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Understanding Soil Science for Safeguarding Environmental and Public Health

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Summary
Soil influences human health directly and indirectly. However, its influence is not routinely discussed compared with other environmental media, specifically, air and water. Though less obvious, soils could have both beneficial and detrimental effects on human health. Over the years the relevance of soil to human health has been largely attributed to crop production. Nonetheless, recent studies have shown that soils play other significant roles in human health than the obvious. Soils interact directly with the aquatic ecosystems and the atmosphere, thus, cannot be overlooked in addressing environmental and public health challenges. Despite this, professionals emerging from the public health field unacquainted with the field of soil science owing to their varied backgrounds have little or no knowledge of this all-important natural resource. The knowledge of soil will determine how it is used, treated and conserved, which eventually impact human health. There is the need to establish soils relevance in the public health field which addresses issues pertaining to total health of population, and this begins with teaching soils and its impact on health to environmental and public health students.

Comprendre la science des sols pour préserver la santé environnementale et publique

Résumé
Le sol influence directement et indirectement la santé humaine. Cependant, son influence ne sont pas abordés régulièrement par rapport aux autres milieux de l'environnement, particulièrement, l'air et l'eau. Bien que moins évidente, les sols pourraient avoir des effets bénéfiques et néfastes sur la santé humaine. Au fil des années, la pertinence du sol pour la santé humaine a été attribuée en grande partie à la production agricole. Néanmoins, des études récentes montrent que les sols ont joué un rôle important sur les autres dans la santé humaine. Les sols agissent directement avec les écosystèmes aquatiques et l'atmosphère. Donc, on ne peut pas le négliger pour relever les défis d'environnement et de santé publique. Malgré cela, les professionnels issus du domaine de la santé publique ne connaissent pas le domaine des sciences du sol. La connaissance du sol déterminera comment il est utilisé, son traitement et sa conservation. Tous, ont un impact finale la santé humaine. Il est

nécessaire d'établir la connaissance des sols dans le domaine de la santé publique pour aborder les questions relatives à la santé globale de la population, et cela commence par l'impact du sol sur la santé publique.

Introduction

Soil does not only perform several ecosystem services; it is indeed a critical natural resource that influences human health greatly. Most of all human life and survival depends on the soil, the foundation for food, fibre, shelter, fuel, water and air filtration (Lal, 2014). Plant and animal raw materials for textile and constructions, as well as antibiotics, originate from soils, simply put, human health is related to many materials found in soil (Brevik and Burgess, 2013). Despite this, the importance of understanding soil is not immediately obvious to many people (Harrison *et al.* 2010). Unfortunately, the demonstration of ignorance about soil does not obliterate its critical role on human health and survival.

Soil often termed dirt and as such treated, is an environmental medium usually inconspicuous to most people studying in other fields other than soil science, agriculture and civil engineering who are familiar with this critical natural resource that support human lives and the economies of most nations of the world. To others, especially most urban dwellers, soil is simply unnoticeable because it is concealed beneath buildings, tarred roads, parks, lawns and so on. The link between air, water and human health is most often very obvious and direct, what is obscure most times is the link between soil and human health (Burras *et al.* 2013; Oliver and Gregory, 2015). Soil can directly and indirectly support or harm humans.

Consequently, there is an intimate link between soil and human health, although, this remains a topical and growing area of soil research (Hartemink, 2015). Adewope *et al.* (2013) highlighted soils and its role on public health and human well-being as one important area of research. Also, the recent effort in the book by Brevik and Burgess (2013) provides additional evidence supporting the need to make a clear link between soils and human health. Moreover, this is all the more needed in achieving the sustainable development goals 2, 11, 12 and 15. It is important that the public be informed that soil can affect their lives directly in many ways other than through crop production (Baveye, 2006). Although, the pressure on soil resources on a global basis is well-known to be huge, only little information reaches the general public on how this might impact their lives (Arnalds, 2006). Therefore, an important medium for the communication of the influence of soil on human health to the public is via education of students in the public health discipline from various backgrounds that have limited and inconsistent knowledge of soil. The need to teach soils in public health discipline has become increasingly important and urgent owing to the effect of soils on human health as well as the need to create greater concern for the soil resource (Steffan *et al.* 2018) by the general public. The objective of this paper is to inform emerging professionals, specifically, students of public health on the impact of soils on human health. Since understanding the relationship of soils to human health necessitates careful interpretation of soil information, this paper will also briefly describe some properties and processes of soils that are connected to human health.

What is Soil?

Soil (Figure 1) is the loose material covering the land surfaces of earth and consisting of a mixture of inorganic materials (sand, silt and clay), organic materials, water and air (Mbila, 2013). Soil is also considered the interface between the lithosphere and the atmosphere, and strongly interacts with the biosphere and the hydrosphere (Lal and Shukla, 2004). It is a vital non-renewal natural resource within a man's lifetime, thus it can be considered as a finite resource (Lal, 2014; Oliver and Gregory, 2015). The inorganic components of soil are the products of rocks disintegration through weathering, and other

Figure 1: An Alfisol (Soil Type) in Southwest Nigeria

natural processes, whilst the organic materials constitute the debris from plants and from the decomposition of the many life forms that inhabit the soil (Brevik, 2013). Soil is actually a dynamic, living system, which directly and indirectly affects all forms of life (Lal and Shukla, 2004; Lal, 2014).

Soil is not only a medium for plant growth but it is multi-functional in nature, thereby providing goods and services including food security, environmental quality, repository for urban/ industrial waste, nutrient recycling, water and air filtration and carbon sequestration to offset the anthropogenic emission of carbon dioxide (CO_2) contributing to climate change (Blanco-Canqui and Lal, 2010; Burgess, 2013), all of which directly affect human health.

General Knowledge of Soil Properties

In order to properly understand the influence soil has on human health, knowledge of soil properties and processes is fundamental, for improving interpretation of its impacts. The following section will briefly discuss some soil properties, not in sufficient details (Details can be found in other books e.g., Brady and Weil, 2002) since the scope of this paper is to address the need for teaching soils to public health students.

Generally, soil properties have three main components, namely, physical, chemical and biological. Soil physical properties include: texture, moisture content, colour, structure, bulk density, temperature and so on. Some of these properties are rarely altered over time when left undisturbed in nature but alterations are likely to occur more rapidly in some of these properties when disturbed (e.g., by humans). Soil chemical properties include: pH, cation exchange capacity (CEC), organic matter, and micro- and macro-elements. The myriads of soil micro- and macro-organisms and their activities majorly constitute the biological properties.

Soil texture

Soil texture is defined as the proportion of the sand, silt and clay, which represents the particle size fractions or separates in a soil (Brevik, 2013). Some properties of these particle size fractions and some of their impacts on the environment as discussed according to Brady and Weil, (2002) are as follows: Sand (2.0 – 0.06 mm) is characterised by large macropores and high infiltration rates thus facilitating the rapid percolation of water and contaminants to ground water. Silt (0.06 – 0.002 mm) has abundant micropores, reduced infiltration and often the dominant particle size fraction in water bodies after an erosion event. Clay (< 0.002 mm) on the other hand, abundant micropores, reduced infiltration and large surface area leading to attraction of organic materials, nutrients and contaminants. Clay can greatly affect the behaviour of soils and a number of soil processes, such as soil erosion (Morgan, 2005).

The lack of knowledge of soil texture and particle size distribution will limit the interpretation of the fate of contaminants (e.g., heavy metal or pathogens) associated with finer particles that could readily detach and move in surface runoff or be lifted as airborne dusts (USEPA, 2011).

Soil structure

Soil structure is the arrangement or grouping of primary soil particles (sand, silt and clay) into secondary units or aggregates (Brady and Weil, 2002). It is determined by how individual soil particles bind together to form aggregates and this impacts on the arrangement of pores. Their arrangements occur in different patterns, namely crumb, granular, blocky, prismatic, columnar, and platy structures (Soil Survey Staff, 2009). Soil structure affects transport and storage of water and nutrient in the soil (Lal and Shukla, 2004), and has huge implication for the fate of contaminants in the environment. It is a dynamic property that is affected by anthropogenic activities such as tillage, irrigation, and construction (Delgado and Go´mez, 2016). This often results in the disruption and reduction of air and water fluxes into the soil (Delgado and Go´mez, 2016). As water infiltration in the soil is reduced, surface runoff increases and soil particles alone and or with associated diseases (pathogens) and adsorbed toxic materials resulting from disrupted soil structures are carried into water bodies or deposited elsewhere.

Bulk density

Bulk density of a soil is defined as the mass of soil per unit volume (Lal and Shukla, 2004). It enables the quantification of elements on hectares' basis. Increased bulk density can result from loss of aggregation owing to increased tillage or vehicular movement and reduction in the quantity of soil organic matter (Brevik, 2013). Soil bulk influences infiltration rates, aeration, root proliferation, and plant growth (Throop et al. 2012; Delgado and Go´mez, 2016).

Soil pH

Soil pH is a measure of the active hydrogen ion (H^+) concentration, and it is an indication of the acidity or alkalinity of a soil. Soil pH is measured on a scale ranging from 0 to 14, where pH 7 serves as the neutral pH, pH < 7.0 is considered acidic and pH > 7.0 is alkaline (Tan, 2011). Soil pH is an indicator of several processes occurring in soils.

However, what is likely to be of importance to students studying health related disciplines is the association of soil pH with the bioavailability of contaminants in soil medium to the food chain via food, water and air borne dust. Soil pH greatly influences the availability for root uptake of many elements, whether they are essential or toxic to the plant (Delgado and Go´mez, 2016). The mobility of contaminants, especially heavy metals is largely controlled by the soil pH, which is achieved when pH influences their solubility and adsorption (He, *et al.,* 2005). Generally, the availability of heavy metals usually decreases with increasing soil pH, while decreasing pH means solubility and uptake of heavy metals, thereby increasing the potential for phytotoxicity (He *et al.,* 2005) as well as food chain contamination.

Cation exchange capacity

In simple terms, the cation exchange capacity (CEC) of soils has been defined as the capacity of soils to adsorb and exchange cations with its surrounding soil solution (Tan, 2011; Mbila, 2013). Cation exchange capacity is highly associated with the surface area and surface charge of clay (Tan, 2011). Surfaces of colloids which are primarily clay minerals and humus typically have negative charges which attract cations - positively charged ions (Brevik, 2013). Cation exchange capacity is highly dependent on the soil texture and amount of organic matter (Mbila, 2013). The implication for the environment and human health is that soil CEC is a major determinant of the soil's capacity to adsorb organic or inorganic pollutants. Also, the CEC of a soil enables it to intercept toxic metals and organic compounds from reaching groundwater, by adsorption on soil colloids, thereby preventing pollution of water bodies (Tan, 2011).

Clays

The discussion on soil properties will be incomplete without addressing the subject 'clays'. Clay is the soil particle size < 0.002 mm. Generally, clays have high reactive surfaces that are predominantly negative charged and provide high capacity for adsorption (Oliver and Gregory, 2015). As a component of soil colloids, clay can control the mobility and adsorption of nutrients and heavy metals in the soil. Also, clays have been known for a long time to have varied beneficial effects to human health since they are used for medicinal purposes (Oliver and Gregory, 2015). Kaolin, a clay type has been widely used for diarrhoea medicines, as well as in treating rash and poison cases (Brevik, 2009; Abraham, 2005: Mbila, 2013; Oliver and Gregory, 2015).

Smectites, another clay type adsorbs aflatoxins, which are naturally occurring carcinogenic mycotoxins produced by several Aspergillus (fungi) species (Richard, 2007). Other uses of soil clays and their therapeutic effects have been outlined (Table 1).

Soil organic matter

Soil organic matter (SOM) is a complex heterogeneous compound comprising of the microbial biomass, the dead decaying remains of plants and animals, dead plant materials and

Table 1: Clay Minerals and their Medicinal uses

Clay Type	Mode of administration	Medicinal Uses
Kaolinite	Orally, topically	Antidiarrhoeal Gastrointestinal protector Dermatological protectors Anti-inflammatory Local anesthetic Cosmetics (creams, powders, and emulsions) Aesthetic medicine (geotherapy*) for treatment of boils, acne, etc.
Mica	Topically	Cosmetics (creams, powders, and emulsions)
Smectite	Orally, topically	Antacid Gastrointestinal protector Antidiarrhoeal Dermatological protectors Cosmetics creams, powders and emulsions

* Geotherapy is the therapeutic mixture of one or more clay minerals with water and its direct application upon the skin to treat diseases.

Sources: Carretero, 2002; Carretero and Pozo, 2010.

detritus, as well as humus, the relatively stable form of soil organic matter (Gregorich *et al.,* 1994; Craswell and Lefroy, 2001; Wander, 2004).The soil humus is a major component of the soil organic matter which can be defined as an amorphous and colloidal mixture of complex organic macromolecular substances, no longer recognizable as tissues. Soil organic matter performs some key physical, chemical and biological functions (Brevik, 2013). It contributes to the chemical properties of soil by increasing the cation exchange capacity (colloidal properties), and buffering capacity against pH change. It serves as a major source of nutrients such as nitrogen and phosphorus, and the energy source for soil organisms (Brevik, 2013). Many micro- and macro-nutrients are retained, and their availability is influenced by SOM (Oliver and Gregory, 2015). Additionally, SOM is an important ecosystem property, that regulates nutrient supply to plants, and microbes, soil moisture, and long-term C storage or sequestration (McLauchlan, and Hobbie, 2004), which plays a significant role in climate change mitigation. Overall, SOM comprising of approximately 58% of SOC (soil organic carbon) is the basis of all physical, chemical, biological, and ecological transformations and reactions within a soil (Lal, 2014).

Soil biological properties

Soil organisms are the main components of the biological properties, with a wide range of biodiversities, including both micro- and macro-organisms such as bacteria, fungi, protozoa, algae, nematodes and so on (Loynachan, 2013).

Soil microbes can either be harmful, thereby causing disease (pathogens, toxins and helminthes) or be a source of natural products that benefit human health, e.g., antibiotics (Pepper *et al.* 2009). Oliver and Gregory, (2015), stated the main routes of exposure of soil pathogenic organisms to humans include: ingestion (for example *Clostridium botulinum*); inhalation (*Aspergillus fumigatus*), and through the skin (hook worm) and skin lesions (*Clostridium tetani*). Although some soil protozoa are known to cause diarrhoea, most are generally not harmful to humans, but actively participate in nutrient cycling in soils (Loynachan, 2013).

Urban Soils: What do we know?

Urban soils can be considered a reservoir for contaminants from heavy atmospheric deposition, surface runoff and rainfall (Galitskova and Murzayeva, 2016). Other sources come from vehicular emissions, indiscriminate disposal of wastes as well as poor and inadequate sanitary conditions, more specifically in developing countries of the world, Nigeria not exempted. Vehicular emissions could contain both inorganic (heavy metals) and organic (constituents of total petroleum hydrocarbons) pollutants, while chemical and biological contaminants are widely associated with industrial, medical, and landfills wastes. The list is endless, making every urban dweller vulnerable to any health issues from contaminated soils. Agbenin *et al.* (2009) reported significant accumulation of heavy metals (Pb, Cr, Cu, Ni and Zn) in *lettuce* and *amaranthus* plants grown on land irrigated with domestic and industrial waste waters in an urban agricultural system in northern Nigeria.

Apart from the ongoing massive crude oil soil contamination in the Niger Delta areas, other sources assuming priority position include lead acid battery recycling sites and landfills, especially in urban areas in Nigeria. Recent studies have reported other numerous sources of ongoing soil contamination, especially in urban areas, to include elevated soil Pb concentrations higher than the USEPA permissible limit (400 $mgkg^{-1}$ soil) by magnitudes of 2 to 5 around a tank farm area at a petroleum product depot in Ibadan, Nigeria, which is a threat to both the environment and living organisms (Oladele *et al.,* 2015). Also, elevated concentrations of heavy metals have been reported in soils within the vicinity of scrap metal recycling factory in southwestern Nigeria (Owode *et al,* 2014). The extent of urban soil contamination in Nigeria is topical and requires more research.

Soils and Human Health

Some concerns noted in the study by Kim *et al.,* (2014), reiterates that literature and media are replete with discussions on the influence of air and water on human health while very little knowledge on the influence of soil on human health is heard (Burras *et al.,* 2013).

Nevertheless, the physical, chemical and biological components of soils can either be directly beneficial or injurious to human health, through ingestion (either deliberate or involuntary), inhalation and dermal absorption (Abrahams, 2002). The soil physical, chemical and biological properties can provide the enabling condition for the survival of both harmful and beneficial organisms. It is therefore, important for students studying to earn degrees in public health fields to understand the impacts soils have on human health. Some direct and indirect impacts of soil on human health are briefly outlined.

Tetanus, a fatal infectious disease is caused by soil-borne bacteria (*Clostridium tetani)* found in the surface layers of soil, especially in the tropics (Abrahams, 2002). This is mostly by direct exposure to spore-bearing soil that comes in contact with the skin (Abrahams, 2002). Also, many different species of soil-transmitted helminthes infect humans, namely, roundworm (*Ascaris lumbricoides)*, whipworm (*Trichuris trichiura*), hookworms (*Necator americanus* and *Ancylostoma duodenale)* and *pin worms* (WHO, 2012; Loynachan, 2013; Oliver and Gregory, 2015). Specifically, hookworms (*Ancylostoma duodenale* and *Necator americanus)* infect humans directly by skin contact with soil (Abrahams, 2002), this has implication for walking barefoot especially in children of poor and developing countries. The main source of these parasitic nematodes stem from soils contaminated with human or animal faeces (WHO, 2012). The estimated number of persons infected with these parasites is >2 billion (WHO, 2012). Infections result from poor and inadequate sanitation and when infected soil is ingested either directly or from contaminated vegetables and fruits (WHO, 2012; Oliver and Gregory, 2015).

Conversely, a number of useful antibiotics that have improved human health have originated from soil micro-organisms (Abrahams, 2002; Pepper *et al.,* 2009; Oliver and Gregory, 2015), such as penicillin and streptomycin from soil fungi and *bacteria* (*Streptomyces)*, respectively (Abrahams, 2002). Furthermore, on soil use as medicines, Pepper *et al.,* (2009) reported that 60% of new cancer drugs approved between the periods of 1983 - 1994 were isolated from soil. On the whole, Pepper *et al.* (2009) concluded that soil is a public health saviour, for as long as the soil is not abused.

The mass lead (Pb) poisoning from contaminated soil in Zamfara State, Nigeria in early 2010 should remain a reality on the minds of students studying public health in Nigeria. This catastrophic event led to elevated blood lead levels and death of many children in the affected areas (Ajumobi *et al.,* 2014). Although adults were equally exposed, children were the most vulnerable owing to their hand-to-mouth behaviour (Ajumobi *et al.,* 2014).

Generally, soil processes such as water erosion with its attendant surface runoff are a major cause of non-point source pollution; removal of organic-rich topsoil for good plant growth; eutrophication of water bodies; destruction of roads translating to increased automobile accidents; soil degradation corresponding to poor soil quality and nutrient-poor food source for man's consumption; and increased water turbidity resulting in poor water quality. On the other hand, wind erosion damages fruits and crops through the effect of wind borne soil particles, reduces air quality, while airborne dust of finest ($\leq$0.002 mm) soil particles burdened with harmful substances (heavy metals, organic compounds, and pathogens) may cause other health problems and diseases (Derbyshire, 2005; Abrahams, 2002).

Soils can impact human health through food and nutrition security, and climate change. Other ongoing issues connecting soil to human health in Nigeria include: increased flooding, e-waste dumping and disposal in soil, seasonal harmattan dust, excessive and indiscriminate use of pesticides and herbicides, illegal mining of natural resources, substantial deforestation and illegal log harvesting. Overall, from the Nigerian context, the potential public health workforce requires knowledge of soil science to confront the current increasing environmental and health challenges.

Conclusion

It has been established that soil performs several critical services that impact human health. However, most of the ongoing human activities have resulted in enormous soil contamination which can harm human health directly or indirectly. The general soil contamination status, especially of urban areas in Nigeria remains largely unknown with several ongoing activities still contributing to further pollution of this all important natural resource. One important way identified in reducing future soil contamination is via teaching soil science to students in the public health discipline which simply begins the nexus between soil and human health, thereby ensuring environmental sustainability and promoting public health responsibility by all.

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