Chapter 4

Core Environment Statistics and Methodological Issues

This chapter identifies and describes specific parameters for air, soil, water, human settlements, and biodiversity statistics relevant to anticipated priority environmental issues in the countries covered by this RETA. Included here are definitions of the various parameters, classification systems, measurement techniques, computational methods, and reporting formats. Examples from databases established by international organizations illustrate how the parameters are derived. The limitations of current data collection efforts are assessed, including problems likely to be encountered with regard to data collection capabilities, standardization of methods, data aggregation, and derivation of regional or global indicators. Solutions recommended by international organizations are included.

Land Use

Environment statistics on land use should be able to track the rates of land use conversions from one type to another to be useful for policy making. To accomplish this, land use data would ideally be compiled from an accounting perspective so that attention is given to "flows" of changes from one use to another, rather than just to "stocks" or status of use at any one time. Conventional reporting focuses on the existing area and percent change over a period for a given land use. Data on conversions from one type of use to another usually are not available.

Unfortunately, attempting to calculate land use conversions from one type to another using past data may not always provide reliable results since definitions of land use categories are often substantially revised from time to time (e.g., as FAO did in 1985 when it excluded from the cropland category land used for shifting cultivation but currently lying fallow). Apparent changes could therefore indicate differences in land classification and data reporting, rather than actual conditions.

Categories for reporting land use vary considerably from one country to another. In general, however, five categories are commonly recognized: cropland, permanent pasture, forest and woodland, built-up areas, and other land. This classification system is the one adopted by FAO (FAO Production Yearbook) and by the World Resources Institute (World Resources Report). Within each general category, there may be additional subclassifications. For example, forest and woodlands may be further classified into closed and open forests (if canopy cover is the criterion), or into rain forest and dry forest (if rainfall is the criterion).

Deforestation

The status of deforestation may be reported with reference to total forests, or with reference to types of forests. FAO reports deforestation with reference to various types of forest formations (also called zones or ecozones). There are two general forest types: lowland forests, and hill and mountain forests. Lowland forests may be further classified into tropical rain forest, moist deciduous forest, dry deciduous forest, very dry forest, and desert forest.

FAO makes two other important distinctions of forest types: one between closed and open forests, and another between natural and plantation forests. These additional classifications may overlap with the forest formation (or ecozone) classification system. A closed forest is defined as land where trees cover a high proportion of the ground. An open forest is defined as one consisting of mixed trees and grasses, with at least 10 percent tree cover and the rest of the area covered by continuous grass cover. In the FAO definitions for tropical forests, “natural” refers to all stands except plantations, including forest areas degraded by fire, logging, or agriculture. Plantations refer to stands established by afforestation and reforestation for industrial and nonindustrial use.

The classification “other wooded area” also appears in some statistical compilations on forest cover. This classification often refers to areas where shrubs and stunted trees cover more than 20 percent of the area. In FAO definitions, trees are distinguished from shrubs on the basis of height (a mature tree is taller than seven meters).

FAO's statistical compilation on forest cover and deforestation rates in various countries is based on a survey of 76 tropical developing countries. Work started in 1980 and was expanded to 129 countries in 1988. Most of the data were provided by national forestry services in the countries covered. Among the countries included in this RETA, FAO assessed Malaysia and Nepal to have very good or good data on both closed forest areas and deforestation rates. Malaysia (Sarawak), Philippines, Sri Lanka, and Viet Nam were assessed by FAO as having very good or good data on forest cover and satisfactory or poor data on deforestation rates. For the other countries, FAO assessed the resulting estimates of both forest cover and deforestation rates as satisfactory or poor. Globally, however, FAO assessed Asia to have the best information obtainable on forest resources.

FAO's 1990 tropical forest resources assessment provides estimates of the extent of forest areas and deforestation rates between 1981 and 1990. A model was used to adjust baseline forest inventory data from each country to a common year. Existing forest inventory data were reviewed and adjusted to a common set of classifications and combined in a database. A geographic information system (GIS) was used to integrate statistical and map data for this purpose.

Various environmental state indicators may be derived from deforestation rate statistics. One indicator is deforestation rate per capita. ESCAP's SOER for Asia and the Pacific (1991) states that the average size of deforested area per person (based on the deforestation estimates of FAO) is about 15 square meters (m^2) per year. Notable countries were Lao People's Democratic Republic (288 m^2 per person per year), Malaysia (176), Thailand (63), and Nepal (60).

The causes of deforestation are familiar, even if the monitoring and statistical compilation of the data related to the causes themselves are not standardized. The five recognized major causes are commercial logging, shifting cultivation, weak institutions (enforcement, regulatory resources), fuelwood consumption, and high population growth. Except for population statistics, the other causes are less systematically monitored and their statistics vary in definition and data reliability from country to country.

Statistics on commercial logging are reported in terms of both area of forests affected and volume of wood extracted. The World Resource Institute (WRI), for example, provides compiled statistics on “managed closed forests” in various countries. These forests are defined as those managed on the basis of a plan and where there is some control of use such as harvesting regulations and silvicultural treatments. These areas are usually covered by forest concessions. The volume of wood extracted is internationally reported in terms of roundwood and processed wood production. Each country will have individual classifications within each of these two general categories (e.g., processed wood may be reported as sawn wood or panels). Statistics on the production of fuelwood and charcoal are inadequate in many countries. FAO uses population data and country-specific per capita consumption figures to derive estimates.

The major drain from the forest is cutting for fuelwood (e.g., some 200 million cubic meters are consumed annually within ASEAN, more than twice the volume of roundwood production). Statistics on institutional capacities — or lack of capacities when examining the causes of deforestation — may properly fall under the category of response in the PSR model. They include forestry laws and regulations, personnel, budgets, and programs. However, data on these are hard to come by on a standardized reporting basis across countries. By far, the most difficult statistic to obtain is the extent of shifting cultivation, for quite obvious reasons: it is in the informal sector where there is no systematic recording system, and the activity involves numerous small actors moving from place to place and, hence, inherently difficult to track.

Aside from strengthening institutional capacities for managing forests, responses to deforestation also include the establishment of protected forests/areas, revegetation of denuded lands (reforestation and afforestation), establishment of forest plantations to divert pressure away from natural forests, and local community involvement in forest protection and utilization. Statistics on reforestation and afforestation are often reported as forest plantation data. Plantation forests are defined as man-made forests used for industrial or nonindustrial (e.g., watershed protection) purposes. Data are usually in terms of size of area planted, though often the forest area actually reestablished is considerably smaller than the area planted (because of such causes as mortality or fire).

In protecting forest areas, the widely adopted approach is to incorporate multiple objectives and resource use. In the context of overall environmental management, protecting the forests should meet the objectives of maintaining natural habitats, preventing land degradation, and providing for the needs of local communities.

The World Conservation Union (formerly known as the International Union for the Conservation of Nature or IUCN), an independent global body that oversees efforts to conserve biodiversity, has developed a system of national protected area classification according to management objectives. Categories I and II refer, respectively, to strict nature reserves and national parks which are, by definition, protected from human exploitation. Other categories (III-VII) accommodate sustainable forms of human activity or land use. For example, multiple-use areas (category VII) may provide for outdoor recreation or even for timber production. Statistics may then be compiled on the extent of the areas under each protection category.

Soil Degradation

Various factors may be used to express the nature, cause, and degree of impairment in soil productivity. Regardless of variations in their definition, degraded soils are usually characterized by poor or undesirable physical, chemical, and biological features. Socioeconomic conditions in areas of such soils are invariably poor as well.

In most developing countries, there is an almost universal lack of reliable, quantitative data on soil properties (and variations in time and space). There is a general lack of data on soil quality at the national level. Keeping track of national soil resources and monitoring changes in relation to human activities have, up to now, received low priority in many national environmental monitoring programs. Databases need to be established to determine which land use systems are causing soil degradation, to assess the effects of various forms of pollution, and to derive meaningful measures of soil quality in relation to human activities.

Currently, standard procedures for evaluating soil quality are still deficient (UNEP 1993). For instance, there is as yet no universally accepted set of criteria for evaluating changes in soil quality. The science for standardizing methods for soil investigation is not as advanced as that for air and water. More fundamentally, the detailed data needed to evaluate soil quality at the national level are often lacking. Various types of soil degradation are present in the countries covered by the present study, and indicators are needed to monitor status, causes, consequences, and effectiveness of remedial actions. To produce these indicators, improved soils databases and standardized methods for soil description and analysis are needed.

In general, the three basic soil quality issues that need to be addressed are (i) productivity (e.g., soil fertility, toxicity); (ii) environment (e.g., water quality and contaminant leaching); and (iii) health (e.g., effects on animals and humans). In the past, emphasis was placed on productivity for agriculture. It is now widely recognized that the perspective needs to be broadened to include environmental quality as well as human and animal health aspects. Soil quality indices should capture all these elements. Essentially, nutritional quality and management would be positive items in such an index, and toxicants would be negative.

To date, the Global Assessment of Soil Degradation (GLASOD) Project coordinated by the International Soil Reference and Information Centre (ISRIC) and sponsored by UNEP provides the most comprehensive compilation of global information on the status and causes of soil degradation. The study, completed in 1991, defined three broad categories of soil degradation: (i) erosion and terrain deformation, (ii) chemical degradation, and (iii) physical degradation.

Actually, GLASOD further divided the first category erosion and terrain deformation into two separate categories: wind and water erosion. Erosion refers to the removal of topsoil due to wind action or through sheet erosion caused by water. Terrain deformation refers to creation of dunes or hollows, and to the scarring of land due to water-caused rill and gully formation, landslides, and collapse of riverbanks. By far, water is the main agent of topsoil erosion and terrain deformation in most of the tropical countries covered by the present study.

Environment statistics for eroded soils are usually reported as the aggregate extent of affected areas (and as a proportion to total land). The degree of erosion may be classified as slight, moderate, or severe. Unfortunately, there is no standard set of definitions for what these classifications mean. Reporting organizations adopt their own definitions, often formulated in terms of ranges of estimated soil loss rates (e.g., severe erosion might be defined as soil loss rate in excess of 50 metric tons a year).

The second category, chemical degradation, has four types: nutrient loss, salinization, pollution, and acidification. Nutrient loss refers to the loss of organic matter in the soil as a result of the clearing of vegetation, burning, and physical removal of fertile topsoil by the action of wind and water. Salinization is an increase in the salt content of the soil due to human-induced activities that cause salt to accumulate in soils. One cause is the inadequate provision of drainage to complement irrigation schemes in semiarid areas. Salts transported with the irrigation water accumulate in the soil as the water evaporates. Salinization may also be caused by saltwater intrusion into groundwater due to overpumping near coastal areas. Intensive cultivation results in rapid water evaporation rates that transport salt from saline groundwater. Pollution refers to the contamination of soils by pesticides, wastes, and substances that are toxic to soil microorganisms. The pollution of soils is often accompanied by the pollution of groundwater. Acidification is the lowering of the soil pH, which may result from the overapplication of fertilizers.

The third category of soil degradation is physical degradation, of which there are three types: compaction, waterlogging, and land subsidence. Soil compaction is the result of trampling by cattle or heavy machinery. This action destroys the soil structure and seals the spaces between soil particles, leaving the soil unable to drain water. Waterlogging is a condition associated with prolonged periods of inundation due to lack of drainage (except for paddy fields purposely flooded). Waterlogging is often accompanied by salinity buildup. Land subsidence results from excessive removal of water from aquifers under pressure (e.g., areas in Bangkok), or the excessive drainage and/or oxidation of organic soils in agricultural areas.

An extreme form of soil degradation (associated with all three categories) is desertification, which is a major concern in arid, semiarid, and dry subhumid areas. Among the 11 countries covered by this RETA, India and Pakistan are the countries with desertification problems. The total affected area in both countries is about 1.7 million hectares (ESCAP 1995).

Theoretically, statistics on the extent of areas affected by soil degradation according to the various types and subtypes could be compiled. However, precise information on the extent of such degraded soils is not usually available. In addition, the types of soil degradation often overlap in any one area, and merely adding up the areas falling under various degradation types could result in misinterpretation or overestimation of the degradation problems. Nonetheless, where data are available, statistics could be compiled for the areal extent of soil degradation under each category.

One approach to environment statistics for soil degradation is based simply on determining the aggregate areas according to a systematic classification of the qualitative degree of soil degradation caused by the separate or combined effects of the various types of degradation. The classification system would include consideration of the soil's rehabilitation potential, and not just the soil's present condition. For example, the GLASOD Project defined four degrees of degradation (Table 4.1). The GLASOD classification system considers the agricultural suitability of the soil, maintenance of biotic functions, and feasibility of soil restoration. Thus, environment statistics on soil degradation would be compiled as the annual or some periodic estimates of the aggregate size of areas falling under each of the four qualitative categories.

Table 4.1

Degrees of Soil Degradation According to the Global Assessment of Soil Degradation Project

Degree	Description
(i) Light	There has been only a small decline in agricultural productivity. Biotic functions are largely intact. Soils can be fully restored with changes in ongoing land use practices.
(ii) Moderate	Still permits continuing agricultural use of an area, but with greatly reduced productivity. Biotic functions are only partly destroyed. Restoration is possible with major changes in land use practices.
(iii) Strong	Agricultural use under local land use management is no longer possible and most biotic functions have been destroyed. Restoration is possible, but at a high cost.
(iv) Extreme	The area has become unsuitable for agriculture and is beyond restoration. Biotic functions are completely destroyed.

Source: World Resources Institute (1993).

Water Resources Availability and Use

Although most countries conduct regular and systematic collection and analysis of hydrometeorological, hydrological, and hydrogeological data, not one specific international organization has a mandate to coordinate national efforts and compile global information, particularly on freshwater resources. Also, in most countries, the collection of water quantity and quality data is not integrated (data collection is done by separate agencies). As a result, policy making and planning for water quantity and quality management are often fragmented.

The renewable water supply of a country is derived from two sources: (i) the rainfall that falls directly on its land area, and (ii) the water that flows in rivers originating from outside the country (also referred to as external water sources). The former is measured in terms of “annual internal renewable water resources,” which is the average annual freshwater flow of rivers and groundwater produced from rainfall that falls within a country. WRI publishes available data or estimates of this parameter. UNEP has supplemented the database with its own estimates, derived from model calculations that use available values of determining factors such as cropland area under irrigation, livestock numbers, and rainfall amounts as inputs. The reliability of these estimates varies considerably from country to country, thus limiting the extent to which comparisons can be made.

About two thirds of the internal renewable water is in the form of flood runoff, which quickly flows out to the sea. Only about one third is “available” as usable surface and underground water supply. The derived available water resources volume does not imply uniform availability throughout the year or across space. Considerable seasonal variations occur, particularly in river flows. There is also considerable spatial variation even within one country. An essential part of the water supply statistical database, then, is an indication of time variation, expressed as average monthly river flows, for example. Recorded river flows may then be combined with catchment area to derive indicators of water flow (or runoff) per unit area.

Although most of the countries in the present study depend mainly on internal water resources, others (Bangladesh, India, Pakistan, and Thailand) depend, to a large extent, on external sources (flows from neighboring countries). For instance, nearly 70 cubic kilometers (km^3) of water flows in from neighboring countries into Thailand every year, an inflow equivalent to more than half of this country's internal water resources.

The renewable water resources statistic is an aggregate annual average figure that is useful mainly as basis for developing indicators of water supply availability. A critical level of utilization is considered reached when the water withdrawal rate reaches or exceeds the average annual available water supply (ESCAP 1992). Another useful indicator is the ratio of available water supply to the total population. The resulting indicator is "per capita available water supply." Based on this indicator, countries may be ranked according to relative per capita water availability or scarcity.

Within each country, of course, the water supply database will be more extensive and desegregated. Normally, each country would have a network of rainfall and river flow measuring stations operated by functional agencies (the public works or irrigation departments). These same agencies also routinely analyze the primary data to derive totals, averages, dependable flows, and time series indicators (of trend and variability), including possibly mapping the information (as in isohyetal maps of rainfall intensities or monthly totals). Here, measures of availability are more refined. For instance, available water may be defined as the water flowing in a river that is available 90 percent of the time (also called "dependable water" in irrigation water terminology). Time series data are important for developing indices of water supply sustainability.

Internal water resources include recharge to the groundwater. Ultimately, the source of all internal water is rainfall, part of which recharges the groundwater. Groundwater supplies rivers with a "base flow" during the months without rainfall. The inability to adequately recharge groundwater (because of soil compaction and removal of vegetation) is an important factor contributing to droughts and agricultural failures, and is a concern that needs to be monitored closely.

Because groundwater acts essentially as a natural reservoir (with stored volume, inflow, and outflow), a water balance approach or an accounting approach to database development seems ideal. Unfortunately, this ideal approach is not always easy to implement. Data may be available on estimates of groundwater volume (which may be expressed in terms of exploitable potential per year derived from analysis). Indonesia, for example, has an estimated exploitable potential of about 460 km^3 per year, nearly 18 percent of its annual internal renewable water resources, while Malaysia and the Philippines have about 30 and 40 km^3 a year, respectively (ESCAP 1992). Locally, changes in usable groundwater volume may be gleaned from measurements of depth to water table or changes in pressure levels for pressurized aquifers.

However, data on inflow (recharge) is harder to estimate. The most accurate data may be that on outflow, derived from records of groundwater withdrawal (pumping), including measurements of river base flows. Still, an accounting approach represents the most logical way of tracking the groundwater supply status and human-induced pressures.

For island or archipelagic countries, in particular, the monitoring of groundwater withdrawals is very important because of their vulnerability to saltwater intrusion. On islands, especially small ones, groundwater occurs as shallow freshwater lenses that float and hold back the surrounding saline water. If too much groundwater pumping occurs (or if there is considerably reduced recharge), the holding effect of the freshwater lens is reduced and salinity advances inland.

Water availability data portray the status aspect of the water supply issue. Human pressure is reflected by data on water utilization. Utilization data may be compiled using a system for classifying water use. Water use is commonly categorized as either consumptive or nonconsumptive in nature. Consumptive use involves taking water out of the source, whereas nonconsumptive use involves use on site. Consumptive uses include irrigation, domestic use, and industrial water. Groundwater use, in particular, is mainly consumptive. Nonconsumptive uses include hydropower generation, fisheries, navigation, and recreation.

Statistics on consumptive use are usually reported as water withdrawals by sector: agriculture, domestic (including households and commercial and public establishments), and industrial (including process water and cooling water). Unfortunately, comparable updated data on water withdrawals across countries are hard to come by.

Consumptive use data may also be desegregated into source of water: surface water or groundwater. Groundwater is an important source for domestic use because it usually has better quality compared with surface water; it is often free of pathogens and is more acceptable in terms of turbidity and color. In India, groundwater supplies 80 percent of rural drinking water compared with 60 percent in Nepal and the Philippines (ESCAP 1995). Surface water, obtained from natural or man-made reservoirs, is a major source for industrial use. In Malaysia, surface water supplies most of the industrial demand, but in India and Nepal, groundwater provides up to 80 percent of industrial water (ESCAP 1995). Water used for agriculture is predominantly surface water, except in arid and semiarid regions where groundwater supplies a considerable volume (e.g., Pakistan).

Since nonconsumptive use does not involve water removal, data are not reported in terms of water use rates or volumes. Rather, the data are in the form of values derived from the use (e.g., electricity generation for hydropower plants). These data commonly include hydropower potential (measured in gigawatt-hours per year), number of dams installed, and production from freshwater fisheries as well as aquaculture (in metric tons per year).

Water Quality Degradation

Overall, water quality in the 11 countries covered by the RETA is being degraded by the combined effects of sewage, industrial effluents, urban and agricultural runoff, and saltwater intrusion. The draft 1995 SOER for the ESCAP Region ranks the severity of water quality issues. Water pollution issues ranked as “major” to “severe” in significance in the Indian subcontinent cover pathogenic agents, organic matter pollution, and high sediment loads in rivers. In Southeast Asia, the major to severe problems are pathogenic agents, organic matter pollution, eutrophication, heavy metal contamination, and high sediment loads. In the Pacific islands, the corresponding main issues are pathogenic agents, salinization, and nitrate contamination.

In general, water quality may be measured in terms of physical, chemical, and biological parameters or variables. For purposes of monitoring, water quality is usually considered in relation to the use of the water and its expected impacts on a water body, or in relation to maintaining a desired quality for a water-based ecosystem. Where it is possible to find sampling locations that are unaffected by human activity, the data collected provide useful baseline information on natural or background water quality, from which the impact of human activity can be better understood.

Specific uses of water - such as for drinking, irrigation, or industrial use – usually have minimum acceptable quality standards defined for selected measurable variables. These are selected according to their known or anticipated effects on human health and ecological values. Usually, water quality monitoring is undertaken to meet certain objectives; these objectives may differ for various water quality management programs. Thus, the water quality monitoring system and the type of data generated across countries may not be the same in terms of the scope of water quality variables, target levels, and standards assigned to them. Differences are to be expected in laboratory techniques (sampling, analytical methods, frequency) as well as the precision and accuracy of equipment (e.g., detection limits). These differences reflect varying availabilities and qualities of monitoring equipment, as well as the varying objectives of specific programs, which are mainly local or national in extent. In response to specific local issues (e.g., eutrophication), governments undertake monitoring programs or special surveys of specific water bodies. The issues faced by individual countries, however, are increasingly becoming common. The situation provides an opportunity to coordinate methods for data collection and reporting.

The UN Economic Commission for Europe (ECE) has developed and tested a system for the standard statistical classification of ecological freshwater quality. The ECE's proposed classification system provides a framework for the compilation and presentation of the water quality in bodies of surface water. It defines five quality classes for variables organized into seven groups of key parameters. The classes range from "excellent" (Class I) to "bad" (Class V). The parameters are oxygen regime, eutrophication, acidification, heavy metals, pesticide residues and other harmful substances, radioactivity, and microbial pollution. Data are reported as annual arithmetic means or medians.

The classification is termed "ecological" because the classification limits and variables selected are based on the requirements for maintaining aquatic life; that is, limits are set on threshold concentrations of substances to keep them from producing an adverse effect on aquatic life in all its forms and life stages. The system is currently being improved using the results of tests done on selected major transboundary rivers in Europe and North America. A similar approach may be used to develop a common water quality classification system applicable to the countries covered by this RETA.

Inland freshwater bodies are not the only ones threatened with water pollution. Coastal waters throughout the Asian and Pacific region are similarly exposed to the combined effects of rapid urbanization, industrialization, pollution, and overexploitation of resources. In its 1990 report, the Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) concluded that the world's open seas are still relatively clean, but that nutrient pollution from land-based sources poses the gravest and most prevalent threat to the marine environment (GESAMP 1990).

Systematic data on organic pollution of coastal waters must be included in national environment statistics. At present, the data generated are usually the product of special studies. Data collection usually stops when the project funds dry up.

Urban Air Pollution

For the 11 countries covered by this RETA, the air pollutants judged to be of high significance are suspended particulate matter (SPM), lead, and sulfur dioxide. Of low to moderate significance are nitrogen oxides, carbon monoxide, and ozone. However, although the current levels of the latter three gaseous pollutants are not high (i.e., levels are below ambient standards in most cities), potential increases in emissions require that they be monitored closely. SPM and sulfur dioxide are associated with respiratory illnesses. For SPM, the monitoring of particles smaller than ten microns (denoted as SPM10) is important because these are the particles within the respirable range. The chemical composition of suspended particulates also determines the seriousness of health effects. Elemental carbon, polynuclear aromatic hydrocarbons (PAHs), and toxic base metals are among the constituents of particulate matter that are important in this regard.

Lead, added to gasoline as an antiknock agent, is released to the atmosphere by motor vehicle emissions. Lead is known to accumulate in the human body, causing damage to the brain, the nervous system, and other vital organs. Children are particularly vulnerable because of potential irreversible damage to their developing nervous system. Carbon monoxide reduces the capacity of the blood to absorb oxygen; almost all of it is traceable to motor vehicles. Nitrogen oxides are a key agent in the occurrence of photochemical smog. As with carbon monoxide, the principal sources of nitrogen oxides in urban areas are motor vehicles. Nitrogen dioxide, a respiratory irritant, and ozone are secondary pollutants derived from nitrogen oxide emissions. Ozone is a major constituent of photochemical smog.

The air pollution characteristics of cities in different countries can vary considerably due to differences in emission structures (e.g., sources of emissions) and meteorological conditions. Atmospheric dispersion characteristics are different for cities located in river valleys, coastal areas, or mountain valleys. Differences in air sampling and meteorological instrumentation in different countries are also a factor. Consequently, cities may have distinctive air pollution patterns that are not directly comparable. Even within one city, air pollution patterns can differ from one part of the city to another, depending on the terrain, elevation, meteorological conditions, and land use (e.g., core urban areas where traffic is congested register higher air pollution levels). Variations in air pollution concentrations could also be significant during different hours of the day and during different months of the whole year. Thus, it is not possible to derive and average air quality in a city unless a fairly dense network of measurement stations exists with frequent air sampling. Such a network is not usually available in most countries. In any case, if others want to derive and average concentrations, the data would have to undergo further analysis using dispersion modeling or other methods of spatial generalization.

For those reasons, data on air pollution are reported station by station, rather than as area-aggregated indicators. Essentially, the stations “represent themselves.” Data interpretation therefore needs to be supplemented by knowledge of the local conditions around each station. Some stations may monitor a larger number of pollutants than other stations do (e.g., station in the urban core area). Within each station, data compilation is often reported as arithmetic means over specified periods, as well as percentile distributions for each pollutant during the same periods. Trend information is derived from the mean values. These mean values may then be compared with guidelines for acceptable long-term exposure of the affected population to the pollutant. Such guidelines are derived from studies (primarily done by WHO at present) on the potential health effects of various air pollutants. Percentile values (e.g., 95 or 98 percentile) are used to measure the occurrence of peak concentrations. (A 95 percentile value means that 95 percent of the data fall below that value.) An alternative to the computed percentile value is an observed high value itself, usually, the second or third highest measurement for a sample period. These data are used to assess the risk of short-term exposure by obtaining the number of days per year (at a station) during which a guideline value or threshold for short-term exposure is exceeded.

Statistics provided by mean and percentile values, by themselves, cannot be used to draw precise conclusions on the actual exposure of individuals. Actual exposure is a function of the exposures in different locations (at home, when commuting, and at work) and at different times of the day. These differences are not reflected by outdoor measurements at fixed locations.

A more informative (and also concise) way of reporting or summarizing air pollution data would show average air pollution concentrations and changes in their values over time, preferably in a graphic format. Levels are typically expressed as means calculated on the basis of daily or monthly values for each year. The summary would also describe or identify the type of the station (e.g., the surrounding land use or average traffic condition), its geographic location (elevation, terrain), dispersion characteristics based on local meteorology, method used for air sampling and analysis, and the major emission sources (e.g., motor vehicles, industry). The report for each station would also include the number of days per year the guidelines for the pollutants are exceeded.

Greenhouse Gases

Greenhouse gases are associated with global warming concerns that are increasingly drawing national and international attention. The three principal greenhouse gases are carbon dioxide, methane, and the halocarbons. The impact of greenhouse gases on global warming is usually examined through the use of complex models. The accuracy of these models depends, to a large extent, on the quality of the database, particularly emissions inventories of the major greenhouse gases.

The Framework Convention on Climate Change, formulated during the 1992 UNCED, includes a requirement for the preparation of inventories of greenhouse gas emissions (as well as sinks). Assistance to individual countries in carrying out this work is being made through a Global Environment Facility (GEF) project. Global efforts toward reducing greenhouse gas emissions are bound to intensify in the coming years. And as the implications for national economies, particularly for developing countries, become evident (for instance, if international agreements have to be reached for limiting industrial gas emissions in individual countries), national statistical agencies will have to improve their capability for estimating (or coordinating the estimate of) national greenhouse gas emissions instead of relying solely on estimates generated by outside groups.

Routine monitoring of atmospheric concentrations of the major greenhouse gases is conducted through global networks operated by international agencies and research bodies. WMO has established the Global Atmosphere Watch (GAW) as an umbrella program for integrating and coordinating such monitoring activities. When fully implemented, the GAW will comprise 30 global stations and 300 regional stations. The data obtained will be stored at the WMO World Data Centre for Greenhouse Gases in Tokyo. However, this global monitoring system looks primarily at overall atmospheric conditions (i.e., ambient conditions) and not at the sources of emissions. Emissions inventories are needed to correlate with data on atmospheric conditions so as to arrive at policy prescriptions.

Much of the greenhouse gas inventory work is done by international research organizations (e.g., Carbon Dioxide Information Analysis Centre [CDIAC] on carbon dioxide emissions). Emissions are generally computed in much the same way as are urban air pollutants, that is, by multiplying the activity levels of sources by their respective emission factors. By itself, the estimate process is prone to considerable uncertainty because sources are difficult to characterize and properly document, especially at the global level. Current calculations involve making a number of major assumptions, which can provoke disagreement over the results, especially when deriving conclusions on national accountability (i.e,. contributions by individual countries) for global emissions. However, if national agencies can improve their capability to prepare estimates or verify outside estimates, the database would improve (particularly the emission factor), and so would the validity of assumptions and the acceptability of the results.

Two examples of a greenhouse gas index are the Global Warming Potential (GWP) developed by the Intergovernmental Panel on Climate Change (IPCC), and the Greenhouse Gas Index (GGI) developed by WRI. The GWP provides a measure of the relative warming effect of key greenhouse gases relative to that of carbon dioxide. For instance, one kilogram of methane has 11 times (earlier estimated at 21 times) the warming effect of the same amount of carbon dioxide, whereas CFC-11 has 3,400 times the warming effect of carbon dioxide. Indices such as these provide policy makers with a basis for evaluating options for controlling emission of various greenhouse gases. These indices are also used to weigh national emissions of the various greenhouse gases to determine accountability for global warming among various countries. The GGI of WRI uses the GWP values (and national emissions inventories, such as those prepared by CDIAC) to derive an index that represents the contribution of individual countries to the global sum of emissions of greenhouse gas. According to this index, the US has the highest percent share of global greenhouse gas emissions; India is in 7th place; Indonesia, 9th; Malaysia, 27th; and the Philippines, 30th.

The approaches described here have limitations of one kind or another. Results have been the subject of intense debate, particularly the ranking of countries according to accountability for global warming. If accountability is to be used as the basis for future restriction on emissions, criteria and methodologies acceptable to the majority of the countries need to be found. In turn, the need to harmonize estimation methods will arise. Guidance is being provided by the IPCC, which is developing an internationally acceptable methodology for calculating and reporting national net emissions (considering both sources and sinks) of greenhouse gases.

Human Settlements

It is essential that a system for collecting and interpreting human settlements statistics be established in all countries. Such statistics must be readily available, easily understood, and designed to provide a quantitative basis for assessing human settlements conditions.

The quality of the environment and the performance of human settlements are inextricably linked. Important elements of the living environment include quality of housing, water supply, sewerage and drainage facilities, energy, and transport, as well as the spatial distribution of housing, all of which have consequences on the sustainability of the environment. An examination of human settlements, especially urban settlements, reveals a strong correlation between poverty and environmental quality. Slums, dilapidated neighborhoods, and squatter settlements are often the places with the poorest environmental quality.

Many factors affect the availability and reliability of human settlements statistics. Statistical systems in many developing countries are still weak while statistical methods, coverage, practices, and definitions differ among countries. The Housing and Urban Indicators Program, which started in 1990 as a joint initiative of the UN Centre for Human Settlements and the World Bank, seeks to implement a permanent data collection facility that will permit regular analysis of statistics on human settlements.

Given the multitude of factors affecting human settlements, separate descriptions of these concerns cannot provide the information required for planning, policy making, and monitoring of performances. However, it is necessary to identify the key subject areas of the physical and service elements that comprise a human settlement and which can, at least, be subjected theoretically to statistical assessment. The key subject areas (listed below) are not the only possible items for statistical assessment. Particular situations and concerns in countries may demand different selections or priorities. The important subject areas are the following:

(i) Housing
(ii) Land use
(iii) Urbanization

(iv) Environmental infrastructure: water supply, sanitation, drainage, and solid waste management
(v) Use of energy
(vi) Transport
(vii) Construction industry activities
(viii) Education
(ix) Population growth and change

The collection and interpretation of human settlements statistics involve several general methodological questions or issues.

A major difficulty in interpreting human settlements data is the diversity of conditions within both rural and urban areas in most countries. Statistical averages for all rural areas or urban centers frequently show large differences among towns and rural areas. Another problem is that poor living conditions, particularly in urban centers, are averaged for an entire city or urban center and may tend to hide large individual differences that are relevant for policy making.

Another important methodological issue is the *generic definition and classification of low-income settlements*. Slums, shanty settlements, marginal settlements, and illegal settlements greatly differ in characteristics, and their relationship to informal sector activities is complex. Data availability and collection from such sources are a general problem of human settlements statistics. Data availability and compatibility are major obstacles in the assessment of marginal settlements, which may differ in size, location, density, growth rates, terrain, and type and age of construction, sanitation, or infrastructure. In addition, there are other differences that cannot be determined by mere physical data, such as the degree of social cohesion among inhabitants, their ethnic composition, and their aspiration, skills, and health conditions. These factors may vary from country to country, within countries, and even from one part of a settlement to another.

As mentioned earlier in this chapter, available statistics on access to potable water and sanitation can be misleading. The various interpretations of “access” and “safe” make statistics on these facilities an inadequate indicator for policy making and monitoring. The statistics on access to toilets or latrines are often inadequate because those statistics do not capture poor design, poor maintenance, or sharing by large numbers, which can be major causes of infection.

In human settlements statistics, data on solid waste are classified on the basis of either the physical or chemical characteristics of the materials contained in solid waste, or the activities that generate solid waste. Waste generation is always measured by solid waste collected; thus, uncollected or dumped waste is not accounted for in the statistical information.

Bioresources

South and Southeast Asia, in which the 11 countries of this RETA (Bangladesh, India, Indonesia, Malaysia, Nepal, Pakistan, Philippines, Samoa, Sri Lanka, Vanuatu, and Viet Nam) are found, are important regions of the world. The regions are not industrialized like Western Europe or North America, but are essentially biomass-based with some amount of industry – bio-industrial, rather than purely industrial. Thus, natural resources like air, water, land and soil, forests, and flora and fauna are critical to their well-being. Their flora and fauna constitute bioresources that are generally regarded as renewable. However, the unfavorable state of a host of environmental factors on which flora and fauna depend could lead to the extinction of such resources. These resources are, therefore, “conditionally sustainable” (UN 1991).

Biogeographic Realms

The biosphere is the part of the earth where all terrestrial and aquatic organisms (plants, animals, and microorganisms) exist. Taken in relation to geography, the biosphere could be divided into discrete biogeographical realms. Often, these realms are regions the size of a continent or a subcontinent. Biogeographic realms are the highest category in biology. According to Udvardy (1975), biogeographic realms are more or less based on individual ecosystems, which share common features of geography as well as of flora and fauna.

Flora and Fauna

Databases for flora and fauna should be established including descriptions of families, genera, and individual species and giving the geographic boundaries of the species. Electronic databases will be advantageous for this group because they are dynamic and expandable systems and can be updated periodically.

Biodiversity

Biological diversity, or biodiversity, reflects the living things that form an interacting system with the atmosphere (air), the lithosphere (land and soil), and the hydrosphere (water, both fresh and marine). The building block of biodiversity is *genetic diversity*, which refers to the heritable variation within and between populations of a species.

Species diversity, another form of biodiversity, measures species richness or the number of species of plants, animals, and microorganisms in a given habitat or country or region.

Thus far, roughly 1.7 million species have been described worldwide. A conservative or working estimate gives the number of species at about 12.5 million (WCMC 1993). Species are composed of *individuals* that occur in *populations*, which are, in turn, sets of interbreeding individuals belonging to the same species. A set of different species of plants, animals, and microorganisms interacting within a system and sharing the same habitat constitute a *community*, and a set of communities living as an interacting system in a ecological region constitutes an ecosystem. The ecological aspect is important because it exercises control over the structure of the community and the overall composition of biodiversity. For instance, in the Alpine Himalayas, a tree stands by itself with a few lichens on its bark. On the other hand, a single tree in the humid tropics is part of a rich biotic resource and may be host to many species of algae, fungi, lichens, liverworts, mosses, epiphytic ferns, and flowering plants. In addition, such a tree may also harbor many species of invertebrate (ants, in particular) and some vertebrate animals. Each tree is indeed a mini-ecosystem. Thus, incalculable losses could occur with the destruction of even a single tree in the humid tropics.

Although the exact measurement of biodiversity in an ecosystem is difficult, biodiversity is usually assessed on the basis of the number of species and the level of uniqueness. Historically, there have been changes in biodiversity, that is, in the composition or mix of species in any ecosystem. However, it has not been possible to establish a rate of extinction in exact terms.

While there are reasonable estimates of the number of higher plants and animals in a country, no such estimates are available for lower plants and animals. Microorganisms have altogether been excluded even if it is known that the earth would be a very dirty habitat without these microorganisms.

Based on recent reports, the diversity of plants and animals can been documented. Information on geographic distribution would reveal the areas in need of surveys on a priority basis.

Fisheries

Innumerable statistics are needed to design policies that will make fishing sustainable. There is a need for timely and reliable statistics to calculate the *allowable catch* to prevent overfishing. In general, however, fish catch is not reported properly. One important information is the market price of the catch, which determines profitability and therefore influences catch intensity. There is a need to analyze catch data to determine any appropriate changes in government regulations on licensing, allowable catch or quotas, and so on.

To properly manage fish stocks and to accurately calculate total allowable catch, information must be reliable and timely. Data are needed on the growth cycle of specific fish stocks, nutrient cycles, changes in ocean currents and water temperature, and the effect of pollution. There is already alarming evidence of shrinking fish stocks in both fresh and marine waters. Aquatic ecosystems are highly vulnerable compared with terrestrial ecosystems.

Wetlands

Cowdrin (1979) defines wetlands as “transitional areas between aquatic and terrestrial ecosystems where the water table is usually at or near the surface or where the land is covered by shallow water." Thus, marshes, floodplains, bogs, peat lands, shallow ponds, the littoral zone of large bodies of water, and tidal marshes are classified as wetlands. Wetlands also have one or more of the following attributes: the area must be predominantly or periodically inundated, must support hydrophytic vegetation, and should have hydric soil.

By and large, the productivity of wetlands per unit of area and time is very high. There are communities living around wetlands and drawing sustenance from them. The important parameters for a database for the management of wetlands are as follows:

(i) general features (name, ownership - government or private);
(ii) geographic location (state, district, latitude, longitude, altitude, area);
(iii) morphometry (length, width, depth, volume, bathymetric map depicting depth profiles);
(iv) hydrology (inflow, outflow, siltation rate, evapotranspiration, soil, moisture, rainfall pattern, temperature characteristics);
(v) ecological features (natural, man-made, temporary, permanent);
(vi) physicochemical features of soil, water, and vegetation;
(vii) landscape type (forests, scrubs, grassland, desert, delta, estuary, lagoon, mangrove, backwater, coastal zone);
(viii) water source (spring, river, irrigation channel, runoff from surrounding area, estuary, sea, etc.);
(ix) flora and fauna with special economic importance, and status of migratory and resident birds and rare or endemic and endangered species;
(x) extraction of economic species and their end use;
(xi) major use of wetlands for local people, annual revenue from seed gathering, fishing, grazing, agriculture, irrigation, drinking water, and tourism;
(xii) legislation, if any, for protection from overfishing, overhunting, or any other activity that threatens the area;
(xiii) threats to wetlands due to weeds, domestic sewage, deforestation, overfishing, shooting, factory effluents, solid waste, inadequate drainage, overgrazing, siltation;
(xiv) educational awareness; and
(xv) conservation measures planned and undertaken.

Methodological Issues in Developing Environment Statistics

The purpose of this section is to highlight the methodological issues associated with the development of environment statistics. It does not intend to cover the entire range of methodological problems, but to provide an insight into the types of issues involved in developing environment statistics. The identification of these issues should help in developing programs that will promote the use of standardized methods across the participating DMCs and encourage the systematic development of an environment statistics system.

The methodological issues may arise from two sources: (i) complexities that are inherent in various environmental systems, and (ii) issues involved in developing higher level statistics such as indicators and indices.

Inherent Complexity of Environmental Resources

The purpose of an environment statistics system is to provide representative and reliable statistics to serve the objectives for which the statistics are compiled. The representativeness and reliability of environment statistics depend on the adequacy of the methodologies used for computing statistics. The methodological issues in developing environment statistics can be attributed to three factors:

(i) inherent characteristics of natural environmental resources or systems that do not allow measurement by enumeration;
(ii) lack of understanding of the complexity of the factors responsible for variations in the system attributes, which the statistics should capture; and
(iii) cost constraints that limit the number of measurements and thereby influence the reliability of the statistics.

For resources or systems such as population and human settlements, simple statistical techniques can be used to compute relevant basic statistics. These systems allow the use of the enumerative measurement technique for collecting data. In principle, the measurement for such systems can cover the entire population as the systems are made of distinguishable statistical units. For example, a population census covers the entire population and measures several of its attributes. Information on such systems could be represented by *descriptive statistics*, such as mean, median, mode, standard deviation, interquartile range, and percentile.

A population census is usually conducted at five- or ten-year intervals, for it involves huge expenses. Periodic surveys are conducted during intermediate periods to update census information. Sample surveys are also conducted at regular intervals to measure other socioeconomic parameters - economically active population, household income and expenditure, employment, and so on – if these are not covered by the census. Usually, these surveys are based on random samples, with the sample size ranging from hundreds to thousands of people. Large sample sizes for these surveys allow the use of the c*entral limit theorem* to make the assumption that sample averages follow a normal distribution. Therefore, statistics computed from these samples could be used to make an inference about the entire population within a known margin of error.

Descriptive statistics cannot be used for environmental resources such as the atmosphere, water, and ecological systems. Since air and water resources are contiguous and measurement units are not distinguishable, samples of air and water need to be taken for the measurement of pollutant concentrations in these resources or media. Statistics computed from these samples could be used to make an inference about the air quality of a region or the water quality of a water resource. For ecological systems, samples also need to be taken for identifying and counting main taxa, to make an inference about the population of flora and fauna in a region. Measuring entire populations of the region would be highly expensive.

Natural environmental resources also show spatial and temporal variations in their characteristics. These variations can arise from both natural and man-induced forces. For example, the uneven distribution of rainfall over a region can be attributed to natural forces. Spatial variations in air and water quality, on the other hand, can be due to the uneven distribution of pollution sources as well as natural factors like wind direction, speed, and topography for air quality; and the volumetric flow rate of a river and river geometry for water quality. The scale of temporal variations for the atmosphere is as short as a few seconds and as long as a year. For a water resource, the scale of temporal variations is determined by the pattern of pollutant discharges into the water body as well as by seasonal and annual weather cycles. For ecological systems, the scale of temporal variations could be several decades, as is evident from ecological succession.

Both spatial and temporal variations need to be captured by statistics in such a manner as to provide useful information with respect to the concerns about the uses of these environmental resources. For example, to monitor the trend in global warming, both spatial and temporal aggregations of greenhouse gas concentrations are required. Spatial aggregation is required over a large area so that the statistics would be free from influences of peak concentrations due to individual sources. To capture all scales of temporal variations, aggregation must be carried out for measurements taken over a year. On the other hand, for statistics representing pollution exposure of the population, aggregation is required to determine maximum one-hour, eight-hour, daily, and annual pollutant concentrations to reflect the risk of both acute and chronic health effects.

In spatial and temporal variations of a resource, attributes or characteristics are of a random nature and follow a normal distribution. Samples taken at random over space and time could be used to infer statistics on the environmental resource, or a part thereof. However, the selection of random samples without considering the heterogeneity of the system due to natural and man-induced forces could result in the loss of valuable information. For example, spatial aggregation of rainfall data based on random samples taken over a large area without considering differences in climatological or rainfall regimes would provide statistics that are useful neither for agricultural planning nor for the management of water resources.

For ecological systems, it is even more important to take into account spatial structure and dynamics when selecting sampling locations or sites. Ecological systems are complex systems made up of an assemblage of communities and abiotic elements that are continuously interacting with each other. Hence, statistics on these systems deal with both structural and functional measures. The selection of sampling locations should capture information on community frontiers to monitor the movement of these frontiers. The choice of the sampling sites should also take into account the changes close to the boundary of the ecosystem to monitor the impact of human settlement pressures or the influence of the buffer zone on the expansion of the ecosystem.

Ignoring the spatial structure of ecological systems while selecting random sample sites will result in loss of information on the structure and dynamics of these systems. Thus, preliminary surveys are generally carried out to gain an understanding of the structure of an ecosystem. Based on this survey, the ecosystem may be divided into several zones to carry out stratified random sampling by a method that is appropriate for the given purpose. The classification of these systems is done by experienced surveyors, but is generally subjective. For developing reliable statistics within each stratified zone, a probability distribution function of the parameter or variable of interest should be known to determine the minimum number of samples required to provide statistics of a given confidence level. In principle, it may be possible to determine the probability distribution function and the minimum number of samples for computing reasonably reliable statistics. However, budgetary constraints may limit the number of samples and thereby influence the reliability of the statistics.

To understand the dynamics of an ecosystem, it is obvious that sampling should be repeated after intervals of several years. However, for repetitive sampling to provide maximum information, some of the previous sampling locations may be changed every time the sampling is repeated.

For a better understanding of the influence of spatial and temporal variations on the development of statistics for air and water resources, a discussion of spatial and temporal aggregation of data or statistics is provided in the following paragraphs.

Spatial aggregation of statistics

Spatial aggregation of data is required to compute statistics that are representative of an area or a domain, e.g., the sulfur dioxide concentration in an urban area, the dissolved oxygen level of a lake, rainfall intensity in a watershed, or the species diversity of an ecosystem. To preserve the heterogeneity of the resource while computing the statistics, areas within a region need to be delineated in such a manner that, for the parameters or variables of interest, variations within each area are low while variations across the areas are high. Samples taken from each can then be used to compute statistics representative of that particular area. If the central tendency of a variable or an attribute over the entire region is required, statistics compiled for individual areas may be used to determine the median or arithmetic mean, as may be appropriate for the type of distribution in the area.

Ideally, the delineation of heterogeneous areas should be based on data collected over a long period of time using a dense monitoring network. These data can be analyzed using such techniques as spatial correlation analysis, cluster analysis, or principal component analysis to delineate areas showing significant differences with respect to given attributes of an environmental system.

For atmospheric systems, representative statistics for an area could also be determined by plotting contours of equal attribute values on a map representing a region. Thus, the average pollutant concentration represented by two consecutive isopleths could be used to represent the pollutant concentration of the area enclosed by these isopleths. Pollutant concentrations estimated in this manner may be used to determine exposure of the population living in the area. Similarly, average rainfall intensity represented by two isohyets (lines joining points of equal rainfall) could stand for the representative rainfall of the area enveloped by these isohyets. Representative rainfall intensity could be used to calculate surface runoff over the area enclosed by isohyets.

Statistics should be not only representative of an area but also reliable. For computing reliable statistics, the probability distribution function of the concerned variable in the area should be known to determine the minimum number of samples required to compute statistics with a given confidence level. For example, if a variable follows a log normal distribution within the area, then the minimum number of sampling stations required to estimate a real mean within a specified confidence level is given by the equation.

$$n = (CG_v)^2 \times t^2/p^2$$

Where:

t = the specified confidence level,

p = the allowable percent departure from the true mean.

CG_v is the coefficient of geographic variation and is given by $CG_v = 100 \text{ antilog } S_g - 100$

One major shortcoming of the above approach for computing spatially representative and reliable statistics is that an extensive database is required to delineate areas, determine the appropriate probability distribution function, and find the minimum number of sampling stations for computing statistics within a given confidence level. The existence of such extensive databases is not likely to be present in most of the participating DMCs. In addition, the required number of sampling locations, based on statistical requirements, may not be met by the budget for monitoring.

Temporal aggregation of statistics

The temporal aggregation of data or statistics should capture the temporal characteristics of variables so that the statistics can be used for different purposes. For the atmosphere, the scale of temporal variations ranges from minutes to a year. For air quality, minute-to-minute variations are caused by changes in wind direction and speed. The daily variations in air quality result from both diurnal variations of the atmosphere as well as daily emission patterns. Macroscale weather fluctuations last for a few days and are important from the viewpoint of air pollution episodes. Seasonal and annual weather cycles also influence the air quality of a place.

Temporal variations in the quality of a water resource may be caused by the daily pollutant discharge pattern. The dilution capacity of a water resource may change in response to seasonal and annual weather cycles, giving rise to variations in the water quality.

Hence, the aggregation of air or water pollutant concentrations over different time scales may be required to derive statistics for different uses. For example, it may be necessary to determine episodic air pollution levels to shut down some industrial units in a region that is susceptible to air pollution episodes. Similarly, it may be of interest to determine the peak water pollution levels and the volumetric flow of a water body during the dry season for water resource planning.

If pollution levels in the air and water media are continuously monitored over time, average concentrations over time intervals and their frequency distribution could easily be determined. However, due to cost constraints, the continuous monitoring of all pollutants at all monitoring stations may not be possible. Therefore, knowledge about the frequency distribution functions is required to determine the frequency of sampling needed to obtain reliable average concentrations for different time intervals. Budgetary constraints may not allow the monitoring to be carried out at the frequency determined on the basis of statistical analysis.

The methodological issues due to the inherent complexity of environmental systems can be summarized as follows:

(i) *Descriptive statistics cannot be used for natural environmental resources such as air, water, and ecological systems*, either because their measurement units to cover large contiguous areas are not distinguishable or because the cost of measuring an entire population is prohibitive. The latter is true for ecological systems.

(ii) *Natural environmental systems show both spatial and temporal variations, which statistics on these systems must capture*. However, while capturing these variations, the heterogeneity of the system should be preserved so that valuable information is not lost. Therefore, a survey is required to stratify or delineate the system before statistics can be computed for each part of that system.

(iii) For developing representative and reliable statistics, *an extensive database is required to delineate areas with significantly different characteristics and to determine the probability distribution functions for the variables.* Such a database is not usually available, especially in developing countries. Therefore, analytical techniques (e.g., simulation modeling) and expert judgment may be required to decide where and when monitoring should take place.

Development of Higher Level Statistics

A socioeconomic decision can have implications on both the socioeconomic and natural environmental systems. A large amount of basic-level statistics pertaining to different domains can overwhelm a decision maker. To facilitate the decision-making process, basic statistics need to be processed into higher level statistics, which should encompass a variety of relevant information with reference to a context. The development of indicators and indices is an attempt to process basic statistics into a form that would facilitate decision making.

In accordance with Wayne Ott's definition, an indicator is derived from a single variable representing an attribute of a system. Indicators are developed to have a simple measure for the state of an environmental resource or system, which otherwise needs to be characterized by a number of variables. An indicator may be descriptive or normative. A descriptive indicator describes a state, and may be used to monitor the trend of or change in the state due to human activity. A normative indicator, on the other hand, provides a measure of the state with respect to a norm. Thus, the *percentage of people below the poverty line* is a normative indicator as it provides a measure of the state of poverty with respect to a minimum desirable level, i.e., the poverty line. On the other hand,, tropospheric ozone concentration, used as an indicator for photochemical oxidants, merely describes the state of the air quality of an area.

While an indicator provides a simple and easily understandable measure for assessing the state of an environmental resource, the information provided by the indicator may not be sufficient for decision making, which has to consider the implications of the decision on various environmental resources. In many situations, it may not even be possible to represent a state by a single, variable-based indicator. In such situations, variables representing a state need to be aggregated in some form to represent the overall state of the environment system.

In contrast with an indicator, which is based on a single variable, an index combines statistics on a number of variables into a single value. Its ability to consolidate information on a number of variables into a single value makes an index attractive for decision making. By allowing the implications of a decision on a particular state or different states of the environment to be represented by a single value, an index facilitates the comparison of various alternatives for selecting the most cost-effective option.

An index may use aggregation, a functional relation, or a structural relation to combine statistics on various variables. A variety of indices have been developed to be used in different contexts. These indices represent states of environmental systems such as air and water (Appendix 2). One common aspect of these indices is that weights have been used in aggregating statistics on different variables to reflect the relative importance of the variable in determining the state of the environment. When no weights are used, the variables are assumed to be equally important.

Ideally, weights used for the aggregation of variables to form an index should have a scientific basis. An index so computed would be noncontroversial and can be used across countries. Very often, however, weights are determined by using subjective methods, making the indices open to criticism. There are indices for which weights cannot have a scientific basis since the weights represent value attached to the variables. Values for such weights should be arrived at by consensus. An example of such an index would be "knowledge," a measure of educational achievement as used in the human development index (HDI). This measure of educational achievement is given as:

$$E = a_1 \text{ Literacy} + a_2 \text{ Years of schooling}$$
$$\text{where: } a_1 = 2/3 \text{ and } a_2 = 1/3.$$

There is no scientific way of determining values for a_1 and a_2 in the above indicator/index. These values have to be based on general consensus.

Another class of indices represent the structure and dynamics of environmental systems. Examples are the niche breadth and niche overlap indices, which represent information on resources partitioning of an ecological system. This information would be valuable in understanding the dynamics of an ecological system. Species richness indices provide information on the composition or structure of such a system.

Indices based on functional relationships, on the other hand, represent the interaction among various environmental systems. This class of indices is, in fact, based on the mathematical simulation of various processes representing these interactions. Many times, interactions among environmental systems are too complex or not well understood to be represented by a simple mathematical equation. In such cases, empirical equations may be used to represent the interactions, as is depicted by the soil loss equation in Appendix 3. For these empirical constants to be valid across different geographical regions, standard classifications of environmental resources are required. For example, a standard classification for soils, topography, and vegetation cover is desirable for uniformly interpreting erodibility across geographical regions.

In summary,

(i) Indicators and indices provide information in a simple and compact form and, therefore, could facilitate decision making.

(ii) Indicators are based on statistics derived from one variable or attribute of a system. They could be descriptive or normative. The former describes a state in a particular context, whereas the latter provides a measure of a state with respect to a norm.

(iii) An index combines information on a number of variables into a single value, which makes it attractive for decision making. By representing various implications of a decision in a single value, an index facilitates the comparison of various alternatives/actions.

(iv) An index may combine information on various variables by simple aggregation or through structural and functional relationships. In the aggregation of variables, weights are used to reflect the relative importance of these variables in determining the state represented by the index. These weights should have a scientific basis so that the indices can be used across countries. For indices where weights reflect value attached to the variable, the value for weights should be determined through consensus.

(v) Indices based on structural and functional relationships are more useful for understanding the structure and dynamics of systems.

One of the objectives of this RETA is to promote the development and use of standard methods for compiling environment statistics so that the statistics are comparable across countries. The need for comparable statistics arises for the following reasons:

(i) Many environmental concerns have assumed global dimensions. Statistics needed for understanding and addressing many of these concerns are compiled at national levels. Standard methods for developing statistics are required so that statistics can be compared across countries.

(ii) Environmental systems or resources transcend political boundaries. As such, the compilation of statistics for the management of these systems or resources should be undertaken in a coordinated manner. Examples of such systems are bioreserves, watersheds, rivers, and lakes, which may be shared by different countries and therefore require coordinated monitoring and management.

This discussion of methodological issues should be seen in the light of the objective of promoting the use of standard methods for developing environmental statistics in the participating DMCs. The points that emerge from the discussion are the following:

(i) Knowledge of the domain is essential to compile statistics without losing valuable information. In view of budgetary constraints and the lack of data on various domains, statistical methods alone cannot be used for determining where, when, and how data need to be collected. Mathematical models that simulate the dynamics of the system, along with expert judgment, may have to be used to gain maximum information with a minimum number of sampling stations. Therefore, for each domain, handbooks need to be developed to guide the development of statistics.

(ii) Indicators and indices can facilitate decision making. However, they should be constructed in such a way that they can be used across countries. Standardized classifications of resources should be adopted by all the countries to allow the use across countries of indices based on empirical relations. The areas requiring the establishment of standardized classifications should therefore be identified. It should be determined if international standardized classifications are available for particular areas. It is also important that a minimum or core set of indicators and indices be identified and accepted by participating countries to be used for presenting information.

Basic Data Standards

It is important to consider data standards because better information will enable a nation to better address its environmental issues at all levels. Environmental indicators, which track changes in environmental conditions over time, are generally developed from multisectoral environmental data or statistics generated by various agencies through their monitoring programs. Furthermore, some raw data are directly used for assessing environmental trends and projections to be used in SOERs. Consistent national, subregional, and regional information is needed for critical indicators of air, soil, and water quality; and of natural resource degradation processes. To be useful, the information should clarify environmental issues as well as provide feedback on the effects of management initiatives, without any bias.

In the context of SOERs and environmental indicators, the data standard indirectly refers to standard data definition, standard units (measuring unit and geographical unit), methods of measurement, sampling standards (sampling locations and frequency of sampling), classification standard, spatial data standards (scale, geographic coverage, and processing), time series requirements, and meta-data standards.

Data Definition

The definitions of the various categories of data vary from country to country and region to region. Aggregating such data for the purpose of SOERs might amount to adding apples and oranges. For example, the definition of open or closed forest varies from country to country in terms of the crown cover percentage. While some countries use the FAO definition, others use their own definition. A similar case exists in the definition of poverty. Thus, aggregating information at a subregional or a regional level may cause a big problem. In the context of spatial data, the variables being measured are mostly well-defined in photogrammetry, remote sensing, surveying, and other measurement-oriented spatial sciences. But for the more interpretational spatial sciences, such as geology, soil science, forestry, or geography, this is far from true, and one person's freshwater marshes can be another's peat lands as both are primarily waterlogged areas.

Standard Units

Standard units are very important in the context of spatial analysis. The units may be countries, states, provinces, watersheds, floodplains, or river basins. To show or assess soil erosion status, a watershed unit could be more appropriate than a country or state unit. Similarly, to assess the degree of flood hazard, a floodplain of a 100-year flood could be more appropriate than one of a 50-year (return period) flood. With regard to statistical data, different units are frequently used for the same parameters, causing many problems in aggregation, interpretation, conversion, and comparison across a subregion or region. For example, per capita commercial energy consumption — which refers to the aggregate final consumption of coal and other solid fuels, petroleum products, gases, electricity — is expressed in kilograms of coal equivalent per capita or in kilograms of oil equivalent per capita. Similarly, the level of acidity in rainwater is expressed in pH value, or simply in terms of sulfate ion concentration, or sulfate ion concentration as equivalent of sulfur dioxide in a volume of air. Decision makers encounter difficulties in comparing this value with the internationally accepted standards of acidity level in rainwater when this value is expressed in various units.

Methods of Measurement

The quality of data significantly depends on the method of measurement. Information derived from raw data obtained from faulty measurements could mislead a person about the real situation. In water quality assessment, for example, various standard methods of measurement should be followed. The concentration of pollutants in water is strongly, sometimes inversely, correlated with flow rates. Therefore, sampling and velocity measurements should be carried out as close in time as possible. By sampling a volume of one liter or more within a minute of the velocity measurement, this variation is reduced significantly. If multiple-point sampling over the cross section of a river is necessary, the hydrological measurements and sampling should be carried out in the same cross section. Water quality data for assessing the potential effects on aquatic life should be based not only on the mean annual flow rate calculated from the daily rate, but also on the minimum flow rate. The minimum flow rate could be operationally defined as the 20th percentile of the distribution of the average daily flow rates for a period that spans many years. Thus, standardization of measurements for different flow conditions is absolutely essential to cover a wider topic than raw water quality data only.

Another example is the measurement of the concentration of fecal coliforms in freshwater bodies to assess the quality of water available to communities for basic needs. Microbial examination provides the most sensitive indication of pollution by fecal matter. Because the growth medium, the conditions of incubation, and the nature and age of the water sample can influence microbiological analysis, the accuracy of results may be variable and the standardization of methods and laboratory procedures is extremely important. Established standard methods are available through the International Organization for Standardization (ISO), American Public Health Association (APHA), the UK Department of Health and Social Security, and WHO. Determination of the sample size is the first important step in this examination. The source of the sample will determine, in the first instance, the concentration of organisms. For example, under normal conditions, the volume of sample for a lake or reservoir would be 100 milliliters (ml); in the case of raw municipal sewage, only 0.001 ml would be required. Larger samples would result in a volume too large to make counting possible. There is also need to ensure that the samples are not exposed to light and are kept preferably at 4-10^{o}C to avoid changes in their bacterial characteristics. Such precautions are particularly important in tropical climates where ambient temperatures are high and sunlight (ultraviolet radiation) is brightest.

Similarly, the selection of an appropriate method is important to achieve the objectives of air quality assessment. In scientific usage, concentrations of most air pollutants are commonly expressed in units of weight-to-volume ratio, such as micrograms per cubic meter; or as volume-to-volume ratio, such as parts per million (ppm). Weight-to-volume measurements depend on temperature and pressure. Therefore, it is common practice to standardize measurements to a given pressure (usually one atmosphere) and temperature. Unfortunately, different national agencies standardize to different temperatures, usually 0^{o}C, 15^{o}C, 20^{o}C, or 25^{o}C. Measurements given in units of weight-to-volume standardized at different temperatures cannot be directly compared. Similarly, the conversion from weight-to-volume unit to volume-to-volume unit, or vice-versa, requires knowledge of temperature and pressure. Different sampling (active sampling or passive sampling) or laboratory methodologies are appropriate for different gaseous species. Established standard sampling and analytical methods are available through the ISO, WMO, Economic Commission for Europe (ECE), European Monitoring and Evaluation Program, WHO, GEMS/Air of UNEP, and Council for Mutual Economic Assistance (CMEA).

In the context of spatial data, for example, land cover classes determined through aerial photography or remote sensing often have known confusion matrices, which give the probability that any one cover class may be confused with any other. Such errors enter the raw data, and stay with them through the entire process of database creation and further use for analysis purpose or in an SOER.

Sampling Standards

The quality of data collected depends first and foremost on how good the sample is, i.e., how well it represents the quality of the body from which it is collected, and whether or not contamination is avoided. There are various methods or techniques for sampling soil, water, and air to assess their quality and condition. The most reliable techniques for collecting samples and for making field measurements contribute to the good quality of the data, increase their precision and accuracy, contribute to the overall improvement of the air or water quality management process, and facilitate international harmonization of environmental measurement.

Sampling techniques generally vary from country to country. However, at least some minimum and necessary sampling techniques should be followed. It is important to consider (i) sampling locations, (ii) frequency and time of sampling, and (iii) sampling procedures. For example, in the assessment of river water quality, the sampling stations must be situated before one end of the human settlement as well as at the other end. It will be observed that the level of pollutants will significantly vary from point 1 to 2 or 3. The level of pollutants at point 2 will be more than that at point 1 because of the load from human settlements. Similarly, the level of pollutants at point 3 will be more than that of at 1 and 2, and so on. For example, the Yamuna River in India receives an estimated 200 million liters of untreated sewage everyday as it passes through New Delhi. The coliform count starts from 7,500 per 100 ml above the city and rises to 24 million per 100 ml below the city (WRI 1995). Similarly, with air quality assessment in major cities, four representative locations could be chosen in each of the cities, with sites in a city center commercial area, an inner suburb residential area, a city center beside a busy road, and a residential area primarily influenced by industrial emissions. Measurements at similar locations in different cities would be comparable.

Frequency and time of sampling are important as the quality of water in rivers or water bodies is rarely, if ever, constant, but is subject to change. In measuring the mean, maximum, and minimum values of water quality variables over a period of time, the closeness of the monitored values to the true values will largely depend on the variability of the variable and the number of samples taken. The larger the number of samples from which the mean is derived, the narrower will be the limits of the probable difference between the observed and true means. To double the reliability of a mean value, the number of samples must be increased to fourfold. With regard to sampling time, the sampling program may stipulate random sampling times, but these should be spread more or less evenly throughout the year, covering all seasons of different activities such as agricultural and industrial activities.

Standard sampling procedures should also be followed to obtain reliable results. For example, specific procedures are followed for river water sampling, lake water sampling, and groundwater sampling. For a river with nonhomogeneous lengths, individual samples may not be representative of the whole water body. It will be necessary then to sample a cross section of the river to obtain average values. Average values are either simple averages or weighted averages. Considering the river length as a series of vertical sections across the chosen site, discrete samples are taken in each section and analyzed separately. The results from all the samples for each section are analyzed separately. To get the average value of the concerned water quality parameter for that site, the results from all the samples are added and the sum is divided by the number of samples.

However, weighted averages are preferable. Flow volume in each section is measured at the time of sampling. To obtain a weighted average, the cross-sectional area of each section must be known and the velocity profiles for each must be prepared. The flow is multiplied by the sample value, the results for all sections are added, and the sum is divided by the total flow to give the flow weighted average. In the case of lakes, many exhibit the phenomenon of seasonal thermal stratification. When stratification exists, a number of samples should be taken vertically according to the position of the metalimnion or thermocline. To measure the lake's temperature or dissolved oxygen levels so as to assess the potential effects on aquatic life, samples should be taken along the vertical profile of the stratification: (i) immediately below the water surface, (ii) immediately above the epilimnion, (iii) immediately below the epilimnion, (iv) at mid-hypolimnion, and (v) one meter above the sediment/water interface.

Classification Standard

Classification provides a structure into which available national information can be cast to arrive at internationally comparable data. The first objective is to provide conceptual and methodological guidance for collection and compilation of statistics on air, water, soil, and land quality and biota statistics for use in relevant international data collections as well as in developing environmental indicators for state-of-the-environment reporting. For example, the overall classification of surface water relates to two water quality aspects that have considerable impacts on aquatic life: the ecological consequences of the regulation of water bodies such as dams, and the freshwater quality of surface water bodies. In the first instance, classification attempts to provide a framework for systematic compilation and presentation of water quality data on water bodies of international importance. Such water bodies are defined as those whose basins are shared by several countries or substantially contribute to coastal pollution. To assess the potential effects on aquatic life, a range of statistical variables could be included under water quality classification as per the principles of oxygen regime, eutrophication, acidification, heavy metals, chlorinated micropollutants and other hazardous substances, radioactivity, etc. Further, the statistical variables under each of the above criteria could be grouped into several classes ranging from acute toxicity to minimum toxicity levels according to potential effects on aquatic life.

Similarly, to determine and to quantify factors with harmful effects on air pollution and to assess possible abatement measures, air pollution can be seen in three broad phases: (i) emission of pollutants, (ii) their concentration in ambient air, and (iii) their deposition. Emission statistics are widely used in the estimation and modeling of air pollution. Air emissions can be measured directly or can be estimated on the basis of fuel and material consumption data and other industrial processes. For this purpose, emission classification could cover emission from stationary sources such as processes (combustion of fuels in power plants and other industrial establishments, domestic heating, and several economic activities) and from activity sources such as roads, railways, and other mobile sources. Data on concentration are primarily used for the monitoring of environmental problems with air quality at various scales. The classification for concentration in ambient air could cover concentration (i) at impact stations (sulfur oxides expressed as sulfur dioxide, nitrogen oxides expressed as nitrogen dioxide, carbon monoxide, volatile organic compounds [VOCs], lead, mercury, cadmium, SPM); (ii) at regional background stations (sulfur oxide, nitrogen oxides, particulate sulfur, nitric acid, particulate NO_3^- (nitrates), ozone [tropospheric], ammonia, VOCs, chemical composition of precipitation such as pH/H+, ammonium, NO3-, Cl- (chlorine), sulfate, Na+ (sodium), K+ (potassium), Mg+(magnesium), Ca+ (calcium), electrical conductivity, etc.); and (iii) at global background stations (carbon dioxide, ozone [stratospheric], methane, CFCs, Ha, nitrous oxide, SPM, etc.). Deposition statistics, together with available information on critical loads of areas or ecosystems concerned, are increasingly requested for research and management purposes. Recommended deposition statistics classifications cover wet deposition of acids and acidifying compounds (sulfur dioxide, sulfate expressed in sulfur content; nitrogen dioxide, nitric acid , NO_3 expressed as nitrogen content; pH/H+, ammonia and ammonium compounds expressed as nitrogen content). The volume of acidifying deposition is calculated as the product of the concentration of the given component in the precipitation and the volume of precipitation.

With the ecosystem constantly evolving, it is important to provide a temporal context for decision makers by reporting on past, current, and future trends. A common historical trend period, for example, 20-25 years, can be used as a guide, but considerable flexibility is required to reflect ecosystem and decision-making circumstances. It is important to anticipate and forecast future consequences of pressures on the environment. To predict future states of the environment, various time scales ranging from 5 to 50 years may be appropriate in terms of different scenarios. This is important because there may be some considerable time delay before the ecosystem responds to new or additional pressure. For example, the effect of fertilizer application on the state of groundwater may not be evident for several years. Preventive action may be too late if the situation is not addressed on time. Furthermore, the implications of new policy and development options on environmental conditions need to be examined prior to implementation.

Meta-Data Standards

Broadly, a meta-database contains data about data, which describe content, quality, condition, and other characteristics of data. The meta-database is required as a quality control measure to maintain updated information. In this sense, the meta-database becomes an SOER product itself with external value. Meta-data are important because they help ensure an organization's investment in data and help reduce wasteful duplication of data among organizations. Considering the nature of the data/information, it could be useful to maintain two distinct meta-databases: (i) a meta-database for environment statistics data, which could cover the following information: data file name, summary description of contents, purpose of the database, name and address of organization, contact persons, access methods, parameters/variables included, geographic coverage, geographic projection, data acquisition methods, units of measurement, period of record, update frequency, database hardware/software, output formats (maps, tables, etc.), language, restrictions and conditions, price information, user guides/manual available, keywords, etc.; (ii) a meta-database for spatial (GIS) data, which could cover data code, title/theme, type-vector or raster, location/geographical name, date, scale, file size, sources, keywords, update frequency, etc.