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Review Article

Heavy Metals and Organopesticides: Ecotoxicology, Health Effects and Mitigation Options with Emphasis on Sub-Saharan Africa

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Abstract

Exposure to contaminants can lead to toxicity to humans. This review highlights aspects of environmental pollution and human toxicity symptoms of such exposure and how Sub Saharan African (SSA) countries could mitigate such effects. There is some extent of environmental pollution and human exposure to toxic materials in the relatively small-scale operation of mining, industry and agriculture in SSA. Huge mineral processing and industrial activities, and high-input agriculture coming into operation in these countries result in exacerbated pollution, with increased possibilities of human exposure and adverse health effects due to exposure to toxic heavy metals and synthetic pesticides. Mining and processing of radioactive minerals also expose the environment and humans to radiation. The SSA countries, newly embarking on all these activities, are presently least equipped to deal with these effects in terms of pollution abatement and prevention or clinical treatment of health effects; they should strive to develop the capacity to do so.

Introduction

Ecotoxicology, or environmental toxicology, the series of events leading to accumulation and dispersion of toxic materials in the environment, is worthy of attention because it is not an end unto itself. It is actually the base that results in human exposure upon which clinical toxicology sets in. Clinical toxicological symptoms of exposure of humans and animals to toxic materials can be a result of occupational exposure or encounter with contaminated environments/foods. Occupational exposure is the result of unsound practices in the processing of raw materials, handling of products and disposal of wastes generated by mining activities, industrial manufacturing activities, and in use of pesticides in agriculture. Such unsound practices have many facets within the improper mining/manufacturing chains, including non-use of prescribed protective gear, thereby exposing the worker(s) to toxic solid, liquid, and gaseous components along the operations chains, and haphazard handling and disposal of wastes, eventually impacting human health. Incidences of these have been amply observed, for example, the physical contact with toxic or corrosive solid wastes such as asbestos, lead, DDT and cadmium, liquid wastes such as inorganic mercury and sulfuric acid [1], and inhaling toxic gases including ammonia, hydrogen chloride, hydrogen sulphide and sulphur dioxide among others within the work environment [2-4].

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Toxicological symptoms can also be the result of encounter with environments, themselves exposed to wastes, for example, in solid-waste dumps [5], wastewater lagoons, polluted water bodies such as rivers [6], lakes/oceans such as an incidence involving detection of radioactive water in the Pacific Ocean following the Daiichi nuclear disaster in Japan [7]. Additionally, symptoms can result in from consumption of contaminated foods (e.g. fish caught from wastewater ponds, pesticide-treated grain [8], fruits, vegetables and within community environments (land and air) in the vicinity of pollutant sources [9-12].

With respect to consumption of contaminated foods in Tanzania, one of these authors (E.S.) witnessed in 1982 the roasting and consumption of fish caught from a wastewater pond receiving mercury-containing wastes from a battery-manufacturing factory in Dares Salaam, Tanzania. The same author (E.S.) witnessed in 1992 farmers in Mbeya, southern Tanzania, and Lushoto, northern Tanzania, harvesting and consuming raw tomatoes at the time of spraying with pesticides. When the people in both scenarios were cautioned about this behavior, their response was that if that danger is real then many people will be affected as these practices were common. If all these practices were, indeed, widely popular, it can be expected that clinical symptoms of poisoning must have occurred in the consumers in due course. Other farmers in Mbeya reported in 1992 that they controlled insects in cabbage by toxaphene, the acaricide used for controlling ticks on cattle; however, the cabbages treated with toxaphene would not be consumed by the family-they were only for sale. Apparently, the farmers must have recognized the high level of residual toxicity on the cabbage that received this pesticide so as not to expose the family to the treated produce.

Because occurrence of clinical effects is to a significant measure connected to the environment, minimizing and eliminating of clinical toxicity occurrences will, in a large part, go hand in hand with prevention, minimizing and control of environmental pollution. This is a multifaceted undertaking, with specific responses depending on the source and nature of the threat. This review presents a generalized survey of selected sources, health effects, and mitigation options specifically targeting the Sub-Saharan Africa (SSA) zone, much of which is currently undertaking expansions and intensification in scope of the various activities having the potential for environmental pollution, which is, therefore, a prelude to clinical toxicology as a social problem.

The objective of this review is to highlight the environmental pollution and human health problems resulting in from large-scale mining, industry and agriculture, and how SSA should position itself to counter them. The principles and operation procedures relating to these activities that lead to environmental pollution and toxicology are well known. Similarly, mitigation measures as relating to specific activities are also common knowledge. Therefore, reference to these will be brief here without being a mere repetition or regurgitation of technicalities. Rather, the aim is to use these as spring board for presenting opportunities or approaches the SSA countries, being new entrants in massive execution of mining, industry, and agriculture, should embark on to avoid a repetition of the mistakes of the earlier practitioners. Proposals will also be given on the whole question of the type of emphasis the SSA should place on environmental and clinical medicine as it relates to toxicology.

Expansion and Intensification of Pollutive Activities in SSA

Mining activities

The African content is endowed with almost every major industrially important mineral resource known [13,14]. What has been lacking for a long time for most of SSA, perhaps with the exception of southern Africa, was the internal massive processing of these resources to useable forms. However, this is now changing, with huge mining and processing activities coming into operation, or planned, in many countries. For example, there are huge gold mining and smelting operations in South Africa and Ghana, and large lead and zinc mining operations in Zambia [14], and coal mining in Tanzania, to mention a few. The gold smelter in Ghana also releases large concentrations of arsenic into the environment [15-17]. There are planned similar operations for nickel, uranium, titaniferous magnetite and niobium in Tanzania. At the same time in Tanzania, and in other countries too, relatively small and artisanal scale operations exist for copper and gold [18]. These operations have been shown to emit metallic wastes to the environment in concentrations in these African countries that are comparable to, and sometimes exceed, those in developed countries. This is because pollution control guidelines are not observed or are not existent [14].

Industry

Many countries, like Tanzania, have initiated industrialization programs as springboard for speeding up their socio-economic development. Large iron and steel, cement, pulp and paper, galvanizing, leather tanning industries, and power generation (using gas or coal) are operational or planned [19,20]. These generate, or have the potential to generate, large quantities of metal-containing wastes and to polluted surrounding areas with such wastes if preventive measures will not be put in place.

A current case in point is the state of pollution of Indonesian rivers by industrial wastes. One example is the pollution of Citarum River. According to Tarahita and Rakhmat [21], this river receives, daily, 20,000 tons of solid wastes and 340,000 tons of wastewaters, mostly from textile factories. This pollution brings with it large quantities of Pb, Al, Mn and Fe. As a result, 60% of fish species have been destroyed. The government there has currently embarked on an operation to clean the river. Similar scenarios must exist in other countries, including those of SSA.

Cottage industries, the small backyard metal-working operations that use metallic products and wastes as raw materials to fabricate other items, have flourished in almost all SSA countries. These include mechanics, metal smiths, welders and soldering works, and others [14]. These use as raw materials all sorts of metallic products and waste metals. Operation of these cottage industries has been documented in Tanzania [22] and Kenya [23], but flourish in other countries as well [24,25]. While individually their areal scales are small, collectively, over time, they harbor a great potential for environmental contamination with all sorts of toxic metals that eventually cause toxicity health problems to humans, beginning with the operators themselves. Some of the metals released from cottage industry operations cited include Cr, Pb, Cd, Cu, and Zn. For example, some soils in the Ngara cottage industrial site within Nairobi city, Kenya, were contaminated by as much as 29.8, 1,156.9, 1.52, 1,711.8 and 262.6mgkg^{-1} of Cr, Pb, Cd, Cu and Zn, respectively, while in the nearby Gikomba site the highest levels were, respectively, 69.9, 2,345.7, 7.2, 1,159.7 and 293.0mgkg^{1} [23]. Comparable levels of Pb, Zn and Cd were reported in backyard industry soils in Morogoro town, Tanzania [22].

Agriculture

Agriculture pollutes the environment through use of pesticides and heavy metal-containing inorganic fertilizers. Use of pesticides has existed for a long time, in both small-scale as well as large-scale agriculture. The crops that have attracted much use of pesticides have been the industrial crops such as cotton and the beverage crops such as coffee and tea. Cotton fields have been polluted over a long period of time with different types of organopesticides. These must have resulted in substantial negative effects on the health of field workers in addition to depositing large quantities of residues into soils [26-29]. There is also evidence of this occurring in a classical example of a large-scale cotton enterprise, the Gezira scheme in the Sudan that has existed since the colonial administration era to date. Soils cultivated to coffee in northern Tanzania were observed to have accumulated large quantities of Cu, in some soils up to 2,670mgkg^{-1}, after long-term use of Cu-based fungicides [30].

Use of P fertilizers can be a source of pollution of soils. Phosphatic fertilizers are manufactured using rock phosphate as the principal raw material. Some rock phosphates, for example, some from Morocco, Senegal among other countries in the SSA, contain large amounts of the toxic metal Cadmium (Cd) [31,32]. Use of such rocks result in high levels of Cd in the finished fertilizers, and this becomes a source of Cd-enrichment of agricultural soils, and the Cd can be passed on to food crops grown on those soils.

As far as organopesticides are concerned, chlorinated hydrocarbons, of which DDT is a member, have played a profound role in insect pest control. DDT was introduced as an agricultural insecticide in the 1940s. It was successfully used to control crop insect pests as well as environmentally in the extermination of insects like malaria-transmitting mosquitoes. Due to its long persistence in the environment (due to low biodegradability), with subsequent accumulation in animals/humans, its use was subsequently banned in many countries. However, it is still of interest environmentally to date as a result of large quantities of residues accumulated mainly in the then manufacturing or formulation environments as well as in dumping sites. In the eastern African countries, as elsewhere in SSA, unused and/or expired consignments of DDT were collected and shipped to Europe for decontamination/incineration as such specialized facilities do not exist in SSA. For example by 2007, Ethiopia, assisted by the FAO, transported 2,574 tones of obsolete pesticides for incineration [33,34].

In many countries, in addition to shipping abroad banned and obsolete stocks for incineration, some of them are still available within the countries, e.g. Ethiopia [33] and Kenya [35]. Still, high concentrations of DDT and other organopesticides exist in many locations that once formulated or stored these products. In Tanzania, such locations include Morogoro, Kibaha (Coast region), Tengeru (in Arusha), Uyole (Mbeya), Dar es Salaam, Zanzibar, Babati and in Hanang (Manyara), etc. [36-38]. These locations are still a threat to human health. In the Morogoro site, which was used as a formulation site up to the 1970s, total DDT residues (including its metabolites) in some sampling points reached a high of 2,273.8mgkg^{-1} [38]. In the same site, other organopesticides were also found, to the tune of 196.6mgkg^{-1} of dieldrin and 386.7mgkg^{-1} of endosulphan [38]. As a result, the U.N. agency UNIDO has financed experimental/demonstration projects in several countries in Africa, Tanzania included, with the objective of establishing the feasibility of phytoremediation of such sites.

Phytoremediation, the clean-up approach that utilizes cultivated plants, is one of the focuses of UNIDO in a demonstration in Arusha and Morogoro, both in Tanzania, where two of the authors (E.S. and H.T.) are involved. Initial observations indicate that this will be a slow process, as plants have limits as to how much of the pesticides they can accumulate in each round. However, given long enough a period of time polluted sites could be cleaned up. An immediate danger in the phytoremediation approach is that if such remediation sites are not strictly guarded, residents adjacent to these sites may look upon the plants as a source of food when food crops are tested. This prospect was observed in Morogoro, where some food crops including pumpkin and sweet potato were seen to be of promise in remediation of DDT. Thus, extreme care and caution have to be exercised to warn people to avoid consuming crops from such contaminated sites.

Waste disposal

In addition to encountering wastes from the above activities in the work environment, deliberate efforts or programs have usually been undertaken to continually dispose of wastes generated from the different operations. Such efforts include construction of huge dumps that in time accommodate huge quantities of wastes. These include dumps for industrial solid wastes, for municipal wastes for combined (industrial+municipal) wastes. Also, large lagoons or ponds are constructed to intercept and store huge volumes of liquid mining wastes (e.g. the case of gold in Tanzania),liquid industrial wastewaters, or combined industrial+municipal wastewaters. These structures can eventually lead to pollution of adjacent environments. A classic example of a waste dump is the one in the U.S., referred to as the Love Canal dump. Named after the constructor of the canal that was to divert Niagara River water for power generation in the late 1880s, the unfinished canal was later used, in the 1940s, as a dump for toxic waste [18]. Much later, in the early 1950s, the Niagara city covered the dump using soil and constructed above it a residential estate, a school and associated playing infrastructure. In the late 1950s the barrels containing the buried wastes started to leak, affecting vegetation and the health of the residents.

Many African countries have designated many locations within and in the vicinity of cities as sites for dumping all sorts of solid wastes. One author (E.S.) observed the existence of a big such dump in the city of Ibadan, Nigeria, in 1978. A similar dump in Tanzania, called the Tabata dump, existed within the Tabata area in Dar es Salaam since the early 1960s. It was subsequently covered and converted to a residential cum industrial area in early 1980s. Such dumps result in pollution of air upon frequent incineration of the wastes, and stream waters via their leachates. There is a need to monitor the environment and humans in such former dump areas to discern any adverse health effects. Since existence of such dumps is known to relevant government ministries and environment protection agencies, coordinated efforts and measures should be taken to cordon them off to preclude easy access by the general population. In addition, education should be given to raise public awareness of the existing dangers. Even when the dumps are relatively small as compared to those in developed countries (e.g. Love Canal), and the scope of risk equally small, the fewer people around them still deserve protection as well as the larger populations in former dumps elsewhere, bearing in mind that the principles behind ecotoxicology, human exposure, health risks and effects are universal.

In Tanzania, liquid wastes from lagoons used for the disposal of gold extraction wastes resulted in cyanide poisoning to nearby residents. Cyanide poisoning has also been reported elsewhere in plants and animals surrounding the structures [39]. Similar scenarios have been reported in other countries.

Transportation

Transportation has been a source of environmental contamination, especially with Pb. The Pb is emitted via vehicle smokes following combustion of leaded petrol. Lead deposited on lands adjacent to roads, and from ruptured accumulators discarded on agricultural soils adjacent to heavily-travelled roads, lead to human exposure to Pb via vegetables cultivated on such soils. Lead migration from points of original disposal to other places has been reported previously [40]. From whatever source, the risk of lead intoxication through eating contaminated plant food materials increases when the soil Pb levels exceed 300mgkg^{-1}.

Toxicology of Heavy Metals

In reviewing the toxicology of heavy metals, classical examples are used as proxy to what could happen following extraction and use of these metals in SSA countries, including other metals that are not as deeply studied in some particular aspects as have the classical examples. In this way, caution is expressed or, at least, implied, that a similar level or depth of toxicological evaluations in respect of other metals, where such evaluation is inadequate or absent, should be undertaken to gain as much knowledge as exists in the case of the classical cases. Implicit is the assumption that while for some metals greater emphasis has been placed on the useful aspects of these metals, the scenario could change as a greater burden of the metals accumulates in the environment following intensified extraction.

For example, while metallic elements like copper or zinc at low levels have positive roles in plant and animal growth and health, a huge environmental burden of them as a result of a greater volume of waste disposal due to intensified mining and smelting may be accompanied with negative effects on animal life forms.Monisha et al. [41], has stated that even with the knowledge of their adverse effects on human health, their positive applications make use of heavy metals to continue to increase worldwide, and the SSA region is no exception. Further exploration of the concept of their toxicity is particularly important in SSA, a relatively virgin area much of which is rich in mineral resources [14], but is now inundated with increasing intensity in mining and industry that will lead to high build-up of wastes.

Some ordinarily toxic heavy metals have had therapeutic uses. For example, Hg has been used in antiseptics and disinfectants, radioactive Indium in tumor detection, Pb for topical applications, and as for leukaemia treatment, etc.[42]. Despite these useful applications, these metals, and others, have had profound negative environmental and human health consequences. Some of the more notable ones include mercury (Hg), lead (Pb), arsenic (As), chromium (Cr). A detailed treatise on this subject has been undertaken by Fergusson [42].

Clinical toxicology

In this review, only a few metals are addressed because of their increased likelihood for human exposure to them. This is as a result of their continued encounter in mining activities, industry (including small scale backyard industries), and exposure to them via various finished products. For example, Hg is encountered in pulp and paper manufacture [41], in ruptured dry cells (batteries), in artisanal gold mining, and in fungicides for treating crop seeds [43,44] and consumption of contaminated fish [45]. Lead can still be found in paints, in accumulators, in solder used in small scale industries, in petrol and in some pesticides [46-49]. Arsenic is used in some pesticides, and is a by-product in gold smelting. Zinc is used in galvanized metal sheets, in dry cells, in some fertilizers and pesticides [50,51]. Cadmium is found in rechargeable batteries [41] and phosphatic fertilizers [52]. Other sources of Cadmium in the environment include cadmium-containing plastics and some pigments and its use in electroplating and steel production [53,54].

All these materials then are sources of environmental pollution and occupational exposure to humans because of continued contact with them in different applications. Due to poor handling procedures in many developing countries, including SSA, these materials, useful on the one side, are also of great concern from the viewpoint of human exposure because of their toxicity.

Mercury: A wide-scale clinical toxicology occurrence of Hg was first observed in humans in the wake of the Minamata poisoning case in the 1950s in Japan. This toxicological effect was observed mainly as the neorotoxicology associated with consumption of Hg-contaminated fish caught in the Minamata Bay [55-57]. This resulted in incoordination, ataxia, paralysis and, ultimately, death. Symptoms of Hg exposure have been proved to include relatively mild symptoms like fatigue and anorexia (among others) to neurological malfunctioning [58]. Mercury poisoning has not been limited to that in Japan. In Iraq in the early 1970s, a similar toxicological scenario was observed in people who had processed and consumed wheat grain treated with organo-Hg fungicides seed dressing [8].

Over the years, much information has been accumulated on the toxicology of Hg. Examples of in-depth and extensive reviews on the metal toxicity, including Hg, are those by Bernhoft [41] and Monisha et al. [59]. The reviews show mercury, in its various forms, to accumulate in many body organs, including (to name a few) lungs, kidney, liver, thyroid, and brain, as well as in fetal tissues. The implication here is that accumulation in these organs inevitably leads to malfunctioning of the organs. Thus, the toxicology of Hg is wide and goes beyond neurotoxicity. The persistence of symptoms of Hg toxicity may be related to different half-life periods of various forms of Hg, which have been found to vary (in different organs) from a few days to several months, and even up to years in the central nervous system [45]. The biochemical mechanisms behind Hg toxicity include the binding of methyl-Hg to SH groups of proteins, and this may be one mechanism relating to the observed cerebral palsy as well as neurodevelopment delays and impaired cognitive effects [60]. Metallic mercury vapour is reported to react by binding with sulfhydryl and selenohydryl groups leading to impaired functions of the brain, the peripheral nerve system, renal and endocrine systems [61-63]. The capacity for this in-depth level of diagnosis is generally lacking in SSA. Consequently, with increased use of toxic metals in industrial processing, coupled with inevitable increases in occupational exposure to the metals, concerted efforts have to be brought to bear to develop and expand the diagnostic capacity side by side with development of exposure mitigation measures.

In countries of the SSA, including Tanzania, artisanal gold miners extract gold using Hg. While the Hg toxicology in humans associated with this practice has not been documented much, a few studies have indicated Hg intoxication of involved miners and/or people of the surrounding communities exposed to Hg as a direct result of artisanal gold mining [44,64-67].

Thus, as small scale gold mining activities expand in SSA and Hg continues to be used in gold extraction, monitoring of the miners and of the environment should continue as prelude to finding a lasting solution in preventing long-term exposure to Hg. Similarly, use of Hg as fungicide in seed dressing, still practised in SSA, should be accompanied by public education to avoid a repetition of what happened in Iraq as mentioned above.

Lead: Like Hg, the toxicology of Pb is also both neurological and physiological. Physiological symptoms of acute toxicity are many, and include (to mention a few) nausea, vomiting, anorexia, anaemia, insomnia, etc. [42,68-70]. Some biochemical effects of Pb that may lead to some of these symptoms include inhibition of haeme biosynthesis, inhibition of some enzyme systems, damage to the renal system, toxicity to foetus leading to still births, negative interactions with other metals that lead to their deficiency within the body. Lead, for example, has no useful purpose in the human body, but at a molecular level, lead inhibits or mimics the actions of calcium and therefore calcium-dependent processes. Lead also has interactions with the body's protein components such as those with sulfhydryl, amine, phosphate, and carboxyl groups. Its ability to interact with so many proteins and protein components makes the body to have virtually no organ systems that is immune to the effects of lead poisoning.

The neurological effects of Pb involve both the central and the peripheral nervous systems [42,71,72]. While the mechanisms of Pb neurotoxicity are still vague, increased levels of delta-aminolevulinic acid, a neurotoxin, in the blood as a result of Pb poisoning, is implied and is thought that this toxin can cross from blood to brain. As indicated above, in the central nervous system, lead substitutes for calcium and, to a lesser extent, zinc in second messenger metabolism triggering processes reliant on calmodulin [73]. The ability of lead to interfere with neurotransmitter release thereby disrupting the functions of GABAergic, dopaminergic, and cholinergic systems has been previously reported [72-74].

In view of this multifaceted toxicity of Pb, it is necessary to curb all pathways of Pb exposure, environmental, occupational, and via the food chain.

Zinc: Most of the clinical concerns with respect to Zn have been on its deficiency; however, of recent, some attention has been directed to the effects of excessive zinc exposure. While Zn is an essential element, toxicity symptoms of excessive Zn exposure/intake have been recognized, including nausea, vomiting, epigastric pains, and fatigue [75]. High levels of Zn have been associated with adverse effects on the ratio of low-density-lipoprotein cholesterol to high-density-lipoprotein cholesterol [75]. There is evidence that neurological toxicity of Zn is mediated by oxidative stress leading to Zn-induced cell death in neurons [76-78]. The negative correlation between elevated Zn levels and copper deficiency is reported to be associated with the characteristic competitive absorption relationship of the two metals in the erythrocytes [79]. Also, high levels of Zn in the body have been thought to affect the utilization of Fe and Cu [80,81].

Currently, most of the commercial production of zinc involves smelting of Zn-rich ores and the galvanizing of iron. Exposure to Zn compounds, as can occur through inhalation in occupational scenarios, results in fatigue, chills, fever, cough, dyspnea, thirst, salivation etc. [82]. In the gastro-intestinal tract Zn results in corrosion of the tract, and negative effects in the renal system [82].

In livestock, high levels of Zn in the pancreas increase the levels of amylase and lipase as a result of pancreatitis and pancreatic necrosis. Glomerular damage and renal tubular epithelial necrosis result in increases in creatinine, amylase, and urine protein [83] and these effects may also be similar in humans.

Cadmium: Cadmium (Cd) is another very toxic metal, with toxicity effects mainly in kidneys, bones and lungs as well as other organs [42,84,85]. It has both acute and chronic effects. Inhalation leads to pneumonia-type disturbances. Oral intake leads to profuse salivation, vomiting, abdominal pains, diarrhea, and other related symptoms, and some of these effects may be associated with its intervention in the metabolism of vitamin D, calcium and phosphate in the body [42,59, 85]. Biochemically, Cd is a competitor of Zn and mercury for binding sites of some ligands, a property that may render some enzymes ineffective [86].

Arsenic: Arsenic poisoning is associated with environmental exposures through geological sources that lead to contamination of food, air, water and soil. Human occupational activities that can lead to Arsenic poisoning include copper smelting since it is a by-product of the process [87,88] and the industrial occupational activities leading to manufacture of a range of arsenic-containing industrial products such paints, fungicides, insecticides, pesticides, herbicides, wood preservatives, and cotton desiccants. Arsenic is also contained as an additive in animal feed as it is a required trace element in some animals [89]. The toxicology of As is also manifested in abdominal pains, nausea, damage to the gastro-intestinal route and liver, in neurological effects and as a carcinogen [42,88,89]. Exposure to As has also been implied in abortion, and has effects on the peripheral nervous system. At the biochemical level, it affects oxidative phosphorylation, and can replace P in the DNA double helix. Enzyme inhibition has been recognized as one biochemical effect of As toxicity.

Environmental toxicology as prelude to clinical toxicology

The human exposures and clinical effects described above have their roots in contaminated environments, workplaces, and foods. This contamination starts in the form of metal-enriched mineralizations in particular locations. Chemical processes occur naturally in these locations, and rains and streams flowing through the areas transmit the solubilized metals to other locations, adjacent as well as farther away. In this way, uncontaminated areas become polluted. However, these natural processes may not be the main avenues of pollution. The intervention of human activities, in the form of mining and processing of the minerals exacerbates such pollution, and this is what is of the main concern. Mining and processing of these mineral resources harnesses the spread of the metals in the environment, including the atmosphere, waters, and land. In the process, humans encounter these toxic metals. These encounters can be acute, whereby humans become exposed to large doses within short time spans. Alternatively, the exposures can be chronic, relatively low exposure doses but sustained over long periods of time. In either case, humans end up with negative health risks as pointed out above. Next to the mere mining and processing of the minerals to obtain the refined metals, the utilization of these refined metals further exposes humans in the work places or at home. Thus, man is exposed to toxic metals through contact with contaminated environments, or through the work places, or in the course of using the metal-containing finished products. Therefore, while the call for increased human socio-economic development is legitimate and has to continue, parallel measures at mitigation of negative effects of toxic materials have also to continue as well. A general lack of mitigation measures is, however, currently prevalent in many developing countries, including the SSA countries.

Mercury: As a natural component of the earth's crust, the earth's crust abundance of mercury stands at around $0.05 mgkg^{-1}$. The metal melts at 38.9°C and boils at 303°C making it liquid at room temperature. It's most common mineral ore is cinnabar (HgS) although more than 25 other ores of mercury are known [90,91]. Apart from the direct mining of mercury ores, environmental (food value chain, water, soil and air) contamination by mercury can be through mercury related processing including smelting, industrial manufacture of various commodities such as Chlor-alkali [92] and waste disposal.

Lead: Lead finds its way into the environment primarily through mined ores and secondarily through recycled scrap metals or other lead-containing substances such as batteries. It is rarely found as a natural metal, but combined with two or more other elements to form lead compounds. The largest use of lead is in storage batteries in cars and other vehicles but it is also included in the manufacture of dyes, paints, ceramic glazes, ammunition, pipes, cable covers and radiation shields [70,93]. As it enters the environment through any pathway, it eventually contaminates the soil, water resources, the food chain and air. Apart from the occupational exposure at the mining facility or industrial manufacture of various items as shown above, exposure through ingestion of contaminated food or water is the most common occurrence.

Zinc: Zinc, which is an essential element required by all organisms, occurs naturally in the earth's crust and its release into the environment occurs either through natural processes or through anthropogenic routes including mining, metallurgic operations involving zinc and a wide assortment of zinc-containing industrial products. Such products may include fertilizers, pesticides, brass and bronze, die casting metal, rubber, paints and some alloys. Furthermore, electroplating, smelting, ore processing and drainage from both active and inactive mining operations are some of industrial processes that help release zinc into the environment [94]. Routes of exposure to excess zinc can be through inhalation of air-borne zinc in the form of industrial fumes and dusts, direct occupational exposure through contact with metallic zinc during galvanizing, smelting, welding, or brass foundry operations.

Cadmium: Cadmium is mined with zinc ore and is released both during mining and smelting (refining) processes. Cadmium is also released into the environment, specifically soil, by man-made activities such as its presence in phosphate fertilizers and various industrial uses such as plating, NiCd batteries, and its presence in certain paints [53]. From contaminated soils, cadmium can be up-taken by cereal based crops such as rice, other crops like tobacco, potatoes and vegetables effectively entering the food chain. Other Cadmium routes of exposure include occupational exposure in the smelting and mining industries [95].

Arsenic: Arsenic, like many other heavy metals, is a natural component of the earth's crust and is widely present in all major segments of the environment including air, land and water [96]. In the earth's crust As occurs both as a natural free element and in mineral forms. Over two hundred minerals containing As are known with the most important mineral ore being arsenopyrite. Mining, metal smelting and burning of fossil fuels are the major industrial routes that contribute to arsenic contamination of environment (air, water and soil) [96]. As also enters the environment through volcanic eruptions and other processes which may carry arsenic-containing vapour generated from solid and liquid forms of arsenic salts. Being so reactive, As enters the environment either geologically through ground water [97] or released into the atmosphere in the form of arsenic trioxide as a by-product of smelting. While in air it adheres to particles and thus transported over long distances. During rain, arsenic can fall down to land or water bodies where it can be converted to stable forms of arsenate. From there arsenic can enter the food chain either though drinking water, or through vegetables irrigated using contaminated water by uptake by edible plants.

The varied processing of these metals, as discussed above, then sets the stage for environmental contamination, followed by subsequent exposure of humans and animals to the metals, with eventual development of clinical symptoms of poisoning.

Toxicology of Radioactive Elements

Radioactive elements, upon disintegration of their atomic nuclei, emit radiation. Some of the radiations are dangerous to human health. Uranium (U) and plutonium (Pu), as well as others, belong to this category of radioactive elements that emit dangerous radiation. However, these elements are also useful in that they have found application in the production of nuclear power. Many developed countries operate nuclear power installations. Eventually, after a long time of producing electricity, their useful productive period ends after the elements have decayed to unproductive but still radioactive products. Leakage or haphazard handling of these products becomes a public health hazard. Additionally, nuclear accidents that had widespread public hazard implications have been documented as a result of operating nuclear power stations. For example, in the USA, a classical example is the Three Mile Island nuclear power incident in Pennsylvania that occurred in 1979 [98,99]. Another is the Chernobyl accident in Ukraine in the then USSR [100,101]. More recently, in 2011, the Fukushima Daiichi incident in Japan added to the list [102].

These incidents spread radioactivity over vast areas in the environment. However, the actual human health hazards following these incidents have been a matter of debate. Some studies report negligible health effects on individuals as a result of the Three Mile island incident [98-100] and around Fukushima [102], although people are still exposed to 137 Cs in milk in Chernobyl [101]. To have presently observed no serious health effects should be no reason for complacency but should serve as springboard for further research, of a long-term nature, to reveal any possible effects not yet observed. Alongside this, efforts should always be strengthened with the aim of striving to improve the engineering standards for construction of power plants and nuclear waste reprocessing and storage facilities for increased safety.

For a long time, nuclear energy has been a preserve of the developed/industrialized countries. In the future, Africa may also opt for this kind of power source. According to Gil [103], the International Atomic Energy Agency (IAEA) has reported that nearly 30 countries in Africa are currently considering the option of nuclear power, and Egypt, Ghana, Kenya, Morocco, Niger, Nigeria and Sudan are in consultation with the IAEA on possibilities for embarking on nuclear programmes [103]. Others are also considering the possibility. In Africa at present, there is only one country with a commercially operational nuclear power installation, South Africa [103]. Others may be constructed in time (even as the developed countries promulgate the desire to de-commission their nuclear power installations for fear of such dangerous incidents).

In addition to nuclear power plants, many countries currently manufacture and have stockpiles of nuclear weapons. While no African country is currently known to have these weapons, the future is open-ended. The effects of radiation released upon detonation of such weapons would be similar to those that occurred in Japan in the wake of use of these weapons at the close of World War II in 1945. However, in SSA, peaceful use of nuclear energy should be the path to be advocated, strictly observing no escalation to weapons production.

The prelude to constructing nuclear power plants and to manufacturing nuclear weapons is the mining of uranium. Large tracts of land enriched with uranium minerals have been discovered in some African countries, including Algeria, Burkina Faso, Gabon, Namibia, and Somalia [14], and Tanzania has also discovered its own deposits. Mining of this resource, as is envisaged in Tanzania, and elsewhere, has the potential for spreading in the environment mining wastes containing U radioactivity if safety precautions are not strictly implemented. Long-term exposure to such wastes would be as dangerous as fallout from detonated nuclear weapons. While no nation should be denied the opportunity for the pursuit for the peaceful development of nuclear energy, great caution will need to be exercised if Africa is to continue exploiting this resource and to expand its engagement in the various facets of the nuclear field.

Clinical toxicology

The human exposure to, and subsequent clinical toxicity of, radioactive elements can occur in any one of the following scenarios: during mining and processing of radioactive minerals, enrichment of radioactive isotopes, radioactive waste management, and environmental workers studying the distribution of mining tailings [104]. Poliakova [104] has classified the radio-toxicity of different elements and their isotopes, and those of uranium, plutonium, thorium, and strontium, among others, have been ranked to have high to very high radio-toxicity. The clinical symptoms of exposure to are varied. For example, exposure to uranium and plutonium via inhalation has been related to lung cancer [105]. A wide-ranging literature survey by Keith et al. [106], cites many effects of uranium based on animal studies and fewer specifically relating to humans, probably due to few human studies as a result of ethical issues requisite of human experimentation. In these animal studies, some observations have been reported relating to gastrointestinal effects, pulmonary effects, renal effects, and immune system effects etc. However, they are not all informative for the human situation. Still, these observations may be a pointer to what could happen to humans upon exposure. Many radioactive nuclides cause mutations in DNA, both somatic and germ cell (heritable) [10] and this is a main area of concern when dealing with radioactive materials. All isotopes of uranium are radioactive [107], a fact that exacerbates the dangers associated with mining and processing of uranium minerals, and handling of all radioactive substances.

Environmental toxicology

The nuclear accidents mentioned above have been a cause for environmental concerns. For example, from the Chernobyl incident, Caesium-137, Strontium-90, and Plutonium-239, all being derivatives of the Uranium used in the power plant, have been detected and are still found in parts of Europe, Asia, and North America, implying the possibility of a global environmental impact [101]. However, according to Choppin and Rydberg [108], these elements, once placed in a particular location, do not migrate much in the environment, even though they have long half-lives. It is reassuring that, following the Three Mile Island accident, it has been estimated that the maximum exposure at the site's boundaries would be only 100 millirems above the background radiation levels, leading to the conclusion that very low levels of radiation would be related to the accident [99] and that the radioactivity released was not enough to cause dangers to public health [108]. Similarly low levels of environmental radiation are implied in the aftermath of the Chernobyl accident [100] and the Fukushima incident [102]. However, in view of animal observations being proxy to possible health effects on humans, radioactive materials/elements should be treated with utmost care wherever encountered in order to minimise not only the environmental but also the possible subsequent human health effects.

Toxicology of Organopesticides

Due to lack of primary manufacturing facilities in most of the SSA countries, organopesticides have had to be imported into these countries. Ethiopia, for example, imported up to 376 different types of pesticides between 2013 and 2016 [109]. Since the 1960s, Ethiopia has been importing 3,800 tons of pesticides annually for use on government farms and for malaria control [110]. In 2003, Tanzania imported 2,500 tons of pesticides [111], and by 2011 a total of 874 types of pesticides were imported into the country [112]. In the case of Kenya, 7,708 tones of pesticides were imported in 2005. An additional 2,960 tons of pesticides were imported for use in the flourishing floriculture enterprise in greenhouses [113]. Between 2008 and 2013, a total of 54,516 tons of assorted pesticides were imported into Kenya [114]. These figures imply expansion of agriculture and other pesticide-demanding activities and, consequently, a large demand for pesticides. Similar scenarios must exist in other countries; this points to a large environmental burden of pesticides in these countries and consequences there from, even if documentation of the incidents is scanty.

Clinical toxicology of organopesticides

Clinical toxicology results in as a result of exposure to a toxic agent. Exacerbated exposure is related to inappropriate use practices in the widest sense, for example non-use of requisite protective gear during manufacture, formulation and/or application, use in the field without regard to prevailing weather conditions, consumption of grossly contaminated products, etc. Incidences of pesticide poisoning have been reported in many countries, including Tanzania [115], Kenya [116] and Uganda [117,118] and the pesticides DDT, hexachlorocyclohexane, aldrin, dieldrin, endosulphan, and others, were involved. While many countries banned the use of DDT, others (India, North Korea, China) still manufacture and use it, and many other countries want to bring it back to use for public health protection (if not for crop protection) [119]. Without further reinforcing any existing moratoria on DDT or, on the other hand, negating them, it suffices to stress that utmost care will have to be exercised to minimize its environmental and health impacts for those still using it and those planning to re-introduce its use. This is particularly significant for SSA, the region that is still widely afflicted by disease vectors to such a large extent that calls for the re-introduction of DDT for public health protection.

DDT and other chlorinated pesticides: Upon exposure to DDT, respiratory/breathing problems, headaches, nausea, dizziness, excessive salivation, blurred vision, tremors were some of the clinical symptoms observed on exposed farmers [115,120-122], in the eastern Africa region. Less severe symptoms were observed in workers in departmentsother than farm fields as compared to farm field workers within the same establishments, as a result of less direct contact with DDT in comparison with greater contact in the case of farmers involved in spraying [120]. Mekonnen and Ejigu [123], in Ethiopia observed lower levels of the cholinesterase enzyme in workers following spraying of the organochlorine pesticides chlorpyrphos and profenofos. Lowering the levels of this enzyme negatively affects neurotransmission functions. Also, the entire class of chlorinated pesticides has been implicated in negative health effects of the endocrine system, development of the embryo, and carcinogenesis. For example, it has been observed that DDT and some of its metabolites are carcinogenic, and affect the functioning of the endocrine system [124]. Haematological effects have also been observed [125]. Exposure of the foetus to DDT and DDE in utero has been observed to result in delays in neurodevelopment in children of farm workers in California [126].

Other organopesticides: Other types of synthetic organopesticides include triazines, organophosphates, and carbamates, among others. Triazines (e.g. simazine, atrazine) are known to disrupt endocrine and reproductive functioning [127]. Atrazine is neurotoxic in that it has anti-dopamine effects, leading to neuronal death [128], thus resulting in impaired nerve functioning. A statistical relationship between exposure to triazine herbicides and breast cancer has been intimated from an epidemiological study [129].

Carbamate pesticides (e.g. carbofuran, aldicarb, carbaryl) have also been associated with disruption of endocrine functioning [127], increased risk for dementia [130], and neurobehavioural effects [131], among others.

Organophosphate pesticides (e.g. Malathion, dimathoate, glyphosate, parathion) have been shown to affect the endocrine system [127], to cause dementia [130], to affect metabolism of carbohydrates, proteins and lipids and to affect the endocrine and nervous systems [132].

The above examples are just a few biochemical/physiological phenomena that lead to manifestation of the different clinical symptoms that are observed following exposure to, and poisoning by, any one of this wide array of pesticides.

Environmental toxicology of organopesticides

Following their manufacture, use, and waste disposal, the environment has shouldered a large burden of these chemicals. This burden has eventually affected not just the environment itself but has also been a source of exposure to other life forms, humans included.

DDT and other chlorinated pesticides: Following their use in agriculture and for public health, these pesticides have eventually accumulated in the environment. For example, DDT and its derivatives, and hexachlorocyclohexane, have been detected in soils and rye plants in Mexico [133], though levels were not very high; in the rye plants they were below the levels deemed dangerous by the Codex Alimentarius Commission maximum residue limits. However, due to their lipophilic nature, it will be desirable for levels in (food and feed) plants to always be low to avoid accumulation in the human and livestock consumers. Cases where levels in soils are high include manufacturing/formulation facilities when strict practices of waste disposal are not followed. An example where levels are high is the Morogoro, Tanzania, defunct pesticide formulation site where soil levels of DDT and its metabolites at the dump site reached as high as 2,273mgkg^{-1} soil [38]. The air at this site was not analyzed for DDT but, as testament to high levels in the air, DDT could be smelled on a sunny day as a result of its volatilization. Organopesticides were found in the atmosphere in the proximity of Lake Victoria in Uganda [118], due to volatilization from sediments and agricultural land exposed to these chemicals. In South Africa, air at a school adjacent to a farm in Western Cape province was observed to have higher levels of endosulphan (0.0113microgram m^{3}) as compared to control sites, an indication of air pollution due to air drift from the farm [134].

Plants tested for remediation of DDT at the Morogoro site contained shoot concentrations as high as 0.7, 0.04, 0.02, 0.02, 0.3, and 0.1mg of total DDTkg^{-1} in carrot, sweet potato, calabash, Irish potato, alfalfa, and pumpkin, respectively [38]. Other chlorinated pesticides (aldrin, dieldrin, and endosulphan were also detected in soils at the Morogoro site. Similar levels of accumulation may be found in contaminated locations in other countries.

These scenarios summarized above, then, may account for exposure to humans and animals traversing such sites, with possible clinical effects upon long-term exposure.

Other organopesticides: Following their manufacture and use, chemicals other than organochlorinated pesticides, such as carbamates and organophosphate pesticides, have also polluted the environment (air soil, waters, and vegetation), resulting in negative environmental effects. Much information about the environmental toxicology of these and other pesticides has been reviewed for many areas, including Asia and North America [135]. Some of these chemicals have shown long residence times in the environment. Among the triazines, for example, it was reported in a lysimeter study that atrazine showed persistence up to 22 years [136] and it persisted for 20 years in a field that received the pesticide [137]. These observations have implications for exposure to vegetation and the human/livestock consumers, opening up possibilities for toxicity [138]. The SSA countries, as they expand their agricultural and public health use of pesticides, should not lose sight of the possible many-faceted negative short- and long-term negative effects of these chemicals even as they reap the benefits of their use.

Mitigation Measures with Emphasis on SSA

Measures for mitigation of the effects of heavy metal and pesticide exposure can today be categorized into two approaches: rehabilitative and preventive. Rehabilitative measures should be strengthened in those locations where pollution has already taken place. This will be by way of environmental clean-up and the clinical treatment of affected individuals. The affected areas/countries should never let up on this approach. Examples where clean-up efforts have been undertaken are at the Love Canal waste dump, and the Three Mile Island, Chernobyl, and Fukushima nuclear power installations mentioned above. Following adoption of these restorative efforts, positive results have been reported.

The second approach, the preventive one, is particularly significant for SSA countries, as they are now entering the age of heavy industrialization and mining. This entails installing pollution abatement equipment to every installation dealing with pollution-prone activities in mining and industry. These countries should not take the easier route of haphazard disposal of untreated toxic wastes in the prospect that remediation to clean up the pollution will be undertaken sometimes in the future. Rather, the outlook and practice should be that of the preventive approach. This should be the in-situ removal of the pollutants, or their capture, at the point and time of emission. To be sure, the technologies for clean-up are expensive. That may be the reason, in part, why they were not resorted to by the pioneers of industry, mining and other processing activities because such mitigation eats into the financial profits. However, it is now past the time to recognize that the unseen cost, environmental and human health deterioration in the absence of prior clean-up, is a more serious prospect.

For SSA, this preventive approach, however expensive financially, should be the decision of choice, and it should be factored into every investment agreement entered to between these countries and any and all investors. Of course, the line between the rehabilitative and the preventive approaches may not all the time be clear cut. At any point in time some waste fall-out to the environment is inevitable. The requirement is to establish a pollution abatement scenario that minimizes fall-out and thereby makes the preventive approach to pollution to be the dominant one, by capturing most of the wastes as they come out. The SSA countries need not repeat the mistakes of an earlier period.

Arguments may be propounded that SSA should not engage in this or that technology for reasons of the high levels of danger and of the safety requirements associated with adoption of such technologies. This argument may also be advanced bearing in mind the current absence in SSA, or the prevailing low level, of requisite knowledge and technical skill in SSA as related to engaging in particular enterprises. As a starting point to addressing these concerns, multifaceted balance sheets should be developed and critically analysed with respect to an intended technology, bringing to the fore every technical and skill requirement, genuine need, pro and con, before decisions are taken. Side by side with this, deliberate efforts should be made in the area of education, to broaden the technical education base to develop and master some critical mass of the requisite skills to address these lapses. An obvious candidate, which is currently surrounded with much controversy worldwide, but little applied especially in SSA, is the nuclear field. The area of education should also include the integration of environmental and public health issues into agricultural extension education. The focus should be to impart the concept of observation of the correct or prescribed use of a pesticide only for the intended purpose, and not for any other purpose. The case in point is that narrated above of farmers in Mbeya, Tanzania, willfully (mis) using the acaricide (toxaphene), usually prescribed for the control of ticks in livestock, but now in this scenario used to control insect pests on cabbage.

In the SSA countries, especially, health provision facilities are not equipped to render specialized services in the diagnosis and treatment of the occupational human health effects emanating from exposure to toxic materials. As governments press on with intensified industrialization and mineral processing, and expansion of heavy input-based agriculture, deliberate efforts need to be directed at starting and/or broadening and intensifying research in, the development and practice of, the field of environmental or ecological medicine. This entails initiating and setting up of specialized hospital departments or institutions, and sufficient technical skill, to address these concerns in a fashion comparable to that in the developed world, in tandem with expanded development of pollution-prone undertakings.

An essential component of mitigation efforts is an efficient regulatory framework. Laws should be enacted and, more importantly, rigorously enforced to back up technical advisories. It is true that some environmental legislation exists in many of these countries (e.g. Tanzania, Kenya, Uganda, Ethiopia) [34,139-144], but the extent of enforcement is sometimes questionable. It is not uncommon for high officials of government environmental agencies in many SSA countries to visit establishments accused of polluting the environment, for example by releasing untreated toxic wastewaters directly into streams or residential areas, and giving orders for rectification. However, in many instances, no legal follow-up is ordered and executed. In the end, there is little compliance. Therefore, legal enforcement should be strengthened on a sustained basis.

Conclusion

Large-scale mining operations in SSA and expansions in agriculture and industry release large concentrations of toxic heavy metals and pesticides into the environment. Planned mining of radioactive minerals may spread radiation to the environment. All these expose humans to the toxic effects, and clinical symptoms of toxicity develop in the exposed humans. These trends have currently been observed to some extent in SSA, but intensification of the pollution activities currently underway or planned stand to increase the extent of these exposures and health effects. The SSA countries should do all that is required to minimize these effects to avoid repetition of mistakes of the developed countries. This will be achieved through strengthening both the education and technical requirements, and legal institutions, to minimize environmental pollution and human health effects.

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