The importance of minerals in medical geology: impacts of the environment on health

Carlos-Alberto Ríos-Reyes[1], María-Paula Ríos-Gutiérrez[2], Santiago Joya-Neira[3]

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Summary

Objective: *the purpose of this work is to review research on the role of minerals in Medical Geology, highlighting the importance and interrelationships between geological factors and human health.* **Materials and methods:** *qualitative study under the documentary approach from which a review of previous studies on the topic of interest was carried out, taking into account that there is an increasing interest between the health and geoscience communities by elucidating the geologic origins and flow of toxic elements in the environment that lead to human exposure through the consumption of food and water.* **Results:** *during the review process of the existing literature, it was evidenced that the advance of science and technology has allowed the opening of new lines of research that require multidisciplinary work with the participation of professionals in different areas of knowledge and the medical geology proposes collaboration between two broad fields of knowledge that apparently have no relationship, such as Earth sciences and biomedical sciences. Several aspects are considered, including the interaction between environment and health, which is very important for an extensive audience, including students, researchers, geological and biomedical professionals, policymakers and general public.* **Conclusion:** *medical geology should be considered as a component of the Colombia's National Health Action Plan and therefore, to be most effective the Colombian geoscience community should be included as one of the key players or agencies involved in environmental health studies.*

Keywords: *health; earth; planet; geosciences; environment; toxicity; minerals.*

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1 Doctor en Ciencias Aplicadas. Escuela de Geología, Facultad de Ingenierías Fisicoquímicas, Universidad Industrial de Santander. Bucaramanga, Colombia. ORCID: 0000-0003-0170-5558. Correo e.: carios@uis.edu.co.

2 Estudiante de Medicina. Programa de Medicina, Facultad de Ciencias de la Salud, Universidad Autónoma de Bucaramanga. Bucaramanga, Colombia. ORCID: 0000-0002-0574-5293. Correo e.: mrios126@unab.edu.co.

3 Estudiante de Medicina. Programa de Medicina, Facultad de Ciencias de la Salud, Universidad Autónoma de Bucaramanga. Bucaramanga, Colombia. ORCID: 0000-0002-8727-3970. Correo e.: sjoya@unab.edu.co.

La importancia de los minerales en la geología médica: impactos del medio ambiente en la salud

Resumen

Objetivo: *la finalidad del presente trabajo es revisar investigaciones sobre el papel de los minerales en Geología Médica, destacando la importancia y las interrelaciones entre los factores geológicos y la salud humana.* **Materiales y métodos:** *estudio de carácter cualitativo bajo el enfoque documental a partir del cual se llevó a cabo una revisión de estudios previos sobre el tópico de interés, teniendo en cuenta que existe un interés creciente entre las comunidades de salud y geociencia al dilucidar los orígenes geológicos y flujo de elementos tóxicos en el medio ambiente que conducen a la exposición humana a través del consumo de alimentos y agua.* **Resultados:** *durante el proceso de revisión de la literatura existente, se evidenció que el avance de la ciencia y la tecnología ha permitido la apertura de nuevas líneas de investigación que requieren un trabajo multidisciplinario con la participación de profesionales en diferentes áreas del conocimiento y la geología médica propone colaboración entre dos amplios campos de conocimiento que aparentemente no tienen relación, como las ciencias de la tierra y las ciencias biomédicas. Se consideran varios aspectos, incluida la interacción entre el medio ambiente y la salud, que es muy importante para una audiencia extensa, incluidos estudiantes, investigadores, profesionales geológicos y biomédicos, encargados de formular políticas y público en general.* **Conclusión:** *la geología médica debe considerarse como un componente del Plan de Acción Nacional de Salud de Colombia y, por lo tanto, para ser más eficaz, la comunidad de geociencia colombiana debe ser incluida como uno de los actores o agencias clave involucradas en los estudios de salud ambiental.*

Palabras clave: *salud; planeta tierra; geociencias; ambiente; toxicidad; minerales.*

Introduction

Medical Geology is an emerging interdisciplinary scientific field, which refers to the relationship between geological factors and human health. Its field of study is complex and is shared by specialists from different areas and scientific domains, including geosciences. The unique and exceptional physicochemical properties of some minerals favor their use in numerous applications in medicine, among which are the formulation of pharmaceutical drugs in the pharmaceutical industry, the manufacture of dental cements and molds in dentistry, the immobilization by fractures or surgical procedures in traumatology or bone grafts or construction of implants in maxillofacial surgery. Minerals are widely used in the pharmaceutical industry. A number of minerals can be used as excipients in pharmaceutical preparations due to their physicochemical properties. However, they must not be toxic for human health. The following minerals are commonly used in medical/health: oxides, hydroxides, sulfates, carbonates, phosphates, chlorides, phyllosilicates and zeolites. Minerals can be applied in contrast media in diagnostic imaging, production of dental cements and molds, immobilization of limbs and fractures, surgeries, construction of implants, spas and aesthetic centers.

Zeolites have attracted the attention of the world scientific community, being considered of strategic importance thanks to their numerous applications. The outstanding physicochemical properties of zeolites make them make them very useful in a variety of technological applications ranging from industrial [1-2] and environmental [3-6] applications to biotechnological [7-9], biomedical [10-11] and medical [9,12-14] functionalities. The properties of zeolites in their interaction with the biological environment, their stability, low toxicity and minimal biological risk, allow their use in human health and nutrition; however, the use of zeolites in medicine has not developed so rapidly as a consequence of the rigor established by the agencies specialized in the quality control of drugs [15]. Recently, an increased number of studies have introduced zeolites in the field of pharmacology as drug delivery for oral and topical administration [16-18]. According to Pavelic *et al*. [19], zeolites contribute to regulate the immune system, since they act as a non-specific immuno-modulator. They can be used as carriers for small drug molecules due to their biocompatibility, low toxicity and small pore size [20]. Previous studies [21-24] indicate the use of zeolites as a novel strategy for drug delivery systems, investigating their ability and efficiency to encapsulate and to release drugs.

Materials and methods

A qualitative study under the documentary approach from which a review of previous studies on the topic of interest was carried out, taking into account the Scopus, Scielo, Dialnet, Redalyc, Science Direct and Pubmed databases, which were used to search and locate the bibliographic sources. The search was conducted from April 2018 to July and 2019 using the following search descriptors: enviromental health, applied mineralogy, minerals, geosciences, health sciences, medical geology, environmental exposure, pollution, health, toxicity. For the selection of the articles, the title and abstract of each one were read. From the selected articles, relevant information about the results obtained was extracted.

Medical geology

The environment is the result of the dynamic interaction of complex of external factors (physical, chemical and biological as well as socioeconomical components), which are not yet fully identified and their interaction with humans is still far from being satisfactorily understood (Figure 1). The human being is the only species capable of generating a positive or negative impact on the environment. However, anthropogenic activity has somehow been causing a devastating effect on the environment, ignoring its own intellectual capacity, which could otherwise be used to focus on a future with better expectations and in benefit of the environment for the living beings. Currently, humanity is immersed in a technological era, in which nature has been relegated to a secondary role in which it only matters as a resource of raw materials for the development of society. Therefore, it is important to be aware of the importance of contributing to the improvement of environmental quality in order to mitigate its progressive deterioration. On the other hand, the environmental mobilization of contaminants by natural phenomena is a subject of much interest; however, inexplicably there are few efforts to investigate its effect on health [25].

It is well known that human beings take advantage of natural resources to satisfy their needs no matter what happens to the environment and its impacts (exposure to toxic levels of trace elements, deficiency of essential trace elements, exposure to mineral dusts or radioactivity) on public health, which is the object of study of medical geology (Figure 2). The advance of science and technology has allowed the opening of new lines of research that require multidisciplinary work with the participation of professionals in different areas of knowledge. Medical geology is an example of this because it proposes collaboration between two broad fields of knowledge that apparently have no relationship, such as Earth sciences and biomedical sciences. Medical geology is a

Figure 1. Environment, natural phenomena and anthropogenic activity Source: Authors.

field of action of the applied sciences that is becoming increasingly popular, which refers to the complex relationships between environmental factors relating to the presence of contaminnats in different geological settings, their mobility, geographical distribution and their effects on in health of humans, animals and plants health [26-29]. It is well known that the environment can affect health in different ways. However, it is necessary to understand the complex interactions between the environment and human health, which requires a multidisciplinary work in which the participation of professionals in the fields of medicine and geology is essential. According to Bunnell *et al.* [30], there are environmental health problems in which medical and geology professionals could interact and contribute to the search for solutions, including exposure to natural dust, radioactivity, toxic elements, toxic organic and inorganic compounds, volcanic emissions, etc. Besides, the advance of a series of tools and databases allows medical geology professionals to study vector-borne diseases, to model the dispersion of pollutants in surface and groundwater, in soils and in the air. The aims of medical geology is to identify geochemical anomalies in water, soils and air that may adversely affect health in living beings, to identify the environmental causes of problems associated with health. Through interaction with professionals in the biomedical sciences and public health, it will be possible to find solutions to prevent or minimize these problems, to establish the role of minerals and geological processes in health, to inform the public about unwarranted concerns health issues associated with minerals and geological processes, and establishing links between developed and developing countries to find solutions to environmental health problems [30]. Its field of study is complex and is shared by specialists from different areas and scientific domains, including geosciences. Therefore, it is expected that medical geology will grow in importance in the future, in order to provide humanity with the necessary resources through sustainable development, contributing to the improvement of environmental quality with concentrations that do not adversely affect human, animal and plant health [31]. Medical geology contributes extensively to scientific knowledge in medicinal and/or pathogenic potential of minerals, geochemical and epidemiological characterization of a territory to know the concentration and geographical distribution of elements and their possible relations with several

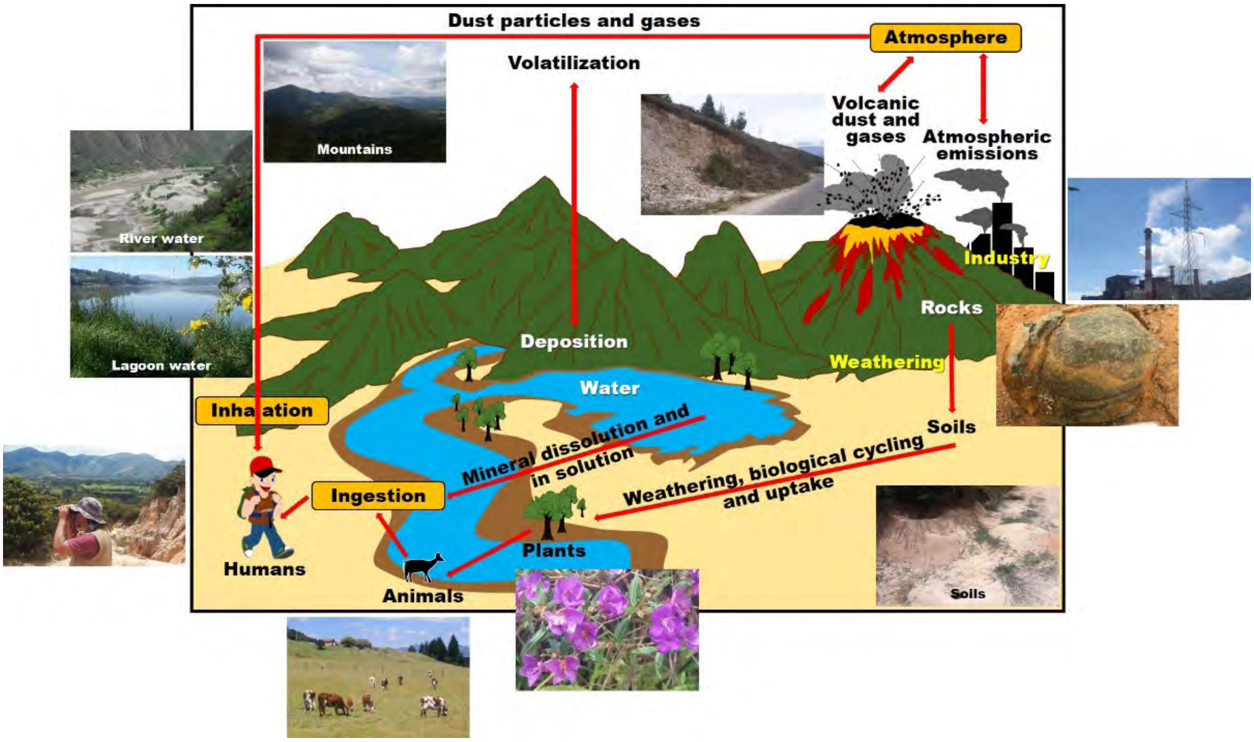

Figure 2. Medical geology and health Source: Authors.

diseases, influence of natural phenomena on the mobility and exposure of potentially hazardous geological materials, impact analysis of natural phenomena and antropogenic activities on environment and health to look for alternative solutions, development of strategies in the elaboration of comprehensive public policies, supporting the investigation on public health.

It is clear that minerals can directly affect the well-being of billions of people worldwide, however, this interaction is not yet clearly understood due in large part to its complexity, since it depends on numerous factors. On the other hand, there is a general lack of understanding of this reality, not only of the population, in general, but also of the scientific community. The main means that interact directly with human beings and can condition their health by being a vehicle of elements that can be harmful or beneficial are soil, dust, air and water. In this way, much of the chemical elements that the organism requires are in its environment and its deficit or excess can generate a negative or positive response in human health. Therefore, it is a social challenge to establish the environment-health link and to know the laws that govern this relationship to improve the quality of life of the population, improving as far as possible the relationship with their environment. In the field of Medical Geology, professionals and scientists linked to different branches of science (geologists, doctors, pharmacists, chemists, toxicologists, epidemiologists, hydrogeologists, geographers, etc.) seek a cause-effect relationship in environmental health patterns. Among the problems that can be addressed are the impacts of the elements that are naturally present in natural dust, in ground and surface waters, or soils, not forgetting natural radiation or exposure to natural materials in the workplace or even in urban areas. It is also necessary to include in this context the most impressive geological processes such as volcanic eruptions, earthquakes or tsunamis, whose consequences on the population's health are evident. Medical geology studies the sources, presence, distribution, concentration and chemistry of elements that can cause problems in human health, trying to establish the exposure channels to, in short, produce maps that illustrate local geological and geochemical factors, regional or global, as well as their relationships with existing or potential health problems.

Impact of minerals on health

Can minerals (Figures 3a-3c) be considered as substances that produce negative effects or benefits on health? Research on minerals (Figures 3d-3e) is important to carry out in order to establish not only their applications in the medical field but also their effects on health. In this way, it is possible to determine carry out the characterization of minerals (Figure 3f) to establish their physical and chemical properties (Figure 3g) in order to determine which could have negative effects as the case of asbestos (Figure 3h) or positive as the case of clays (Figure 3i) and zeolites (Figure 3j). Minerals can exert a strong impact on health and influence this in several ways. The unique and exceptional physicochemical properties of some minerals favor their beneficial use in the supply of essential nutrients to produce nutritious food products, environmental remediation and different drugs (Figures 3a-3c). There are numerous applications in medicine, such as the formulation of pharmaceutical drugs in the pharmaceutical industry, the manufacture of dental cements and molds in dentistry, the immobilization by fractures or surgical procedures in traumatology or bone grafts or construction of implants in maxillofacial surgery. The porosity, adsorption capacity and ion exchange properties of natural zeolites make them extremely useful in a variety of applications in health sciences as promising vehicle to encapsulate and to release drugs. On the other hand, some minerals can produce a negative influence due to exposure to hazardous substances, such as metal(loid)s, radioactive metals and isotopes occurring naturally in georesources, which can be released from their source into the environment as a result of mobilization through biogeochemical activity promoted by different natural and anthropogenic processes [31]. Therefore, substances, such as As, Pb, Cd, Hg, U and asbestos or their components can be toxic, and, according to Fergusson [32], their consumption by food, water, soil or air carries out by ingestion, inhalation or dermal absorption. In this way, considering the physical and chemical properties of the minerals, they can be essential to keep human health in good condition, but under adverse conditions, deficiency or excess of minerals can influence the generation of diseases [28,33-35].

Figure 4 shows a periodic table of elements distinguishing the non essential, biologically essential, essential trace, toxic and radioactive elements. The essential elements marked in green constitute the main (something more

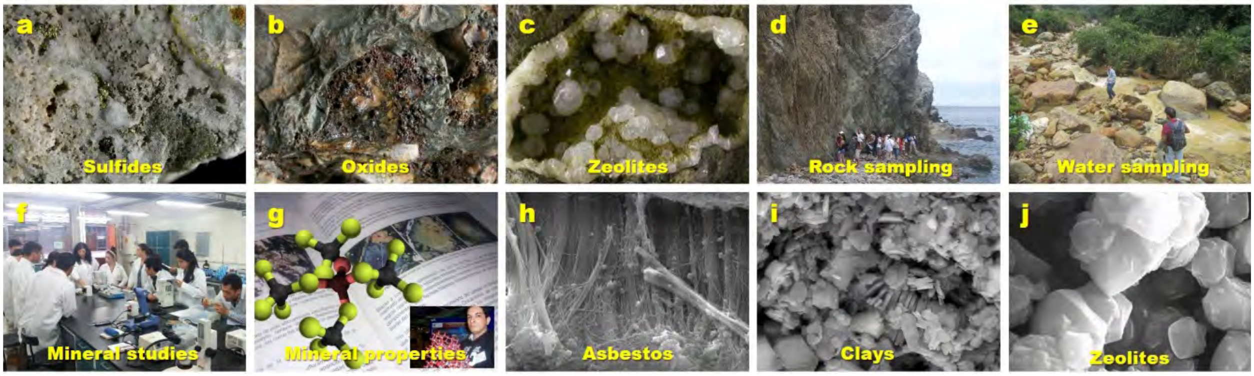

Figure 3. Minerals and health

Source: Authors.

than 97% of the living beings) and secondary (around 2.5 of the living beings) bioelements; the essential trace elements marked in pink, sometimes called temporary bioelements, are bioelements present in small quantities (less than 0.5%) in living beings, although their absence or excess can be harmful to the organism, becoming pathological. There are elements which are dangerous because of their inherent toxicity (toxic elements marked in red) and those that present a risk because of extreme reactivity (radioactive elements marked in yellow).

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Ti	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
				Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
				Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Non essential
Essential
Essential trace
Toxic
Radioactive

Figure 4. Periodic table of non essential, biologically essential, essential trace, toxic and radioactive elements
Source: Authors.

The sources and intake pathways of minerals and their derivates chemical elements as well as the effects of pollution on human health are shown in Figure 5. Hazardous materials present in the environment due to natural fenomena or anthropogenic activities may cause adverse effects on human health. In human health, most of the problems are related to the dietary deficiencies and excesses of certain essential chemical elements characterized by specific functions (I, Ca, Mg, K, Na, Fe, Zn, Cu, F, and Se As [27,35-38]. It is very important to understand the role of minerals in environmental sciences, and, therefore, in human health [39]. They are essential to every living being that inhabits the Earth planet. Minerals present in soil, surface and underground water and in the atmosphere (mineral dust, emissions from volcanic and anthropogenic activities and radon) play an important role in promoting an untold number of gastro-intestinal, muscular–skeletal, respiratory and dermatological diseases [40-44].

Air carries always aerosols of dispersed fine mineral particles such as quartz, feldspar, mica, clay minerals, etc. [45]. Wind and volca-

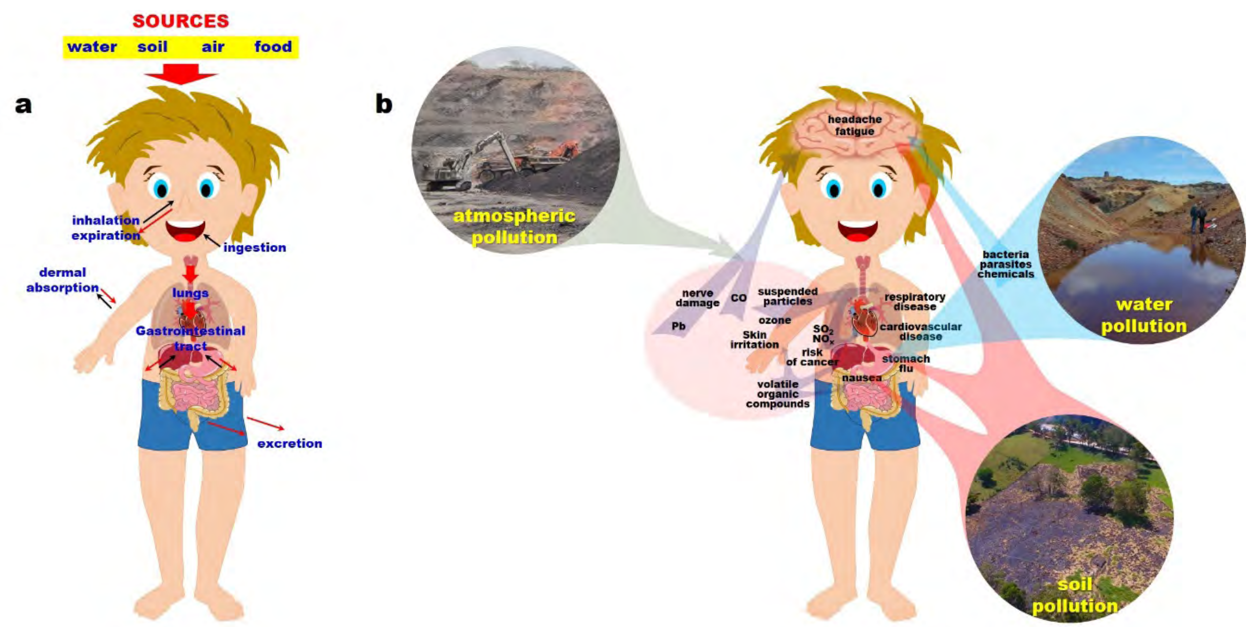

Figure 5. (a) Sources, intake pathways, and uptake of minerals by the human body. (b) Effects of pollution on human health
Source: Adapted and modified from Fergusson [36].

nic eruptions are important sources not only of mineral dust which can be transported over thousands of kilometers [46-47]. Air pollution is composed of a complex mixture of substances and represents health risks and an overall decrease in quality of life [48-49]. Air quality is a consequence of a complex interaction between natural and anthropogenic factors [50], which include type of relief (physical factor), chemical reactions of pollutants in the atmosphere and their dispersion (chemical and meteorological factors), uses and customs of the population (social factors), economic activities and the use and exploitation of technology (economic and technological factors). In general, air quality in cities is essentially attributed to the pollutant emissions generated by the use of cars, industrial, commercial production and services [50-53]. According to Kampa and Castanas [54], air pollutants as carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), ozone (O_3), heavy metals and respirable particulate matter (PM2.5 and PM10). PM2.5 particulate material is the most aggressive contaminant and is found to cause adverse health effects and premature mortality in people [55]. Atmospheric particles can be emitted by a wide variety of sources of natural or anthropogenic origin: primary particles are directly emitted into the atmosphere by various anthropogenic sources, such as vehicles, engines and power plants, and biogenic sources, whereas secondary particles form as a consequence of the atmospheric oxidation of emitted precursor gases [56-57]. The combustion of coal is a global concern and burning coal may cause significant environmental problems [58] being responsible for the progressive change in atmospheric composition, contaminating the air with CO, SO_2, NO_x, VOCs, O_3, heavy metals, and particulate materias, which, despite being in very low concentrations, are very harmful, particularly to human health. The presence of pollutants in the air can produce acute and chronic effects on human health, which include respiratory, heart, or cancer diseases, and short and long-term exposures can contribute to premature mortality and reduced life expectancy [54,59-60].

Water pollution is one of the problems of greatest concern worldwide, especially in relation to the high concentration of heavy metals. Natural waters play a fundamental role in the transfer of potentially toxic substances from the physical environment to the biosphere, which constitutes a complex dynamic interrelation between the environment and human health. The geological environment is the one that conditions the presence of certain chemical elements in surface and groundwater to a greater extent and, although rocks and minerals generally do not have high concentrations of heavy metals, it is relatively easy to find waters with concentrations that exceed those allowed for drinking water by the World Health Organization (WHO). Society will have to face the future of water resources on a globalized planet [61], in which georesourses will be scarce and the impact on the environment and human health due to anthropogenic activity will be very high. The surface and underground hydric resources represents a source of water supply, although anthropogenic sources of contaminants from mining, agriculture, domestic and industrial wastes have been affecting its water quality. The contamination of water promotes the loss of fauna and flora as protective elements and quality of life and deteriorates the ecosystem and, therefore, the quality of life of human beings [62]. In industrial processes, particularly in mining operations, electroplating plants, power plants, appliance factories, and tanneries, liquid effluents are generated with high concentrations of highly toxic, non-biodegradable and carcinogenic substances [63].

Metals occur naturally in the Earth's crust as a combined state or as a free state. The geographical distribution of metals can vary between different regions resulting in spatial variations of background concentrations, which is governed by the physical and chemical properties of metals and several environmental factors [64]. Approximately 30 metals and metalloids are potentially toxic [65]. Heavy metals are the generic term for metallic elements having an atomic weight higher than 40.04 [66]. However, these are known both for their high density and for their adverse effects on ecosystems and living beings [67]. Heavy metals are distributed in the environment through several natural processes such as volcanic eruptions, spring waters, erosion, and bacterial activity, and through anthropogenic activities such as fossil fuel combustion, mining, industrial discharges, urban runoff, sewage effluents, pest or disease control agents applied to plants, air pollution fallout, feeding and a number of others [64,68].

Although heavy metals are present in several ecosystems, their exposure to living beings is through various anthropogenic activities. Heavy metals occur in ore minerals, which are exploited through open pit or underground mining. They can exist both as sulfides (argentite, Ag_2S; sphalerite, ZnS; cinnabar, HgS; stibine, Sb_2S_3; galena, PbS; oropiment, As_2S_3; rejalgar, AsS; pyrite, FeS_2) or oxides (magnetite, Fe_3O_4; hematite, Fe_2O_3; cuprite, Cu_2O; casiterite, SnO_2; pyrolusite, MnO_2; uraninite, U_2O). Some heavy metals can exist both as sulfides and oxides and in some minerals such as chalcopyrite ($CuFeS_2$) at least two heavy metals can occur together. As mentiones before, heavy metals occur in mineral ores as a close system. However, because of the development of mining activities, they are released from the mineral ores and scattered in the environment, which is accompanied by the generation of acid mine water (AMW). AMW results as a consequence of a complex series of geochemical reactions that occur when sulphide minerals are exposed and interact with the atmosphere, surface and underground water, conditioning the chemical composition and quality of water and producing polluted waters strongly acidic with high concentrations of toxic metals, responsible for the resulting damage to health of aquatic flora and fauna. Future predictios from inactive mine sites suggest that sulphide oxidation and the release of dissolved metals will continue for decades to centuries [69]. Sulphide minerals, especially pyrite (FeS_2), contribute the most to formation of acid mine water. The pyrite oxidation is controlled by bacterial species, such as *Acidithiobacillus ferrooxidans* [70].

As can be lethal to livings beings when being exposed to this element through several means, which include industrial sources as smelting and microelectronic industries, and its toxic effects depend specially on oxidation state and chemical species, among others [65]. Drinking water may be contaminated with As [71], which is present in wood preservatives, herbicides, pesticides, fungicides and paints [72]. As is considered carcinogenic and is related mainly to lung, kidney, bladder, and skin disorders [71,73-74].

The main sources of Pb exposure include drinking water, food, cigarette, industrial processes and domestic sources [65]. The industrial sources of Pb include gasoline, house paint, plumbing pipes, lead bullets, storage batteries, sheets for roofing to screens for X-rays and radioactive emissions, pewter pitchers, toys and faucets [65,75]. Pb as a toxicologically relevant element has been brought into the environment by man in extreme amounts, despite its low geochemical mobility and has been distributed worldwide [76]. Pb is released into the atmosphere from industrial processes as well as from vehicle exhausts [65]. Therefore, it can enter the soil and flow into the aquifers, and human Pb exposure can also be through food or drinking water [77].

The tannery industry not only generates a large amount of toxic waste but also has negative effects on the environment and human health [78]. In these effluents, Cr can be found as Cr^{6+} or Cr^{3+}; however, Cr^{6+} form is very toxic, mutagenic, and carcinogenic [79-80]. Exposure to Cr may cause many chronic diseases such as dermatitis, perforation of the nasal septum, respiratory illness, and lung and nasal cancer [81].

Cd is generally used in the production of paints, pigment alloys, coatings, batteries, and plastics, however, most of the Cd is consumed in the production of alkaline batteries [65]. Significant human exposure to Cd may be due to ingestion of contaminated food and beverages [82,83] or by inhalation through incineration of municipal waste [65].

Cu is used in the production of tubes, cables, wires, kitchen utensils, intrauterine devices, and birth control pills or in water treatment [84]. This element can accumulate in the soil and be absorbed by plants.

Gasoline vapors contain VOCs that contribute to the formation of ground-level ozone. In addition, they contain many other toxic substances, such as Mn [85]. Mn, like other elements, cannot be degraded in the environment but can change shape or adhere or detach itself from particles. The Mn-containing agent added to gasoline can rapidly degrade in the environment when exposed to natural light, thereby releasing Mn. However, there are factors that determine whether exposure to Mn can be harmful or not.

Ni is used in the production of batteries, nickel-plated jewelry, machine parts, nickel plating on metal objects, steel fabrication, cigarette smoking, cables, electrical parts, etc. This element can also be found in contaminated food and alcoholic beverages [85].

According to Haidouti [86], the main sources of soil, water and air pollution from mercury (Hg) are associated with mining processes, smelting of minerals, burning of fossil fuels, industrial production processes and consumption-related discharges. Hg is ranked third by the US Government Agency for Toxic Substances and Disease Registry of the most toxic elements or substances on the planet to As and Pb that continues to be dumped into our waterways and soil, spilled into our atmosphere, and consumed in our food and water [87]. Soil contaminated by Hg or the redistribution of contaminated water has the potential to enter the food chain through plant and livestock [88-89]. Once in the food chain Hg can bioaccumulate causing adverse effects to human health [40,43]. Hg toxicity has been linked to with nervous system damage in adults and impaired neurological development in infants and children, and it has profound cellular, cardiovascular, hematological, pulmonary, renal, immunological, neurological, endocrine, reproductive, and embryonic toxicological effects [43,90-92].

U and Th are the most common radioactive elements in the Earth and their radioactive decay generates a range of radioactive daughter elements [93-94]. They play a very important role in the current and future supply of fossil energy and minerals. Essentially all rocks and soils exhibit a low-level of natural radioactivity as a consequence of the decay of radionuclides, and the primary sources of natural radioactivity are radionuclides of the elements U and Th, specifically the U^{238} and Th^{232}, which, however, may contribute to the radioactivity of groundwater [94]. The most common "primary" radioactive minerals are uraninite (UO_2) and thorianite (ThO_2), which can be affected by weathering producing "secondary" radioactive minerals such as carbonates, sulphates, phosphates, arsenates, vanadates and silicates, which contain radioactive elements [93]. Radioactive minerals can cause adverse effects on human health, which include from renal failure and diminished bone growth to damage to the DNA [95-96]. They possess both chemical toxicity and radioactivity. The effects of low-level radioactivity include cancer, shortening of life, and subtle changes in fertility or viability of offspring [97].

Oil spills are the accidental or intentional discharges of crude oil and petroleum products into the natural environment as a result of anthropogenic activities [98]. The consequences of oil spills are usually evaluated in terms of environmental damage, effects on marine species and economic losses in the fisheries and tourism industries, however, relatively little is known about their impact on human health [99]. They are considered as a form of pollution, which is hazardous and problematic worldwide [100]. Contamination of soils by petroleum hydrocarbons (PHCs) represents a major environmental concern and a serious hazard to human health, causes organic pollution of underground water which limits its use, causes economic loss, environmental problems, and decreases the agricultural productivity of the soil [101-102]. Oil spills may involve health risks for people participating in the cleanup operations and coastal inhabitants, given the toxicological properties of the oil components [44]. PHCs can cause skin irritations and rashes [28] and they are highly toxic and carcinogenic substances [103]. Potential health effects of oil spills have been evaluated through epidemiological studies on people participating in the cleanup operations and coastal inhabitants, which have been summarized in recent studies [44,104-105], providing evidence on the association between exposure to oil spills and the appearance of diseases in exposed population [99].

Heavy metals are assimilated by living things, causing adverse health effects at the cellular level [65]. They can affect the central nervous system, deteriorate the blood system and organs such as the lungs, kidneys, liver, among others, promote diseases such as Parkinson's and Alzheimer's, damage nucleic acids, mutation or cancer [106-107]. The various sources of heavy metals are summarized by Morais *et al*. [64] in Figure 6. Living organisms can ingest heavy metals through consumption of contaminated animal and plant-based foods or water, inhalation of contaminated air, or occupational exposure in the workplace [66]. The chain of heavy metal contamination begins from industry to the atmosphere, soil, water and food, and ends in humans [108]. Heavy metals can enter the body through the gastrointestinal route, by inhalation or absorption through the skin. Most heavy metals are distributed in the body through the blood to the tissues [109]. They have no beneficial effects in humans, and there is no known homeostasis mechanism for them [110]. They are generally considered the most toxic to living beings; the adverse health effects associated with exposure to them, even at low concentrations, are diverse and include, but are not limited to, neurotoxic and carcinogenic actions [111].

A further disease is mainly caused by a group of fibrous silicates called asbestos [112,113].

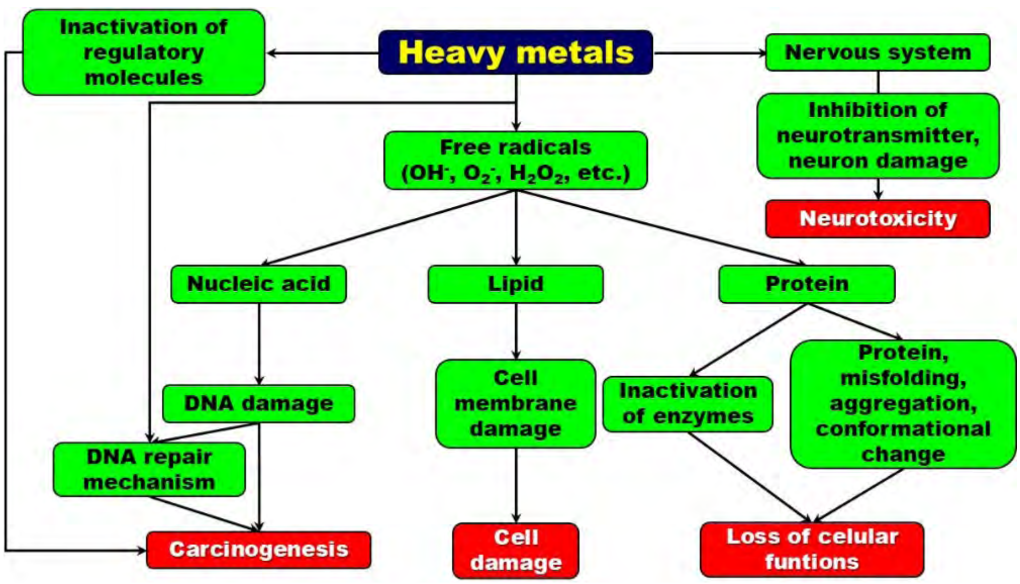

Figure 6. Pathway of heavy metals sources and exposure to humans
Source: Adapted and modified from Engwa *et al*. [114].

Asbestos were recognized in 1960 by the World Health Organization (WHO) as potentially carcinogenic, being banned only few years afterwards from important industrial applications (for instance, asbestos cement and lining of pipes where fluids circulated to heat buildings) in which they were used for their fire-resistant and thermal insulation properties. However, these days various asbestos substitutes are being used over a wide range of industrial applications, raising concern about the safety of workers exposed to these fibers in occupational environments.

There is abundant literature regarding health problems caused by the excess or deficiency of trace elements, exposure to environmental dust and other health problems or geologically related health problems for which tools, techniques or bases could be applied of data for geosciences [27,29,41,64,71,112,115-116]. However, in relation to the benefits that minerals provide in health, little attention has been devoted, considering that the medicinal use of minerals is most probably as old as mankind itself and that there are evidences on their use as curative or healing materials in Mesopotamia, Ancient Egypt and Ancient Greece in diseases of the alimentary tract, of the urinary tract, of metabolism, of the muscular–skeletal system, of the respiratory system, of the circulatory system, and of the dermal system [28,117]. Potential health benefits of minerals include essential nutrients, pharmaceuticals, talismans and amulets, hot springs or geophagia.

Every day the human body produces the essential nutrients that make life possible. Human body requires essential minerals, which can be divided up into major minerals (Ca, Mg, Na, K, P and S) and trace minerals (Fe, Si, F, Cu, Zn, Mn, Se, Mo, Cr, and I), which are very important in the functioning of human beings, although trace minerals are needed in smaller amounts than major minerals. Essential minerals are inorganic substances required by the human body in small amounts for a variety of different functions, taking into account that they contribute to the formation of skin, muscles, bones and teeth, are essential constituents of body fluids and tissues, are components of enzyme systems and promote normal nerve function [28,118]. To accomplish these goals, the human body requires raw materials, vitamins (organic micronutrients, lipid-soluble like A, D, E, K, or watersoluble like B and C) and minerals, which are obtained through food or nutritional supplements [28]. When essential minerals are missing, deficient or unbalanced in our diets, our bodies fail to perform optimally and this can result in the development of many non-communicable diseases, which are the main contributor to mortality and morbidity globally [119-120]. However, different amounts of each mineral are required by the human body according to the age, sex, physiological state and sometimes state of health of the living beings. Accurate knowledge on mineral intake is an important issue for disease prevention, which is being considered very carefully by public health organisations [121]. In this way, it is possible to contribute to the improvement of the quality of life of human beings and to mitigate the costs of medical care [122-123].

The relationship between minerals and health is very close since there are about 20 essential substances of this type that are necessary as substrates in the formation of functional products for chemical reactions of the organism, are part of the structure of the skeletal system, actively participate of the transport of oxygen in the bloodstream, in the production of hormones necessary for metabolism and its regulation, among others of equal physiological importance. It is essential to assess the importance of these and promote their consumption in the diet from various sources of animal and plant origin as well as reduce the factors that prevent the adequate absorption of minerals (age, amount ingested, interactions with substances consumed and problems in the barrier intestinal absorptive) in order to ensure an optimal environment that allows the performance of the processes dependent on these substances and maintain a state of health in good condition. On the other hand, the appearance of pathologies due to the absence or excess of different types of minerals such as iron deficiency anemia, goitre secondary to hypothyroidism, osteoporosis, kidney stones, among others, represent a challenge for primary care entities, responsible for the promotion and prevention of health, since the incidence of these diseases should be reduced to the smallest possible number, generating, in turn, a considerable cost reduction in the health system to act on health conditions that are required since, in to a large extent, it is possible to avoid organic dysfunctions by maintaining a balance between excess and lack of minerals.

Minerals can be added in formulations of medicines, not only in their elementary form but also as inorganic or organic salts or as other chemical compounds [28]. On the other hand, individual patients might be expected to react differently to health treatments using natural means, the so-called naturotherapy, which is is a healing system using the power of nature and it is considered an art, science and philosophy [124-125]. Table 1 depicted the main hazardous or beneficial minerals and their effect in health.

Table 1. Minerals based of their hazardous or beneficial character.

Hazardous Minerals	Characteristic/Source	Effect on heatlh
Radioactive minerals (U or Th concentration > 0,1%)	Main source of U and Th.	Renal function, liver effects, hematological alterations, neuroendocrine hormone levels, semen characteristics, bone function, neurocogntive effects, and genotoxicity.
Crocidolite (Na2(Fe2+,Mg)3Fe3+2Si8O22(OH)2)	Blue asbesto.	Lung diseases, including lung and mesothelial cancer.
Hydroxyapatite (Ca5(PO4)3(OH))	Main component of teeth and bones.	Form deposits in human heart valves and arteries.cause acute or chronic arthritis in a manner similar to that caused by monosodium urate deposition
Erionite (NaK2MgCa1.5)(Al8Si28)O72.28H2O)	Fibrous zeolite (sometimes referred to as a molecular sieve).	Malignant mesotheliomas in humans.
Phenacite (BeSiO4)	Beryllium (Be)-containing dust is highly poisonous.	Highly poisonous.
K-Feldspar (KAlSi3O8)	Contains small quantities of radioactive U, a major source of Pb.	Lung cancer; tiredness or weakness a feeling of numbness or tingling nausea or vomiting trouble breathing chest pain palpitations or irregular heartbeats.
Chrysotile (Mg3Si2O5(OH)4)	White asbesto.	Chronic exposure can cause asbestosis, a progressive lung disease that causes hardening of lung tissue resulting in loss of elasticity and difficulty in breathing.
Quartz (SiO2)	Fine particulate.	Respiratory effects (silicosis or silicotuberculosis), lung cancer and other cancers, kidney disease, and immunological problems.
Fluorite (CaF2)	Major F-containing mineral.	A very severe bone disorder, resulting in an irreversible disease referred to as skeletal fluorosis.
Pyrite (FeS2)	Main source of acid mine waters associated with sulfide mine tailings.	Solubilization of toxic heavy metals, resulting in their dispersal in the environment, affecting millions of people.
Galena (PbS)	Main source of Pb.	Developmental and nervous system disorders in fetuses and children, cardiovascular disease in adults.
Cinnabar (HgS)	Main source of Hg; Methyl mercury and dimethyl mercury are two of the most toxic compounds known to human.	Developmental and nervous system disorders in fetuses and children, and can kill at low concentration levels.

Beneficial Minerals	Characteristic/Source	Benefits
Clay minerals	Holding nutrient elements, which are necessary for plant growth.	Formulation of various medicines based on the ability to adsorb and retain harmful and toxic substances.
Hydroxyapatite ($Ca_5(PO_4)_3(OH)$)	Main component of teeth and bones.	Surgeries involving bones and tooth enamel.
Phosphates	Source of P; meat, fish, poultry, eggs, milk, processed foods (including soda pop).	Essential plant nutrient used in fertilizers.
Calcite ($CaCO_3$)	Main source of Ca; acid-neutralizing ability; milk and milk products; canned fish with bones (salmon, sardines); fortified tofu and fortified soy milk; greens (broccoli, mustard greens); legumes.	Neutralization of stomach acidity; ingredient in numerous medicaments used to treat digestive and other ailments; builds bones and teeth; activates enzymes throughout the body; helps regulate blood pressure; and helps muscles to contract, nerves to send messages and blood to clot.
Magnesite ($MgCO_3$)	Major source of Mg; nuts and seeds; legumes; leafy, green vegetables; seafood; chocolate; artichokes; “hard” drinking water.	Builds bones and teeth. It also helps to regulate blood pressure and blood sugar and enables muscles to contract, nerves to send messages, blood to clot, and enzymes to work.
Quartz (SiO_2)	Crystals	Accelerates the healing of the afflictions derived from stress and struggle alike and strengthens the capacity for psychic and emotional recovery.
Halite (NaCl)	Essential nutrient; table salt, soy sauce; large amounts in processed foods; small amounts in milk, breads, vegetables, and unprocessed meats.	Flavor enhancer; seasoning and preservation; supplement for the trace elements; promotes neural communication; prevents cancer; fights against asthma; mantains bone and muscle health; balances fluids in the body, helps send nerve impulses and helps make muscles contract.
Gypsum ($CaSO_4.2H_2O$)	Non-hazardous, non-toxic, inherently safe material.	Soil amendment; impression plasters in dentistry; no long term adverse medical effects from ingestion of gypsum.
Zeolites	Molecular sieves.	Cracking of petroleum to make gasoline, in chemical catalysis, and as cation exchangers in softening H_2O.
Ferrihydrite (˜$Fe(OH)_3$)	Enterosorbent.	Sorbers of toxic heavy metals and metalloids.
Cu minerals	Major source of Cu; legumes, nuts and seeds, whole grains, organ meats, drinking water.	Essential trace mineral, which along with amino and fatty acids as well as vitamins is required for normal metabolic processes, making red blood cells, regulating neurotransmitters, and mopping up free radicals.
Fe oxides	Main source of Fe; organ meats; red meats; fish; poultry; shellfish (especially clams); egg yolks; legumes; dried fruits; dark, leafy greens; iron-enriched breads and cereals; and fortified cereals.	Essential trace mineral; emerging therapy for neuronal disorders as well as cancer and regenerative medicine; helps make hemoglobin (the oxygen-carrying chemical in the body’s red blood cells) and myoglobin (a protein in muscle cells); essential for activating certain enzymes and for making amino acids, collagen, neurotransmitters and hormones.
Bauxite and Al-hydroxides	Main source of Al.	Food and pharmaceutical applications.
Cromite (Cr_2O_3)	Main source of Cr; unrefined foods, especially liver, brewer’s yeast, whole grains, nuts, cheeses.	Essential trace mineral; kitchen appliances, food processing equipment, and medical and dental tools; Helps maintain normal blood sugar levels and helps cells draw energy from blood sugar.
Pyrolusite (MnO_2)	Main source of Mn; widespread in foods, especially plant foods.	Essential trace mineral; helps form bones and helps metabolize amino acids, cholesterol, and carbohydrates; part of many enzymes.
Molibdenite (MoO_2)	Main source of Mo; legumes; breads and grains; leafy greens; leafy, green vegetables; milk; liver.	Essential trace mineral; activates several enzymes that break down toxins and prevents the buildup of harmful sulfites in the body.

Orthoclase ($KAlSi_3O_8$)	Main source of K; meats, milk, fresh fruits and vegetables, whole grains, legumes.	Balances fluids in the body, helps to maintain a steady heartbeat and to make muscles contract, and may benefit bones and blood pressure.
Sphalerite (ZnS)	Main source of Zn; meats, fish, poultry, leavened whole grains, vegetables.	Essential trace mineral; helps blood clot, helps make proteins and DNA, bolsters the immune system, and helps with wound healing and cell division.
Fluorite (CaF_2)	Main source of F; drinking water (either fluoridated or naturally containing fluoride), fish, and most teas.	Essential trace mineral, which helps in formation of bones and teeth and prevents tooth decay.

Source: adapted and modified from Brown and Calas [126-127] and Markov [128].

Environmental health and social repercussions

Global warming is a concern due to the accelerated process that it has had in recent years as it is affecting health and threatening the future of humanity [129]. The geological environment is a factor that can condition the environmental health of an area, so that a relationship between the medium can be established natural and health of the population of that environment. This relationship occurs both in urban and rural areas, but talking about the natural environment, the geological environment, this link is especially evident in rural areas and mainly in the poorest and disadvantaged. The modern worldview, based on the anthropocentrism and marked by the development of science has driven human action towards world domination in the mid-twentieth century the called environmental ethics [130], which raised a reflection critical and rational about the intrinsic value that the natural environment and its non-human elements. Since then, the need to become aware of the way in which living things must interact with the environment has become credible in recent years due to the proliferation of numerous diseases. Both deterioration environmental as the influence of the natural environment, when unfavorable, they can be aggravated by the action and responsibility of public authorities, since most policies have consequences environmental and regulatory, and generally ignore ethical aspects of them. Modern civilization and the values that support it are behind the ecological crisis: Excessive opulence brings inequality, discrimination and poverty. Precisely, poverty is a factor fundamental in environmental deterioration are the countries poor and, specifically, people with minors income those that are most exposed to the natural environment. Often these people have to work or live in close relationship with the environment that when harmful, makes this segment of the population in the most vulnerable. In order to maintain a balance between environmental health and that of living beings, it is essential to contribute to the preservation of natural resources, mitigating the environmental damage caused by anthropogenic activity. This will be the basis for providing a healthy environment (Figure 7) and preventing diseases, applying available technologies, policies and prevention and public health measures. On the other hand, a better knowledge of the effects associated with various environmental factors can therefore help guide the regulatory bodies in the design of preventive health measures that not only contribute to mitigate the proliferation of diseases but also the costs for the health system. In addition, the awareness of society in relation to the importance of carrying out best practices in relation to environmental care within the framework of sustainable development in order to reduce environmental hazards and exposure to them can generate numerous benefits, which include the improvement of the quality of life and well-being, as well as the opportunities for education and employment.

Figure 7. Healthy environment

Source: Authors.

Conclusions

Future studies in the field of medical geology should focus on establishing a better understanding of the role of minerals in ecosystems and their interaction with biological organisms, for which it will be necessary to resort to the use of advanced technologies in the characterization of samples, providing valuable information not only in relation to environmental conditions but also in relation to the state of human health. However, it is necessary to consider essentiality and non-essentiality minerals with reference to human health, sources of exposure of toxic elements, and health effects induced by deficiency and excess of minerals. This will be essential in defining environmental and public health strategies. Therefore, to be most effective the Colombian geoscience community should be included as one of the key players or agencies involved in environmental health studies. Earth planet contributes to the pollution through volcanic eruptions, radiation, toxic elements, dust, etc., however, if the anthropogenic activities continue contributing to increase the levels of contamination, it would be very difficult to protect the humanity.

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