SOIL POLLUTION: CAUSES, EFFECTS, REMEDIATION AND MATHEMATICAL MODELING

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Keywords: Soil formation, pollutants, soil contamination, food chain, pesticides, fertilizers, pesticides, synthetic fertilizers, groundwater, health effects, environmental effects, restoration, *ex-situ* restoration, *in-situ* restoration, Darcy's law, continuity of flow, mathematical modeling.

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Industrial and other activities worldwide for wealth creation through economic development is exacting an increasing toll in terms of relentless environmental degradation of nature's environmental capital without which life on earth cannot exist.

Indeed, today environmental degradation is so ubiquitous and so increasingly serious for all three compartments of the environment — air, water and soil — that it is hard to be optimistic about the prospects of future generations.

The global economic down-turn, which began in earnest in 2008 has also exacerbated matters considerably to the extent that today most people everywhere, including even the educated and hitherto fairly well-to-do people in North America and Europe, are having a hard time providing food and shelter for themselves and their families; under these circumstances the finer points of environmental protection and sustainable development are a distraction they can scarcely afford.

Fertile soil, without which much of the food and fiber we consume cannot be grown, is obviously one of nature's crucial benedictions without which it would be difficult for life on earth to exist and flourish. Yet, mainly modern industrial and agricultural activities have been degrading soil worldwide as never before, and this does not augur well for future generations.

This chapter is mainly for the benefit of readers whose knowledge of soil pollution is currently limited and who would like to know more about it. A fairly comprehensive account of soil pollution is given focusing on the following and closely related issues, including the on-going global economic down-turn: Causes of soil contamination; how soil contaminants reach the food chain; health impacts of soil contamination; environmental impacts of soil contamination; methods of cleaning-up contaminated soil; and mathematical modeling of groundwater flow in saturated soil media.

The style of writing is deliberately simple, and a relatively large glossary is included mainly to explain technical terms used in text. It is very much hoped that Readers will derive significant benefit in terms of knowledge gained from this chapter.

Keywords: soil; contamination; synthetic; fertilizers; pesticides; groundwater; flow; health effects; environmental effects; heavy; metals; impacts; restoration; *ex-situ* restoration; *in-situ* restoration; Darcy's law; continuity of flow; mathematical; modeling.

1. Introduction

"Man has lost the capacity to foresee and to forestall. He will end by destroying the earth". Albert Schweitzer

It is no exaggeration to say that modern "civilized" lifestyle, which is quintessentially Western in origin and has deeply permeated practically all societies everywhere, has been extracting an increasingly high price in terms of relentless environmental degradation which it has been causing in all three compartments of nature — air, water and soil. In fact, conversion of the remainder of the world population to this particular lifestyle using a variety of ploys, including colonial subjugation, has been so effective and thorough that communities everywhere have been gleefully abandoning their ancient cultural values that taught them to live in harmony with nature and adopting western values that are based on gross abuse and exploitation of nature's bountiful benediction without which life on earth cannot exist (Nath, 2003). The following excerpt from the *Living Planet Report 2000* (WWF, 2000) concentrates the mind with regard to the severity of degradation being inflicted on Mother Earth:

"Man has wiped out a third of the natural world in the last thirty years and soon will have to start looking for a new planet to live on……..The scale of devastation is so great that man will have used up all the Earth's natural resources by 2075……If every human alive today continues to consume resources and produce carbon dioxide at the same rate as the average Briton, we will need to colonize at least two Earths to survive…….Our current rate of consumption is eroding the very fabric of our planet and will ultimately threaten our long-term survival." (WWF, 2000)

It is sobering to consider the logical implication of the above. If we fail to colonize at least two earths by around 2075 — and we have yet to find even one in the unimaginable vastness of the Cosmos let alone colonize it — the earth will become so polluted and denuded of vital life-support systems that it would no longer be fit for human habitation.

However, the culture on which the aforementioned "civilized" lifestyle is based, and especially the profligate, polluting and unsustainable consumption of nature's precious environmental capital which sustains it, has now been unraveling to expose its ugly foundation which is now seen by all to be made of several of the seven deadly sins — acute and insatiable corporate greed of the rich and powerful US corporations in particular that are even dictating US federal legislation and regulatory agenda. Many of the so-called "Financial terrorists" (Keiser and Herbert, 2011) come from such corporations and large US banks; some of the latter are characterized as "too big to fail". Although these "Terrorists" represent a mere one percent or so of US population, comprising mainly of bankers, financiers and CEOs of large corporations and their assorted political lackeys in Washington DC and elsewhere, allegedly at present this tiny minority owns an estimated sixty percent of that country's wealth (Keiser and Herbert, 2011). Certainly, greed is a rather unattractive feature of human nature and even the ancient Greeks knew that the demands of greed are open-ended (see, for example, Aristophane's *Wealth*). However, extreme and all-consuming greed, which appears to have seriously infected this "one percent", is something else — it is altogether more pernicious as never before. This greed of the "one percent" has been (and continues to be) so all-consuming and ruinous for everyone else that in 2008 it nearly brought the entire global infrastructure of capitalism to its knees. By using all kinds of criminal ploys — from creative accounting to fraud, deceit and theft — this "one percent" has hugely benefited at the expense of everyone else. And, given the door-mat like timidity of governments to legislate effectively against such criminal behavior driven by extreme greed, there is no guarantee that in future the "one percent" will not repeat the same performance which has been so profitable to them. It is interesting to speculate if Karl Marx had such extreme form of greed in mind when he observed in his book, *Das Kapital*, that "…capitalism contains the seeds of its own destruction" (Marx, 2009).

The genesis of the current economic catastrophe engulfing much of the world, which began to manifest itself in 2007-2008, can be traced back to the excessive greed of many of the US bankers and their cohorts who perpetrated the gigantic and scandalous "sub-prime mortgage" swindle. The swindle was deliberately designed to enrich them by defrauding the poor people of the USA, mainly the Hispanic and black people. Far too many of them have now lost everything, thanks to that swindle. These mortgages were sold by well-known and hitherto respected US banks and financial institutions to other banks worldwide as "highly profitable and attractive investment products" after making them as incomprehensible as possible so that even the financial experts at the purchasing banks could not understand them. They bought them nevertheless in good faith on the understandable assumption that respected banks in the "Land of the free" could not possibly stoop so low as to swindle them. However, soon afterwards these "attractive" investment products were found out to be what they really were — worthless and fraudulent "toxic investment" products. Amazingly, none of the perpetrators of the swindle has yet been brought before a court of law to answer charges of criminal fraud and/or misdemeanor.

This swindle is having a serious impact on the environment, too. This is because historically, and for entirely understandable reasons, environmental projects and activities either suffer badly during an economic down-turn, or are cancelled because of scarcity of funds. This reflects the fact that in the epic struggle between ecology and economy the latter is the winner most of the time, if not all the time. Slow-down in environmental activities is already happening, and it is very likely to exacerbate in the years to come before hopefully world economy recovers from its current man-made predicament.

Global environmental prospects were gloomy even before the onset of this economic predicament and, by all accounts, the current economic crisis is likely to make it worse before it gets better. Indeed, growing environmental degradation is now so ubiquitous and becoming so serious that it is increasingly hard to find reasons to be optimistic about the prospects of any of the three compartments of the environment — air, water and soil. Even so, determined efforts must continue to be made in the interests of both intra-generational and inter-generational equity, especially the latter for the benefit of generations yet unborn.

This chapter is about soil pollution. Unquestionably, soil fertility is one of nature's crucial benedictions without which food or fiber cannot be grown at the very least. Yet, fertile soil is being lost and degraded worldwide at an alarming rate due to a variety of reasons including erosion, desertification and contamination. The last is due to the application of synthetic fertilizers, pesticides and herbicides in agriculture as well as contamination of soil by heavy metals and harmful industrial chemicals. Many of these contaminants enter the food chain following their uptake by growing plants. Our purpose here is to inform the uninformed and students of environmental science, technology or management about soil contamination focusing on the following:

- Causes of soil contamination.
- How soil contaminants reach the food chain.
- Health impacts of soil contamination.
- Environmental impacts of soil contamination.
- Methods of cleaning-up contaminated soil.
- Mathematical modeling of groundwater flow in saturated soil media.

The style of writing is deliberately simple for the benefit of readers with limited knowledge of soil pollution and closely related issues. A fairly extensive Glossary is provided to help matters to that end.

2. Soil Formation and Key Soil Properties Relevant to the Transport of Pollutants in Soil and Their Fate

2.1. Soil Formation

In common parlance the word "Soil" refers to the upper layer of earth on which plants grow and which is generally composed of disintegrated rock usually mixed with organic matter, living organisms and micro-organisms. By contrast decomposed rock, called *rigolith*, does not contain organic matter or living organisms or micro-organisms. Soil is a complex biogeochemical material which forms the interface between earth's crust and the atmosphere. Generically it is made up of mineral grains, rock fragments and organic matter; and the relative proportions of these constituents vary from place to place. Soil is also known as "Earth" — the name of our planet — and its composition as well as physical, chemical and biological properties vary widely from place to place depending on the properties of the underlying weathering parent rock, climatic conditions and micro-organisms among others. Disintegrated rock refers to rocks that have been broken down into particles over geological time by chemical and environmental processes including weathering and erosion (Buol *et al*. 2003). With a mass density of between 1 and 2 gm/cm^3, soil is a natural material whose formation usually occurs in layers called "Soil horizons". And these horizons form the basis of the morphological classification of soil. Soil is also earth's most abundant ecosystem because just one gram of some soils may contains up to one million microbe species, most of which are still unknown to science (Kohnke and Franzmeier, 1994).

People's perception of soil differs widely. To a farmer or a horticulturalist it is the medium on which to grow plants. To a geologist it is the product of past processes that occurred on earth's surface over time; a pedologist sees it as a natural medium in which current physical, chemical and biological processes are taking place; while to a civil or geotechnical engineer it is a material on which to build all kinds of structures such as roads, bridges, tunnels, buildings, dams, etc. Soil properties of interest also vary accordingly. For example, a farmer would be most interested in those properties of soil (such as pH and nutrients) essential for strong and healthy plant growth, while a civil engineer would be most interested in the mechanical properties of soil such as shear strength, permeability, etc.

The process of soil formation, also called *pedogenesis*, begins when the parent rock (i.e. rock which is disintegrated, generally in part, eventually to become soil) is acted upon in concert by physical, chemical, biological as well as anthropogenic processes. Different kinds of parent rock (or parent material) eventually become soil, such as weathered primary bedrock; secondary material such as alluvium and colluvium transported from other locations by wind, water and/or gravity; old soil formations; as well as anthropogenic materials such as landfill or mine waste. The processes mentioned above variously involve additions, transformations, losses and translocation (i.e. movement of material from one area to another) of materials that produce soil and create horizons (layers) in the soil profile. These processes also unlock the mineral contents present in the parent rock to provide mineral trace elements in soil which plants need for healthy growth (Kohnke and Franzmeier, 1994; Schaetzl and Anderson, 2005).

In terms of mass, the proportion of organic matter in soils is small compared with non-organic matter. Even so, organic matter has a disproportionately large influence on the physical and chemical properties of soil, especially with regard to the behavior of pollutants in soil.

All soils contain organic matter, called "Humus", although the amount and type of such matter may vary considerably. Most living things in soils such as plants, insects, bacteria, etc., need humus for energy and nutrition. Important constituents of humus, which is a highly polymerized and colloidal substance, as well as humic compounds are *humic acid* and *fulvic acid* which derive from decaying plant residues such as roots, stem and foliage. Deposition and breakdown of these residues is accompanied by the formation and accumulation in the soil of *humin*, *lignin* and *lignin complexes*; and an increase in proteins occurs as the decaying plant matter is consumed by micro-organisms (Buol *et al.*, 2003). When plants die, they fall on soil surface where they decompose and are consumed by various organisms. This causes mixing of dead organic matter with upper soil layers and, as a result, the organic matter eventually becomes part of the soil itself (Kohnke and Franzmeier, 1994).

Plants, fungi, bacteria, animals and even humans affect the process of soil formation. Typically, feeding activities of burrowing animals (such as earthworms) and micro-organisms mix soils and create pores in the soil that allow moisture and gases to seep into deeper layers, while roots of plants, especially plants with deep taproots (such as alfalfa, forage radish and yellow clover) that can penetrate many meters through different soil layers, bring up plant nutrients and trace elements from deep soil horizons. Micro-organisms such as fungi and bacteria also affect chemical changes that occur between plant roots and soil; they also act as a reserve of nutrients.

The impact of vegetation on soils can be significant or even substantial and, clearly, the type and amount of vegetation that grows at a given location depends on soil properties and climatic conditions prevailing at that location. While the root system of vegetation acts as the fabric of a "Carpet" on soil surface holding particles and parcels of soil together, removal of that fabric by humans, and especially by grazing animals such as goats, can make soil vulnerable to erosion, often rendering it barren in arid regions. In some countries of Sub-Sahelian Africa and Central America (Geist, 2005), among others, this process has caused serious loss of top soil by floods, water and wind leading to catastrophic landslides and desertification in several cases. Surface vegetation also acts as a cover which significantly reduces evaporation of soil moisture.

Soil formation, as well as surface horizons of soils, is a function of time, too. Under dry conditions, during a prolonged drought for example, top soil is likely to be blown away by wind and deposited elsewhere either to increase the thickness of the top soil there, or to build up new soil horizons there. In short, soils and especially soil horizons near the earth's surface are always changing following their own dynamic as determined by the interactions of climate and other soil-forming factors. What should concentrate the mind *vis-à-vis* soil conservation is the fact that nature takes between 800 and 1,000 years to form a fertile soil layer just 25 mm thick (Kohnke and Franzmeier, 1994; Schaetzl and Anderson, 2005).

2.2. Relevant Properties of Soil

Soil permeability, pH and redox conditions are three of the many physical, chemical and biological properties of soil. Permeability is the property which significantly influences the behavior of pollutants in soil with particular regard to their movement (transport) and fate. In soil mechanics permeability of a saturated porous material such as soil is defined as a measure of its ability to allow a fluid such as water to flow through it, while the pH value of a soil indicates how acidic or basic it is (see Glossary).

Regardless of particle size, a soil sample contains void spaces between soil particles which, with good connectivity, form a continuous system of pores that may contain air and/or water and through which water can flow when the soil is fully saturated (Figure 1). The amount of void space in a given soil is determined by the size and shape of the dominant mineral grains and their grading characteristics. And clearly, greater the void space, greater the soil porosity, and therefore greater the soil permeability. Thus, a soil containing mostly large-size grains, such as coarse sand with grain size of 0.6 to 2.0 mm for example (see Table 1), is more porous and therefore more permeable than coarse silt with grain size of 0.02 to 0.06 mm. Such porous and therefore permeable soils, whose average pore diameter is greater than 30μm ($1\mu m=10^{-6}m$), are unable to hold pore water against gravity, and water seeps out as a result. On the other hand, soils with average pore diameter smaller than 30μm can hold pore water against gravity, and much of this water may be available to plant roots (Kohnke and Franzmeier, 1994; Cedergren, 1997). Typically, intrinsic permeability of well-sorted sand can vary from 10^{-5} to 10^{-8} cm^2, and from 10^{-9} to10^{-14} cm^2 for silty clay (Reible, 1999, page 453).

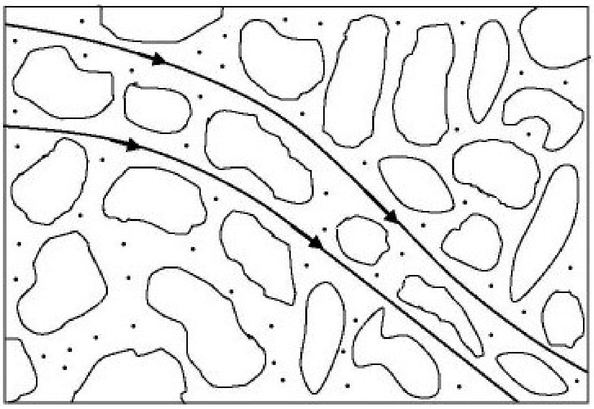

Figure 1. Schematic showing how joined-up voids in soil create continuous channels through which groundwater flow takes place

In principle, what is called *specific or intrinsic permeability* of a soil medium is determined only by the relevant characteristics of the medium itself. However, in reality there are examples in which relevant characteristics of the medium, and consequently its permeability, are altered by (a) actions of the flowing fluid; and (b) by the properties and/or composition of the fluid itself. Water flowing through swelling clays is a typical example of (a), while an example of (b) is the flow through soil of water containing fatty substances whereby soil pores are clogged up, much like cholesterol clogs up human arteries, and this alters (reduces) the permeability and related properties of the soil medium in question.

	Type	Size (mm)
	Boulders	>200
	Cobbles	60–200
Gravel (G)	Coarse Medium Fine	20–60 6–20 2–6
Sand (S)	Coarse Medium Fine	0.6–2.0 0.2–0.6 0.06–0.2
Silt (M)	Coarse Medium Fine	0.02–0.06 0.006–0.02 0.002–0.006
Clay (C)		<0.002

Source: British Soil Classification System; BS 5930:1981; *Site Investigation.*

Table 1. British Soil Classification System

Clearly, the ease with which water or moisture is able to move in a soil medium is determined by its permeability — greater the porosity and therefore permeability, greater the ease of motion. The pH of soil, on the other hand, is an important physico-chemical parameter which affects plant growth as well as behavior of soil pollutants. The pH value of a soil sample gives the concentration of H^+ ions in the pore water of the soil that are in equilibrium with the negatively charged surfaces of the soil particles.

Normally pH values of soils lie within the range 4–8.5. In humid regions of the world soils tend to be acidic (pH=5 to 7), while they tend to be basic (pH=7 to 9) in the arid regions. In the temperate regions, such as northern Europe for example, optimum pH values for arable soils and grasslands are 6.5 and 6.0 respectively (Alloway, 1994). An important way in which soil acidity affects the behavior and fate of organic pollutants is when soil pH lies outside the range of 6-8; because then microbial degradation of organic pollutants becomes ineffective.

What is called the Redox Condition (see Glossary) is a useful indicator of the oxygen available in soils to supply the biological demands of plant roots and resident micro-organisms. It is also a significant determinant of the fate of pollutants in soils. While micro-organisms act as catalysts in redox reactions in soils, a much larger quantity of oxygen is consumed by flora, fauna and micro-organisms that live in soils. Elements such as C, N, O, S, Fe and Mn, and to a lesser extent Ag, As, Cr, Cu, Hg and Pb, are affected by redox conditions in soils (Alloway, 1994; Sparks, 2002). Some of these and other metals (such Mo, Ni and Sb) tend to have strong affinity for adsorption by certain types of clay and soil organic matter. Furthermore, their mobility and bioavailability depends on the organic matter content of the soil, its pH as well as radox conditions (Alloway, 1994; Sparks, 2002). It follows, therefore, that a proper analysis of the fate of pollutants in soils should of necessity include the impacts of soil pH and redox conditions, especially since anaerobic respiratory conditions may exist for micro-organisms when air is squeezed out of the soil by over-compaction and/or water-logging; and this may alter the decomposition products of organic matter (such as volatile acids) and in the speciation of the susceptible metals mentioned above (Alloway, 1994; Sparks, 2002).

3. Causes of Soil Contamination

Historically, in most if not all human communities and settlements earth's surface was perceived and used as something of a waste disposal facility and, unfortunately, more or less the same perception and practice still continue in many parts of the world. However, the difference is that while in the past "waste" comprised mainly food waste, human and animal excreta and other such materials that nature could deal with relatively easily, today's waste is characteristic of so-called "civilized" and "civilizing" societies and comprises increasing quantities of industrial products containing complex xenobiotic chemicals that nature has difficulty in dealing with. As a result there is now relentless contamination of soil by all kinds of man-made chemicals, some of which are increasingly being used either to artificially increase earth's agricultural/horticultural productivity or to extract resources from within it as profitably as possible. In many cases such activities are causing irreversible ecological harm and serious health problems. Extraction of oil and gas from earth's shale formations using what is called "Hydraulic fracturing" (also called "fracking") provides a typical example of this. Currently being practiced in several countries and mainly in the USA, this technology can be environmentally sound if it is properly implemented. If not, or if corners are cut for making greater profit, it can cause, *and it is causing*, soil and groundwater pollution problems impacting on, and with serious implications for, both ecosystems and human health. The fact remains, however, that today we know little about the health impacts — carcinogenic and mutagenic potentials in particular — of dangerous chemicals such as dioxins, PCBs, etc., after they have been ingested.

The other obstacle thwarting progress towards a more robust regime for the regulation of toxic and very toxic man-made chemicals, and banning them if deemed necessary to do so, is lack of political will in countries like Canada and the USA where, incredulous as it may appear, the all too powerful chemicals industry fronted by its lobbyists in Washington DC are allegedly setting the agenda for regulating such chemicals. Normally, what should concentrate the minds of policy-makers are many examples that can be given, of which the following is typical: currently it is perfectly legal in Canada to bathe babies in a bubble-bath containing a known carcinogen which is banned in the EU (Garcia, 2011). But it is not happening in Canada or the USA, and policy-makers there do not seem to be bothered by this, probably because clever spin-doctors who work for giant chemicals corporations, and/or politicians in their payroll who ostensibly act as their "Consultants", are handsomely rewarded for publicly refuting any such negative claims that are patently bad for corporate "bottom lines". Also, allegedly policy-makers would consider tightening-up regulation to control toxic and highly toxic man-made chemicals in the USA if/when they see “bodies floating in the river” (Garcia, 2011). How exquisitely grotesque! Indeed, it may be argued that in framing legislation to control known toxic chemicals and products, more often than not the US Chemical Lobby gets its way in the US Senate (e.g. http://www.commondreams.org/newswire/2010/11/19-5).

In this regard the situation in the EU is hardly any different. For example, ever since the REACH (Registration, Evaluation and Authorisation of Chemicals) program began to be discussed for possible development and implementation to control toxic and very toxic chemicals within the EU, the Anti-REACH Alliance of the EU went into overdrive aiming to kill off the program because, as they saw it, it was bad for their business. This powerful alliance included the European Chemical Industry Council (CEFIC), the German Chemical Industry Association (VCI) and, surprisingly, a certain Mr. Günter Verheugen who was the then Vice-President of the European Commission, and Commissioner responsible for Enterprise and Industry. With its enormous financial resources and political clout the Anti-REACH Alliance has been successful, however, because in the final version of REACH, which was accepted and came into force on the first of June 2007, original REACH proposals have been so diluted as to make them virtually “toothless” and probably significantly useless, too (Contiero, 2006; Nath, 2008).

Soil is a non-renewable environmental resource without which foodstuff cannot be grown. Unfortunately, it is being degraded alarmingly — loss of organic matter and relentless contamination by all kinds of man-made chemicals being the most serious causes for concern in Europe (Tóth, Montanarella and Rusco, 2002) and in many other parts of the world. In many of the countries of the world there are regulatory regimes in place for controlling pollutant dumping that look impressive on paper. Unfortunately, enforcement is often lax and problematic, not least because those responsible for enforcement can be persuaded by suitable inducements to turn a blind eye, even in the USA where apparently money and profit transcend *all* other considerations. Indeed, in the USA alone millions of tons of chemical waste are being dumped in the soil and sea, and spewed out into air resulting in long-term adverse implications for all life. And soil is contaminated with over one hundred or so active pesticides which damage immune and endocrine systems; cause cancer and congenital birth defects as well as genetic mutation in both humans and animals (www.buzzle.com/articles/soil-pollution-facts.html). It is indeed sobering to know that sustained and high economic growth of the People’s Republic of China since the 1970s has exacted a high price in the form of increased soil pollution. According to scientific sampling, 100,000 km^2 of that country’s cultivated land has been polluted; and an estimated 12 million tonnes of grain are contaminated by heavy metals every year causing direct losses of an estimated 2.57 billion USD (20 billion Yuan) (en.wikipedia.org/wiki/soil_contamination).

A wide variety of mainly anthropogenic pollution sources are responsible for contaminating soil (Alloway, 1994; Paul and Barrass, 2001), and these sources are mainly and sometimes exclusively meant for, or concerned with, producing goods for macroeconomic development through industrialization and/or services for human welfare in industrialized and industrializing societies. Some of these sources are described below. It is pointed out, however, that the list is by no means complete.

(a) *Dry and wet deposition:* There are numerous industrial, economic and related anthropogenic activities, some mentioned below, which create all kinds of atmospheric pollutants including heavy metals such as Cd, Pb and Hg discharged from smelting and other manufacturing plants. In due course they are brought down to earth's surface (land or water) by dry or wet deposition (see Glossary) either in their original form or in a chemically or bio-chemically altered form. What is called "Acid rain" provides an excellent example of this. Large quantities of SO_2 are being emitted into the atmosphere from coal-burning production facilities. In the Boundary Layer and Troposphere of earth's atmosphere SO_2 oxidizes into SO_3^- and SO_4^-. Oxidized SO_3^- and $S\,SO_4^-$ species then react with water droplets to form sulfurous acid (H_2SO_3) and sulfuric acid (H_2SO_4). In due course they are brought down to earth's surface by dry or wet deposition to contaminate land or water bodies depending on where precipitation occurs. The following is a partial list of the sources of such contaminants: Pb and Poly Aromatic Hydrocarbons (PAHs) from automobile exhausts; As, Cd, Cu, Cr, Ni, Pb, Sb and Zn from metal smelting facilities; organic micro-pollutants and Hg from chemical and pharmaceutical production facilities; accidental leak of radioactive materials from nuclear plants, atmospheric testing of nuclear weapons, and radioactive leaks from research laboratories and medical facilities. TCDDs and TCDFs (see Glossary) from waste incinerators, etc.

Heavy metals — Pb, Cd and Hg in particular — are common air pollutants which eventually become soil contaminants as explained above. They are being emitted in ever greater quantities from all kinds of industrial activities and are substantially contributing to their deposition and build-up in soils, especially in highly industrialized countries such as the USA and Germany, and rapidly industrializing countries such as China and India.

(b) *Synthetic agricultural inputs:* Currently a fairly wide range of man-made chemicals is applied to agricultural crops for increasing productivity. These include pesticides that are chlorinated hydrocarbons such as DDT and BHC (see Glossary); herbicides such as 2,4-D and 2,4,5-T containing TCDD; fungicides containing Cu, Zn, Hg and organic molecules; and synthetic fertilizers such as phosphates containing Cd and other impurities. While synthetic fertilizers and generally N, P, K nutrients are directly applied to soil, pesticides, herbicides and fungicides are sprayed on to crop foliage. However, only a small proportion of the applied chemicals reach targeted foliage while the remainder contaminates both soil and the atmosphere.

(c) *Waste disposal:* Many of the waste disposal practices also contribute, and have contributed, in good measure to soil pollution. For example, in some parts of the world, including Canada and the USA, the practice of spreading sewage sludge over agricultural land was encouraged in the sincere belief that it would enrich soil. Interestingly, in order to facilitate this practice and to remove any public anxiety arising from it, in North America sewage sludge was renamed "fertilizer" or "dust suppressant". Sewage sludge can be a good or reasonably good fertilizer if it contained nothing more toxic than human waste. But it contains many other things besides, including a rich cocktail of numerous industrial chemicals that make it a veritable soil pollutant. For example, sewage sludge is generally rich in heavy metals such as Cd and Zn, organic pollutants, and PAHs and PCBs among others. It is clear therefore this practice pollutes soil and deteriorates its quality rather than improving it. Similarly pig and poultry manures can pollute soil because they contain As and Cu; and so can composted domestic waste which contains heavy metals. It is relatively easy to kill pathogens present in these potentially useful manures and leachate from landfills. However, the difficult task is to eliminate heavy metals from them. Not surprisingly, sewage sludge often contains asbestos and is mutagenic in the sense that it can cause inheritable genetic changes in organisms.

A landfill can also contaminate the soil on which it is built if its primary lining is damaged or ruptured, or if its surface water and drainage control systems are badly designed or cease to work properly, thus making it possible for leachate to seep into the soil below. Illegal dumping of domestic, industrial and building waste, called "fly-tipping", is becoming widespread in large cities like London and Liverpool as legal disposal of such waste at official, regulated sites becomes more and more expensive. Fly-tipping is becoming ubiquitous and a worrying source of soil pollution as local authorities, responsible for cleaning-up such illegal sites and for policing against such illegal practice, become increasingly hard-pressed financially.

(d) *Derelict industrial sites:* A wide range of contaminants are released from derelict industrial sites during facility demolition, decommissioning and production associated with such sites, including the following: (i) Phenols, tars, cyanides, As and Cd in the case of gas works; (ii) Cu, Zn, Pb, PCBs and solvents in the case of electrical installations such as transformer stations; (iii) Cr in the case of tanneries; and (iv) metals, PCBs and hydrocarbons in the case of shipyards.

(e) *Some other sources:* Soil is also contaminated by the following unless effective remedial measures are undertaken: (i) leakage from domestic and industrial underground tanks in which petrol, chlorinated solvents, etc., are stored; (ii) corrosion of metal in contact with soil, for example Zn from galvanized metal and Cu and Pb from roofing materials; (iii) creosote, As and Cu from wood preservatives used on fencing; (iv) Pb from gun shot and fishing weights; Pb, Cd, Ni and Hg from discarded batteries; hydrocarbons from spilt petrol and all kinds of lubricating oil; and (v) ammunitions made with depleted uranium (DU; see Glossary) for use in theatres of war (e.g. Kosovo, Iraq and Afghanisthan).

4. Effects of Soil Contamination

The main impacts of soil pollution are two-fold: health impacts and environmental impacts. And, in terms of (economic) externality, both impacts are fundamentally adverse. Also, the subject-matters of both are extensive (e.g. Carson, 1962; WHO, 1990; Preedy and Watson, 2005; Kabata-Pendias and Mukherjee, 2007). For example, in 2005 the total number of different chemicals discharged to the environment by an estimated 60,000 European production facilities was a staggering 103,000, of which about 1,500 were characterized as "substances of very high concern" (Nath, 2008). Clearly, it is not possible in a chapter such as this to do justice to such vast subject-matters in terms of depth or scope. In what follows we will therefore focus on the main problems and related issues concerning health and environmental impacts of only a very small number of soil pollutants that have achieved notoriety to date for their toxicity and capacity for causing harm. *This applies especially to what is said in Sections 4.2 to 4.5 inclusive.*

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Buol, S.W, Southard, R.J, Graham, R.C and McDaniel, P.A. (2003), *Soil Genesis and Classification*, Fifth edition, Wiley-Blackwell, New York. [In this comprehensive work the authors cover a fairly wide range of topics from soil formation and categorization through soil classification to factors and processes which soils may be subject to].

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Cedergren, H.R, (1997), *Seepage, Drainage, and Flow Nets*, Wiley Classics in Ecology and Environmental Science, Third edition, Wiley-Interscience, New York [It is a definitive reference book on drainage and seepage through soils. Recommended for those interested in or concerned with generic problems of groundwater flow, although knowledge of both hydraulics and soil mechanics at a fairly high level is required to fully understand what is presented].

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Garcia, E.S (2011), "The Idiot Cycle: What you aren't being told about cancer", screened by "Russia Today" TV (www.rt.com) on 11 November 2011 [It is a French-Canadian documentary shot in Canada (Sarnia, Ottawa and Saskatoon), the United States (Memphis, TN, Midland MI and Washington, DC), the Netherlands (Amsterdam), France (Agen and Paris), Italy (Bologna), Germany (Weilheim, Frankfurt, Burladingen and Tubingen), Belgium (Brussels) and England (London and Hemel Hampstead). It alleges that six major chemical companies are responsible for decades of cancer-causing chemicals and pollution, while also developing cancer treatments and drugs. It also argues that these companies own the most patents on genetically modified crops that have never been tested for long-term health impacts such as cancer].

Geist, H (2005), *The Causes and Progression of Desertification* (Ashgate Studies in Environmental Policy & Practice), Ashgate Publications Ltd., Aldershot, UK. [This book gives an excellent account of the causes and progression of desertification as well as why and how dry lands are being relentlessly degraded. Essential reading for those interested in the better management of such problems and/or global environmental sustainability].

Iskandar, I.K (ed.) (2000), *Environmental Restoration of Metals-Contaminated Soils*, CRC Press, New York [Written by a group of scientists from a number of countries, this book provides a summary of the current environmental remediation technology pertaining to soils contaminated with metals. The topics covered include: mechanics of metal retention and release from soils; chemical remediation of soil contaminated with Cd and Pb; physical and electrical separation methods for soil remediation; process of metal removal by chelation using amino acids; and metal uptake by agricultural crops from soils treated with sewage-sludge].

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Kabata-Pendias, A and Mukherjee, A.B (2007), *Trace Elements from Soil to Human*, Springer, New York [In this excellent and comprehensive text the authors review the key trace elements in soil and in our environment how they affect plants and the food web. Specific properties of trace elements in both biotic and abiotic environments are also examined. Also presented in parallel are key geotechnical processes and information on international legislation on trace elements as both micro-nutrients and soil and food contaminants].

Kamrin, M.A (ed.) (1997), *Pesticide Profiles: Toxicity, Environmental Impact, and Fate*, CRC Press, New York [This book provides specific information on about 135 pesticides including regulatory information, toxicity assessments, acceptable exposure limit values and environmental fate. It also explains, in simple non-technical terms, the meaning of carcinogenicity and how it is assessed].

Keiser, M and Herbert, S. (2011), "Capitalism Needs Regulation", *Keiser Report broadcast on 2 November 2011.* www.maxkeiser.com [In this program Max Keiser and Stacy Herbert regularly expose fraudulent, corrupt and scandalous business dealings of largely US financial institutions, large corporations, their CEOs and other senior officials, not to mention the politicians and cronies on their payrolls as their "Consultants". In this particular program broadcast on 2 November Keiser and Herbert explore the reasons why Banks and other large US corporations campaign ceaselessly for de-regulation and conclude that regulation of private business enterprises is the essential pre-requisite for the proper functioning of the capitalist economic system].

Kohnke, H. and Franzmeier, D.P. (1994), *Soil Science Simplified*, Fourth edition, Waveland Press Inc., Illinois, USA. [This well-written paperback contains a wealth of information and is meant mainly for those with modest knowledge of soil science. The scientific principles on which soil science is based are explained in a simple way for ease of understanding and application].

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Marx, K. (2009), *Das Capital: A Critique of Political Economy,* Regency Publishing inc., New York [In this famous book Karl Marx sets out the fundamental principles of communism which was subsequently imposed on more than twenty countries, notably by V.I. Lenin and Mao Tse-tung].

Miller, G.T (2004), *Living in the Environment: Principles, Connections, and Solutions*, Fourteenth edition, Brooks Cole, New York [Currently this book is the most comprehensive and up-to-date environmental science textbook on the market. In a balanced and bias-free approach in this book the author focuses on the prevention of environmental problems, and their solution after they have occurred].

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Nath, B. (2008), "A Heuristic for Setting Effective Standards to Ensure Global Environmental Sustainability", *Environment, Development and Sustainability*, Volume 10, pp 471-486 [It is argued in this paper that as a biogeochemical entity the Earth has limited self-regenerative capacity (SRC) to cope with anthropogenic pollution, and all kinds of environmental problems ensue when that limit is exceeded. In order to be effective and sustainable, it is clear therefore that environmental standards ought to be set below Earth's natural SRC. Unfortunately, at present there is little information on Earth's ERC. This needs to be remedied without delay. In the meantime earth's 'Carrying capacity' may be used as a surrogate of SRC].

Nicolopoulu-Stamati, P., Hens, L and Howard, V.C (eds.) (2001), Endocrine-*Disrupters: Environmental Health and Policies*, Springer, Dordrecht, The Netherlands [This book contains the proceedings of a workshop held in September 1999 at the *International Hippocrates Foundation* on Kos Island, Greece. It not only overviews the effects of endocrine-disrupting substances on human health, but it also addresses the regulatory problems from the standpoints of international organisations such as the WHO, the EU and the Chlorine industry].

Odum, H.T (ed.) (2000), *Heavy Metals in the Environment: Using Wetlands for Their Removal*, CRC Press, New York [A fairly comprehensive discussion is presented in this book on the heavy metal contamination of wetlands how such contamination could be reduced or eliminated. It also tries to address questions such as: Can systems powered by sunlight deal with toxins more efficiently than conventional methods?].

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Preedy, V.R and Watson, R.R (ed.) (2005), *Reviews in Food and Nutrition Toxicity*, Volume 4, CRC Press (Taylor & Francis), London [This clearly written book contains a veritable wealth of information on toxicology which should be of much interest to those interested in or concerned with environmental health impacts, environmental medicine, and researchers in toxicology].

Reible, Danny D (1999), *Fundamentals of Environmental Engineering*, Lewis Publishers, London [This book provides a good introduction to the rapidly growing and multi-disciplinary field of Environmental Engineering, exploring the fundamentals of environmental pollutants, engineering principles, and mass and energy balances among other topics in the context of problems of air, water and soil pollution].

Schaetzl, R.J and Anderson, S (2005), *Soils: Genesis and Geomorphology*, Cambridge University Press, UK. [This lavishly illustrated, well-written, up-to-date and comprehensive textbook covers pedology, soil geomorphology as well as essential areas of soil science. Perhaps the main strength of the book is that it takes a fresh look at soil genesis essentially from a distillation of a variety of scientific concepts some of which apparently cannot be juxtaposed].

Schnoor, J.L (1996), *Environmental Modelling: Fate and Transport of Pollutants in Water, Air and Soil,* A Wiley-Interscience Publication, John Wiley & Sons Inc., New York [This book brings a uniquely contemporary perspective to the assessment of environmental quality, addressing key questions about fate, transport and long-term impacts of chemical pollutants in the environment].

Sparks, D.L. (2002), *Environmental Soil Chemistry*, Second Edition, Academic Press, New York [This concise and authoritative text covers not only the essential areas of environmental soil chemistry in which students as well as practitioners would be interested, but it also provides latest scientific and technological advances in the subject. Advanced analytical methods are included as are topics on environmental geochemistry and soil science].

Sposito, G (2008), *The Chemistry of Soils*, Second edition, Oxford University Press, Oxford, UK [The approach to a clearer understanding of soil chemistry taken by the author of this book is that of physical chemistry. This edition includes the increasingly important topic of climate change which is explored by examining the interaction between organic carbon and soil. It is highly recommended for everyone interested in soil science as students, teachers and professionals].

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US EPA (2007), *What is a pesticide?,* Report of the United States Environment Protection Agency, Boston (also available on the internet under epa.gov) [In this timely and authoritative report the definition of pesticide is given in a direct and succinct way that is easy to understand and apply].

Van Emden, H.F and Peakall, D.B. (1996), *Beyond Silent Spring*, Springer, New York [This book gives an excellent review of integrated pest management (IPM) practices and how pesticides can be integrated into IPM with minimum environmental risk. This book should be of interest to teachers, students, industrialists and others concerned with IPM].

WHO (1990), *Public Health Impact of Pesticides Used in Agriculture*, The World Health Organisation, Geneva [In this report an assessment is made of the scope and severity, globally and regionally, of exposure to pesticides with a view to estimating future trends and to reviewing the effects of pesticides on human health with particular reference to the general population in developing countries. This report is intended for use principally by national health officials responsible for pesticide management and by research workers concerned with epidemiology of pesticide poisoning].

WWF (2000), *The Living Planet Report 2000*, World Wildlife Fund, London [In this timely report the World Wildlife Fund (WWF) paints a gloomy but object picture of the prospects of human life on this planet if we continue to degrade and destroy its environmental capital without which life on earth cannot exist].

Biographical Sketch

Professor Bhaskar Nath received his Bachelor's degree in Civil Engineering from the Indian Institute of Technology, Kharagpur, India, in 1960, followed by the Ph.D. degree from the University of Wales, UK, in 1964. In 1983 he was awarded the D.Sc. degree by the University of London for his outstanding original research (according to citation) in numerical mathematics. In 2001 he was awarded the Doctor Honoris Causa (Dr.H.C.) by the University of Chemical Technology and Metallurgy, Sofia, Bulgaria, for his contribution to environmental education.

After having taught at the University of London for more than 27 years, currently Professor Nath is Director of the European Centre for Pollution Research, London; Executive Director of International Centre for Technical Research, London; Editor of Environment, Development and Sustainability published by Springer; visiting professor to several European universities, and consultant to a number of international companies and organizations. Professor Nath’s research interests include Numerical Mathematics, Elasto-Hydrodynamics, Philosophy, Environmental Economics, Sustainable Development, and Environmental Education. He has more than 100 scientific publications in these and related areas including 13 books.