Ecotoxicology and Climate
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Introduction, Conclusions, and Recommendations

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1.1 INTRODUCTION

Man-made chemicals are increasingly used throughout the world, particularly in regions outside the temperate zone, where most of the developing countries are situated. Yet, what is known of the fate and effects of these chemicals on the environment is based essentially on a body of knowledge acquired in the temperate zone. The need was felt, therefore, to review and assess the information available on exposure to chemicals and on their environmental behaviour and effects in warm (hot, wet, and dry) and cold climates and to verify the applicability of basic ecotoxicological principles under these conditions. This is the object of the present report.

The rapid development process whereby humanity aspires to attain a better quality of life is a mixed blessing in that a certain degree of consequent environmental degradation becomes almost unavoidable. Chemical pollution is the most visible cause of environmental degradation, with its potential to impair human health and to produce undesirable disturbances in ecological equilibria. It is also recognized that some chemicals which are essential to sustain life and improve its quality from the viewpoint of today's mode and style of living can indeed have a negative impact on human health and the environment.

Ecotoxicology, a relatively young subject, represents a multidisciplinary approach to the study of the adverse effects of environmental chemicals on individuals, populations, biocoenoses, and whole ecosystems, as opposed to toxicology, a much older subject, which deals with the harmful effects of chemicals on a given species of the living system. The need for rapid test systems to assess the toxic outcome, if any, of chemicals designed as therapeutic agents has led to a much wider understanding of the comparative effects of chemicals on a variety of laboratory animals, mostly rodents. Indeed, the cornerstone of the safety evaluation of chemicals on human health consists in the meaningful extrapolation of information derived from their effects under controlled conditions on a number of target species for both short-term and long-term effects. Obviously, the plethora of acute, chronic, and sublethal effects that can be expected to be elicited on ecosystems under natural conditions will be more diverse and not bear any direct resemblance to health effects seen on a single species by the same chemical. Furthermore, under natural conditions one has to take into account a variety of factors: interaction among species; climate; food-web interrelationship; synergism between chemicals; comparative biochemistry; etc. Whole ecosystems may be irreversibly changed through chemical disturbance affecting directly only part of them or particular species.

During the past two decades, a growing awareness of the principles governing the behaviour and effects of environmental chemicals has been developed, partly through the activities of SCOPE and the resulting reports: SCOPE 11, *Principles of Ecotoxicology* (1978); SCOPE 20/SGOMSEC I, *Methods for Assessing the Effects of Chemicals on Reproductive Functions* (1983); SCOPE 22, *Effects of Pollutants at the Ecosystem Level* (1984); SCOPE 25, *Appraisal of Tests to Predict the Environmental Behaviour of Chemicals* (1985).

This work was done mainly on the basis of the experience of industrialized countries, mostly located in temperate climate zones and with histories of much longer exposure to anthropogenic chemicals. During the recent past, particularly since the late sixties, the chemical industry has grown rapidly in many developing countries located in non-temperate climatic zones. It has thus become important to ask whether the ecotoxicological principles evolved as a result of retrospective study of conditions prevalent in industrialized countries of the temperate zone of Europe and North America are applicable universally to the present situation in rapidly developing countries in the tropical zone or the semi-arid zone. Moreover, are these principles relevant to the fate and impact of toxic chemicals in the arctic and antarctic zones or in high elevation ecosystems?

These questions have been addressed in the present project, while the somewhat related issue of acidification was the object of another SCOPE study, to be published under the title 'Acidification in Tropical Countries' (H. Rohde, editor), SCOPE 36.

1.1.1 Quantity and Range of Chemicals

It has been estimated that there are at present over 60 000 man-made chemical substances in use today, of which some 4000, accounting for 99% of total production volume, are in common use globally. In addition, many naturally occurring chemicals and those produced by the metabolic activity of many microbial organisms, insects and other pests, snakes, etc. are known to be extremely toxic to animal life. Risks of exposure to chemicals faced by ecosystems arise in many ways, but mainly through their production, storage, transport, use and disposal. Some hazardous chemicals, even when their use is restricted, can escape into the environment by accidental release. Others widely used in industry, agriculture, food, commerce or the home are readily dispersed in the environment. Thus many anthropogenic chemicals will ultimately appear as pollutants in air, water, soil and food, either as metabolites or residues, or as wastes. Furthermore, human activities related to mining, dredging, land development, and coastal management release naturally occurring chemicals at a rate more rapid than that attained by normal geochemical processes. The consequent disturbances of chemical dynamics can have serious repercussions on various ecosystems.

Other dimensions of pollution by chemicals are their spread, which can transcend frontiers from the region where they are produced to a region where they are diffused and eventually deposited in the sinks, and their fate at the interfaces between land and water, particularly in the oceans, as well as between air and land, as when chemical clouds move over large tracts of vegetation. The impact of transfrontier export of air pollutants on terrestrial (e.g. forests) and aquatic ecosystems has attracted much attention.

There is growing recognition of the fact that for sustainable development one must ensure prevention of the adverse effects of environmental chemicals. At the same time a balance has to be struck between the essential needs of chemicals for attaining development goals and the urgency of recycling and conservation of non-renewable resources of the earth.

It thus becomes imperative to determine whether the toxic effects of chemicals on ecosystems manifest themselves in varied forms in different climatic zones. It is equally important to establish a more scientific basis for the control of environmental chemicals in different parts of the world.

1.1.2 Content

The background material presented in Chapter 2 includes overviews on climates of the world from an ecotoxicological angle (2.1), the diversity of ecosystems (2.2), atmospheric transport of chemicals (2.3) and aquatic transport of chemicals (2.4). The environmental fate of chemicals determined by abiotic degradation and by biotic degradation is described in Chapter 3. Also in Chapter 3, existing knowledge of exposure of non-temperate ecosystems to environmental chemicals is synthesized for cold environments (3.3) and for tropical and arid regions (3.4). Chapter 4 deals with the role of temperature and humidity on comparative toxic effects on diverse living systems (4.1), toxic effects seen in arid regions (4.2), tropical marine ecosystems (4.3), arctic and subarctic ecosystems (4.4) and on domestic animals (4.5). Chapter 5 contains eight case studies: coastal pollution in the Indian subcontinent (5.1), biodegradation of pesticides in rice ecosystems (5.2), effects of insecticides on rice ecosystems (5.3), fate and effects of aldrin/dieldrin in terrestrial ecosystems in hot climates (5.4), blackfly control in West Africa (5.5), herbicides in warfare and effects on coastal ecosystems (5.6), effects of pesticides in Egypt (5.7), and mercury in Canadian rivers (5.8).

The assessment of the above-mentioned papers led to the conclusions and recommendations for future research listed in the following sections.

1.2 CONCLUSIONS

1.2.1 Exposure of Ecosystems to Chemicals

In carrying out this study, it soon became evident that few data were available on the kinds and amounts of chemicals used in non-temperate regions. Information on residue levels, environmental concentration, effects on health and on the environment, is even scarcer.

With world trade in chemicals and chemical products burgeoning in an unprecedented manner and with their ever increasing use in developing countries in every sector, the potential for chemical pollution has expanded by leaps and bounds. Most of the data discussed in this study came from non-temperate climatic zones of developed countries and rapidly industrializing countries in the Third World: Egypt, India, Indonesia, Israel, the Philippines. Some data from Vietnam and West Africa were also available.

A wider coverage, however desirable, was not possible within the constraints of the present study. No uniform system is followed in the different countries for maintaining statistics of production, import, export, and use of chemicals. Except for the FAO statistical reports there appears to be no consistent international effort to compile data on production of classes of chemicals. FAO reports deal primarily with agrochemicals, viz. fertilizers and pesticides.

Statistics of production and use of bulk chemicals and fine chemicals are maintained by some countries of the industrial world and are accessible for survey and analysis. Data are also collected for internal use by industrial associations of chemical manufacturers. This source of information is not readily available. There is a paucity of information on the internal trade of chemicals among the Eastern European countries. In regard to developing countries with programmes of rapid growth of chemical industries, this study could cover only the data for industrial chemicals for India and the data for production, import, and use of pesticides globally. Thus information on chemical production and usage pattern in China, Indonesia, Malaysia, and the Latin American countries could not be obtained.

Note has been taken of the exceedingly useful work being done by the International Registry of Potentially Toxic Chemicals (IRPTC) as part of the UNEP activities to compile information as a register of a select group of toxic chemicals. The network of national correspondents of IRPTC should enable the organization to widen the scope of the Register in the coming years. The elaborate list prepared by the Environmental Protection Agency, USA, in connection with the Toxic Chemicals Control Act, is a useful compendium for assessing chemical exposure in the USA. Similar lists are available in the European

Communities (EINECS). Thus the framework for establishing registers is already in existence and can be used in compiling and collecting information from developing countries.

Some of the tropical countries, like India, have sizeable industrial chemical complexes and processing plants with a high potential for pollution, being located on the banks of inland water bodies, including rivers, in coastal areas, or in the proximity of pristine forests. Emissions into air as smoke, particulates, and gaseous vapours are on the increase, as is evident from the data being generated by the national network of air monitoring stations, particularly in industrial and urban zones. Chemicals discharged as effluents into inland water bodies and coastal waters also show an increasing trend of aquatic pollution. By and large, the impact of biological pollution on human health has been of primary concern from the point of view of control.

Even for industry, the problems of dealing with BOD due to discharge of biodegradable effluents have received far greater attention than related problems resulting from discharge of toxic chemicals.

Another uncharted problem area is the size and nature of chemical wastes generated or deposited in non-temperate ecosystems. There is a growing trade in chemical wastes generated in industrialized countries in the temperate zone being disposed of in developing countries in non-temperate regions. Stricter environmental controls exercised in industrialized countries in the developed world have also encouraged the manufacture and export of hazardous chemicals from developing countries in the non-temperate regions. As of today, no concerted efforts seem to have been made to locate toxic waste dumps in developing countries and to assess their impact on the environment. However, even the limited information available from India, indicates that the problems of diffusion of toxic chemicals from waste dumps may assume serious proportions if appropriate checks are not introduced.

Although data are sparse, there is a growing use of chemicals in all non-temperate climate zones and, where data are available, levels in the environment of the persistent chemicals appear to be on the increase. In particular, there is evidence of an increasing use of chemical pesticides in tropical countries, a trend which is not likely to be reversed in the foreseeable future.

The problem is compounded in some places by the inadequacy of administrative and legislative structures for implementing pollution control.

It is not easy to quantify the increase, region by region, nor is it feasible to identify the chemical species involved as the use patterns exhibit wide changes. While the use of persistent pesticides, particularly the chlorinated ones, is being phased out in some countries, there is no evidence that the use and diffusion of some of them on a global scale is decreasing. It may be recalled that the assay of levels of DDT, HCH, and PCB residues in human blood and human milk fat executed under the GEMS programme of WHO/UNEP revealed a several-fold difference between the values reported from China, India, and

Mexico on the one hand and Sweden, France and Yugoslavia on the other. Obviously this high tissue level reflects an unexpectedly high level in the environment and a consequently greater uptake by living systems. Pesticide residue levels in food crops, milk and dairy products, poultry and animal food are available from some tropical areas, such as India.

1.2.2 Environmental Fate

Basic climatic and oceanographic patterns are sufficiently well-known on a global basis for the purpose of this study. Long-range transport of chemicals by air and water occurs between various climatic zones. Tropical storms accelerate the rate of removal of chemicals from the atmosphere by rain and eventually lead them to the seas. There is perceptible evidence of accumulation of toxic chemicals by coastal leaching in continental shelves and eventual drift to colder regions. Natural transport of chemicals between hemispheres accounts for 25% per annum of global transport.

Disappearance of chemicals from the environment appears to be greater in hot-humid rather than in cold-dry or high-altitude regions. In hot climatic zones, movement of chemicals through the media of soil, water or air may be enhanced by vaporization. Solubility in water increases also with temperature. Under hot-dry conditions microbial degradation of chemicals is, however, decreased. Information as to whether this is compensated for by thermal degradation or photodegradation is not adequate. One expects significant differences in the ecology of soil microflora between hot-humid, hot-dry, and temperate zones and hence divergences in the pathways of microbial degradation.

As far as cold regions are concerned, it appears that chemicals tend to concentrate in various ecosystem compartments, probably because of slower reaction rates.

Mention should also be made here of the effects of fluorinated and chlorinated hydrocarbons on the ozone layer, especially in the arctic and antarctic regions (the so-called antarctic ozone 'hole').

1.2.3 Ecosystem Effects

Information on the presence of chemical hazards in the environment and their adverse effects on the ecosystems is fragmentary. This is particularly true of the possible chronic or synergistic effects or the effects elicited in highly exposed or relatively more susceptible populations. Adverse effects on ecology of toxic chemicals documented so far range from description of the effects on a single species to those on whole ecosystems. The synergistic effects of naturally occurring chemicals and man-made chemicals could present an altogether different picture. The impact of physical agents, such as heat, humidity or radiation, may exacerbate ecotoxic effects. Furthermore, metabolic disturbances elicited by a toxic chemical in one species of an ecosystem may lead to irreversible changes in the ecosystem as a whole.

Against the background of ecotoxicological principles derived from observations on the temperate zone, the present study showed that ecosystems with low diversity, such as mangroves or tundras of the arctic zone, have a greater potential sensitivity to environmental chemicals than those with high diversity. In general, warmer climates tend to favour an acceleration of the ecotoxic effects of chemicals. In arid systems there is a slower degradation of chemicals due presumably to lower microbial activity. However, this does not seem to modify the spectrum of effects on the ecosystem.

The accumulation of chemicals in subpolar and arctic ecosystems may be due not only to the fact that reaction rates are slow but also that lipophilic chemicals can accumulate in fat, which is abundantly present in the tissues of the organisms inhabiting cold regions. In these ecosystems the melting snow releases certain chemicals and induces an additional seasonal stress.

Episodic soil flushing has been reported from tropical rain forests, and pulse emissions of dissolved organic matter into the drainage can reach levels toxic to aquatic life.

In general, there appears to be little basic difference between ecotoxic effects seen in terrestrial tropical ecosystems and those seen in temperate ecosystems. The same is not true in the marine environment. However, there are differences among species in their sensitivity to chemicals. The difference is thus not qualitative but quantitative. It is likely that a species' sensitivity might result in overall deterioration of the ecosystem if the species is critical in maintaining ecological balance. As regards effects on managed systems, no data are available on the corresponding effects on the related natural ecosystems. For a managed ecosystem like the rice ecosystem, ecotoxic effects of a given chemical appear to be the same whether the managed ecosystem is located in the temperate or the tropical zone.

1.3 RECOMMENDATIONS FOR RESEARCH AND MONITORING

1.3.1 Exposure Assessment and Monitoring of Ecotoxic Effects

More quantitative information is required on the persistence of chemicals in non-temperate zone ecosystems to enable assessment of exposures in both the short term and the long term. The tropical zones support and sustain a variety of managed ecosystems: rice, coconut, cocoa, sugar-cane, and monoculture-based forest systems for biomass and fuel. The help of the chemical industry and of agriculture and silviculture must be sought to accomplish this task.

There is an urgent need to build and update data bases on the types of chemicals to which non-temperate ecosystems are presently exposed or are likely to be exposed in the coming years. This could go hand in hand with sustained monitoring programmes on selected managed ecosystems to unravel subtle changes in the fragility and resilience of such systems.

1.3.2 Modulation of Ecotoxic Effects by Physical Factors

So far, degradation and mobility studies on environmental chemicals have been undertaken for the range of temperature, humidity and light intensity found in temperate zones. It is recommended that carefully designed studies should be conducted under conditions found in tropical and polar zones.

Current understanding of the interrelations between toxicity and temperature, toxicity and humidity, and toxicity and light intensity is inadequate. There is scope for further research in this area using selected specific species representing diverse ecosystems from different climatic zones.

1.3.3 Soil and Sediment Parameters

There are known differences in soil parameters between climatic zones. It is recommended that studies be undertaken to assess the extent to which such differences modulate rate of degradation and toxicity.

The role of sediments in absorption, storage and release of pesticides in tropical aquatic environments is not well known and should be further investigated.

1.3.4 Transport of Chemicals

Transport of chemicals within the temperate zone is relatively well understood. Using that experience it is desirable to establish transport models in and between other zones, by field observations as well as by experimental studies.

1.3.5 Ecotoxic Effects Produced by Degradation Products

The nature of degradation products formed by the combined action of microbes and light remains to be explored, especially from the point of view of exacerbating toxic effects or producing new toxic manifestations. The potential of degradation products to produce long-term effects, particularly mutagenic effects, on sensitive species remains to be explored.

1.3.6 Experimental Ecotoxicology

Experimental toxicological work on non-human species is normally undertaken at an ambient temperature of 25°C. It may be worthwhile to carry out a series of experiments over a range of temperatures, e.g. 10°C, 25°C and 40°C (but not more than 30°C for aquatic organisms), using a range of species more representative of different ecosystems.

1.3.7 Methodological Problems

Several problems related to methodologies of assessing toxic effects of chemicals on the ecosystem as a whole were highlighted in SCOPE 22. These have not been resolved and further systematic work is required towards devising suitable ecotoxicological models, microcosms, etc. The need for more precisely defined end-points of toxic effects is also apparent. So far productivity has been the main criterion in assessing effects on whole ecosystems.

A more specific recommendation can be made regarding pesticide research in arid zones. Parameters such as temperature, humidity, solar radiation and soil type cannot be simulated properly in the laboratory. Experiments *in situ* under field conditions would yield more accurate information and thus should be preferred to laboratory tests.