Comparative Risk Assessment

Comparative risk assessment provides a systematic way of looking at environmental problems that pose different types and degrees of health risk. It combines information on the inherent hazards of pollutants, exposure levels, and population characteristics to predict the resulting health effects. Using data from available sources, rapid, inexpensive comparative risk assessments can identify the most significant health problems. Together with consideration of costs, technical feasibility, and other factors, the results of comparative risk assessment can be used to set priorities for environmental management.

Comparative risk assessment provides a general framework for evaluating environmental problems that affect human health.[1] Risk assessment does not have to be cumbersome or costly to provide useful insights. Rapid, inexpensive approaches can be considered risk assessment as long as certain basic concepts are included. There are four generally recognized steps in assessing human health risks, as described by the U.S. National Research Council:

- *Hazard identification* is the process of describing the inherent toxicity of a chemical on the basis of toxicological data from laboratory or epidemiologic studies.
- *Exposure assessment* combines data on the distribution and concentrations of pollution in the environment with information on behavior and physiology to estimate the amount, or dose, of a pollutant to which humans are exposed. Exposure is typically estimated by modeling the dispersion of emissions from a polluting source.
- *Dose-response assessment* relates the probability of a health effect to the dose of pollutant (see the Annex) It relies on statistical or biologically based models to describe this relationship, using either experimental animal data or epidemiologic studies. Estimated dose-response relationships (DRRs) are readily available for a large number of industrial chemicals and other types of pollutants and need not be derived separately for each individual country. However, relationships based on site-specific epidemiologic data are preferred, if available.
- *Risk characterization*, the final step in risk assessment, combines the exposure and dose-response assessments to calculate the health risk estimates, such as the number of people predicted to experience a particular disease, for the population of concern. Risk characterization also describes uncertainties in the calculations and provides other information to help interpret the results of the analysis.

Comparative risk assessment is a simplified, focused methodology for deriving reasonable findings from readily available data. It is used to provide understanding and guidance in the absence of detailed scientific studies and analysis.

Issues in the Use of Risk Assessment

Defining the Scope of the Analysis

An effective risk assessment must have a well-defined scope. The appropriate scope depends on the purpose of the analysis. For example, an evaluation of emissions from a particular industrial facility is likely to concentrate on the health effects on local population; a project to set national environmental priorities may include a broader range of issues, such as the effects of national policies on emissions of greenhouse gases and ozone-depleting substances.

The purpose of most comparative risk assessments is to identify the most important health risks from the point of view of the people affected. Although the options for mitigating risks may be evaluated on a sectoral basis, the initial analysis should consider all types and sources of environmental risk in making the ranking.

The analyst must choose the types of risks and populations to assess. These may include:

- Type and duration of health end point (acute or chronic, cancer or noncancer, occupational disease)
- Special target populations such as children, pregnant women, and asthmatics
- Ecological effects (for example, on populations, unique habitats, or biodiversity).

An assessment of a particular industrial project or sector typically begins with a description of the source of pollution. Models of the transport and potential transformation of the pollutants in the environment are used to estimate the concentration of contaminants in air, water, or soil. Concentrations in these media are used to estimate the human dose, which, combined with dose-response information, predicts the occurrence of disease.

For some pollutants, monitored data on concentrations in air or water may be available, obviating the need for modeling the transport and fate of the pollutant. In other cases, data on measures of pollutants in the human body, such as blood lead levels, or measures of characteristic clinical responses to exposures, such as elevations in blood enzyme levels, may be available. These may be used as a direct measure of exposure in the dose-response functions, rather than using estimated exposure rates.

Complexity of Analysis

Risk assessment does not necessarily require sophisticated techniques or extensive data collection. Reasonable, practical results can be derived using minimal available information on pollution and the populations exposed to it.

For example, in a study by the U.S. Agency for International Development (USAID 1994), an American team worked in Cairo for six weeks with Egyptian counterparts to refine the methodology to be used, identify sources, and collect data. The study relied on existing data without any additional environmental sampling or monitoring. Such rapid evaluations usually mean greater uncertainty in the results, but they are still useful for getting a general idea of the magnitude of problems associated with pollution sources and to demonstrate to decisionmakers that the problems posed by pollution are real and significant.

Comparative risk assessment is an important tool for helping to prioritize solutions to health problems by distinguishing *actual* risk from *potential* exposure. Its strength lies in its ability to compare and evaluate the effects of two or three pollutants or other hazards. Nonetheless, because these techniques emphasize pollution, they do not necessarily portray the complete range of environmental health problems. Thus, for example, vector-related diseases such as malaria, dengue fever, and schistosomiasis—all still very important in developing countries—would not necessarily be covered in an assessment. Additional public health inputs may therefore be required to gain a complete portrait of environmental health risks.

The results of rapid assessments are likely to be most valuable when they are used in a relative or comparative, rather than an absolute, way. The appropriate complexity of analysis will be influenced by a number of factors, including the likelihood that additional refinement would resolve the uncertainties in budgets, time constraints, availability of data, and use of the results.

Quality of Data Required

The quality and quantity of data needed to produce a meaningful analysis will depend on how much uncertainty the analyst is willing to accept. Ideally, high-quality local data for all parts of the analysis, including locally based epidemiology for the dose-response functions, would be available. The ideal will rarely, if ever, be the case. However, limited good data can be supplemented through techniques that fill data gaps with reasonable assumptions and extrapolations. For example, data on ambient concentrations of many chemicals are often unavailable, since monitoring is expensive and is likely to be directed at only a few constituents. In its place, emissions data can be used in conjunction with environmental modeling systems to estimate concentrations in the environment.

Two such systems developed within the World Bank are the Decision Support System and the Industrial Pollution Projection System. The USEPA has also developed and published emissions factors for air pollution sources; these include AP-42 (USEPA 1985) for "criteria" pollutants and Toxic Air Pollutant Emission Factors, or TAPEF.

Adjustments for Site-Specific Conditions

Many of the data sources and analytical techniques used in a risk assessment will, by necessity, be transferred from OECD contexts. It may be possible to adjust such data on the basis of a comparison of country-specific conditions with the conditions in the countries where the data were derived. For example, epidemiologic studies frequently use measures of ambient pollutant concentrations to represent personal exposure. To adjust the results of such studies, the analyst will consider how the relationship between ambient concentrations and personal exposures may differ in the country of interest.

Examples of Comparative Risk Assessment

In Industrial Countries

Risk assessment has been used during the past decade in a number of OECD countries. In the United States, it has been used to set overall environmental priorities for the nation, to guide legislation, and to choose among regulatory approaches. Almost every environmental program within the USEPA now uses risk assessment to determine regulatory priorities, to perform cost-benefit analysis, or to target enforcement activities. Risk assessment has been used, for example, to decide which air pollutants to control, which pesticides to allow and which to ban, and to what degree contaminated hazardous waste sites should be cleaned up. In Western Europe, both the EU and individual countries are working to adjust risk assessment techniques for application within their contexts.

In Developing Countries and Transition Economies

Comparative risk assessment can help regions and countries allocate limited resources efficiently (see Table 1). For example, the method has been applied on a citywide basis in Bangkok and in Cairo to identify specific recommendations for targeted actions such as reducing lead in gasoline and managing traffic situations to decrease levels of particulate matter. The method was also applied in the Silesia region of the Czech Republic and Poland, where it was coupled with an effort to identify realistic, cost-effective solutions (USEPA 1992b, 1994).

Many of the comparative risk assessments performed in developing countries have examined urban areas that do not have significant industrial sources of pollution. These studies have identified a consistent set of priority problems: particulate air pollution and microbiological diseases caused by water and food contamination. These problems are likely to be of high concern in any rapidly developing area that lacks adequate municipal infrastructure and is experiencing a rise in industrial activity and traffic volume. Comparative risk assessments performed in such settings may direct resources to examining these problems first, although the specific conditions of each urban area may suggest additional priorities.

Key Issues in Risk Characterization and Priority Setting

Risk assessment attempts to evaluate environmental problems using objective, scientifically based measures. Risk management considers not only the magnitude and severity of the health risks posed by pollution but also the costs and technical feasibility of abatement and the political will and institutional capacity to manage risks. By itself, it cannot establish environmental management priorities. It is the first of several steps in the process of setting priorities, structuring policies, and implementing strategies to deal with pollution.

The use of risk assessment in cost-benefit analysis and priority setting has typically meant the use of overall population risk measures, such

Table 1. Summary of Risk Assessment Projects in Developing Countries and Transition Economies

Study location (reference)	*Intent of study*	*Scope of problems examined*	*Notable features*	*Major findings*
Bangkok (USAID 1990)	Comparative risk across a range of environmental problems	Air, and water pollution; solid and hazardous waste disposal; microbiological disease	Estimated incidence and severity index used to rank problems	Highest-priority problems: airborne particulate matter; lead; infectious disease
Bangkok follow-up (World Bank 1994)	Focus on air pollution from energy, transport and manufacturing sectors; identification of cost-effective risk reduction strategies	Primary reanalysis focus on air pollution, but other media examined	Included economic valuation component	Priority problems: particulate matter and lead; surface water pollution from microorganisms; congestion; air pollution control strategies for energy and road transport discussed
Cairo (USAID 1994)	Comparative risk across a range of environmental problems	Air and water pollution; solid and hazardous waste disposal; microbiological disease	Used estimated incidence and qualitative estimate of severity and probability to rank problems	Highest-priority problems: particulate matter; lead; food and water contamination leading to disease
Quito (USAID 1993a)	Comparative risk scoring across a broad range of environmental and health problems; other problems	Air and water pollution; solid waste; occupational disease; traffic	Used both quantitative risk assessment and health outcome data; performed site-specific ethnographic study; performed explicit scoring of problems based on probability and severity	Highest-priority problems: air pollution, and food contamination with microorganisms
Silesia region, Czech Republic and Poland (USEPA, 1992b, 1994)	Identification of actions to reduce risk and improve environmental management capabilities in a coal- and steel-producing region	Air, food, water, and solid waste; occupational disease; ecological risks for water pollution	Examined ecological as well as human health risks; used two dimensions—severity and scale—to characterize risk	High risks from particulate matter and toxic air pollution (coke oven emissions); food contamination with PCBs; high occupational risks; severe risks to aquatic life
URBAIR projects: Mumbai, Jakarta, Manila (Shah and Nagpal 1997a, 1997b, 1997d)	Estimate the health and economic impacts of air pollution resulting from continued urban growth	Air pollution only	Estimated health effects using monitoring data and U.S.-based concentration-response functions; some studies include explicit monetization of health effects	All studies found significant effects of air pollution (thousands of deaths, tens to hundreds of thousands of cases of illness)

as the number of cases of disease predicted, as the preferred risk descriptor. But there may be other important measures, such as levels of individual risk, the distribution of risks across the general population and highly exposed subpopulations, identification of special at-risk populations, and consideration of the relative severity of the effects characterized.

Vital to the interpretation of risk assessments is the identification of major sources of uncertainty. Open, frank description of the uncertainties in the analysis enhances its credibility and provides a context in which the results should be viewed.

Resources Required

The scale and cost of some risk assessments that have been conducted demonstrate that the practical application of standard techniques of risk assessment can enhance project design without being overly resource-intensive.

USAID (1993b) presents a typical schedule for conducting an environmental health analysis. The example suggests a project lasting four to six months, from project planning through the final report. The schedule assumes a full-scale analysis of many types of problems; the actual time required may be less for site-specific projects, where a narrower set of likely pollution problems can be identified. (See Table 2 for some recent examples.)

The types of consultants needed for a risk assessment will depend on the data available and the problems to be assessed. If industrial pollution sources are the focus, the project may need environmental scientists or engineers familiar with predicting the fate of emissions in the environment. The exposure assessment, dose-response, and risk characterization steps typically require individuals with training in risk assessment, toxicology, or epidemiology. The task manager may also want specialists familiar with the particular country's governmental and social structure to facilitate the collection of data from diverse sources.

Some Sources of Data

Environmental Quality Data

The most important sources of environmental quality data are local and regional. When local data are not available, other sources may provide limited information. For example, some international organizations maintain environmental quality data for certain pollutants: the United Nations Environment Programme (UNEP) Glo-

Table 2. Time and Resource Requirements of Some Recent Studies

Location (reference)	*Time required*	*Approximate resources (U.S. dollars)*	*Notes*
Bangkok (USAID 1990)	Approximately 3 weeks on the ground; a few months total to prepare report	On the order of 60,000–70,000	
Bangkok follow-up (World Bank 1994)	Four to 5 person-weeks for risk assessment portion (20 person-weeks for entire report)	25,000 for risk assessment; 100,000 for entire report	Covered risk assessment, cost-effectiveness analysis, and development of policy framework
Cairo (USAID 1994)	Six weeks on the ground	"Moderate cost"	
Quito (USAID 1993a)	Five to 6 months, with local consultants on the ground in advance; shorter time in country	Approximately 200,000	Included health risk assessment, environmental health survey, and ethnographic survey
URBAIR projects (Shah, Nagpal, and Brandon 1997; Shah and Nagpal 1997a, 1997b, 1997c, 1997d)			Covered only air problems

bal Environmental Monitoring Network System is an example of such a source. Other organizations may have collected environmental quality data for specific purposes, such as USAID environmental action plans and World Bank country reports on environmental management. The World Resources Institute compiles environmental data from a variety of sources for its annual *World Resources* report.

Human Health and Ecological Toxicity Data

International organizations are good sources of information on hazard evaluations of chemicals, including environmental standards and, for some pollutants, dose-response evaluations. The World Health Organization (WHO) develops guidelines for acceptable concentrations in environmental media based on protection of human health. Often, the background documents supporting these guidelines can provide further information on chemical hazards. The International Agency for Research on Cancer (IARC) supplies data on the carcinogenic effects of pollutants.

Since risk assessment is widely practiced in the United States, the USEPA is an important source of information on toxicological information and evaluation methods. The agency maintains a centralized, on-line database, the Integrated Risk Information System (IRIS), containing toxicological information on over 600 chemicals, which can be easily accessed by risk assessment practitioners. Other USEPA documents, such as the scientific documents that support standards for the criteria pollutants (PM_{10}, sulfur dioxide, lead, ozone, nitrogen oxides, and carbon monoxide), contain substantial reviews and evaluations of the literature on these major air pollutants.

A recent World Bank report (Ostro 1994) summarizes much of this same information, with additional discussion of its applicability to developing countries. In particular, it reviews health effects studies commonly used in assessing risk from particulate matter and ozone exposure. The studies were performed primarily in North America and Europe, and many of them are time-series studies that focus on short-term (e.g., daily) changes in morbidity and mortality in response to short-term changes in pollution concentrations. A peer review of Ostro pointed out the difficulties of extrapolating these results to developing countries, due to differences in the populations and exposures considered. The peer reviewers expressed concern that the time-series studies capture primarily the acute effects of air pollution on mortality. Short-term fluctuations in mortality due to air pollution episodes may largely reflect the hastening (by days or weeks) of the deaths of diseased individuals in the population. If so, this component of overall mortality results in fewer life-years lost and may be of less significance to public health than the chronic effects of long-term exposure to air pollution in otherwise healthy individuals.

Two recent cohort studies, Dockery et al. (1993) and Pope et al. (1995), have reported a significant and dramatic association between mortality in the study cohorts and long-term exposure to airborne particulate matter. Because such studies better reflect the morbidity and mortality effects of interest, using the results of chronic effects studies in comparative risk assessment is preferred, when they are available.

Factors for Human Exposure Assessment

Exposure assessment requires the integration of environmental quality data with an estimate of the rate of human contact with contaminated media. This stage of risk assessment should rely heavily on local data, since it allows an assessment of how particular local conditions and cultural practices affect risk potential. Local data on food consumption patterns, indoor-outdoor activity patterns, types of housing, prevalence of health conditions, and so on can all be important to the assessment process. These data can be obtained from local health department and social service ministries, environmental ministries, NGOs, or sociological investigations conducted as part of the analysis.

Annex. Dose-Response Functions and the Health Impacts of Air Pollution

Few would question that too much air pollution is a bad thing. Not only does air pollution reduce visibility and destroy the aesthetic beauty of our surroundings; it has been generally recognized as a health hazard. The question is not whether air pollution should be controlled but, rather, how much should be spent to control it. To answer this question it is necessary to estimate the reductions in health damages that are likely to occur if air pollution is reduced.

Dose-response functions measure the relationship between exposure to pollution and specific health outcomes. By regressing a specific measure of health on a measure of pollution exposure while controlling for other factors, the role of pollution in causing the health effect can be estimated. This estimate can then be used to predict the health improvement corresponding to a decrease in exposure. In short, dose-response functions translate changes in air quality into changes in health.

Both humans and animals have been the subjects of studies that examine the effects of air pollution exposure on health. This annex discusses only epidemiologic studies—those based on human populations.

Exposure to Air Pollution

Exposure to air pollution is usually measured in terms of ambient levels of pollutants. Not surprisingly, the pollutants included in the epidemiologic literature are limited by the availability of data. Those commonly monitored by environmental authorities can be divided into four categories:

- Sulfur oxides, nitrogen oxides, and particulates generated by burning fossil fuels
- Photochemical oxidants (e.g., ozone) created by the interaction of motor vehicle emissions (hydrocarbons, nitrogen oxides, and the like) in the atmosphere
- Other pollutants generated by mobile sources (e.g., carbon monoxide and lead)
- Miscellaneous pollutants (e.g., cadmium and lead) generated by localized point sources such as smelters and manufacturing plants.

Health Outcomes

Health outcomes are usually precisely defined. They are often expressed as a measure of breathing capacity, such as forced expiratory volume (FEV), forced vital capacity (FVC), or forced expiratory flow (FEF). However, respiratory symptoms such as cough, phlegm, and throat irritation, the incidence of respiratory disease, including bronchitis and pneumonia, and mortality rates are studied as well. Table A.1 shows some health effects associated with selected common pollutants.

To date, most studies have examined the effects of acute (short-term) exposure to pollution. This should not be interpreted to mean that long-term exposure has no effect on health. Long-term exposure to low levels of pollution has been shown to affect an individual's tolerance of short-term exposure to high levels of pollutants. Furthermore, questions have been raised concerning the relationship between long-term exposure and the incidence of cancer and heart disease. Unfortunately, long-term exposure is often difficult to measure due to the high immigration rates in some urban populations.

Confounding Factors

A good study will attempt to control for confounding factors that may contribute to an individual's likelihood of experiencing the health outcome in question. However, these factors are often not easy to control for and can weaken the results of the research.

For instance, although individuals may be affected by a combination of pollutants, the presence of other pollutants may not be incorporated into the study due to the limited availability of pollution data. Other confounding factors include temperature, humidity, physical activity, smoking habits, occupational exposure to pollutants, dietary factors, availability and quality of

Table A.1. Health Effects of Common Air Pollutants

Pollutant	*Health effect*
Particulate matter; sulfur dioxide	Decreased lung function; increased respiratory morbidity among susceptible adults and children; increased mortality among the elderly and the chronically ill
Ozone	Eye, nose, and throat irritation; chest tightness; cough; shortness of breath; pain on inspiration
Nitrogen oxides	Increased risk of respiratory disease in children under 12 years old
Lead	Impaired neurological development; high blood pressure

medical care, and age. The age structure of the population is especially important because children and the elderly are more susceptible to respiratory infection.

Applying the Dose-Response Function

Calculating the total health impact of a proposed pollution control program is relatively easy once the dose-response functions have been estimated. The dose-response equation given below is taken from Evans et al. (1984), which summarizes the results of numerous cross-sectional analyses. The equation relates excess mortality to total suspended particulates (TSP).

$$\text{Excess mortality} = 0.45 \times r\mathit{TSP} \times \mathit{POP}$$

where *POP* is the size of the exposed population and r*TSP* is the magnitude of the proposed change in pollution measured in micrograms per cubic meter (µg/m^3). Excess mortality is expressed as the age-adjusted mortality rate per 100,000 persons.

Ideally, the total life-years saved as a result of an environmental improvement would be measured. This can be done only when the dose-response function is estimated separately for different age groups—which, unfortunately, seldom occurs.

Recently, dose-response functions estimated for one country have been applied to populations lacking their own epidemiologic studies in order to estimate the effects of exposure to air pollution. Although this practice, referred to as "benefits transfer," does provide a rough estimate of the adverse health effects caused by pollution in these previously unstudied countries, it should be applied with caution. Without further testing, there is no reason to believe that the dose-response relationship calculated for one area will be exactly the same as that for another. Differences in the composition of air pollution, in the age distribution of the population, in access to and quality of medical care, in baseline health, and in education and other behavioral and socioeconomic variables may cause variations in the response to air pollution exposure.

In an effort to estimate the health effects of air pollution in Latin America, where few epidemiologic studies have been done to obtain dose-response functions, Romieu, Weitzenfeld, and Finkelman (1990) applied to a hypothetical population dose-response functions for TSP found in the literature (see Table A.2). The hypothetical population was similar in size and age distribution to the sum of all "high-risk" Latin American cities. The assumption used was that among the total population of 81 million people, 14.5 million would be exposed to a very high level of TSP (250 µg/m^3), 23.5 million would be exposed to a high level of TSP (150 µg/m^3), and 43 million would be exposed to a moderate level of TSP (100 µg/m^3). Table A.2 shows the health impacts attributable to TSP levels above the WHO guideline value of 75 µg/m^3. For instance, over 24,000 deaths, representing 6% of annual mortality, would be avoided if TSP levels were reduced to 75 µg/m^3.

Note

1. The term *risk assessment* is used in a wide variety of contexts and meanings. Here, comparative risk assessment refers to an analytical approach to estimating the key environmental health risks faced by a population group. The approach does not address ecosystem impacts, which should be considered separately.

Table A.2. Health Effects of Selected Annual Mean TSP Levels in a Hypothetical Population

	Micrograms per cubic meter			
Excess number	*250*	*150*	*100*	*Total*
Mortality (thousands per year)	11.5	7.9	4.9	24.3
Chronic cough in children (millions per year)	1.1	0.76	0.47	2.3
Respiratory-related restricted activity days (RRAD) in adults (millions of days per year)	32.0	21.0	12.0	65.0
Chronic bronchitis in the elderly (thousands)	50.0	33.0	22.0	105.0

Source: Romieu, Weitzenfeld, and Finkelman 1990.

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