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Review Article

The unique pharmaceutical potential applications of soils to livelihoods

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Abstract

Soil is a natural resource and a mixture of many varied abiotic and biotic components, which give its true identity and value as the main component of the earth's ecosystem and a precious "skin of the earth" with interfaces between the lithosphere, hydrosphere, atmosphere and biosphere. The concept of "medicinal soil" is well recognized since pre-historic times. Nevertheless, full potential value of soil in the mainstream of either traditional or conventional sense has not been realized, may be due to lack of evidence-based research results. It supports, holistically, all kinds of earthly livelihoods, either directly and/or indirectly. The value of soil to livelihoods is comprehensively evaluated with focus on its raw active ingredients applicable in pharmaceutical, agricultural, health and cosmetic industries. In this manuscript, medicinal value of soil and its influence to human life is reviewed with special emphasis of author's experiences from Kenya. To understand comprehensively the full potential of soils to human livelihood, interdisciplinary research collaborations and networks are greatly needed to discover the underlying science and spearhead the subsequent discussions with a focus on impacts of climate change and contaminate wastes such as e-wastes, heavy metals, chemicals and radioactive/hazardous materials on soils and their composition.

Key words: Soils and uses, Microorganisms and minerals, Geophagy and nutraceuticals, Therapy and pharmaceuticals, Human livelihood

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INTRODUCTION

New challenges such as drug-resistance, high costs of available drugs, appearance of new and re-appearance of old pathogens, toxicities associated with the available drugs, undesirable effects on non-target beneficial and target organisms sharing the same ecosystem, unavailability of essential drugs in some areas and so on, have necessitated the ever increasing needs and demands to develop and isolate novel molecules of medicines (Newman et al., 2000; Koehn and Carter, 2005; Newman, 2008; Ranjbariyan et al., 2011; Villarreal-Gómez et al., 2013). It is hoped that the current drum up for naturally-based new molecules of medicines may lead to undergo the developmental research that will yield new drug agents, which are highly effective and efficient, less expensive, possess low toxicity and have a minor environmental impact that does not cause a significant socio-economic loss to the society (Strobel and Daisy, 2003; Carretero and Pozo, 2010; Brevik and Burgess, 2013). For a long period of time, in human history, the chemical compounds found in organisms such as plants, atmospheric air, animals, microorganisms and in natural environments such as soils, have been useful sources for developing these new bioactive agents deployed in pharmaceutical, cosmetic, health and agricultural industries for their myriad advantages against the conventional counterparts (Stermitz et al., 2000; Beghyn et al., 2008; Mondal et al., 2012; Brevik and Burgess, 2013; Villarreal-Gómez et al., 2013; Kim et al., 2014; Pereira et al., 2014). Furthermore, such natural products have also been precious source of motivation for organic chemists to develop novel drug candidates in the laboratory (Ji et al., 2009) and this synthesis mechanisms further helps the evaluation of the possible synergism effect if any (Hunter, 2008; Li and Zhang, 2008). This therefore explains the existing estimation between 40% and 80% of the current drugs in today's pharmaceutical industry having their origin in natural products (Strobel and Daisy, 2003). Of particular importance, are those organisms and naturally occurring chemical compounds of medicinal value, found in different types of naturally occurring soils, mainly comprising: microbial inoculants, organic materials such as composts and fermentation formulations and crushed rock and "naturally occurring minerals" such as granite, alunite, hot spring deposits, clays and coal-like minerals (Carretero and Pozo, 2010; Mbila, 2013; Christensen, 2014). Moreover, biosynthesis of antibiotics widely used in human and veterinary medicines also occurs in different soil types (Gottlieb, 1976; Mbila, 2013). In whole and/or in parts, these soil components are responsible for the observed medicinal properties of different types of soils (Zimmermann et al., 2007) and further, their presence, interaction and composition help to give future directions on the development of new medicines based on such natural products (Verpoorte et al., 2009). However, the importance of soils on human health has not been widely understood and recognized to the expected levels. This review, nonetheless, identifies soil as a precious field of bioprospecting the new molecules of naturally-based medicines useful in today's pharmaceutical industry to promote human health as demonstrated by Mbila (2013). The review further brings forth the current status of knowledge of soil and human health while putting into considerations some field observational surveys as experiences of the authors in an African context.

Interactions and associations between soils and humanity life

Soils are a very complex multilayered surface of mixtures of natural and artificial components, interacting continuously in response to natural and imposed biological, chemical and physical forces. Conversely, soil has been considered a precious "skin of the earth" with interfaces between the lithosphere, hydrosphere, atmosphere and biosphere (Chesworth, 2008). Soil has ever remained in close contact with humanity, both the young and old at all levels in the society and in many different ways (Donahue et al., 1977), with a view to sustaining plant and animal productivity, maintaining or enhancing water and air quality and supporting human health and habitation on earth (Brevik and Hartemink, 2010). In particular, crawling babies, more so in developing countries are on daily basis in contact with soils, some of which are heavily contaminated, thus providing a source of a wide range of deadly dangerous helminths, nematodes, arthropod, protozoan, bacterial, fungal and viral infections in optimally enabling environments such as in the tropics (Bagdasaryan, 1964; Duboise et al., 1976; Brown et al., 1979; Rowbotham, 1980; Hagedorn et al., 1981; Waldron, 1985; Gilles and Ball, 1991; Cook and Zumla, 2009; Pepper et al., 2009;

Baumgardner, 2012; Brevik and Burgess, 2013; Mbila, 2013). Conversely, before the advent of shoes, humanity bare-footed legs were continuously in contact with soil throughout life, particularly following the development and evolution of arable farming systems, which involved continuous tilting of land throughout life (Bramble and Lieberman, 2004), thereby implying, purposely continued contact. However, research indicates that soil-human interactions have a relaxing effect on human life (Hanyu et al., 2014), but additional research is needed to investigate this finding. In history, some of the earliest equipments such as pottery, jewellery, ceramics and other precious items that man made use of to improve early life were directly and indirectly made from soils (Barnett and Hoopes, 1995), with diversified socio-cultural and socio-economic values and identity. This dependence of human livelihood to equipments, tools, structures (such as buildings, bridges etc.) and other wares made from soils has ever since remained to date. This brief account perhaps only helps us to understand the existing long history of contact, association and henceforth, interaction of humanity and soils with, probably, a view for enhancing, promoting and supporting the much needed quality of life on the planet, Earth.

Soils as medicines

Naturally-occurring soil-based compounds produced by organisms

The knowledge about soil physics, biology, chemistry and biochemistry has made it possible to discover useful molecules such as enzymes such as urease, vitamins, antibiotics and other naturally-based compounds from soil-based organisms like helminths, arthropods, protozoa, virus, bacteria, fungi, plants, and nematodes, that are useful in promoting plant, human and animal health (Jeffery and van der Putten, 2011). This discovery was very successful due to the understanding of the intriguing interactions and associations between soil and its abiotic and biotic environments with a view to better appreciating the underlying co-survival mechanisms of a myriad of organisms belonging to many different species present in a handful of soil, comprising 25% of earth's species (Jeffery and van der Putten, 2011). Recent research indicates that exposure to these soil microorganisms is important in the prevention and control of allergies and other immunity-related health conditions (Kay, 2000; Matricardi and Bonini, 2000; Haahtela et al., 2008; Rook, 2010). The truth about these allegations is yet to be known.

Despite the fact that many people partially and/or repletely identify the significant contractual obligations that soil naturally performs and exists as part of the pedosphere in our everyday lives such as being: - a carbon sink, a water purification system, a food store for plants, a waste disposal site, a home of biodiversity, a source site for water, an anchorage site for fences, buildings, plants, mountains, rocks, a source site for oils/gas/minerals, a foundation for roads, railway lines, and a source of building materials, earth sheltering such as cement, bricks, most people do not realize that soil is indeed a "powerhouse of medicines" that safe life on daily basis throughout the world (Ponge, 2003; Lal, 2004; De Deyn and van der Putten, 2005; Hansen et al., 2008; Moeckel et al., 2008; Kohne et al., 2009; Diplock et al., 2009; Rezaei et al., 2009; Blakeslee, 2010; Leake and Haege, 2014). Additionally, soil has been viewed as a perfect "natural laboratory" for the manufacture of the much needed medicines (Nobel e-Museum, 1999; Mbila, 2013) due to soil's provision of conducive environment with optimum conditions for the survival of billions of organisms (Jeffery and van der Putten, 2011). For instance, scientists from various disciplines are currently exploring the possibility that many biological species use soils among other therapeutic agents as "medicines" in ways that guard against future illness (preventive medicine) and/or relieve unpleasant symptoms (curative or therapeutic medicines) (Raman and Kandula, 2008; Mishra et al., 2014). Even in human history, soils have been described as a source of important "ethnomedicines" for human and livestock ill-health problems as well as those problems affecting plants' health in the society (Christensen, 2014). The underlying rationale for this important aspect of soil is deeply rooted in the nature of the composition of soil and as a home of innumerable organisms (Jeffery and van der Putten, 2011), each contributing chemical and biochemical factors on its own unique way to this pervasive and complex ecosystem of the earth (Vining, 1990). In particular, soil microorganisms have been shown to be capable of producing some of the most important medicinal molecules ever developed (Table 1) (Kumar et al., 2010). For instance, almost 80% of the world's antibiotics are known to come from actinomycetes, mostly from the genera *Streptomyces* and *Micromonospora*, which are found in the soils (Berdy, 1995; Pandey et al., 2004; Berdy, 2005; Okami and Hotta, 1988). Further, these organisms are known to stay in the soils for many years without losing their virulence (Waksman, 1932). Starting with the discovery of actinomycin in 1940 until his retirement in 1958, Prof. Dr. Selman Abraham Waksman and his students and associates derived over 22 different antibiotic compounds from actinomycetes. Three of these antibiotics (actinomycin, neomycin and streptomycin) became commonly used (Nobel e-Museum, 1999; Waksman and Lechevalier, 2008). A number of these antibiotic compounds have ever since become standards for the treatment of tumours, skin, eye and ear infections, tuberculosis and many other illnesses worldwide. While vancomycin, an antibiotic isolated in 1956 from a species of actinomycete found in Indian and Indonesian soils, is extremely powerful and the current last line of defence for the treatment of bacterial infections (Nobel e-Museum, 1999). Since the 1940s when soil bacteria were first identified as producers of antibiotic substances, over 10,000 biologically active compounds have been isolated from these organisms, including over 3,000 antibiotics (Lechevalier, 1980; Sanglier et al., 1993; Miyadoh 1993; Mahmud, 2010). These discoveries of antibiotics from the isolates of cultures of soil actinomycetes made Dr. Waksman a celebrity and this culminated into his award of Nobel Prize in Physiology or Medicine 1952 for his discovery of streptomycin, the first antibiotic effective against tuberculosis (Brevik, 2013) and many other awards in soil microbiology (Waksman and Lechevalier, 2008). However, there arose a very serious controversy over the discovery of streptomycin between Prof. Dr. Selman Abraham Waksman and his former PhD student, Dr. Albert Schatz that culminated into a lawsuit that has not been clearly resolved in scientific domain (American Chemical Society National Historic Chemical Landmarks, 2005). It is therefore apparent that soils are a major source of antibiotics and other natural medicines that promote health services on a broader scale. In contrast, innocuous soil bacteria could be the original source of some antibiotic-resistant genes observed in some hospitals (Sarah, 2012) as a major emerging threat in pharmaceutical industry (Fischbach and Walsh, 2009; Mbila, 2013). It is therefore hoped that future studies will help to uncover their underlying mechanisms of resistance and the functions of some of those genes conferring resistance may reveal new molecular pathways to target with antibiotics. The new target and source of new molecules for managing drug-resistant pathogens, has been argued out to be the soil biodiversity (Fischbach and Walsh, 2009; Mbila, 2013) and research is currently underway to evaluate this possibility that promises to safe humans, animals and plants from a wide range of ill-health conditions.

Utilization of naturally-occurring soil-based minerals and mineral by-products

The soil environment has many naturally-occurring useful metallic and non-metallic minerals, ore minerals, aggregates and mineral by-products that are valuable to humanity, plants and animals, and partly comprise the field of medical geology (Gomes and Silva, 2007; Carretero and Pozo, 2009, and references therein). In particular, soil minerals have been used in medical practices ever since ancient times with over 30 out of 4,500 soil minerals applied in pharmaceutical and cosmetic industries (Table 2) (Carretero and Pozo, 2010). The list of valuable soil minerals, ore minerals, aggregates and mineral by-products shown in Table 2 is by no means exhaustive. However, in certain circumstances, deficiency or excess of these soil minerals, ore minerals, aggregates and mineral by-products can be causal factors of ill-health conditions in humans', animals' and plants' health life (Gomes and Silva, 2007). Soil minerals, ore minerals, aggregates and mineral by-products are used either as active principles, and/or as excipients in certain medicines, which are orally supplied as formulations of medicines and nutritional supplements or topically applied as formulations in balneotherapy, dermopharmacy and in dermocosmetics (Carretero et al., 2006; Gomes and Silva, 2007; Carretero and Pozo, 2009; 2010). For instance, kaolinite is widely used to treat diarrhoea by absorbing bacterial toxins (Mbila, 2013) with sepiolite, and palygorskite also used as pharmaceutical and cosmetic products (Carretero and Pozo, 2010). On the other hand, montmorillnite has been used as anti-poison (Abraham, 2005) while kaolin is used in dental health for formulation of toothpaste products (Mbila, 2013). Other health uses of kaolin tablets include: - the treatment of diaper rash, poison ivy, poison oak and poison

Table 1. Some of the soil-based microorganisms and the corresponding compound(s) isolated from them with different biological and pharmacological effects and the underlying mechanism of their function.

Soil-based microorganism(s)	Bioactive compound(s) isolated from the microorganism(s)	Bioactivity	Underlying mechanism	Reference
Thiobacillus thiooxidans	Sulphur compounds	Antibiotic	Sulfur-oxidizing organism.	Joffe, 1922
A spore-forming bacillus (*Bacillus brevis*)	Tyrothricin (cyclic polypeptide-antibiotic)	Antibacterial	Contain tyrocidine, a lysin that attacks the membranes of both Gram +ve and –ve bacteria and gramicidin a bacteriostatic agent that selectively inhibits growth of Gram +ve bacteria.	Dubos , 1939a;b Hotchkiss and Dubos, 1940 Dubos and Hotchkiss, 1941 van Epps, 2006
Actinomycete isolates from soils	Actinomycin (Polypeptide antibiotics from soil bacteria)	Antibacterial	Bacteriostatic that inhibits bacterial growth.	Waksman and Woodruff, 1940
Actinomyces	Streptomycin (an amino glycoside)	Antibacterial	Inhibits growth of both Gram +ve and –ve bacteria.	Schatz et al., 1944, Schatz and Waksman, 1944 Schatz , 1945 Hinshaw, 1954 Sakula, 1988
Actinomycetes (soil-dwelling microbe *Streptomyces fradiae*)	Neomycin (amino glycoside), tylosin (bacteriostat food additive) and fosfomycin	Antibiotic	Effective in particular on *Streptococci* and gram-positive *Bacilli* as a DNA binder.	Waksman and Lechevalier, 1949 Woodyer et al., 2006
Soil *Penicillium* fungi (ascomycetous fungi)	Penicillin	Antibacterial effect against mainly *Streptococci*, *Staphylococci*, *Clostridium*, and *Listeria*	Cell wall synthesis inhibitor.	Garrod, 1960
***Streptomyces strain* PM0324667**	NFAT-133 (immunosuppressive agent)	Antidiabetic	Induces glucose uptake in L6 skeletal muscle cells.	Mayer et al., 2011
Clostridium cellulolyticum	Closthioamide (polythioamide antibiotic)	Antibiotic	*Staphylococci* multi-resistance inhibition.	Kulkarni-Almeida et al., 2011
***Gordonia sputi* DSM 43896**	G48 JF905613 Compound	Antimicrobial	*C. albicans*, *S. aureus* inhibition	Lincke et al., 2010
Actinomycetes isolates from soils	3Ba3 Compound	Antibacterial	*E. amylovora*, *P. viridiflova*, *A. tumefaciens*, *B. subtilis* ATCC 663, *E. coli* ATCC 29998 3 inhibition.	Lee et al., 2012
***Micromonospora* spp.**	Diazepinomicin/ECO-4601	Antimicrobial	Unspecific	Oskay et al., 2004
***Streptomyces* CMU-PA101 and *Streptomyces* CMU-SK126**	Indole-3-acetic acid (IAA) and Siderophores	Antifungal	Unspecific	Khamna et al., 2009
Actinomycete isolates from soils	Unspecific	Antibacterial activity.	Growth inhibition.	Rahman et al., 2011
Bacillus* spp., *Streptomyces* spp., *Pseudomonas chlororaphis* and *Acinetobacter baumannii.	Unspecific	Antifungal	Growth inhibition of *Aspergillus niger*, *A. flavus*, *Fusarium moniliforme* and *Penicillium marneffei*.	Ranjbariyan et al., 2011

sumac cases and uses as adsorbents in water and waste water treatments (Brevik, 2009; Leiviskä et al., 2012). As Carretero and Pozo (2009) noted, there could be some underlying reasons for special focus on the application of soil-based metallic and non-metallic minerals, aggregates, ore minerals and mineral by-products in pharmaceutical, agricultural, health and cosmetic industries. One reason could be probably because their production in the laboratory is perplexing and costly, thus making the synthetic products out of reach of the target consumer population. Alternatively, the

Table 2. Some of the soil-based metallic and non-metallic minerals, ore minerals and mineral by-products that are used to make active ingredients in pharmaceutical, agricultural, health and cosmetic industries for improvement of livelihood in the society.

Mineral groups and examples within the group	Chemical formulae of the form in which the mineral element(s) exist in the soil (earth's crust)	Method of administration and/or application	Therapeutic activity, cosmetic action and/or related applicable use in agriculture and health industries.
Oxide minerals			
Rutile	TiO_2	Topical application	Dermatological and solar protector.
Periclase	MgO	Oral application	Antacid, osmotic oral laxative and mineral supplement.
Zincite	ZnO	Topical application	Zinc oxide is used in medicine as antiseptic and disinfectant, dermatological protector, solar protector etc. The oxide is also used in sun-block lotions.
Carbonate minerals			
Calcite	$CaCO_3$	Oral, topical and industrial applications (food, cosmetics and pharmaceuticals)	Antacid, anti-diarrhoeic, mineral supplement, abrasive and polishing agent in toothpaste. Mineral element may also be used in adhesives and sealants, cosmetics, foods, paint, paper, plastics, rubber and for the production of lime.
Dolomite	$CaMg(CO_3)_2$		
Magnesite	$MgCO_3$	Oral application	Antacid, osmotic oral laxative, and mineral supplement.
Trona	Trisodium hydrogendicarbonate dihydrate (also sodium sesquicarbonate dihydrate): $Na_3 (CO_3) (HCO_3) 2H_2O$ is a non-marine evaporite mineral.	Topical and oral applications	Trona is used in liquid detergents, medicine, food additives and control of water p^H.
Hydrozincite	$Zn_5(CO_3)_2(OH)_6$	Topical application	Dermatological protector.
Smithsonite	$ZnCO_3$	Topical application	Dermatological protector.
Sulphate minerals			
Epsomite	$MgSO_4.7H_2O$	Oral and topical applications	Osmotic oral laxative, mineral supplement and bathroom salts.
Mirabilite	$Na_2SO_4.10H_2O$	Oral and topical applications	Osmotic oral laxative and bathroom salts.
Melanterite	$FeSO_4.7H_2O$	Oral and topical applications	Anti-anaemic and mineral supplement.
Chalcanthite	$CuSO_4.5H_2O$	Oral and topical applications	Direct emetic, anti-septic and disinfectant.
Zincosite	$ZnSO_4$	Oral and topical applications	Direct emetic, anti-septic and disinfectant.
Goslarite	$ZnSO_4.7H_2O$	Oral and topical applications	Direct emetic, anti-septic and disinfectant.
Alum	$KAl(SO_4)_2.12H_2O$	Topical application	Anti-septic and disinfectant, deodorant.
Gypsum	Calcium Sulphate dihydrate: $CaSO. 2H_2O$	Industrial applications	Processed gypsum is used in industrial and for agriculture applications.
Chloride minerals			
Halite	$NaCl$	Oral, topical and parenteral applications.	Used in homeostatic and decongestive eye drops preparations. Halite is used in the human and animal diet, primarily as food seasoning and as a food preservative. Also used for curing of hides, mineral waters, soap manufacture and home water softeners.
		Oral, topical and	Homeostatic, mineral

Sylvite	KCl	parenteral applications.	supplement, bathroom salts.
Hydroxide minerals			
Brucite	$Mg(OH)_2$	Oral application	Antacid, osmotic oral laxative and mineral supplement.
Gibbsite	$Al(OH)_3$	Oral application	Antacid, gastrointestinal protector and anti-diarrhoeic.
Hydrotalcite	$Mg_6Al_2(CO_3)(OH)_{16}.4H_2O$	Oral application	Antacid.
Phosphates			
Phosphate rock	PO_4 mineral	Oral application	Used to produce ammoniated phosphate fertilizers and feed additives for livestock.
Hydroxyapatite	$Ca_5(PO_4)_3(OH)$	Oral application	Mineral supplement.
Silicate minerals- Over 600 are known: Phyllosilicates			
Smectites	Montmorillonite: $(Al_{1,67}Mg_{0,33})Si_4O_{10}(OH)_2M+_{0,33}$	Oral and topical applications	Antacid, gastrointestinal protector, anti-diarrhoeic, dermatological protector, cosmetic creams, powders and emulsions.
	Saponite: $Mg_3(Si_{3,67}Al_{0,33})O_{10}(OH)_2M+_{0,33}$	Oral and topical applications	
	Hectorite: $(Mg_{2.67}Li_{0,33})Si_4O_{10}(OH)_2M+_{0,33}$	Oral and topical applications	
Palygorskite	$(Mg,Al,Fe_3+)_5(Si,Al)_8O_{20}(OH)_2(OH_2)_4.4H_2O$	Oral and topical applications	Antacid, gastrointestinal protector, anti-diarrhoeic, cosmetic creams, powders and emulsions.
Sepiolite	$Mg_8Si1_2O_{30}(OH)_4(OH_2)_4.8H_2O$	Oral and topical applications	Antacid, gastrointestinal protector, anti-diarrhoeic, cosmetic creams, powders and emulsions.
Feldspar	Rock-forming tectosilicate minerals: - ($KAlSi_3O_8$ – $NaAlSi_3O_8$ – $CaAl_2Si_2O_8$)	Topical application	Pharmaceutical industry.
Talc	$Mg_3Si_4O_{10}(OH)_2$	Topical application	Dermatological protector, cosmetic creams, powders and emulsions. Has also an application in agriculture. Talc is found in many common household products, such as baby powder (Talcum) and deodorant.
Mica	Muscovite: $KAl_2(Si_3Al)O_{10}(OH)_2$	Topical application	Cosmetic creams, powders and emulsions.
Kaolinite	$Al_2Si_2O_5(OH)_4$	Oral and topical applications	Gastrointestinal protector, cosmetic creams, in toothpaste, dermatological protector, anti-inflammatory and local anaesthetic, as adsorbents in water and wastewater treatment, for treatment of diarrhoea, as a spray applied to crops to deter insect damage powders and emulsions.
Zeolite	Microporous, aluminosilicate minerals: Natrolite: $Na_2Al_2Si_3O_{10}·2H_2O$	Industrial applications	Uses include: - removing ammonia from water in fish hatcheries, water softener, catalysts, cat litter, odour control and removing radioactive ions from nuclear-plant effluent.
Olivine	$(Fe,Mg)_2SiO_4$	Oral and topical applications	Produces Magnesium used in the manufacture of chemicals, fertilizers, animal feed and pharmaceuticals.
Silicon	In form of silicon oxides (SiO_2) and as combination of oxygen, silicon and other elements (e.g. aluminum, magnesium, calcium, sodium, potassium, titanium, manganese, lithium, or iron) forming silicate minerals	Oral application	Silicon supplements are used as medicine. Silicon is used for weak bones (osteoporosis), heart disease and stroke (cardiovascular disease), Alzheimer's disease, hair loss, and improving hair and nail quality. It is also used for improving skin healing; and for treating sprains and strains, as well as digestive system disorders.

Silicon carbide (Carborundum)	SiC	Oral application	Silicon carbide is used in dentistry as an abrasive agent.
Other groups of soil minerals			
Sulphur	S	Topical and agricultural applications	Antiseptic and disinfectant, keratolytic reducer. Sulphur is of importance to every sector of the world's manufacturing processes, drugs, and fertilizer complexes.
Greenockite	CdS	Topical application	Keratolytic reducer.
Borax	$Na_2B_4O_7.10H_2O$	Topical application	Antiseptic and disinfectant.
Niter	KNO_3	Topical application	Anaesthetic in toothpastes.
Beryllium	Be	Hospital applications for human health	Beryllium salts are used in x-ray tubes.
Bismuth	Bi	Oral and topical application	Bismuth compounds are used in stomach-upset medicines (hence the trademarked name Pepto-Bismol), treatment of stomach ulcers, soothing creams, and cosmetics.
Boron	B	Oral applications in medicine, topical applications in other pharmaceutical areas/cosmetics and in agriculture and chemical industries	Boron is used to make glass, ceramics, enamels, fibre glass, make water softeners, soaps and detergents. Other uses are in agricultural chemicals, pest controls, fire retardants, fireworks, medicine, and various minor industrial applications.
Bromine	Br	Applications in health.	Used in sanitary preparations. Some bromine-containing compounds are used as fire retardant and as sedatives.
Clays	Clay minerals	Oral and topical application	Clays are used in the manufacturing of sanitary wear and cosmetics.
Linneaite	Co_3S_4	Topical applications	Used in cosmetic industry.
Cobaltite	$CoAsS$		
IronNickelCobalt complex compounds	$(Fe,Ni,Co)_{1-x}S_x$.		
Diatomite	Also known as diatomaceous earth is the naturally occurring fossilized remains of diatoms.	Oral and industrial applications	Used in food and pharmaceutical industry such as toothpaste and also used as an insecticide due to its abrasive and physico-sorptive properties.
Halide minerals: Fluorite	Also called fluorspar, is the mineral form of calcium fluoride, CaF_2.	Oral applications	Used for making toothpaste as a source of fluorine
Gold	Au	Oral application	Gold is used in dentistry and medicine.
Iodine	I	Oral and topical application	Iodine is used as an antibacterial agent in soaps and cleaning products in restrooms, in iodized salt to prevent goitre, and in first aid boxes as an antiseptic.
Platinum Group Metals (PGMs)	platinum, palladium, rhodium, iridium, osmium and ruthenium (scarcest of the metallic elements in the earth's crust)	Industrial applications	Platinum is used principally in catalytic converters in catalysts to produce acids, organic chemicals and pharmaceuticals.
Uranium	U	Health industry	Used in nuclear-medicine, x-ray machines and atomic dating.
Tungsten	W	Health industry	Used in radiation shielding.

Source: *Data adapted and modified from Kesler, 1994 and Carretero, M.I. and Pozo M., 2010, Applied Clay Science, 47: 171–181.*

natural counterparts are repletely utilized for probably their abundance in the earth's crust in considerably high amounts, thus becoming easily exploited in ways that are less costly.

Soil chewing and eating behaviour amongst humans and animals

Definition and understanding the soil chewing and eating behaviour

Geophagy or geophagia, also known as clay-eating is the art and science of consumption of soils (Abrahams and Parsons, 1996; Wilson, 2003; Dominy et al., 2004; Abrahams, 2005) practiced worldwide. The practice has indeed been a puzzle to many conventional practitioners as to how it has been considered a form of medical practice amongst human societies. In some parts of the world like United States, geophagy is considered an abnormal behaviour and those practising it are diagnosed with psychological disorders (Magnetic Clay Baths, 2006). Whether or not geophagy is a socio-cultural behaviour, a psychological condition, a form of nutritional supplements as nutraceuticals/foodstuff and/or a medical practice amongst organisms is yet to be comprehensively determined and subsequently evaluated to provide evidence-based underlying science (Hunter, 1973; Hunter and de Kleine, 1984; Vermeer and Ferrell Jr., 1985; Johns, 1999; Krief et al., 2006). In its current state, geophagy shouldn't be dismissed as a whole for a lot of useful medical information to humanity will be lost; instead, planned and organized scientific research involving all concerned and related disciplines and professionals should be conducted to provide correctly validated information.

A historical perspective of soil chewing and eating behaviour

Geophagy has been described in folk medicine as medicinal clay ever since prehistoric times and first appeared in records of civilization of ancient Mesopotamia. As early as 1400 BC, the concept of the value of soils to human health was already born in human civilization and the realization continued into 1700s and 1800s, thus becoming significant in the end of 20th century and the beginning of 21st century but with a strong agricultural bias rather than pharmaceutical (Oliver, 1997; Brevik and Sauer, 2014). Galen, the Greek philosopher and physician, was the first to record animal geophagy in the second century AD (Diamond, 1999). Early records on medicinal clay mainly focused on explaining the importance of mineral elements in the soil on human health through plant and animal productivity and the associated biological interactions (Browne, 1938; Kellogg, 1938; McMurtrey and Robinson, 1938; Kerr et al., 1939; Hayne, 1940; Voisin, 1959). In the modern world, the knowledge of soils and human health has considerably increased together with its prominence in medicine (Skinner and Berger, 2003; Selinus et al., 2005; Gardner et al., 2012; Brevik and Burgess, 2013; Burras et al., 2013; Brevik and Sauer, 2014). However, the impact of this knowledge is partially evaluated and henceforth, understood and this therefore awaits future work for successful and fruitful impacts to be realized on the advantageous links between soils and human health. From a socio-cultural and historical perspective point of view, some human societies have used soil chewing and eating behaviour as a strategic mechanism to treat cholera and bacterial conditions. During the Greek, Roman and Christian civilizations, a holy tablet, religiously and ritually made from soil was listed in pharmacopeia in 1848 for its therapeutic properties for relieving poison effects (detoxification) and plague conditions (Magnetic Clay Baths, 2006). On the other hand, the soil chewing and eating behaviour has been considered to have origins and evolution like that of conventional medicine albeit its persistence remaining a mystery and just a mere riddle in public health as it is continuously ignored by conventional practitioners (Voisin, 1959). It is hoped that the recognition and prominence of soil chewing and eating behaviour is receiving in the 21st century (Strobel and Daisy, 2003; Carretero and Pozo, 2010; Villarreal-Gómez et al., 2013; Brevik and Sauer, 2014) may help change this attitude a great deal.

geophagy

Geophagy is an act of deliberately consuming soils, stones, rocks and other non-food substances by herbivorous and omnivorous mammals, birds, reptiles and insects for medicinal, nutritional requirements, recreational, and/or religious purposes (Hunter, 1973; Hunter and de Kleine, 1984; Setz et al., 1999; Diamond, 1999). This behaviour has been observed and studied in the context of self-medication in Japanese macaques (*Macacca mulatta* Zimmermann, 1780), mountain gorillas (*Gorilla gorilla* Savage, 1847), chimpanzees (*Pan troglodytes* Blumenbach, 1776) and African elephants (*Loxodonta africana* Georges Cuvier, 1825) (Highfield, 2008). In particular, some monkeys have been noted to consume soil, together with their preferred food (tree foliage and fruits), in order to alleviate tannin toxicity (Setz et al., 1999). Additionally, geophagy is suggested as a means to maintain gut pH, to meet nutritional requirements for trace mineral elements, to satisfy hunger for sodium ions, to detoxify previously consumed plant secondary metabolites and to combat intestinal problems like diarrhoea (Mishra et al., 2014). While in the Bukusu community, animals fed on salty soils (called *Silongo* in Bukusu vernacular), were known to be healthy and tick free (Wanzala, 2009; Wanzala, 2012). While indigenous chickens are fed on fine soil to keep them in good health by improving their digestibility. It therefore follows with logical necessity that the observed frequenting behaviours of salt licks by mammals such as deer, cattle, sheep and sometimes dogs to obtain minerals such as sodium, calcium, iron, phosphorous and zinc etc could help explain the reason of geophagy amongst animals as being pegged on nutritional requirements (Magnetic Clay Baths, 2006) rather than being pegged on socio-cultural and –economic values.

Human geophagy

The practice of human geophagy is as old as human history (Selinus, 2007; Alloway, 2005) and the practice has ever since remained amongst the indigenous peoples around the world (Diamond, 1999). Many pregnant women worldwide chew and eat soils (Wiley and Solomon, 1998; Abrahams et al., 2006) as a source of irons, which is a key component of blood haemoglobin, the oxygen transporting factor in the body. This particular type of geophagy is also hoped to improve their appetite during pregnancy. This geophagy amongst pregnant women is also used to meet their iron and calcium requirements in the bodies (Mascolo et al., 1999). Just like pregnant women, many children also like practicing geophagy, particularly using soils from termite mounds to prevent diarrhoea and enabling the body's ability to digest valuable nutrients in food consumed alongside soil (Geissler, 2000; Magnetic Clay Baths, 2006) and in some cases, for unclear reasons. In sub-Saharan Africa, white, grey and yellowish colouration of soils (in form of stones) are harvested and sold on local markets for consumption, targeting pregnant women as the major clients (Figure 1) whereas kaolin is harvested and sold as medicinal Kaopectate in South America to aid in suppressing diarrhoea and reducing toxic effects in the digestive system (Hunter, 1973). However, it is not clear whether or not nutritional requirements for minerals such as iron and calcium, pronounced cravings for clay soil to protect digestive tract lining from toxins and digestive difficulties such as nausea (morning sickness) and vomiting underlie geophagy in pregnant women (Hunter, 1973; Hunter and de Kleine, 1984; Magnetic Clay Baths, 2006). Nevertheless, it may not be true that Africans practice geophagy more than Americans because of significant mineral deficiency in their diets and due to high incidence and prevalence rates of parasitic infections (Hunter, 1973). Such allegations require a considerable amount of valid and realistic, evidence-based scientific data that will shade light on a broader picture of the entire human race in a statistically comparative and contrasting manner, albeit the idea under considerations being perplexing (Wiley and Solomon, 1998; Carretero and Pozo, 2010; Mbila, 2013; Brevik and Sauer, 2014). At the same time as in Nigeria, soils are appropriately combined with plant substances to form medicinal soils, which are used to ease stomach ailments and dysentery (Magnetic Clay Baths, 2006). Whereas in Bolivia, Peru and Arizona geophagy was used to eliminate the bitterness of wild potatoes during consumption and prevent stomach pains and vomiting (Wilson, 2003) and consequently, any form of human toxicity as previously observed in California, Sardinia and Sweden (Magnetic Clay Baths, 2006).

Beyond geophagy, as shown in Table 2, a number of local communities in Kenya use soil pastes to relive immediate burns as a first aid strategy. This practice is commonly known amongst ethnopractitioners of almost every local community. Whereas in a number of African communities such as those of South Africa, clay soils have been traditionally used for cleansing and cosmetic purposes involving sunscreening and body beautification (Matike et al., 2010; 2011).

Types of soils chewed and eaten in Kenya

Clay stones

In Kenya, the interviewee claimed that the clay stones sold to them come from Kisii, Mombasa, Baringo, Meru, Murang'a and Migori Counties with almost a wide range of colours. For instance in Migori County, the clay stones obtained are yellow and brown while the rest from other Counties are mainly gray, cream white and brownish as shown in Figures 1 (a) and (b). This difference in colouration could be attributed to the differences in the mineral elements' composition of the soils, more particularly, the composition of iron, aluminium, copper, silicon, zinc and manganese compounds as well as quartz, granite and heavy black minerals are crucial. For instance; yellow or red soils suggest the presence of iron oxide compounds, which may exist as oxidized forms

(a) (b) (c)

Figure 1. Gray (left) and brownish (right) (a) clay soil stones harvested, prepared and brought to the market for sale, targeting women, particularly pregnant ones. The soil stones were obtained from a local market, Korokocho in Nairobi, Kenya (b). They had been harvested from Murang'a County, central Kenya and brought to Nairobi where they were cut into small pieces using a panga for sale by vendors in small green grosseries while packed in polythene bags and plastic tins as shown in Figures 1 (b) and (c). About 9,000Kgs of clay soil stones are brought to Nairobi at any one given moment as alleged by the vendor of this Kiosk in Figure 1 (b) in Korokocho Market. *Photographs were taken from Ruaraka Subcounty, Nairobi County, Kenya.*

(a) (b)

Figure 2. Soils from ordinary arable farming system (a) and walls of mud houses (b) are occassionally the source sites for chewing and eating soils in many local communities in Kenya. *Photographs were taken from Kakamega, Bungoma and Lamu Counties, Kenya.*

(a) (b) (c) (d)

Figure 3. Termite shelter tubes on:- (a) a tree trunk provide cover for the trail from nest to forest floor, building it by making use of cork of trees (*Accacia* spp. in this case), (b) dried pieces of wood lying on the vegetation in open grasslands (c) bare ground in dry areas and (d) walls of buildings. *Photographs were taken from Kasarani Subcounty, Nairobi County ((a), (b) and (d)) and Kitui County (c), respectively, Kenya*.

(a) (b)

Figure 4. The trunks of trees without enough cork and/or the required termite nutrients in the canopies do not have protective termite shelter tubes, the extensions of the mound tunnels. *Photograph was taken from Kasarani Subcounty, Nairobi County (a) and Kitui County (b), respectively, Kenya*.

(c) (c) (c)

Figure 5. The natural selective behaviour of termites during the building of termite shelter tubes on dried pieces of wood (a) and (b) and the building of termite mound through dried thickets (c) in the wild. *Photographs were taken from Kasarani Subcounty, Nairobi County (a) and Kitui County (b) and (c), respectively, Kenya.*

(indicating red soils), hydrated oxides (indicating yellow soils) and as reduced forms (indicating gray soils) (Lynn and Pearson, 2000; Brady and Weil, 2006). Conversely, soil colour, while easily recognized and may give a clue to mineral content of a soil, has little use in predicting soil characteristics (Donahue et al., 1977). However, this is contrary to the suggestions of Carretero and Pozo (2009) in their review of the physical and physico-chemical properties of clay and non-clay minerals in Spain. Eating and/or chewing these clay stones by people generally other than pregnant women is believed to prevent frequent spitting of saliva, a behaviour that is considered abnormal/disreputable as it makes the environment dirty and even make other people in the neighbourhood to vomit and lose appetite for food. The brownish stones harvested from Murang'a County in central Kenya are believed to ease kidney and liver ill-health problems and a number of women interviewed at the site during the visit at Korokocho market (Figure 1) preferred the gray stones for their high nutritional and medicinal values of iron as they are made to understand. The vendor of the Kiosk shown in Figure 1 (b) further claimed that a number of health workers (particularly nurses from hospitals) normally come to buy the clay stones from him for use to alleviate health problems and how they use them is not known. In the course of the discussion at Korokocho market in Nairobi, some women confirmed that when they take conventional iron tablets, the graving behaviour of chewing and eating soils disappears, thus confirming the nutritional value and requirement associated with geophagy (Hooda et al., 2004; Abrahams et al., 2006; Abrahams et al., 2013). This further underscores the advice of conventional practitioners to pregnant mothers to use iron tablets instead of chewing and eating soils, which are considered to be a health risk (Abrahams, 2012) and to contain undetermined amounts of elemental iron content in the consumed soil sample (Nielsen et al., 1990; Smith et al., 2000).

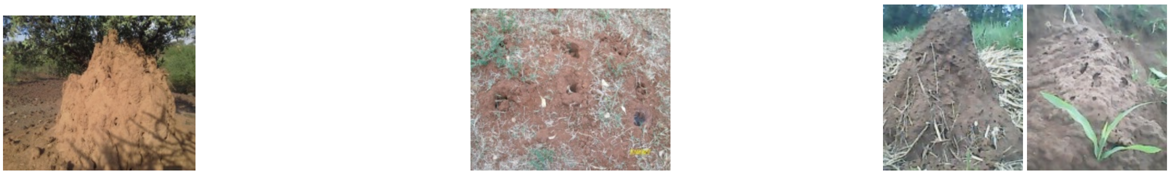
Soil from ordinary arable farms and walls of mud houses

Some women from Kenya particularly in Luo, Kikuyu, Meru, Embu, Nandi, Kisii, Teso and Luhya communities alleged that the smell of soil following rain during a dry season increases the appetite of chewing and eating soils. When this happens, the affected person takes the soil from ordinary arable farming systems immediately for chewing and eating (Figure 2 (a)). While other persons prefer to dig out soils from the walls of mud houses for chewing and eating (Figure 2 (b)). It should however be noted that soils from the walls of mud houses are prepared from ordinary arable farming systems (Figure 2 (a)). The mechanism underlying this graving behaviour is not yet clearly understood albeit being a health risk too as infections from the existing soil helminths, arthropods, protozoa, virus, bacteria, fungi, plants and nematodes of medical importance are inevitable (Jeffery and van der Putten, 2011).

Soils from shelter tubes of termites

Termites are weak and relatively fragile insects that need to stay moist and well protected in order to survive (Turner et al., 2006). They can be easily overpowered by their enemies such as ants and other predators when exposed and/or unprotected. The termites circumvent these risks by covering their trails with shelter tubes made from faeces, plant matter, saliva and soil as extensions of their mound tunnels (Figure 3) (Aanen, 2006; Wilson, 2007). Thus, the termites can remain hidden and wall out unfavourable environmental conditions and remain safe for a long period of time, thus ensuring sustainability. Sometimes these shelter tubes will extend for many metres, starting from deep down in the soil up to the soil surface to the tree canopies, looking for dead branches and other organic materials to feed on (Figure 3). In Kenya, some people particularly children, when in the field playing and/or working; prefer eating this type of clay soil from termite shelter tubes for unknown reasons. One chewing and eating soils from the termite shelter tubes in Figures 3 (b) and (c) nevertheless, has health risks of contracting soil-borne infections particularly those emanating from helminths and nematode infections in particular due to deposition of infested human feaces and sewage leaks that may be spread around by rainwater, floods and/or moving animals.

More surprisingly, trees without cork on their surface did not have shelter tubes, implying that cork plays a significant role in shelter tube formation on tree trunks and whether or not it contributes to its preference by soil eaters is not known (Figure 4). It will be interesting too to evaluate how cork and selected dried pieces of



(a) *Lifwetere* (Luhya-Wanga) [*Liresi* (Luhya-Bukusu)] (b) *Tsindawa* (Luhya-Wanga) [*Chindawa* (Luhya-Bukusu)] (c) *Eshirunda* (Luhya-Wanga) [*Sirunda* (Luhya-Bukusu)]

Figure 6. Varieties of termite mounds with different clay soils preferred by different persons for chewing and eating. Other termite mounds such as those of *Tsisisi* (Luhya-Wanga) [*Chisisi* (Luhya-Bukusu)] and *Amakabuli* (Luhya-Wanga) [*Kamabuli* (Luhya-Bukusu)] remain underground and do not emerge to appear on the earth's surface and/or above the ground like the ones in this Figure. *Photographs were taken from Kajiado County and Kasarani Subcounty, Nairobi County ((a) and (b), respectively) and Bumula Subcounty, Bungoma County (c), Kenya.*

Figure 7. Termite mound being built by obtaining soil from deep down, rich in mineral elements and exposed on the surface for those practicing geophagy to access it with a lot of ease. *Photograph was taken from Kitui County, Kenya.*

wood (Figure 5), influence the building of termite shelter tubes as demonstrated in Figure 3. Of interest too is the evaluation of the composition of the soils emanating from different termite shelter tubes (Figure 3) and how this difference, if any influence geophagy practices. In Figure 4 (a), across the tarmac road, the faint brownish markings on trunks of trees are shelter tubes and close observation revealed that the trunks have considerable amount of cork. However, the selective building of termite shelter tubes on tree trunks shown in Figure 4 (b) is unique and requires further studies to help explain the underlying differential selection.

Note that, in the background of Figure 5, both plant species (*Tithonia diversifolia* (Hemsl.) A. Gray (a) and *Accacia* spp. (b)), there were other dried pieces of wood including dried grasses but they were not affected in any ways by the termites. More surprisingly, the attacked pieces of wood belong to *T. diversifolia*, a plant that is known in literature to be insecticidal in nature due to the compounds it possesses (Wanzala, 2009; Wanzala, 2014). This selective behaviour of termites on which plant species to feed is further observed during building of termite mounds through dried thickets, which, depending on the type of plants, is never eaten in any ways, the case of Figure 5(c). This behaviour perhaps helps us to identify plants with antifeedant effects and/or insecticidal properties in nature and from which, probably useful phytochemicals can be developed (Midiwo et al., 1997).

Termite mounds

The termite mounds (termitaria) are constructed out of a mixture of soils, termite saliva and dung from termites (Theraulaz et al., 1998; Schmidt and Korb, 2006; Wilson, 2007). In Africa and Australia, the mounds are generally known as “ant hills”. Termites can dig downwards into the soil as far as six feet deep and sometimes beyond, thus bringing hidden soil mineral elements from deep down to the surface (Lobeck, 1939; Turner, 2001; Turner et al., 2006). Different termites build mounds with different soil colours and tastes, thus probably providing the basis for observed preference amongst the users (Figure 6). For instance, in Luo community in Kenya, the soil eaters prefer brown soils to red one for unclear reasons whereas in the Luhya community, the practitioners of geophagy do not like the red soil as it is culturally believed to have been built from the grave site. Nevertheless, preference of soils amongst the population practicing geophagy could be due to its composition related to mineral elements and dietary requirements (Carretero and Pozo, 2009; 2010) rather than being pegged on fun and/or socio-cultural reasons. While a considerable proportion of young women prefer eating soil originating from the termite shelter tubes described in Figures 3 and 5. This could well be placed in the category of nutraceuticals for the sake of clarity in public domain. However, this sorely requires further research to understand the underlying science that may be linked to mound type, its soil composition and preference behaviour amongst geophagy practitioners.

The most striking issue is the fact that these termite mounds shown in Figure 6 are made up of soils obtained from deep down, the main base and source of the much needed nutritional mineral elements in organisms’ bodies (Figure 7). Moreover, this type of soil may be relatively less contaminated compared to the mostly encountered surface soil. This therefore implies that geophagy practised amongst organisms’ including humans may by as a result of meeting body nutritional requirements, thus partly underscoring its nutraceutical significance (Carretero and Pozo, 2009; 2010; Brevik and Sauer, 2014).

CONCLUSION

Despite a long history of linking the value of soils to human health, there has not been a great amount of attention focused on this area when compared to many other fields of scientific and medical study as evidenced from the existing body of literature. However, up until the late 20th century much of this linkage was based on antecedal evidence rather than valid and realistic evidence-based scientific research (Brevik and Sauer, 2014). From the foregoing discussions, geophagy may have been the first form of early ethnotherapy applicable to both humans and animals as well as plants but over time, preceded by the robust advancements of conventional medicine. This need to be realized, recognized and pursued in a broader sense of scientific research in a complex framework of different professionals and a strong funding rather than being ignored (Voisin, 1959) and/or narrowing the research to a single field of profession with limited funding (Handschumacher and Schwartz, 2010). Effects such as the influence of geophagy on the evolution of particular DNA sequences (Sing and Sing, 2010) sorely need further investigations as hygiene remains the biggest challenge. To comprehensively understand the full potential of soils to human health, complex interdisciplinary research collaborations and networks are greatly needed to effectively help spearhead the discussions and the underlying science with a special focus on the impacts of the climate change and contaminate wastes such as e-wastes, heavy metals, inorganic and organic chemicals and radioactive/hazardous materials on soils (Morgan, 2013; Loynachan, 2013; Brevik, 2013b; Brevik and Sauer, 2014).

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REFERENCES

1. D.K.Aanen; Biology Letters, 2(2), 209, (2006).
2. P.W.Abrahams, J.A.Parsons; Geogr. J., 162, 63, (1996).
3. P.W.Abrahams; Geophagy and the Involuntary Ingestion of Soil, pp. 435–458, in O.Selinus, B.Alloway, J.A.Centeno, R.B.Finkelman, R.Fuge, U.Lindh, P.Smedley Ed., 'Essentials of Medical Geology', Elsevier Academic Press, Amsterdam, The Netherlands (2005).
4. P.W.Abrahams; Appl Geochem., 27, 954 (2012).
5. P.W.Abrahams, T.C.Davies, A.O.Solomon, A.J.Trow, J.Wragg; PLoS ONE 8(1), e53304 (2013).
6. P.W.Abrahams, M.H.Follansbee, A.Hunt, B.Smith, J.Wragg; Appl. Geochem., 21, 98, (2006).
7. B.J.Alloway; 'Essentials of Medical Geology: Impacts of the Natural Environment on Public Health', Illustrated Ed., Elsevier Academic Press; Amsterdam, (2005).
8. [ACS] American Chemical Society; National Historic Chemical Landmarks, Selman Waksman and Antibiotics. The Waksman Institute, Waksman Foundation for Microbiology, Rutgers University. http://www.acs.org/content/acs/en/education/whatischemistry/ landmarks/selmanwaksman.html., (2005); as retrieved on Tuesday, 19th August, 2014 at 4:59 PM East African Time.
9. G.A.Bagdasaryan; J. Hyg. Epid. Microbiol. Immunol., 8, 497 (1964).
10. W.K.Barnett, J.W.Hoopes; The Emergence of Pottery: Technology and Innovation in Ancient Society, pg 19, in W.K.Barnett, J.W.Hoopes Ed., 'The Emergence of Pottery: Technology and Innovation in Ancient Society', Smithsonian Institution Press, Smithsonian (1995).
11. D.J.Baumgardner; J. Am. Board Fam. Med., 25(5), 734 (2012).
12. T.Beghyn, R.Deprez-Poulain, N.Willand, B.Folleas, B.Deprez; Chem. Biol. Drug Des., 72, 3 (2008).
13. J.Berdy; Are Actinomycetes exhausted as a source of secondary metabolites?, in pg 13–34, 'Proceedings of the 9th Symposium on Actinomycetes' (1995).
14. J.Berdy; J. Antibiot., 58 (1), 1 (2005).
15. T.R.Blakeslee; Greening deserts for carbon credits. Renewable energy World.com. http://www.renewableenergyworld.com/rea/news/article/2010/02/greening-deserts-for-carbon-credits., (2010); as retrieved on Wednesday, 22nd October, 2014 at 1:36 PM East African Time.
16. N.C.Brady, R.R.Weil; 'Elements of the nature and properties of soils', 3rd Ed., Prentice Hall. Inc. (2006).
17. D.M.Bramble, D.E.Lieberman; Nature, 432, 345 (2004).
18. E.C.Brevik, L.C.Burgess Ed., 'Soils and human health'. CRC Press, Taylor and Francis Group, LLC., Boca Raton, (FL) (2013).
19. E.C.Brevik, A.E.Hartemink; Catena, 83, 23 (2010).
20. E.C.Brevik, T.J.Sauer; SOIL Discuss., 1, 51 (2014).
21. E.C.Brevik; Soils and human health – an overview, pg 29–56, in E.C.Brevik, and L.C.Burgess Ed., 'Soils and human health', CRC Press, Taylor and Francis Group, LLC., Boca Raton, (FL) (2013a).
22. E.C.Brevik; Agric., 3, 398 (2013b).
23. K.W.Brown, H.W.Wolf, K.C.Donnelly, J.F.Slowey; J. Environ. Qual., 9, 121 (1979).
24. C.A.Browne; Some relationships of soil to plant and animal nutrition – the major elements, pg. 777-806, in H.G.Knight, C.E.Kellogg, C.P.Barnes, M.A.McCall, B.W.Allin, A.L.Patrick, O.E.Baker, C.R.Enlow, E.N.Bressman, E.N.Munns, G.Hambidge Ed., 'Soils and Men: Yearbook of Agriculture 1938', United States Government Printing Office, Washington DC (1938).

25. C.L.Burras, M.Nyasimi, L.Butler; 2013, Soils, human health, and wealth: A complicated Relationship, pg. 215-226, in E.C.Brevik, and L.C.Burgess Ed., 'Soils and human health', CRC Press, Taylor and Francis Group, LLC., Boca Raton, (FL) (2013).
26. M.I. Carretero, M.Pozo; Appl. Clay Sci., 46, 73 (2009).
27. M.I.Carretero, M.Pozo; Appl. Clay Sci., 47, 171 (2010).
28. M.I.Carretero, C.Gomes, F.Tateo; Clays and human health, pg. 717-741, in F.Bergaya, B.K.G.Theng, G.Lagaly Ed., 'Handbook of Clay Science', Elsevier Academic Press; Amsterdam (2006).
29. W.Chesworth Ed., 'Encyclopedia of soil science', Springer, Dordrecht, The Netherlands (2008).
30. P.D.Christensen; What about soil medicines? Extension Soils Specialist. Cooperative Extension Service, Utah State University, Logan, Utah. www.kalklig.com/Documents/3.1.7%20**Soil**%20**medicines**.pdf., (2014); as retrieved on Tuesday, August 12, 2014 at 3:03 PM, East Africa Time.
31. G.C.Cook, A.I.Zumla; 'Manson's Tropical Diseases', 22nd Ed., Saunders Ltd (2009).
32. G.B.de Deyn, W.H.van der Putten; Trends Ecol. Evol., 20 (11), 625 (2005).
33. J.M.Diamond; Nature, 400, 120 (1999).
34. E.E.Diplock, D.P.Mardlin, K.S.Killham, G.I.Paton; Environ. Poll., 157 (6), 1831 (2009).
35. N.J.Dominy, E.Davoust, M.Minekus; J. Exp. Biol., 207, 319 (2004).
36. R.L.Donahue, R.W.Miller, J.C.Shickluna; 'Soils: An Introduction to Soils and Plant Growth, Prentice-Hall (1977).
37. S.M.Duboise, B.E.Moore, B.P.Sagik; Appl. Environ. Microb., 31, 536 (1976).
38. R.J.Dubos; J. Exp. Med., 70, 1(1939a).
39. R.J.Dubos; J. Exp. Med., 70, 11(1939b).
40. R.J.Dubos, R.D.Hotchkiss; J. Exp. Med., 73, 629 (1941).
41. M.A.Fischbach, C.T.Walsh; Sci., 325, 1089 (2009).
42. T.Gardner, V.Acosta-Martinez, F.J.Calderón, T.M.Zobeck, M.Baddock, R.S.van Pelt, Z.Senwo, S.Dowd, S.Cox; J. Environ. Qual., 41, 744 (2012).
43. L.P.Garrod; Brit. Med. J., 1 (5172), 527 (1960).
44. P.W.Geissler; Afri., 70 (4), 653 (2000).
45. H.M.Gilles, P.A.J.Ball Ed.,` 'Hookworm infections', Elsevier Academic Press, Amsterdam, The Netherlands, (1991).
46. C.S.F.Gomes, J.B.P.Silva; Appl. Clay Sci., 36, 4 (2007).
47. D.Gottlieb; J. Antibiot., 29, 987 (1976).
48. T.Haahtela, L.von Hertzen, M.Mäkelä, M.Hannuksela, M.Erhola, M.Kaila, R.Kauppinen, L.Killström, T.Klaukka, K.Korhonen, A.Lauerma, J.Lindgren, S.Lähteinen, P.Paakkinen, J.Pekkanen, A.Pietinalho, A.Pouta, E.Toskala, O.Vaarala, E.Valovirta, E.Vartiainen, P.Vidgren; Algy., 63, 634 (2008).
49. C.Hagedorn, E.L.McCoy, T.M.Rahe; J. Environ. Qual., 10, 1 (1981).
50. P.Handschumacher, D.Schwartz; Do pedo-epidemiological systems exist?, pg. 355-368, in E.R.Landa, C.Feller Ed., 'Soil and culture', Springer, New York (NY) (2010).
51. J.Hansen, M.Sato, P.Kharecha, D.Beerling, R.Berner, V.Masson-Delmotte, M.Pagani, M.Raymo, D.Royer, J.Zachos; Open Atmos. Sci. J., 2, 217 (2008).
52. K.Hanyu, K.Tamura, H.Mori; Open J. Soil Sci., 4, 36 (2014).
53. R.A.Hayne; 'Make the soil productive: We can't grow good crops on poor land', Educational Series 2, International Harvester Company, Chicago (IL) (1940).
54. R.Highfield; The medicinal monkey; Roots of modern healing found in our hairy relatives. Daily Telegraph, 3rd April, AL9 (2008).
55. H.C.Hinshaw; Am. Rev Tuberculosis**,** 70, 9 (1954).
56. P.S.Hooda, C.J.K.Henry, T.A.Seyoum, L.D.M.Armstrong, M.B.Fowler; Sci. Total Environ., 33, 75 (2004).
57. R.D.Hotchkiss, R.J.Dubos; J. Biol. Chem., 136, 803 (1940).
58. J.M.Hunter, R.de Kleine; Geogr. Rev. 74(2), 157 (1984).
59. J.M.Hunter; Geogr. Rev., 63, 170 (1973).
60. P.Hunter; Harnessing Nature's wisdom. Turning to Nature for inspiration and avoiding her follies. The European

Molecular Biology Organization Reports, 9: 838–840 (2008).
61. S.Jeffery, W.H.van der Putten; Soil borne diseases of humans. Joint Research Centre (JRC) 65787 Scientific and Technical Reports. ISBN 978-92-79-20796-9 (print) (ISBN 978-92-79-20797-6 (pdf)). Publications Office of the European Union, Luxembourg, Italy. http://scholar.google.com/citations?view_op=view_citation&hl=en&user=UkRE4w4AAAAJ&citation_for_view=UkRE4w4AAAAJ:UeHWp8X0CEIC., (2011); as retrieved on Saturday, August 16th 2014, East African Time.
62. H-F.Ji, X-J.Li, H-Y.Zhang; Eur Mol. Biol. Org. Rep., 10(3), 194 (2009).
63. J.S.Joffe; J. Bacteriol., 7, 239 (1922).
64. T.Johns; Annu. Rev. Anthropol., 28, 27 (1999).
65. A.B.Kay, Brit. Med. Bull., 56, 843 (2000).
66. C.E.Kellogg; Soil and society, pg. 863–886, in H.G.Knight, C.E.Kellogg, C.P.Barnes, M.A.McCall, B.W.Allin, A.L.Patrick, O.E.Baker, C.R.Enlow, E.N.Bressman, E.N.Munns, G.Hambidge Ed., 'Soils and Men: Yearbook of Agriculture 1938', United States Government Printing Office, Washington DC (1938).
67. E.S.Kesler; Mineral Resources, Economics and the Environment. Macmillan College Publishing Company, New York, (1994).
68. J.Kerr, N.A.Boswell, J.B.Bennett, F.G.Allan, H.Jaffe, G.Binns, J.H.Kerr, O.H.Blacklay, R.E.Loney, H.E.Bower, W.S.Lynd, H.D.Brice, J.Murphy, J.W.Chadwick, J.B.Murphy, J.D.Chisholm, M.Parkes, R.B.Davidson, J.N.Platt, W.W.Dickson, L.T.Pollard, M.Dwyer, J.R.Robertson, H.English, W.J.A.Russell, F.M.Fellows, W.E.C.Thomas, J.B.Fulton, F.Wraith, R.F.Gerrard, L.J.Picton; Medical Testament – County Palatine of Chester Local Medical and Panel Committee, available at http://journeytoforever.org/farm_library/medtest/medtest.html., (1939); as retrieved on 16th December 2013 at 5:25PM East African Time.
69. S.Khamna, Y.Yokota, S.Lumyong; World J. Microbiol. Biotechnol. 25(4), 649 (2009).
70. I.Kim, E.Yang, D.Shin, K.Son, H.Park, J.Lee; Mol. Med. Reports, 10(2), 1025 (2014).
71. F.E.Koehn, G.T.Carter; Nat. Rev. Drug Discov., 4, 206 (2005).
72. J.M.Kohne, S.Koehne, J.Simunek; J. Contam. Hydrol., 104 (1–4), 34 (2009).
73. S.Krief, M.A.Huffman, T.Sévenet, C.-M.Hladik, P.Grellier, P.M.Loiseau, R.W.Wrangham; Am. J. Primatol. 68(1), 51 (2006).
74. A.A.Kulkarni-Almeida, M.K.Brahma, P. Padmanabhan, P.D.Mishra, R.R.Parab, N.V.Gaikwad; AMB Express, 21, 1(1), 42 (2011).
75. N.Kumar, R.K.Singh, S.K.Mishra, A.K.Singh, U.C.Pachouri; Int. J. Microbiol. Res., 2 (2), 12 (2010).
76. R.Lal; Sci., 304 (5677), 1623 (2004).
77. S.Leake, E.Haege; 'Soils for Landscape Development', CSIRO Publishing, (2014).
78. H.A.Lechevalier; The Search for Antibiotics at Rutgers University, in J. Parascandola Ed., 'The History of Antibiotics: A Symposium American Institute of the History of Pharmacy', Madison (1980).
79. L.H.Lee, Y.K.Cheah, S.M.A.Sidik, N.S.Mutalib, Y.T.Tang, H.P.Lin, K.Hong; World J. Microbiol. Biotechnol., 28, 2125 (2012).
80. T.Leiviskä, S.Gehör, E.Eijärvi, A.Sarpola, J.Tanskanen; Cent Eur. J. Eng., 2 (2), 239 (2012).
81. X-J.Li, H-Y.Zhang; Trends Pharmacol. Sci., 29, 331 (2008).
82. T.Lincke, S.Behnken, K.Ishida, M.Roth, C.Hertweck; Angew. Chem. Int. Ed. Engl., 8, 49(11), 2011 (2010).
83. L.J.Villarreal-Gómez, I.E.Soria-Mercado, A.L.Iglesias, G.L.Perez-Gonzalez; Air, Water and Soil: Resources for Drug Discovery, pg. 309-324, in H.El-Shemy Ed., 'Drug Discovery', 1st Ed., InTech, (2013). Available from: http://www.intechopen.com/books/drug-discovery/air-water-and-soil-resources-for-drug-discovery., as retrieved on

Thursday, October 23rd 2014 at 2:50PM East Africa Time.
84. A.K.Lobeck; 'Geomorphology: An introduction to the study of landscape.' McGraw–Hill Book Company, New York (1939).
85. T.E.Loynachan; Human disease from introduced and resident soil borne pathogens, pg. 107-136, in E.C.Brevik, and L.C.Burgess Ed., 'Soils and human health', CRC Press, Taylor and Francis Group, LLC., Boca Raton, (FL) (2013).
86. W.C.Lynn, M.J.Pearson; The Colour of Soil, The Science Teacher. United States Department of Agriculture, Natural Resources Conservation Services: Soil. Available from: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054286., (2000); as retrieved on Thursday, October 23rd 2014 at 3:38PM East Africa Time.
87. Magnetic Clay Baths; Eating Clay: Lessons on Medicine from Worldwide Cultures. Available from: http://www.magneticclay.com/eating-clay.php., (2006); as retrieved on Friday, 15th August 2014 at 4:50PM East African time.
88. T.Mahmud; Nature's Medicine Chest. Oregon State University laboratory, College of Pharmacy. Available from: http://oregonstate.edu/terra/2010/07/nature%E2%80%99s-medicine-chest/., (2010); as retrieved from Wednesday, August 13th 2014 at 7:02 PM East African Time.
89. N.Mascolo, V.Summa, F.Tateo; Appl. Clay Sci., 15 (5–6), 491 (1999).
90. P.M.Matricardi, S.Bonini; Respir. Res., 1, 129 (2000).
91. A.M.S.Mayer, A.D.Rodríguez, R.G.S.Berlinck, N.Fusetani; Comp. Biochem. Physiol. Part C. Mar. Pharmacol. 2007–8, 153, 191 (2011).
92. M.Mbila; Soil minerals, organisms and human health: Medicinal uses of soils and soil materials, pg. 408, in E.C.Brevik, and L.C.Burgess Ed., 'Soils and human health', CRC Press, Taylor and Francis Group, LLC., Boca Raton, (FL) (2013).
93. J.E.McMurtrey, W.O.Robinson; Neglected soil constituents that affect plant and animal development, pg. 807-829, in H.G.Knight, C.E.Kellogg, C.P.Barnes, M.A.McCall, B.W.Allin, A.L.Patrick, O.E.Baker, C.R.Enlow, E.N.Bressman, E.N.Munns, G.Hambidge Ed., 'Soils and Men: Yearbook of Agriculture 1938', United States Government Printing Office, Washington DC (1938).
94. J.O.Midiwo, A.L.Mang'uro, W.Wanzala, P.C. Kiprono, W.Kraus, (1997) Anti-feedant principles from the Myrsinaceae and *Polygonum senegalense*. Research paper presented at the workshop on: 'Funding of Agricultural Research: Experiences and Future Perspectives'. Kenya Agricultural Research Institute, Headquarters, Nairobi, Kenya, (1997).
95. P.Mishra, B.C.Semwai, S.Singh; Zoopharmacognosy: Nature's Pharmacy used by animals. Available from: http://greatapetrust.org/zoopharmacognosy-natures-pharmacy-used-by-animals.html/., (2014); as retrieved on Thursday, 23rd October, 2014 at 4:17PM East Africa Time..
96. D.M.E.Matike, G.E.Ekosse, V.M.Ngole; Indilinga: Afr. J. Indigen. Know. Syst., 9 (2): 138 (2010).
97. D.M.E.Matike, G.E.Ekosse, V.M.Ngole; Int. J. Phys. Sci., 6 (33), 7557 (2011).
98. S.Miyadoh; Actinomycetologica, 9, 100 (1993).
99. C.Moeckel, L.Nizzetto, A.Di Guardo, E.Steinnes, M.Freppaz, G.Filippa, P.Camporini, J.Benner, K.C.Jones; Environ. Sci. Technol., 42 (22), 8374 (2008).
100. S.Mondal, S.Bandyopadhyay, M.K.Ghosh, S.Mukhopadhyay, S.Roy, C.Mandal; Med. Chem., 12(1), 49 (2012).
101. R.Morgan; Soil, heavy metals, and human health, pg. 59-82, in E.C.Brevik, L.C.Burgess Ed., 'Soils and human health', CRC Press, Taylor and Francis Group, LLC., Boca Raton, (FL) (2013).
102. D.J.Newman; J. Med. Chem., 51, 2589 (2008).
103. D.J.Newman, G.M.Gragg, K.M.Snader; Nat. Prod. Rep., 17: 215 (2000).
104. G.D.Nielsen, L.V.Jepson, P.J.Jørgensen, P.Grandjean, F.Brandrup; Brit. J. Dermatol. 122, 299 (1990).

105.Nobel e-Museum; Medicines from the Soil: Actinomycetes, in N.Brady, R.Weil, ‘Pfizer Corporation, the Bureau of Land Management: The Nature and Property of Soils’, 12th Ed., Prentice Hall, Inc., Saddle River, (NJ) (1999).
106.Y.Okami, K.Hotta; Search and discovery of new antibiotics, pg. 37-67, in M.Goodfellow, S.T.Williams, M.Mordarski, Ed., ‘Actinomycetes in Biotechnology’, Academic Press, London, UK (1988).
107.M.A.Oliver; Eur. J. Soil Sci., 48, 573 (1997).
108.M.Oskay, Ü. A.Tamer, C.Azeri; Afr. J. Biotechnol., 3 (9), 441 (2004).
109.B.Pandey, P.Ghimire, V.P.Agrawal; International Conference on the Great Himalayas: Climate, Health, Ecology, Management and Conservation, Kathmandu, Organized by Kathmandu University and the Aquatic Ecosystem Health and Management Society, Canada (2004).
110.I.L.Pepper, C.P.Gerba, D.T.Newby, C.W.Rice; Crit. Rev. Env. Sci. Tec., 39, 416 (2009).
111.F.V.Pereira, C.A.Ferreira-Guimarães, T.Paschoalin, J.A.Scutti, F.M.Melo, L.S.Silva, A.C.Melo, P.Silva, M.Tiago, A.L.Matsuo, L.Juliano, M.A.Juliano, A.K.Carmona, L.R.Travassos, E.G.Rodrigues; PLoS One, 9(4), e96141 (2014).
112.J.Ponge; Soil Biol. Biochem., 35 (7), 935 (2003).
113.A.Rahman, M.Z.Islam, A.U.Islam; Biotech. Res. Int., (2011).
114.R.Raman, S.Kandula; Resonance: 245 (2008).
115.A.R.Ranjbariyan, M.Shams-Ghahfarokhi, S.Kalantari, M.Razzaghi-Abyaneh; Iran. J. Microbiol., 3(3), 140 (2011).
116.K.Rezaei, B.Guest, A.Friedrich, F.Fayazi, M.Nakhaei, S.M.F.Aghda, A.Beitollahi; J. Soils & Sediments, 9, 23 (2009).
117.G.A.W.Rook; Clin. Exp. Immunol., 160, 70 (2010).
118.T.J.Rowbotham; J. Clin. Pathol., 33, 1179 (1980).
119.A.Sakula;, Brit. J. Dis. Chest, 82, 23 (1988).
120.J.J.Sanglier, H.Haag, T.A.Huck, T.Fehr; Res. Microbiol., 144 (8), 633 (1993).
121.C.P.W.Sarah; Soil may be source of drug-resistant Bacteria. Available from: http://news.sciencemag.org/biology/2012/08/soil-may-be-source-drug-resistant-bacteria., (2012); as retrieved on Tuesday, August 12th, 2014 at 3:03PM, East Africa Time.
122.A.Schatz; Streptomycin, an antibiotic produced by *Actinomyces griseus*, PhD dissertation, Rutgers University, New Jersey, USA.
123.A.Schatz, S.A.Waksman; Proc. Soc. Exptl. Biol. and Med., 57, 244 (1944).
124.A.Schatz, E.Bugie, S.A.Waksman; Ibid, 55, 66 (1944).
125.A.M.Schmidt, J.Korb; The biological significance of magnetic termite mounds, The IUSSI 2006 Congress, Washington, DC. Available from: http://iussi.confex.com/iussi/2006/techprogram/P1435.HTM., (2006); as retrieved on Tuesday, August 12th, 2014 at 4:45 PM, East Africa Time.
126.O.Selinus; AMBIO: A J. Hum. Environ., 36 (1), 114 (2007).
127.O.Selinus, B.Alloway, J.A.Centeno, R.B.Finkelman, R.Fuge, U.Lindh, P.Smedley, Ed., ‘Essentials of medical geology’, Elsevier Publishing Press, Amsterdam, The Netherlands, (2005).
128.E.Z.F.Setz, J.Enzweiler, V.N.Solferini, M.P.Amendola, R.S.Berton; J. Zool., 247 (1), 91 (1999).
129.D.Sing, C.F.Sing; Int. J. Environ. Res. Publ. Health., 7, 1205 (2010).
130.H.C.W.Skinner, A.R.Berger; Ed., ‘Geology and health: Closing the gap’, Oxford University Press, Oxford, UK (2003).
131.B.Smith, B.G.Rawlins, M.J.A.R.Cordeiro, M.G.Hutchins, J.V.Tiberindwa; J. Geol. Soc. London, 157, 885 (2000).
132.F.R.Stermitz, P.Lorenz, J.N.Tawara, L.A.Zenewicz, K.Lewis; Proc. Natl. Acad. Sci. USA 97, 1433 (2000).
133.G.Strobel, B.Daisy; Microbiol. Mol. Biol. Rev., 67 (4), 491 (2003).
134.G.Theraulaz, E.Bonabeau, J.-L.Deneubourg; Complexity, 3(6), 15 (1998).

135. J.S.Turner; Physiol. Biochem. Zool., 74(6), 798 (2001).
136. J.S.Turner, E.Marais, M.Vinte, A.Mudengi, W.L.Park; Agricola, 16, 40 (2006).
137. H.L.van Epps; J. Exptl. Med., 203, 259 (2006).
138. D.E.Vermeer, R.E.Ferrell Jr.; Sci., 227, 634 (1985).
139. R.Verpoorte, D.Crommelin, M.Danhof, L.J.Gilissen, H.Schuitmaker, J.van der Greef, R.F.Witkamp; J. Ethnopharmacol., 121, 479 (2009).
140. L.C.Vining; Annu. Rev. Microbiol., 44, 395 (1990).
141. Voisin, A., 1959, Soil, grass, and cancer, New York, NY, USA, Philosophical Library Inc.
142. B.H.Waksman, H.A.Lechevalier; Waksman, Selman Abraham. Complete Dictionary of Scientific Biography. Available from: http://www.encyclopedia.com., (2008); as retrieved on Tuesday, 19th August, 2014 at 11:29AM East Africa Time.
143. S.A.Waksman, H.A.Lechevalier; Sci., 109, 305 (1949).
144. S.A.Waksman, H.B.Woodruff; Proc. Soc. Exp. Biol. Med., 45, 609 (1940).
145. S.A.Waksman; 'Principles of Soil Microbiology', Williams & Wilkins Co., Baltimore, (1932).
146. H.A.Waldron; Brit. J. Ind. Med., 42, 793 (1985).
147. W.Wanzala; 2009, 'Ethnobotanicals for management of the brown ear tick, *Rhipicephalus appendiculatus* in western Kenya', 1st Ed., Printed by Ponsen & Looijen, Wageningen, The Netherlands, (2009).
148. W.Wanzala; A survey of the management of livestock ticks and other aspects of animal ethno health in Bukusu community, western Kenya. Livestock Research for Rural Development. Volume 24, Article #173. Retrieved October 3rd, 2012, available from http://www.lrrd.org/lrrd24/10/wanz24173.htm., (2012).
149. W.Wanzala; Chemical composition of essential oil of *Tithonia diversifolia* (Hemsl.) A. Gray from the southern slopes of Mount Elgon in western Kenya. Journal of Essential Oil Bearing Plants (in press).
150. A.S.Wiley, H.K.Solomon; Curr. Anthropol., 39 (4), 532 (1998).
151. M.J.Wilson; J. Chem. Ecol., 29, 1525 (2003).
152. T.V.Wilson; How Termites Work. Published on 11th September, 2007, available from: HowStuffWorks.com. http://animals.howstuffworks.com/insects/termite.htm., (2007); as retrieved on Sunday, 17th August, 2014.
153. R.D.Woodyer, Z.Shao, P.M.Thomas, N.L.Kelleher, J.A.V.Blodgett, W.W.Metcalf, W.A.van der Donk, H.Zhao; Chem. Boil., 13 (11), 1171 (2006).
154. G.R.Zimmermann, J.Lehár, C.T.Keith; Drug Discov. Today, 12, 34 (2007).