Perspectives on R&D in environmental science and technology in India

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Emerging issues in environmental management

The sociocultural roots of our present environmental crisis lie in the paradigms of scientific materialism and economic determinism which fail to recognize the physical limits imposed by ecological systems on economic activity. The economies must expand within ecosystems which have limited regenerative capacities. Contrary to the neoclassical theory of continuous material growth, economic activities directly undermine the potential for development through over-exploitation of natural resources, and indirectly compromise future production through the discharge of residuals. The entrenchment with quantitative growth as a major instrument of social policy is thus quite paradoxical.

The emergence of the concept of sustainable development in recent years has brought in the general realization that societal perceptions must shift towards ecological determinism so as to achieve qualitative growth within the limits of ecosystem carrying capacity. Reorientation of the development process to take into consideration the limited assimilative and supportive capacities of regional environments is, therefore, one of the key issues in environmental management today.

The options for environmental management include, on the one hand, reactive control measures and on the other, anticipative and preventive strategies. With limited budgets for environmental protection, the dilemma today is whether to rehabilitate existing environmental damage or allocate funds for prevention of future damage. Considerations of resource conservation and economic efficiency warrant the adoption, as far as possible, of a preventive strategy because reactive control measures, more often than not, transfer pollutants from one environmental medium to another and consume resources out of proportion to the accrued benefits.

The environment provides constraints as well as opportunities for economic growth and social well-being. Environmental constraints are often interlinked with the state of technology and, accordingly, there is an urgent need for bringing about a transition towards innovative technologies of production that conserve resources with concomitant minimization of pollution thereby raising the levels of ecologic and economic efficiency. In the industry sector, particularly, there is a need for conscious endeavour towards implementation of low- and non-waste technologies of production and untilization of wastes as secondary resources.

Many developed countries have been able to achieve high rates of economic growth at reduced levels of energy and raw material inputs—factors that are primarily responsible for environmental depletion. The delinking of economic growth from resource consumption is attributed to changes in economic structure from environmentally harmful forms of production and consumption to forms more suited ecologically. Intersectoral structural changes, therefore, provide pragmatic avenues for preventive environmental intervention.

Environmental impact assessment could form a major instrument for the assessment of developmental activities in the context of regional carrying capacity, provided the conceptual framework is extended to the cumulative assessment of policies, plans and projects on a regional basis.

Implementation of preventive and reactive measures requires inter-policy coordination among sectors like industry, agriculture, energy, mining and others that have a part in regulating the material cycles and corresponding technological systems. This also applies to the fiscal sector because pricing policies and the range of financial incentives often play a decisive role in preventing or causing environmental damage.

Priority areas of environmental action

Discernible positive movement towards the overall aspirational goal of sustainable development warrants analysis of the existing and future environmental issues emanating from developmental objectives and policies in various economic sectors. Identification of critical environmental issues and concomitant corrective measures that need to be pursued at the policy, plan and programme levels could enable formulation of an effective R&D programme in environmental management. Accordingly, the task related to the preparation of Perspective National Environmental Plan (PNEP) was undertaken at the National Environmental Engineering Research Institute (NEERI), Nagpur in July 1989.

The PNEP, while drawing upon the report of the World Commission on Environment and Development and the Environmental Perspective adopted by the UN General Assembly in 1987, presents situation analysis of environmentally critical sectors such as population; food, agriculture and forestry; energy; industry; and health and human settlements. The priority areas of environmental action emerging from this analysis are presented in Table 1.

Thrust areas of R&D

In keeping with the priority areas of environmental action, six thrust areas of R&D in environmental science and technology could be identified, viz. environmental biotechnology, environmental chemistry, hazardous waste management, environmental systems modelling and optimization, environmental impact and risk assessment, and environmental policy. Significant R&D activities undertaken at NEERI in these areas are presented in Table 2.

Table 1. Priority areas of environmental action.

Policy level	Plan level	Programme level
Carrying capacity based developmental process	Supportive capacity based developmental planning	Development and implementation of village/district/regional/national sustainability model
	Assimilative capacity-based environmental management	Assimilative capacity-based location of developmental projects Establishment of a centre for studies on policy issues
Preventive environmental intervention	Introduction of environmentally benign technologies and services in various economic sectors	R&D and implementation of low and non-waste technologies of production and recycle and reuse technologies for end-of-the-pipe treatment in industry
		Use of renewable resources in energy sector
		Greater use of biotechnology and ecocultivation in agriculture sector
		Use of fuel-efficient engines in transport sector
		Use of renewable and environmentally compatible building materials in construction sector
		Establishment of a centre for studies on low and non waste technologies of production
	Structural change towards less resource and energy-intensive sectors of economy	Substitution of non-renewable with renewable resource base in manufacturing sector, use of biofertilizer and biocides in agriculture, use of non-conventional sources in energy sector
		Expansion of tertiary sector of economy
	Conservation of raw material and energy resources	Environmental audit including resource and energy audits of developmental activities
		Development of resource- and energy-efficient systems
	Application of EIA in sectoral decision making	Development of sectoral guidelines for environmental review
		R&D on screening, scoping and computer-aided EIA methodologies
		Preparation of model studies on EMP and DMP
		Development of objective criteria for delineation of environmentally sensitive areas
		Legislative framework for implementation of EIA stipulations
		Establishment of an autonomous national environmental impact assessment agency
	Inter-sector policy coordination	Review of sectoral plans from environmental considerations
		Creation of infrastructure within MEF for inter-policy coordination
		Creation of environmental cells in various ministries
Measurement of qualitative growth	Development of indicators of qualitative growth	Development of a national ecologic-economic database (NEED) Development of concept of gross ecologic product (GEP)
Restoration of environmental quality	Assimilative capacity-based environmental standards	Assessment of regional assimilative capacity and formulation of location-specific standards
		Implementation of environmental assimilative capacity-based standards
		Formulation of standards for industrial sludges
	Operationalization of polluter pays principle	Introduction of effluent tax
		Introduction of resource cess for industry
		Implementation of standards based on resource consumption and production capacity
	Damage-cost functions and cross-media analysis as basis for environmental quality standards	Development of damage-cost functions and concomitant environmental standards
		Analysis of cross-media pollution transfer for integrated pollution control
	Legislative and fiscal measures to induce waste utilization	Collation of information on nature, volume, location and accessibility of wastes, economically viable technologies for waste utilization and potential market for recoverable materials
		Development of stabilized market support for recovered materials
		Establishment of a national waste utilization board (NWUB)
		Establishment of a centre for studies on waste utilization
	Integrated landuse planning	Apportionment of land for meeting competitive sectoral demands
		Integration of physical and environmental planning concepts for devising national/regional/district/town landuse plans
		Establishment of a centre for studies on land environment

Table 1. (*Contd.*)

	Reclamation of degraded lands and restoration of fragile ecosytems	R&D and implementation of technologies for reclamation of mining lands, water bodies, wetlands and catchment areas
		R&D and implementation of technologies for restoration and enhanced utilization of forests, mangroves, wetlands, island and coastal ecosytems, arid and semiarid zones
	Development of wastelands	Identification of wastelands
		R&D and implementation of technologies for development of wastelands
	Ecosystem-compatible and need-based afforestation	Vegetation mapping of the country
		Development of afforestation plans to meet demands for forest-based products particularly for rural poor
Information, education and training	Use of integrated ecologic-economic database for sectoral decision making	Creation of nodal agency for establishment of a national ecologic-economic database
	Human resource development for environmental management	Introduction of environmental subjects in curricula of schools and colleges
		Introduction of specialized graduate and post-graduate programmes on environment
		Continuing education of professionals
		Extension of employment guarantee scheme to environmental restoration programmes
	Awareness building for enlightened public participation in environmental decision making	Development of mass communication techniques
		Development of centralized facility for acquisition, documentation, storage and dissemination of environmental education material in form of environmental resource centre
		Establishment of regional/local ENVIS centres

Table 2. Significant R&D activities at NEERI.

Thrust erea	Significant R&D activities
Environmental biotechnology	Methane recovery and treatment systems based on anaerobic activated sludge and fixed-film anaerobic process for low, medium and high strength wastes such as sewage, tannery, pulp and paper, food processing, brewery, pharmaceutical and distillery wastes
	Bioaugmentation of anaerobic treatment process through addition of nutrients such as cobalt, boron, tin, molybdenum and selenium to anaerobic digesters and denitrification systems
	Development of simple, reliable and efficient method for elution and reconcentration of viruses from water samples
	Rapid detection of water-borne enteric viruses employing chemiluminiscent enzyme immunoassay and enzyme immunofiltration techniques
	Development of gene probe for detection and enumeration of water-borne enteric viruses
	Isolation and mass culture of microbial strains for biodetoxification of hazardous and recalcitrant wastes bearing high concentrations of phenols, cyanides, aromatics and other substances
	Design of biological wastewater treatment systems for low temperature carbonization, coal and coke oven, sodium cyanide, organic chemicals, synthetic drugs, photofilm, and opium and alkaloid-manufacturing industrial units
	Production of 2,3 butanediol from water hyacinth
	Production of hydrogen and chemicals from biomass
	Development of oxidative and chemobiochemical techniques for microbial desulphurization of coal, oil and gas
Environmental chemistry	Development of analytical schemes for physico-chemical speciation of trace metals such as Cu, Pb, Cd, Zn, Cr and Hg in natural waters and treated industrial effluents
	Development of analytical schemes for speciation of metals in soils
	Development of gas-air tracer techniques for estimation of Freon-12, Freon-13 and sulphur hexafluoride in air
	Study of dynamic characteristics of carbon cycle and its perturbations due to anthropogenic activities with recourse to mathematical modelling
	Development of schemes for monitoring greenhouse gases
	Development of schemes for monitoring dry and wet deposition
	Development of methods for estimation of elemental forms of C, N and P and evaluation of biokinetic and geochemical kinetic constants in aquatic ecosystems
	Application of speciation schemes for trace metal bio-availability and assessment of relationship with thermodynamic availability
	Participation in IGBP

Table 2. (*Contd.*)

Hazardous waste management	Standardization of techniques for estimation of amino, chloro, nitro, nitrochloro and hydroxy-substituted aromatics as also a variety of biocides from industrial wastewaters and raw water sources
	Estimation of degree of hazard of various substances in terms of toxicity, ignitability, corrosivity and reactivity
	Development of sampling trains for estimation of hazardous waste emissions and identification and quantification of carcinogens
	Development of molten salt combustor for destruction of hazardous industrial wastes
	Assessment of given industrial site for pollution damage due to past chemical waste disposal activity
	Evaluation of hazardous waste incinerators for destruction of principal organic hazardous constituents
	Study on thermal destruction of hazardous wastes
	Preparation of guidelines for siting of hazardous waste treatment facilities, and identification and management of abandoned hazardous waste sites
	Treatment of coke oven effluent from steel plant
Environmental systems modelling and optimization	Development of general purpose, self-callibration river water quality model SIMQUAL
	Development of structural models for village and district ecosystems
	Development of non-causal models for environmental systems using group method of data handling
	Application of off-the-shelf air and water quality models such as AQS, UNAMAP, QUAL-IIe and WASP 3
	Optimal design of branched and looped water distribution systems
	Optimal design of wastewater collection systems
	Optimal design of aerobic and anaerobic systems for wastewater treatment
	Optimal design of solid waste transportation systems
	Optimal design of air quality monitoring networks
	Calibration and verification of air and water quality (lakes, riverine and estuarine systems) models for selected regions under deterministic environment
Environmental impact and risk assessment	Guidelines for environmental review of industrial projects
	Environmental guidelines for oil refineries
	Environmental guidelines for oil transportation pipelines
	Development of methodology for computer-aided EIA
	Development of conceptual framework for EIA of Ganga Action Plan and its validation at two selected centres
	Development of user interactive computer package employing GMDH for use of non-causal models in impact prediction
	EIA of nuclear power plants at Rawatbhata and Kaiga
	EIA of Gandhar Oilfields, ONGC
	EIA of Uran Onshore facilities, ONGC
	EIA of Mangalore refinery and petrochemicals, MRPL
	EIA of lube plant expansion for MRL
	EIA of oil/gas field development at Godawari offshore basin of ONGC, Madras
	EIA of oil/gas field development at Bombay offshore basin of ONGC
	RA of Hazira gas processing complex, ONGC
	EIA of crude stabilization unit of ONGC, Hazira
	EIA of gas collecting station of ONGC, Thatipaka
	EIA of Dankuni Coal Complex, CIL
	EIA of HPC paper mills at Nagaon and Cachar, HPC
	EIA of Manuguru projects of M/s Singereni Collieries Company Ltd, Kotagudam
	EIA of thermal plant expansion for Neyveli Lignite Corporation
	EIA of Korba industrial region under SADA
	EIA of fertilizer plant, Vijaipur
	RA of HPC paper mills at Nagaon and Cachar
	EIRA of additional facilities at Bombay refinery complex of BPCL
	EIRA of augmentation facilities of lube base stock at Bombay refinery complex of HPCL
	Risk assessment of chemical plant with recourse to Monte Carlo simulation technique
Environmental policy	Preparation of perspective national environmental plan
	White paper on preventive environmental policy for industry in India
	Policy paper on waste utilization in India
	Development of structural modelling approach to village sustainability
	Development of computer simulation model for district planning
	Development of carrying capacity-based regional planning model
	Development of assimilative capacity-based environmental management model
	Analysis of structural change in Indian economy and its impact on environment

Environmental biotechnology

Biotechnology is an emerging discipline that holds promise to offer long-range solutions to common developmental and environmental concerns. In its accepted connotation, however, environmental biotechnology has been restricted to waste treatment, with some emphasis on resource recovery.

The emergence and acceptance of the concept of sustainable development warrants that the scope of environmental biotechnology be enlarged to include applications in the areas of environmental monitoring, restoration of environmental quality, resource/residue/waste-recovery/utilization/treatment, and substitution of non-renewable finite resource base with renewable resources.

In order to review current status and future prospects for application of biotechnological processes, tools and techniques in environmental management, a brainstorming session on enviornmental biotechnology was held at NEERI under the sponsorship of the Department of Biotechnology (DBT) in April 1989. The session recommended recognition of environmental biotechnology as an explicit thrust area of DBT and constitution of a task force for initiation, pursuance, development and integration of plans and programmes in this emerging and challenging discipline.

Environmental chemistry

Nearly 5 million chemicals have been synthesized in the last 40 years and chemical industries produce several million tons of synthetic chemicals annually. Many of the chemical products and wastes are released into the environment causing interference with natural biogeochemical cycles and resulting in acute health and environmental risks.

Study of reactions in the environment; distribution and equilibria between environmental components; and reaction pathways, thermodynamics and kinetics is essential for devising sound strategies for environmental management.

Major areas of research interests that have emerged in the recent years in the domain of environmental chemistry relate to ozone layer depletion, greenhouse effect, chemical speciation, acidic deposition and biogeochemical cycles.

Ozone layer depletion. Anthropogenic trace gases like nitrogen oxides and chlorofluorocarbons are responsible for increasing the destruction rates of ozone concentrations. This could affect the radiation balance and chemistry of the atmosphere as also agricultural ecosystem. It is, therefore, considered necessary to establish baseline stations to monitor ozone and its precursors. The results would help in establishing relationship between ozone and its precursors and throw light on mechanism of ozone layer depletion.

Greenhouse effect. Despite a large network of meteorological and a few background air pollution monitoring stations, India does not have any data on greenhouse gases. In view of our critical dependence on monsoons, it is essential that the interaction of gradually warming atmosphere with factors controlling monsoon dynamics is clearly understood. The role of greenhouse gases (principally CO_2, CH_4, O_3, N_2O, $CFCL_3$ and CF_2Cl_2) warrants particular attention.

Chemical speciation. Chemicals released into the environment undergo physicochemical and biological changes resulting in forms that have markedly different properties than the parent entity. A study of chemical speciation is, therefore, necessary for understanding the distribution and impact of chemicals in the environment. While most studies on chemical speciation have so far been directed towards determination of physico-chemical forms in isolated samples, efforts are now underway to develop reliable and generally applicable analytical methods to speciate elements in the environment.

Acidic deposition. The major sources of acidifying substances in the atmosphere are sulphur and nitrogen compounds emitted from power plants, industrial processes, vehicular transport and domestic sources. Considering the present levels of these air pollutants in the country, it is imperative that studies on acidic deposition be given due priority.

Biogeochemical cycles in aquatic ecosystems. Study of biogeochemical cycle of an element provides insight into transformations among different forms of the element, transformation rates, and distribution in the atmosphere, biosphere, hydrosphere and lithosphere. Such studies are considered essential for dealing with the complexities of the total environment.

Hazardous waste management

In recent years, there has been an increasing awareness on the quantity and diversity of hazardous wastes generated by the industry and the risks posed to human health and environmental quality by some of the disposal methods for such wastes. These concerns have prompted several countries to undertake effective technological, administrative, legal and policy measures to address the problem of hazardous waste management.

India, too, has witnessed a five-fold increase in industrial production in the last three decades, bringing in its wake serious threats from toxic and hazardous substances. As per correlation between economic activity and hazardous waste generation established by the Organization for Economic Cooperation and Development (OECD), the hazardous waste generation in India has been estimated to be 0.3 million tonnes during 1984.

However, except sporadic attempts made by the CPCB, DOE and NEERI, no systematic assessment of the quantity and pollution potential of hazardous wastes has been undertaken in the country. In view of the current status, sufficient thrust needs to be given to development of database with respect to generation, storage, treatment and disposal of hazardous wastes; development of technology/techniques for hazardous waste management; development of guidelines for siting of hazardous waste disposal facilities; and formulation of disaster management plans to deal with industrial accidents.

Environmental systems modelling and optimization

The mathematical problems in environmental management could be of two types, viz. optimal planning and optimal control. Solutions to both warrant recourse to the techniques of systems analysis incorporating mathematical modelling and optimization.

Mathematical modelling. A substantial amount of research supported by extensive monitoring is required to develop well calibrated and validated mathematical models for air quality, surface and groundwater quality, and ecological systems in our country.

There is also a need for adequate representation of a system variability and uncertainties in mathematical modelling of environmental systems. Further, since environmental systems are complex and interactions among subcomponents are not well understood, it is necessary to develop techniques that allow flexibility in model identification and provide means to incorporate inherent system uncertainties in the modelling procedure.

Optimization of environmental systems. Despite availability of a large number of formulations for optimal design of environmental systems covering the entire spectrum of design problems, few have found application in practice due to the deterministic nature of available software.

Incorporation of reliability considerations in optimization of environmental systems requires development of chance-constrained linear and non-linear programming and stochastic dynamic programming formulations.

Environmental management. Planning for sustainable development warrants optimal utilization of supportive and assimilative capacities of the environment. Development of management models for various environmental subsystems and their integration to furnish an effective tool for overall developmental planning is yet another area that requires substantial research inputs.

Environmental impact and risk assessment (EIA)

This is potentially one of the most valuable, interdisciplinary, objective decision-making tool with respect to alternate routes for development, project sites and process technologies. In its present form, however, EIA suffers from several limitations at the conceptual, methodological and procedural levels.

Conceptual limitations. EIA is presently conceived merely as a project level tool and does not address to developmental programmes at the policy and planning levels. Environmental assessment of developmental activities in the context of regional carrying capacity warrants that the conceptual framework for EIA be extended to the cumulative assessment of developmental policies and plans on a regional basis.

EIA also does not deal adequately with the strategies of preventive environmental intervention. The issues of resource conservation, waste minimization, by-product recovery, and improvement in efficiency of equipment could be pursued as explicit goals in EIA.

Methodological limitations. EIA methodologies in vogue require considerable inputs in terms of data, manpower, time and financial resources. These constraints could be overcome through development of screening, scoping and computer-aided methodologies for EIA.

There are also uncertainties related to data and prediction/evaluation methodologies that warrant research and development of improved methodologies.

Procedural limitations. The present environmental review procedures lack objective criteria for deciding whether a project requires comprehensive EIA or not. EIA is presently carried out only for projects that require funding from PIB. The public acceptance of impact assessment is another issue of procedural concern that needs to be incorporated in the environmental review process. Sectoral guidelines for environmental review, therefore, need to be formulated to aid review authorities, project proponents and consultants undertaking EIA.

Environmental policy

Present day environmental problems are not so much due to lack of governmental thrust as to the direction of these efforts resulting in sectoral, media-specific, repair-oriented environmental planning and management that overlooks the interactive nature of common environmental and developmental concerns.

The inadequacies of reactive environmental policy could be overcome through a preventive policy framework which influences technological considerations preceding investment decision-making in such a way that resource utilization as also the cost of environmental protection and damage are minimized while economic productivity and innovative capacity are maximized.

Such an approach requires pragmatic management of natural resources through positive and realistic planning that balances human expectations with ecosystems carrying capacity. It aims not only at environmental harmony but also at long-term sustainability of the natural resource base and economic efficiency in resource utilization vital for ensuring sustainable development.

Development of computer simulation models for district planning and village sustainability with recourse to structural modelling approach could aid in carrying capacity-based developmental planning process. The state variables, parameters and exogenous forcing functions of the model must correspond to real components of district system emphasis on the study of feedback control, stability of the system and sensitivity of one component of the system to changes in other components.

Epilogue

The policy-makers faced with long-term environmental problems often argue that they cannot afford to worry about the remote and the abstract when surrounded by the immediate and the concrete. The problems that overwhelm us today are precisely those which, through a similar approach, we failed to solve decades ago.

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