AIR, WATER AND SOIL POLLUTION AND MODELLING: THE PROBLEM IN CONTEXT

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Contents

Summary

Relentless degradation of earth's natural environment and environmental capital being caused by anthropogenic pollution has been and continues to be so comprehensive and ubiquitous that today it is hard to find a single aspect of the natural environment that has been immune to such pollution. As typical examples of anthropogenic pollution this article begins with the degradation being caused by the discharge of a large number of chemicals into the environment and the relentless acidification of the oceans being caused by the release of gases such as CO_2 and SO_2 into the atmosphere from human activities. Discussion then moves on to the issue of the exponential growth of human population which has very serious implications for the life-sustaining resources and life-support systems which the Earth provides.

Although in many cases we know what needs to be done to arrest or even reverse the damage we have been causing to earth's environment and environmental capital, the latter being a unique resource base from which all wealth is created, the international community seems to have been cursed with a peculiar 'Lemming' syndrome thwarting all remedial efforts in its ceaseless pursuit of short-term economic benefits for a 'Civilised' lifestyle at the expense of earth's long-term future. It is worrying that we understand little of the characteristics of many of the global environmental problems we have created and know even less about their long-term impacts or how to alleviate them. An understanding of these problems is facilitated by model studies of environmental systems. It is for this reason that the role of models in analysing the behaviour of engineering and environmental systems is then briefly discussed.

The discussion in this article is intended to set the scene for the remainder of the theme which is substantially about the modelling of environmental systems.

1. Introduction to Anthropogenic Pollution of the Natural Environment

What can only be described as man's headlong rush for economic development through industrialisation has caused, and is causing, environmental pollution problems that are increasingly so ubiquitous and complex that they are now challenging our capacity to cope with them in ways that are benign and economically viable; and increasingly this is casting a deep shadow over the welfare of future generations and their essential access to earth's unique natural environmental capital that sustains life on earth.

Indeed, the impacts of man's industrial activities on the natural environment that are meant to deliver and maintain a 'Civilised' lifestyle has been and continues to be so comprehensive and unrelenting that today it is increasingly hard to find a single aspect of the three natural environmental compartments — namely air, water and soil — that remains unaffected by those activities. And, by all accounts the situation is deteriorating. What is said in sections 1.1 and 1.2 below represents but a small selection of the negative impacts of those activities, exacerbated by population growth (section 1.3), that have been degrading both the integrity of earth's natural environment and nature's life-support systems. These sections also give an idea of the apparently insurmountable challenges confronting the international community for achieving even a modest degree of sustainability of global environmental capital or sustainable development

1.1 Man-Made Chemicals and their Environmental Impacts

The current situation with regard to man-made industrial chemicals is causing increasing concern. World production of such chemicals increased from just one million tonnes in 1930 to 400 million tonnes in 2000 (EU, 2006). According to a study conducted by the EU, in 2005 there were 31,000 companies in the EU discharging more than 104,000 different chemicals to the environment. Of these 100,106 (called 'existing substances') had been on the market before 1981 and 4,000 (called 'new substances') were introduced after 1981 (EU, 2006).

An estimated 1,500 of these chemicals are 'Substances of very high concern'. They are variously carcinogenic, mutagenic, bio-accumulative, persistent or highly persistence. In Europe many of these chemicals are suspected to be contributing to increasing incidences of asthma, reproductive disorders (e.g. low sperm counts) and allergies. Some of these chemicals react with each other, or with other chemicals or compounds already present in the environment, to produce a whole range of derivative compounds, notably what are called endocrine-disrupting compounds (also called "Gender-bending compounds" and "Hormone-mimicking compounds"). Typical examples are *Ortho-N-Nonylphenol* and *Bisphenol A* (BPA). These increasingly ubiquitous compounds are mainly synthetic estrogens that have affinity for the fatty tissues of mammals which they enter, and by doing so they interfere with mammalian sexuality and reproductive functions. Clearly, this has profound implications for mammals including humans and therefore human societies (Colborn, von Saal and Soto, 1993; Nicolopoulou-Stamati, Hens & Howard, 2010).

The uncomfortable truth is that we know very little about the vast majority of the chemicals in use today, including endocrine-disrupters, and their long-term impacts on the environment, and on human, animal and plant life. For 99% of chemicals (by volume) information on their properties, uses and risks is sketchy. Sufficient information is available only for some of those chemicals that are produced in high volumes (i.e. above 1000 tonnes per year), although currently no data are available for about 21% of these, and insufficient data are available for 65% (EU, 2006; Allanou, Hansen & van der Bilt, 2003).

Following a comprehensive consultation process and lobbying, European Union ministers approved a landmark law seeking to control some of the chemicals. That law, called Registration, Evaluation and Authorization of Chemicals (REACH), came into force on the 1st. of June 2007 with a phased implementation over the next decade, and it replaced about forty different European Directives and Regulations with a single system. The aims of REACH are (HSE, 2007; Erler, 2009):

- To provide a high level of protection of human health and the environment from the use of chemicals.
- To make those who place chemicals on the market (i.e. manufacturers and importers) responsible for understanding and managing the risks associated with them.
- To allow free movement of substances within the EU.
- To enhance innovation in and competitiveness of the EU chemicals industry.
- To promote the use of alternative methods for the assessment of the hazardous properties of substances such as quantitative structure-activity relationships (QSAR).

REACH is certainly a significant improvement on the plethora of different Directives and Regulations which it replaced. However, there is unease over the watered-down version of the original proposals that finally came into law, the following in particular (Knight, 2005; Nath, 2008):

- By arguing that their use will be controlled, industry could continue to use ‘Substances of very high concern’ even when safer alternatives are available.
- To cut costs and to minimise animal testing, companies that produce the same chemical should be legally obliged to share safety information, and it should be compulsory to have just one registration per chemical.
- There is concern over the potential for a very significant increase in animal testing under the new proposal.
- In the EU importers should be forced to meet the same standards as manufacturers.
- Some countries, notably the United States, India and Brazil claimed that REACH would hamper global trade.

However, despite above reservations REACH is to be welcomed for it represents an overdue initiative to control hazardous man-made chemicals that are all around us, have contaminated every environment (even the pristine Antarctica), and are absorbed by wildlife and humans through the skin or ingested in food and water. Clearly, if rigorously implemented, REACH would reduce future pollution impacts of chemicals used within the EU on human health and the environment. However, what it will not do, and cannot do, is to alleviate or undo the damage that chemicals have already inflicted on the natural environment.

1.2 Ocean Acidification

'Ocean acidification' is a term widely used in literature to describe changes in the chemistry of the seas of the World, primarily caused by the burning of fossil fuels (i.e. coal, oil and gas). Since the beginning of the Industrial Revolution around 1750, primarily the burning of fossil fuels in ever increasing quantities to drive the engine of economic development has been burdening earth's atmosphere with a growing 'excess' of CO_2 (here 'excess' means in excess of the 0.03 percent by volume of CO_2 which is naturally present in pure air). While the 'excess' CO_2 in the atmosphere and its environmental and health impacts are well documented and reported in both scientific literature and mass media, a much less known fact is that to date the oceans of the world have absorbed up to 50 percent of the total 'excess' of anthropogenic CO_2 emissions. In other words, to date the seas and oceans of the world have absorbed roughly the same amount of 'excess' CO_2 as there is in earth's atmosphere (BBC, 2009; Allsopp *et al*., 2008; Royal Society, 2005).

There are two main mechanisms by which CO_2 is absorbed by the oceans, namely a *physical mechanism* and a *biological mechanism* (BBC, 2009). In the former, CO_2 dissolves in cold ocean water near the poles. It is then carried to the deep ocean by sinking currents where it stays for a long time. Over time thermal mixing brings the CO_2-laden water to the surface whereupon CO_2 is released into the atmosphere in the Tropical regions. In the biological mechanism phytoplankton use CO_2 in the presence of sunlight to produce carbohydrates and oxygen through photosynthesis. When plankton and the sea animals which eat them die, they sink to the ocean floor and a small percentage of carbon in the remains of the dead creatures is eventually buried in the sediment. Generally this exchange of CO_2 between land, sea and air should be in equilibrium as per earth's carbon cycle. But this equilibrium is being increasingly undermined by the 'excess' CO_2 mentioned above.

"Along with climate change, the rising acidity of our oceans is yet another reason for us to be concerned about the carbon dioxide we are pumping into the atmosphere. Our world leaders…....must commit to taking decisive and significant action to cut carbon dioxide emissions. Failure to do so may mean that there is no place in the oceans of the future for many of the species and ecosystems that we know today……The oceans play a vital role in the Earth's climate and other natural systems which are all interconnected. By blindly meddling with one part of this complex mechanism, we run the risk of unwittingly triggering far reaching effects."
Professor John Raven
Chair, Royal Society Working Group on Ocean Acidification. London

It is sobering to note that in 1750 the concentration of CO_2 in the atmosphere was 278 ppmv compared to 390 ppmv in 2010; and that over this time average pH of the surface waters of the oceans will have decreased from 8.2 in 1750 to a predicted value of 7.8 in 2100 (BBC, 2009; Allsopp et al., 2008). It is to be noted that the pH of the world's oceans is not uniform or consistent across the globe.

The following are the major impacts of increasing acidity of earth's oceans (BBC, 2009; Allsopp *et al*., 2008; Royal Society, 2005):

- In earth's seas and oceans absorbed CO_2 reacts with water (H_2O) to form carbonic acid (H_2CO_3), thus lowering the pH of sea water. As a result hydrogen ion (H^+) concentration in sea water increases while concentration of carbonate ion $(CO_3)^{-2}$ decreases. The latter has a serious impact on marine creatures such as plankton, coral and molluscs which need carbonate ions to build their shells and skeletons and, with decreasing availability of these ions, they struggle to do so for survival.
- Researchers in the USA believe that calcification rates of warm-water corals will be reduced by up to 60 percent and that this would adversely affect reef structures mainly because their growth depends on the ability of corals to build faster than the rate of skeleton erosion. Clearly, weaker structures would be more vulnerable to erosion caused by storms and large waves.
- Cold-water corals, found throughout the World's oceans, often provide vital habitat for a variety of commercially harvested fish. According to many scientists about 70 percent of these corals could be under threat by the end of the century.
- Planktons are tiny organisms that play an important part in the marine food chain; several groups of planktons also produce calcium carbonate. Ocean acidification can greatly reduce the distribution of planktons with very serious implications especially for corals and molluscs including invertebrates such as mussels and oysters whose shells may become thin or deformed. Currently our understanding of the impacts of ocean acidification on these tiny creatures is woefully limited and much research remains to be done in this area.
- Not all habitats are adversely affected by ocean acidification, however — for example, sea grasses grow better in waters rich in CO_2. These grasses often offer valuable feeding and spawning sites for a variety of fish including commercially valuable fish.

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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 a Ph.D. degree from the University of Wales, UK, in 1964. In 1983 he was awarded a 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, Bhaskar Nath is currently: 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 organisations. His 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.