non-essential chemical elements accumulate with ageing of leaves. Contents of Cd, Pb and Zn in soil, water, Manihot esculenta tuber and Oreochromis niloticus in a phosphate exploitation precinct determined during dry and wet seasons (Bouka et al., 2013) depicted that in soil, Cd and Zn contents significantly depreciated during dry season compared to wet season. During wet season, Cd concentrations in water were lower than 0.003 mg L^{-1}, but in dry season these were higher than the recommended maximum concentration. During wet season, Pb levels of 0.204 to 0.313 mg/l were more than values recommended by WHO. In cassava tubers, all Pb concentrations were less than critical value of 2 mg/kg; the highest concentrations of Cd, 0.673 mg/kg and Pb, 1.868 mg/kg were observed. Zn contents ranged from circa 60 mg/kg to 104.660 mg/kg. The values of Cd and Pb in Oreochromis niloticus were below 1and 2 mg/kg, respectively, but Cd contents during wet season were up to 3.014 mg/kg, with a maximal level of Zn, 113.370 mg/kg during wet season higher than 100 mg/kg. It was observed that aspects of the phosphate exploitation precinct are polluted by the mining operations and subjected the fauna and flora population to health and environmental risks via the food chain. Warm, dry climates and, to a certain magnitude, humid, hot climates induce upward translocation of trace elements in soil profiles (Kabata-Pendias and Pendias, 1992).

Despite the sampling period, metal levels in soils and plants are greater than background values (Bidar et al., 2009). In contradistinction to certain heavy metals which accumulate mostly in senescent leaves and leaf sheaths, Zn ostensibly has a uniform distribution in the entire plant. The relative Pb uptake of rice seedlings was greatest in the pH range of 4.5-5.9, and least in the pH range 5-6.5 (Chukwuma, 1994c). Pb content of rice grain is, therefore, highly dependent on the soil pH and is the highest at mean pH 5.3-5.9. Rice grain uptake of Cd was highest in the pH range 5.4-5.9, and lowest in the pH range 4.5-6.5 (Chukwuma, 1994c). Cd content of rice grains is markedly dependent on the soil pH and is the maximum at pH 5.5 (Bingham et al., 1980). Cd accumulates less in leaves than in lower parts; but was not evident in rice leaves to which 109Cd was introduced (Kitagishi and Yamane, 1981). There is a perspicuous retardation of Pb translocation from root to shoot, as merely a small quantity is translocated to the shoot.

Heavy metal levels in soils and plants in the transect of a copper-tungsten mine demonstrated the impact of erstwhile base metal mining on the surficial ambient. Metal levels in soils depreciated with distance farther from the mine, and was manovered mainly by aquatic mobility and topography (Jung, 2008). As determined (Chukwuma 1993b), metal contents in leaves were higher than in grains. The factors associated with the bioavailability of metals include soil pH, cation exchange capacity, organic matter content, soil texture and chemical interactions (Jung 2008).

Plants containing Zn at phytotoxic concentrations are not implicated in any toxicity in animals and humans because its adverse effect is attenuated in the food chain. Zn phytotoxicity may result at pH 6.5 or less. Due to the antagonistic relationship of Cd and Zn, the Cd/Zn ratio (0.002-0.004) in soils is ostensibly beneficial in the prevention or obliteration of toxic accumulation of Cd in food crops (Chukwuma 1993a; Chukwuma, 1994a,b). Certain repercussions exist in the interaction of Cd with other metals, especially Zn. Cd and Zn are in the same group and share similar chemical attributes. They both exhibit biochemical antagonism; and their ratios are critical in biochemical outcomes. This similarity grants the latitude for their usual occurrence together with Zn predominating or in abundance. The established Cd:Zn ratio in most staple foods is circa 1:100 (National Academy of Science, 1977). Data from a derelict mine transect revealed that the Cd:Zn ratios were 1:100 and 1.57 respectively, for cultivated (staple foods) and wild plant species (Chukwuma, 1993a). It is suggested that there is an amelioration in the potential toxicity of Cd by Zn via simple mass action effect specifically for cultivars, while other superimposed tolerance or adaptive mechanisms are operative in the wild plants.

The presentation of toxic elements in the soil-plant system correlates to their discrete states. Elemental toxicity as determined by plant uptake is associated with the outcome both in the liquid and solid states of the soil. Toxic elements have stronger adsorption at high pH with more significant effect in light textured soils. Indubitably, pH variations influence trace metal solubility, as they are inter alia also governed by reductive dissolution and organic acid production (Charlatchka and Cambier, 2000). In a mine transect, the mean soil pH was 6.01, and light textured brown powdery soil had the highest Zn and Cd concentrations (Chukwuma, 1994b). There was disparity of the energy binding of each element to the soil. It was easier for Cu and Zn to be extracted from soil solution than Cd and Pb (Huang et al., 1977). There were fluctuations of metal levels in plant parts in contrast to soils over time. Bioaccumulation and transfer factors indicated that metals were preferentially stored in the roots in the order: Cd>Zn>Pb, with inhibited transfer to shoots. Foliar metal deposition was also depicted. The findings illustrated that there were seasonal and annual variations of metal accumulation in the plant species. These variations were related to specific organs and patterned after the plant species (Huang et al., 1977). These alterations were in terms of the seasonal and temporal variations of metal levels. The magnitude differences pertain in the concentrations of Cd, Pb and Zn between species were suggestive of disparate tolerance mechanisms regarding excess trace elements. The tolerance was likely be genetically controlled, or sulphide ore minerals at the periphery of the earth's surface could potentiate the ore metals to accumulate in soil with resultant specialized metal-tolerant floral associations (Davies and Jones, 1988), or communities.

A sole measurement is not enough to assess, evaluate and elucidate the contamination level of the prevalent heavy metals or trace elements. This is arguably so, as affixed value cannot provide a defined measure of elemental contents in plants and soils due to spatiotemporal variations between sampled units. Even though, the variation could be attributed to verifiable aetiologies or factors, a residual component remains that is beyond complete elucidation or control that must have resulted from chance (Bajpai et al., 1992). This random variation explicates the rationale for disparate elemental contents in two samples of soils or plants from the same point vary from one season to the other (Chukwuma, 1994a). The two plants, rice and cassava investigated in mine transect in relation to corresponding soil parameters had Cd, Pb and Zn levels which reflected preferences for these heavy metals rather than seasonal variations or differing climatic conditions.. As the plants and soils were collated at the same transect, it will preclude the polemics to determine the trends and variations in inter- and intra-species differences and soil attributes (Chukwuma, 1995a; Chukwuma 2011).

Genetic factors and characteristics of evolutionary adaptive/tolerance are critical in the survival of these plants in soils containing excessive quantities of trace elements and heavy metals in abandoned mines. Natural selection for morphological features adapting plants to unfavourable or stressed mine precinct may also be taken into cognizance. Non-highly tolerant plant species tend to exhibit elemental toxicity symptoms in ore-assemblage or be non-extant over the ore. Growth stimulation of tolerant plants in metal-saturated soils may be depicted, but this is seldom in non-tolerant flora. As plants primarily function in the biotransformation of chemical elements from soil, water and air, elemental uptake via the soil solution is strongly dependent on the availability and the chemical speciation of the element. The chemical elements in a soil may provide a broad chemical framework or spectrum.

Analytical variances resulting from poor sample preparations, measurement methods or data evaluation seldom culminate in strong deviations from the mean as depicted in biological variations between samples from a natural environment (Lieth and Markert, 1990), including cultivated fields. In addition to abiotic alterations or fluctuations, plants are amenable to manoeuvre the horizons of a soil profile correlated with its growth potential, plant age or season. The form of the species may alter the uptake and distribution or translocation. The introduction of chemical elements as litter to the soil, plants create and pattern their own profile. The pattern or shape may be altered by anthropogenic activities or natural biological interactions.

Environmental monitoring, remediation and management

Plant colonies have evolved certain physiological mechanisms for tolerance of elemental toxicity in metalliferous, highly mineralized soils and stressed environments. These mechanisms do not inhibit metal uptake but the resultant effect is internal detoxification. Two basic modalities of plant responses are as accumulators and excluders. Accumulators concentrate metals in plant parts from all available precinct, whereas excluders discretionarily uptake and transport between root and shoot culminating invariably in low shoot levels above an expansive range of external levels. Indicators are an extrapolated response pattern whereby concomitant relatedness exist between elemental concentrations in the specific soil, uptake and accumulation in plant parts. Plants are classified as accumulators, indicators or excluders as peculiar to any element (Gisbert et al., 2008). Accumulators take up elevated concentrations of certain heavy metals without the plants exhibiting any toxicity effect (Kabata-Pendias and Kabata, 1992), and as related to hyperaccumulators which concentrate tremendous quantities of elements in the aerial portions or shoots (Rascio and Navari-Izzo, 2011) in excess of background biomass. The principle of hyperaccumulation is "elemental defence" or "element protection" mechanism for plants to excessively concentrate heavy metals against natural foes, such as herbivores. Another functionality to hyperaccumulate is for heavy metals to operate in synergistically organic defensive assemblage for overall enhanced plant defence.

Heavy metal contaminated soils are an ever-increasing dilemma to plant, human and animal quality of life and health. Metal accumulating species become useful for phytoremediation (the extraction of metal contaminants from soils) or phytomining (the cultivation of plants to harvest the metals). Also, some heavy metals or trace elements hyperaccumulated are essential nutrients, with concomitant ascertainment of food fortification and phytoremediation (Rascio and Navari-Izzo, 2011). Indicators take up metals as to reflect their contents in the soil ambient. They are beneficial as indicators and predictors of the source and the intensity. Excluders have a discriminatory effect against metal ions, and biopurify as regards particular elements (Chukwuma, 1993b).

Rice, yam and cassava are cultivated as major staple foods in the West African sub-region, and are likely indicator species. Ranges of Cd and Pb levels in the leaves of these plants and rice grains were not so broad but also depicted high concentrations of these metals. Panicum maximum, guinea grass is broadly distributed throughout West Africa, and is common in the vicinity of farm lands and provides good silage and hay. It is ostensibly barrier-free to Pb and Cd uptake, and thus, constitutes a reliable environmental indicator and phytoremediators for these chemical elements. Broader concentration ranges for this plant were evident in the derelict mine transect, and narrower ranges farther away reflect and depict higher soil load of chemical elements at the mine and its periphery. The findings were that Panicum maximum is the best indicator species for Cd and Pb for the investigated soils (Chukwuma, 1994c). The most appropriate indicator plant species for trace element levels for the investigated cultivated areas were grass (Cu), yam leaves (Cu, Ni), rice leaves (Mn), rice leaves and grains (Ni) and cassava leaves (Zn). The greatest range was described for Mn in yam leaves, and the least variation for Ni in rice leaves (Chukwuma, 1995b).

Imperata cylindrica accumulated Pb but excluded both Zn and Cd. Ageratum conyzoides was determined as either an accumulator or indicator depending on the chemical element or whether it was being classified as regards plant uptake or the plant/soil ratio system (Chukwuma, 1993b).Thiaspi calaminare, a variant of the mountain pansy, Violea lutea accumulated >10%, whereas Equisetum arvense took up 0.1 to 1% Zn, and other trace elements in Western Europe (Edington and Edington, 1977). The basil Becium homblei is associated with copper deposits in Africa (Edington and Edington, 1977). The grass, Eriachne mucronata is associated with lead uptake (Cannon, 1971) in Australia. In Poland, dandelion, orchard grass, plantain, and lichens are ostensibly the best indicator plants for Cd levels in soils (Kabata-Pendias and Dudka, 1990). To elucidate the food-chain linkage in the bioaccumulation of heavy metals, the goat weed, Ageratum conyzoides may serve as a better indicator of the distribution of Zn, Pb and Cd. Imperata cylindrica and Bryophyllum pinnatum may be tenable for biopurification purposes. Dioscorea bulbifera could be useful for biological locating of ores (Chukwuma, 1993b). The mungbean may impose as a nickel indicator, accumulator, or excluder (Ahmad et al., 2007).

The usage of plants for monitoring heavy metal pollution in the terrestrial environment must inculcate the complex, integrated impacts of pollutant and contaminant sources as well as soil-plant variables. In order to be detectable in plants, it becomes critical that pollutant and contaminant sources markedly spike the plant available metal level in soils.

The essential and non-essential heavy metals Fe, Ni, Mn, Zn, Cu, Cd, Cr) and Pb analyzed in four selected medicinal plants, Capparis spinosa, Peganum harmala, Rhazya stricta, and Tamarix articulate (Shah et al., 2013) showed that these plants are widely consumed as traditional medicine for treatment of diverse ailments. The heavy metal concentrations in the plants was found to decrease in the order: Fe > Zn > Mn > Cu > Ni > Cr > Cd > Pb. These medicinal plants accumulate these elements at varied levels. Monitoring such medicinal plants for heavy metal contents is immensely valuable to physicians, health planners, health care professionals, and policymakers for the protection of the public from their adverse toxicity impacts.

Microorganisms which are capable of resisting elevated concentrations of toxic heavy metals are effective agents of bioremediation regarding such contaminants and pollutants. Halophilic microorganisms are useful in bioremediation due to their efficient and effective removal of heavy metals (Sowmya et al., 2014) in soil contaminated with various levels of Ni. The rates of germination and percentage significantly diminished in the plants (Jamil et al., 2014). The pigments of photosynthesis, chlorophyll a, chlorophyll b, and carotenoids also when different Ni concentrations were applied to the soil. Total protein and organic nitrogen decreased at elevated Ni levels. Bacteria serve in competent phytoremediation of heavy metal deranged soil. Improvement in seed germination and biochemical attribute of plants following Ni stress were detected with the inoculation of Bacillus licheniformis NCCP-59 strain. This bacterial strain may protect plants from the debilitating impacts of Ni, and useful for the phytoremediation of Ni contaminated soils.

The reclamation of nonferrous metal-polluted soil via phytoremediation requires an entirely permanent plant cover. Selection of the most appropriate plant species necessitates the investigation of chemical element effects on plants over the specified period, and assurance that the chemical elements remain stored in root systems and not transferred to the aerial aspects. It then becomes imperative to study the seasonal and annual variations of metal bioaccumulation, transfer, and phytotoxicity (Chukwuma, 1993a; Bidar et al., 2009). Investigations of the spatiotemporal variations of sediment quality containing selected heavy metals and total hydrocarbons (THC) with the application of multivariate statistical techniques, such as principal components, cluster and lineal discriminant analyses discerned the environmental interpretation of a limited dataset for the identification of environmental quality (Alvarez et al., 2014). It was determined that Zn, Cu, Pb, V, As and THC significantly contributed to sediment quality variations during the sampling period.

Environmental variability and resource dynamics

Soil constitutes an aspect of a vital environmental, ecological and agricultural resource that needs protection from further degradation. An optimum supply of healthy food (Chukwuma 2020a; Chukwuma 2021) is required for the bourgeoning global population. Chemical elements can affect both the yield and composition of crops. Therefore, a determination of the elemental status of all cultivated lands has to be made for the identification of yield-limiting deficiencies of essential micronutrients and the corresponding contaminated and polluted soils. The extensive variability of soil composition is influenced by several factors, the most vital of which are climatic status and parent material. Research on the association between trace elements and soil constituents explicates their behaviour in soils and in plant uptake. The fate and pattern of mobilized chemical elements by dissolution of parent substances are dependent on the ionic speciation of the soil solution. Significant alterations in element concentrations in soil solutions result due to precipitation, evaporation, and plant transpiration. The trajectories of trace element distribution, translocation and accumulation vary expansively for any element, plant species, and growth season.

Environmental pollution data depicting environmental variability vary extensively and are susceptible to disparate uncertainties, such as inter alia distance, pollution sources, natural background variation, spatiotemporal pollution build-up or degradation.. Environmental variability relates to the unique variation in pollution levels between population units. In essence, the levels, dynamics and significance of heavy metals in composted waste materials are critical from two potentially conflicting dimensions of environmental legislation as to: (a) explicate and define end-of-waste criteria and augment recycling of composted residuals on land and(b) protect and preserve soil quality as well as create a barrier to contamination and pollution (Smith, 2009; Chukwuma, 1996). The development of a monitoring programme for the sampling of the same plant species using standardized sampling and analytical methods for the maximization of the comparability of data is pertinent (Chukwuma, 1998). There are expansive highly metalliferous precincts with ponds, lakes, rivers, streams, and other aquatic resources (Chukwuma 2020c). with diverse fauna and flora which are vulnerable to extreme quantities of trace elements or heavy metals which may be inimical to the ambient, animal and human health. Most of these plants are ubiquitous, and could be sampled regularly with standardized sampling and analytical techniques to monitor the time-trend or spatiotemporal dissemination of chemical elements which are potential environmental, animal and human health hazards.

DISCUSSION

Invariably, there is the overwhelming need for the simultaneous management of soil on the entire spectrum of essential and toxic elements. Crops and livestock usually become subjected to latent hunger or latent toxicities. Plant response to an element or nutrient may be suppressed when growth or development is inhibited by toxicity or deficiency of another element antagonistically or synergistically. Soils with low levels of contaminants need protection using stringent measures from superimposed contamination, that is, pollution. Soils polluted by heavy metals must either be cleaned or at the least, elemental removal conducted to meet minimal concentration requirements for human health, optimum growth for plant and soil micro- and macro-organisms. Observed elemental concentrations in a given soil which exceed normal values, may be indications of untoward in-puts by agricultural activities, emissions via the air, parent rocks, and transportation of accumulated pollutants to soils, waters and plants (Gupta, 1991: Chukwuma, 2014).

Although, it is not every ambient that has been adversely exposed and susceptible to heavy metal and trace element contamination, pollution and toxicity, there is pertinence for concern (Guan and Peart, 2006; Chukwuma, 2014). Pb levels were found to be substantially higher in tree leaves on roadsides than in a park. Heavy metal concentrations were lower in the roots than in leaves; thus suggesting that heavy metal pollution of trees was mainly due to air pollution (Guan and Peart, 2006).

it is pertinent to address environmental perturbations in all aspects. Mobilization of different chemical elements at toxic levels in the environment can accumulate in the food chain. There is need for continuous investigation on the effects of mobility of metals for the evaluation of pollutants and contaminants to be absorbed by the biota and transferred to groundwater. This will provide for a replicable method for the assessment of aquatic ecosystem health in adjacent plateau reservoirs (Wu et al., 2014) and mine precinct. also, bio accessibility tests are valuable on contaminated and polluted soils to evaluate phytostabilization impacts on the exposition risks for fauna and flora (Chukwuma, 2014).

CONCLUSION

Trace elements and their compounds constitute vital components of the biotic environment, and a vast majority of them are essential for the health of the fauna and flora. However, essential chemical elements can accumulate to toxic concentrations in the environment via anthropogenic activities, such as non-ferrous metal mining operations. It is pertinent to monitor the concentrations of elements which are bio accumulated in wild terrestrial plant species for monitoring purposes. Certain plants specifically take up select trace elements in metal-contaminated or polluted soils, and have been used to locate ores. Data acquisition and collation using well-defined monitoring programme regarding the spatiotemporal distribution of metal-contaminants in a particular plant species, particularly in ambients with similar plant and soil features.

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