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ENVIRONMENTAL IMPACTS OF TECHNOLOGY

At the beginning of the third millennium, many global environmental problems, such as diminishing biodiversity, climate change, ozone depletion, overpopulation, and hazardous wastes, are causing significant concerns. Problems of air and water pollution and toxic waste disposal are common in all industrialized countries. In developing nations, millions lack access to sanitation services and safe drinking water, while dust and soot in air are said to contribute to hundreds of thousands of deaths each year. Moreover, serious damage from pollution and overuse of renewable sources challenges world fisheries, agriculture, and forests, with significant present and possible adverse effects on the physical environment (1).

It is undoubtedly true that twenty-first-century people are causing significant environmental changes, notably in the biosphere, hydrosphere, and atmosphere. These changes are the results of local actions of many individuals accumulated in time and space, leading to global environmental problems (2). For example, in the United States, emissions of primary pollutants into the atmosphere are due to transportation (46%), fuel consumption in stationary sources (29%), industrial processes (16%), solid waste disposal (2%), and miscellaneous (7%). The breakdown of pollutants by weight is 48% carbon monoxide, 16% nitrogen oxides, 16% sulfur oxides, 15% volatile organic compounds, and 5% particulate matter. Other developed countries exhibit similar statistics, but for developing countries these percentages vary considerably since their activities are quite different (3).

Discussions of the environmental impact of technology can be approached in many interdisciplinary ways. The natural sciences are concerned with *anthropogenic* planetary processes and transformations—those induced by human activities. In this respect, the analysis and discussions are concentrated on physical, chemical, and biological systems through diverse disciplines such as geology, atmospheric chemistry, hydrology, soil science, and plant biology (4). However, many social science professionals are also involved in these discussions, since analysis of environmental changes also involves social causes. The scope of human intervention in the environment and how it is managed bear particular importance in that humans are now the main causes of environmental changes (5).

People affect the biophysical system by diverting resources (e.g., energy and matter) to human uses, and by introducing waste into the environment, thus causing environmental problems. Some environmental problems occur locally on micro levels (water quality and quantity, noise, local air pollution, hazardous materials, traffic, overcrowding, etc.) and can be solved by local decision makers, while others take place globally on the macro level (acid rain, desertification, natural-resource depletion, climate change, depletion of biodiversity, hazardous materials, toxic and nuclear wastes) and necessitate international cooperation. However, there are crucial manifestations of global environmental problems as local problems accumulate to become global crises (5). In this article both micro-level and macro-level environmental problems will be discussed, and references to the sources of information will be made when necessary.

One of the major causes of environmental problems is technology and how humans use it. Technology can be both source and remedy of environmental problems. It also plays a critical role as an instrument for observing and monitoring the environment on global and local scales (4). Although technology has a crucial role in finding solutions to environmental problems, by itself it cannot fix anything. Technology is a social construct

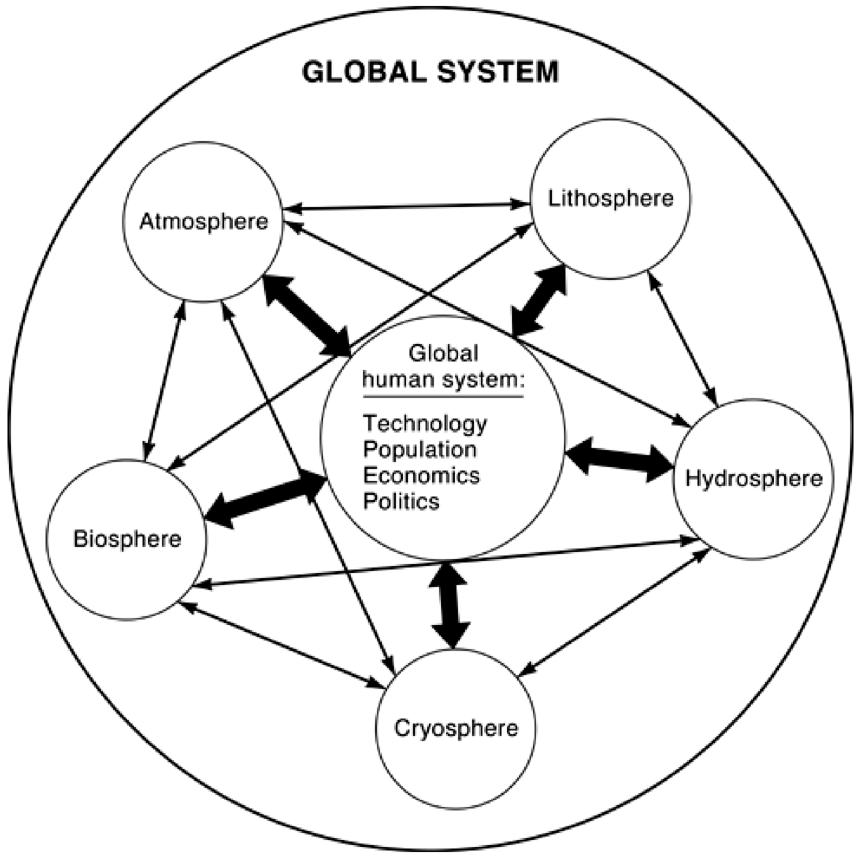

Fig. 1. Representation of global environmental system in the form of biophysical earth system and human earth system. Humans continuously interact with the biophysical earth system, and for the first time in history they are not dominated by the environment. Humans have the technology and ability to influence and upset the interaction between the components of the biophysical earth system.

responding to social, cultural, political, and economic demands and priorities. These factors determine not only whether technology is used positively or negatively, but which forms of technology are developed, accepted, and used in the first place.

Environmental impacts of technology depend on what technologies are used and how they are used. Technology is an intermediary agent of global change rather than the prime cause of it; that is, the design, selection, and application of technology are a matter of social choice. Therefore, in a balanced article such as this one, it is important to maintain a continuous link between technology and human behavior (economics, culture, demography, etc.).

This article considers natural science and social science in an interactive manner for the study of what can broadly be termed *biophysical earth systems* and *human earth systems*. The biophysical earth system can be viewed as having five major components: the atmosphere, hydrosphere, cryosphere (frozen water), lithosphere (rock and soil), and biosphere (living things). The human earth system can be analyzed into population, economic, political, and technological spheres, all interacting with each other as illustrated in Fig. 1. The human system interacts strongly with the biophysical system.

This article is divided into two major sections.

In the first section, environment and technology are defined and discussed separately. In the first half of that section, the environment is viewed as the biophysical Earth system having as major components the lithosphere, atmosphere, hydrosphere, cryosphere, and biosphere. In the second half, technology is grouped into three main components: agriculture, industry, and services. A brief historical information is provided for each of these components in order to provide a strong background for understanding how and why that particular technology exists in its current form.

Undoubtedly the growth and location of the world's population are the key determinants of global environmental change. Therefore the relationship between population and environment and between technology and economics will be highlighted. The scientific methods for assessing and controlling the effect of technology on the environment will be discussed, and issues surrounding international cooperation will be briefly explained. The understanding of this first section is important in that the development and environmental effects of technology are dependent on human behavior, and on the social and economic forces in place.

The second section comprises the bulk of the article. The impact of technology in specific areas, such as land use, soil contamination, toxic waste, water pollution, resource depletion, air pollution, greenhouse effect, noise and electromagnetic pollution, climate changes, and ozone depletion, will be discussed in detail, and conclusions will be given.

Environment and Technology

Environment.

Environment concerns all individuals and living things, since it is a common, a commodity possessed by all. As this article deals on the effect of technology on the environment, it is important to understand its meaning fully. Among many other definitions, here, the environment is defined as *the conditions under which an individual or thing exists, lives, or develops*. In the case of humans, environment embraces the whole physical world, and as well as social and cultural conditions. The environment for humanity includes factors such as land, atmosphere, climate, sounds, other human beings and social factors, fauna, flora, ecology, bacteria, and so on.

Lithosphere. Humans are land-bound; therefore the lithosphere, which consists of land (rocks and soil), has special importance in the formation of civilizations.

The earth may be viewed as made up of three layers: the core, the mantle, and the crust (6). The core and mantle together account for well over 99% of Earth's mass and volume. In the composition of the earth as a whole the crust has little importance, but it bears special significance for humans and other living things. The crust can be divided into two parts: the upper crust and the lower crust. The upper crust itself has two parts. The top few kilometers are variable and are largely formed by sedimentary, igneous, and metamorphic rocks and soil. The sedimentary rocks are those that have been built up from layers of material deposited by water and wind. The rest of the upper crust consists largely of igneous rocks and metamorphic rocks. These two types account for at least 85% of the mass and volume of the upper 20 km of the crust.

Soils form on land surfaces where the hard rocks or soft loose sediments are modified by many physical, chemical, and biological processes. Soil is basis of agriculture and thus of civilization. Soil becomes suitable for agriculture when it becomes a mixture of rock and fresh or decayed organic matter.

The lower crust is believed to contain largely coarse-grained igneous rocks.

Atmosphere. The atmosphere is a mixture of gases; it contains 75% nitrogen, 23% oxygen, 0.05% carbon dioxide, and 1.28% argon. There are other inert gases such as helium and neon in minute amounts. It also contains water vapor in variable quantities from 0.01% to 3%. Another variable component is sulfur dioxide, estimated to be present in a mass of about 10 million tons in the atmosphere at any time. At heights of 15 km to 50 km above the earth's surface there is a layer of ozone; the estimated amount of ozone is about 4 billion tons (3).

The atmosphere is divided into various layers. The first 11 km is known as the *troposphere*; it occupies about 1.5% of the total volume but contains about 80% of the mass. Near the ground level visible and infrared radiation is absorbed and the temperature is high. The second layer (up to 50 km) is called the *stratosphere*. This is the region of the ozone layer in which the sun's harmful ultraviolet rays are absorbed. The next layer, the *mesosphere*, extends from the stratosphere a further 80 km. Above the mesosphere lies the *thermosphere*. This layer absorbs ultraviolet rays and is the source of the ionosphere.

Since the formation of atmosphere, there has been close interaction between the biosphere and atmosphere, one influencing the other. This continues today as society affects the chemical composition of atmosphere through pollution and deforestation.

Hydrosphere. The earth is a watery planet. Land today occupies one-third of Earth's surface covering about 36% (29% exposed and 7% under water). The remaining 64% (362 million km^2) of Earth's surface is covered by oceans with a mean depth of 3.8 km. The ocean contains 1350 million km^3 of water. Ocean water is not pure; it contains virtually all elements, though most occur in minute amounts. Prominent solutes are various salts, collectively called *salinity*. Approximately 97% of the water on the earth is in the oceans. Fresh water makes up only about 85 million km^3. Of this, approximately 60 million km^3 is groundwater, 24 million km^3 is in ice sheets, 300,000 km^3 is in lakes, reservoirs, and rivers, less than 100,000 km^3 is in soil moisture, and 14,000 km^3 is in the atmosphere.

Water is naturally cycled between land, sea, and atmosphere, as shown in Fig. 2. The global hydrological cycle is important for all living things. Water evaporates from the oceans, seas, and land and redistributes around the globe. Although more than 90% of water precipitation returns directly to the oceans and seas, a significant portion is carried by winds over the continents, where it falls as rain and snow. Upon reaching the ground, a portion of the water is absorbed by the soil, and the remaining water evaporates back into the atmosphere or forms rivers, streams, lakes, and swamps as groundwater. However, factors such as climate as well as human activities can affect the balance of the hydrological cycle (6).

The annual transport of water is estimated to be about 600,000 km^3/yr. Precipitation over land is about 120,000 km^3/yr, of which 70,000 km^3/yr is evaporated. Currently, humans use about 3000 km^3/yr of water, which shows that there is no immediate scarcity. Nevertheless, both quantitative and qualitative trends in water demand caution.

Cryosphere. "Cryo" means cold or freezing. The part of the earth's surface, such as glaciers, sea ice, and areas of frozen ground, that remains perennially frozen covers 15 million km^2 (about one-tenth of the land surface). It is estimated that 24 million km^3 (about 2%) of the water exists in the cryosphere (6). The cryosphere directly influences climate through enhancing the equator-to-pole thermal gradient. It also plays an important role in the global energy balance and water mass balance. It is estimated that the melting of ice in Antarctic alone could result a rise in the sea level by 18 m (3).

Studies in the cryosphere yield accurate observations on climate patterns on long time scales. Modern scientific methods allow the unveiling of historical information on the earth's climate changes through the study of ice sheets in Greenland and at the North and South Poles. Global changes in CO_2, CH_4, volcanic activities, biogenic sources, dust, radioactivity, and so on can also be studied (3).

Biosphere. The biosphere contains the ecosystem and biological diversity (biodiversity) of the world. Biodiversity encompasses the number and variability of all living organisms, both within a species and between species. Estimates for the number of species in the world range from 5 to over 50 million, of which only about 1.7 million have been described to date (7). Estimates for the loss of species within the next 50 years are 5% to 50%. Anthropogenic factors responsible for loss of biological diversity may be listed as:

(1) Destruction, alteration, or fragmentation of habitats
(2) Pollution and excessive application of agrochemicals
(3) Greenhouse effects and depletion of ozone layer

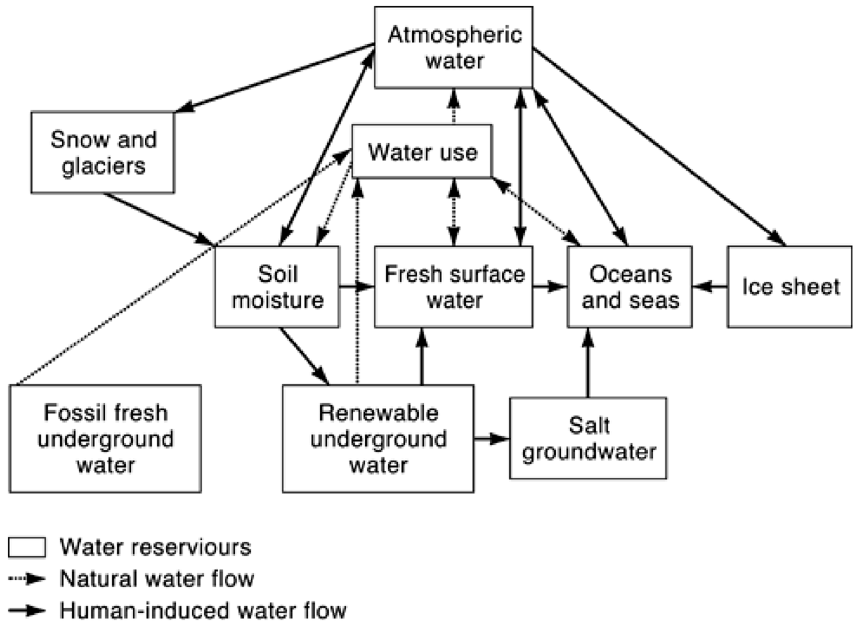

Fig. 2. Water is involved in the natural hydrological cycle between land, sea, and atmosphere. Human activities interferes with this cycle and add additional components such as exposure of fossil fresh underground water that has been in the ground for millions of years and not very likely to enter the natural cycle.

(4) Overexploitation of flora, fauna, and marine life
(5) Deliberate annihilation of pests or introduction of pests
(6) Deliberate importation of exotic species
(7) Reduction of genetic diversity

Technology. Technology is manmade hardware and knowledge used to produce objects to enhance human capabilities for performing tasks they could not otherwise perform. The objects are invented, designed, manufactured, and consumed. This requires a large system with inputs such as labor, energy, raw materials, and skills. Throughout history, humans have acquired powerful capabilities by developing and using technology to transform the way that they lived; formed societies; and affected the natural environment on local, regional, and global levels (4).

It is important to understand that the development and acceptance of technology is dynamic, systematic, and cumulative. New technologies evolve from uncertain embryonic stages with frequent rejection of proposed solutions. If they are accepted, diffusion follows, and the technologies continue to grow and improve with widened possible applications to be integrated with the existing technologies and infrastructures. Demand growth is the result of complex interacting demographic, economic, and lifestyle forces. Ultimately, the improvement potential of the existing technology becomes exhausted and the diffusion saturates, paving ways for the introduction of alternative solutions (5). At any time, three different kinds of technology can exist: (1) mature technology for which no further improvements are possible, (2) incremental technology that can be improved by learning and R&D, and (3) revolutionary technology.

Technology's impacts on the environment have been both direct and indirect.

- Direct impacts are mostly made by new technologies by the creation of entirely new substances [(e.g., DDT and chlorofluorocarbons (CFCs)] possible. Many of these new substances lead to novel and direct environmental impacts.
- Indirect impacts arise from the human ability to mobilize vast resources and greatly expand economic output by means of productivity and efficiency gains from continuous technological change. For example, the disappearance of infectious diseases like typhoid and cholera has increased the life span, and that, together with shorter working hours and rising incomes, has changed time budgets and expenditure patterns, allowing the manipulation of human behavior to cause significant environmental changes.

The impact of technology on environment is not uniform throughout the world, since the development and use of technology is not uniformly distributed. That is because development, acceptance and use of technology by humans is uneven and varies vastly from region to region and nation to nation, depending on their economic and social conditions (5). Today, still, there are billions of people who have been excluded from current technology or have a very small share of it.

The effects of technology can be divided into three main areas: agriculture, industry, and services.

Agriculture. Next to fire, agriculture is the oldest human technology and has affected the natural environment for millennia. Agriculture is the largest user of land and water resources. Intensive soil cultivation, reservoirs, and irrigation have been part of many civilizations since antiquity. Since the 1700s the world population has risen considerably. To be able to supply food for the rising population, an estimated 12 million km^2 of land has been converted from forests and wetlands to croplands.

One of the major impacts of technology is through vastly improved agricultural practices in the last few centuries. This improvement has permitted an increasing share of the growing population to move to cities. In most industrialized countries today, less than 3% of the work force works on farms. Prior to the industrial revolution, and still in many countries, that figure was about 75%, and the shift out of agricultural employment has led to urbanization. Many countries are now in the process of this shift. Coupled with the overall population growth, the increasing rural-to-urban migration causes infrastructure, health, housing, and transportation problems.

Industry. In order to appreciate how and why current industry has been developed and how it affects the environment, it is important to look at the historical development of industry.

While important technological innovations can be identified in earlier historical periods, the most important ones that significantly influence the environment took place in the eighteenth century. The rise of industry as we know it today began with the textile industry in the UK, which led to mechanization and factory systems by the 1820s. Steam power also started in England, led to powerful mechanized industries, and spread quickly to other countries, reaching to its apex in the 1870s to 1920s. In this period, innovations combined with accumulation of knowledge and social transformations reinforced one another to drive the *industrial revolution*. During the industrial revolutions there were three main tendencies operating: (a) substitution of machines for human effort and skill on large scales, (b) substitution of fossil fuels for animal power, which greatly increased the available power, and (c) the use of new and abundant raw materials.

Fueled by coal, heavy industries (e.g., steel production) dominated industry between the 1850s and the 1940s. During this period other technologies such as petrochemicals, synthetics, radio, and electricity emerged. In the 1920s mass production and consumption technology started, and it continues to the present time. The mass production techniques, together with scientific management styles, resulted in an increase in productivity and efficiency by means of economies of scale, and the emergence of multinationals operating on the global level. Railways have been replaced by roads and the internal combustion engine vehicles; air transportation and communication networks (radio, telephone, TV, Internet) have overcome physical distance and enhanced cultural and information exchange. All these have led to changes in social values, new technologies, and new ways of organizing production, thus shifting occupational profiles and encouraging global competition. This period can be characterized by an unprecedented increase in many different products for consumers.

Also, higher productivity and consequent increased resource use resulted in higher incomes and reduction in working hours, in turn leading to more consumption (and more waste) and an increase in leisure and travel time, whence more energy use and more emission.

In the new millennium the mass production–consumption era still continues strongly. The environmental impacts of this era are significant in that it generates wastes and pollutants of whose long-term effects we remain ignorant. The number of new materials and substances introduced over the last 50 years is large. Plastics, composite materials, pesticides, drugs and vaccines, and nuclear isotopes are just a few of the major ones. The properties, functions, and services these new products provide are spectacular. Penicillin and other antibiotics have almost wiped out a large number of infectious diseases and significantly increased life expectancy. Plastic containers and packaging have improved hygiene and food preservation. New materials such as alloys and ceramics have found many diverse applications.

Today, industrialization is at the core of global change. Because of the success of industrialization, artificial transformations of matter and energy have assumed global dimensions. Industry mobilizes about 20 billion tons of materials annually in the form of fossil fuel, minerals, and renewable raw materials. The extraction, conversion, and disposal of these quantities produce 40 billion tons of solid wastes per year. In comparison, total materials transport by natural river runoff is about 10 to 25 billion tons a year. In addition to quantity, quality also matters. For example, release of less than one ton per year of dioxins and furans is responsible for major human health and environmental concerns.

Services. An emerging and important technological sector, which is likely to dominate human behavior and environmental impacts of technology in the near future, is the *services and information* industry. In it, the consumption activities are decentralized and driven by complex motivational structures. Its constraints are no longer dependent only on the natural and economic resources and technological limitations, but also on human activities. In industrialized countries, the service sector typically accounts for about two-thirds of economic output and employment. In the United States the service sector provides 72% of employment. Studies in the the United States indicate that growing categories in the service sector will be largely in health, virtual reality media (telephone, audio, video, computers), and recreational services, approaching about 40% of personal incomes. Previously, services were regarded as low-tech activities, but they are now large consumers of new technologies, particularly information and communications technologies (4).

Technology and Economics. Most societies in recent human history have sought to increase their level of economic activity through economic growth and increased capacity to provide goods and services. Economic growth requires inputs and greater consumption of resources; it accelerates the flow of matter and energy through the society to produce outputs (Fig. 3). As discussed above, technology helps this economic growth; hence technology and economics are closely related and can be treated with macroeconomic or microeconomic models. The main drivers of this relation are population, demography, income levels and living standards, and resource use (5).

Since the onset of the industrial revolution in the middle of the eighteenth century, global industrial output and productivity have risen spectacularly. Data offered by various researchers indicate that global industrial output has risen by approximately a factor of 100 since the 1750s. Over the last 100 years, output has grown by a factor of 40, an average growth rate of 3.5% per year. Per capita industrial production has increased by a factor of 11, equivalent to a growth rate of 2.3% per year. Taking the United Kingdom as an example, the average number of hours worked in a lifetime in 1956 was estimated to be about 150,000 for men and about 63,000 for women. In 1981 it was estimated to be about 88,000 for men and 40,000 for women, signifying a 40% drop for men and 37% for women (4).

Over the last 100 years, real wages in industry have risen by more than a factor of 10, and working time has fallen by a factor of 2, thus bringing affluence and leisure. Material productivity and energy productivity have also risen sharply. Producing a ton of steel requires only one-tenth of the energy input that it required about 100 years ego. Higher productivity and more output have enabled higher wages and shorter working hours; both are important elements of consumer societies. Higher consumption is the necessary counterpart to

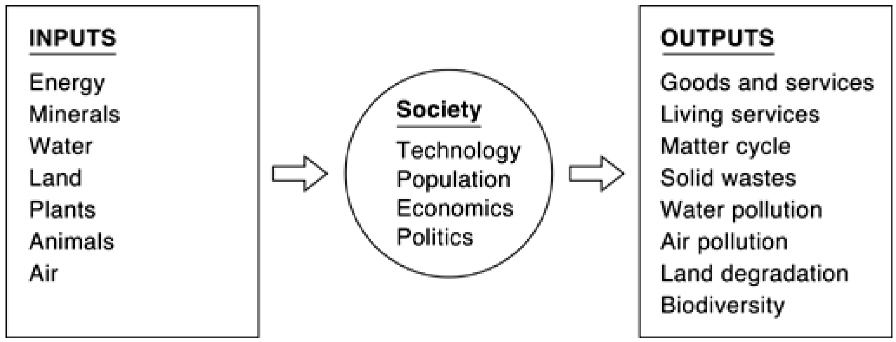

Fig. 3. Human economic activities lead to growth and prosperity. But the growth requires greater consumption of natural resources. Use of natural resources throughout human society leads to many environmental effects such as air and water pollution, land degradation, and climate changes.

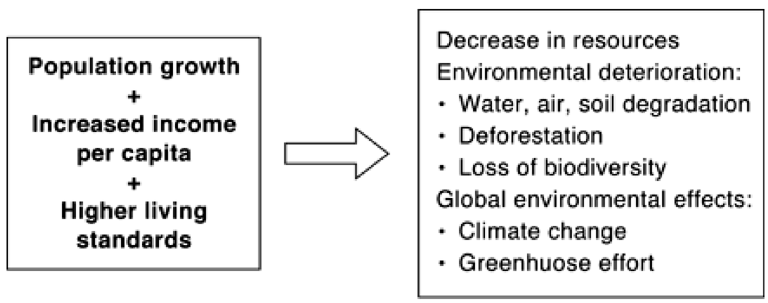

Fig. 4. The population growth, increase in incomes, and higher standards of living through the use of technology lead to many environmental changes. The intensity of environmental impact of technology and population can be expressed by a simple formula $I = PAT$, where I is the environmental impact, P is the population, A is the affluence factor, and T is the damaging effect of technology.

higher production of the industrial sector. At the same time, new environmental concerns have emerged at the local and global levels. For example, synthetic substances are depleting the ozone layer and are increasing the concentration on the greenhouse gases, causing global warming.

Technology, Population, and Environment. The relation between environmental changes, population, and economic growth is important, since environmental damage can be directly related to the growth and location of world's population. Clearly, more people require more food, more space, more fuel and raw materials. Environmental damage can be associated with population, per capita income, the gross domestic product, and so on; see Fig. 4. At the same time, an improved standard of living is a critical need for a substantial portion of the world's population. As a result, the key issue is not whether there should be additional growth, but rather how to achieve without thwarting important social, economic, and environmental goals.

Information on population size and growth is of fundamental importance for evaluations of environmental change (5). Data on the distribution and age structure of a population is a prerequisite for the assessment and prediction of its environmental, socioeconomic, and health problems. The world population increased from about 890 million in 1750 to 3 billion in 1960 and 6 billion in 2000. The population has been increasing rapidly since 1970s (1.7%/year), particularly in developing countries, due to increased life expectancy and the number of births exceeding the number of deaths.

Today, the distribution of the world population of 6 billion is as follows: 59.4% in Asia, 4.7% in North America, 8.5% in South America, 13.8% in Africa, 8.2% in Europe, 0.5% in Oceania, and 4.9% in the former Soviet Union. Overall, the population in the industrialized countries is about 20%, and in the developing countries 80%. Although there are disagreements and variations in the estimation of future population from one to another source and from one to another year, the UNPD and World Bank estimate that world population will reach 8.5 billion by 2030 and will be just under 12 billion by 2050. About 90% of the world population increase is in the low-income nations of Africa, Asia, and Latin America, where in 42 countries the growth rate exceeds 3%. In 48 countries, mainly in Europe and North America, the growth rate has stabilized at less than 1%. By the year 2030 the distribution of the world population will change considerably: 57.8% in Asia, 3.9% in North America, 8.9% in South America, 18.8% in Africa, 6.1% in Europe, 0.4% in Oceania, and 4.1% in the former Soviet Union. The population in the industrialized countries will be about 15.9%, in developing countries 84.1%. For more information on population see the Annual Report of the German Advisory Council on Global Changes, 1995 (8).

One of the important environmental problems is due to rapid urbanization, which has resulted in the formation of cities and megacities. In 1800 less than 3% of the world's population was living in cities with 20,000 or more inhabitants; now this percentage is more than 40%. Global urbanization is set to continue, with increasing tempo in the developing world. It is estimated that more than 80% of the population in developed and more than 50% in developing countries will live in urban areas by the year 2025. The annual average growth rate of the urban population is about 2.7% per year. This continuing expansion presents many environmental problems and requires the provision of basic services such as water supply, sanitation, housing, transport, and health services. Particularly where squatter settlements proliferate on the outskirts of cities, a common occurrence in developing countries, access to drinking water and sanitation facilities may be inadequate or entirely lacking. Rural populations in many developing countries have very poor access to safe water.

Cities will play a crucial role in the world in the new millennium. Despite their seeming insignificance in terms of area (only around 0.3% of the earth's surface), they have vast effects on the regional and global scales. Many cities, accommodating over 1 billion people, are built on coasts, rivers, and estuaries. Because of these locations, large pollution loads in both air and water transport the effects of urban activities over long distances. Cities also cause major alterations to topography, drainage systems, climate, economies, and social systems. For example, while photochemical smog affects the local urban population's health, damage to vegetation from high concentrations of troposphere ozone is a regional problem, as is the destruction of forests and lakes from acid rain; burning fossil fuels for industrial and domestic energy, largely in urban areas, contributes to the intensification of pollution and enhances the greenhouse effect.

Moreover, in parallel with the predicted increase in population, global per capita income is estimated to increase by over 80% between 1990 and 2030, and developing-country per capita income may grow by 140%. As a result, by 2030 world economic output could be as much as 3.5 times its present value. If the environmental impacts rose in step with these projected developments, the result would be detrimental to environment and humans. Nevertheless, the intensity of damage can be reduced through existing technologies and approaches that make more efficient, sustainable use of resources, such as energy conservation, recycling, and more efficient and cleaner industry.

Assessing and Controlling of the Effect of Technology. As indicated earlier, technology affects the environment through human behavior. The effects need to be monitored, measured, and interpreted in a scientific manner. One approach to evaluating the effect of technology is modeling. Both conceptual and mathematical approaches are available for modeling technological impacts on environment (9). Nonetheless, the modeling is only a first step toward a good understanding of the process. There is always uncertainty on many issues such as future technological configurations, their social acceptability, and their environmental implications. In the absence of deterministic models, empirical base patterns are used to determine the effect of technology on the environment (4). Empirical observations indicate that technological change is continuous, pervasive, and incremental. Technological impacts on the environment are ubiquitous in space and time, across different technologies, and across societies, being shaped by what and how societies produce and consume, and how they interact with the environment (10).

Indeed, efforts to solve environmental problems can only be successful when based on sound understanding and reliable data (11). Regrettably, although there are increasing number of published environmental compendia of various types, a comprehensive coverage of many regions of the world still is not available. Here, technology helps by providing better data on environment and human activities, and giving powerful means of analyzing the data to build models and management plans. For this purpose accurate environmental instruments and instrumentation will help to increase the amount of reliable information available.

Despite the growing number and efforts of environmental monitoring programs, significant gaps in national and international environmental statistics still exist, due to differences in definitions and lack of understanding of the significance of the problems in many nations. Nowadays, conventional monitoring methods have been complemented by observations from satellites specifically devoted to earth resources monitoring (11). The main advantages of satellite sensing are the provision of repetitive and large-scale data in remote and/or inaccessible regions. There are, however, some disadvantages to satellite monitoring that still have to be overcome, particularly technical limitations of sensors. Nevertheless, satellite remote sensing now has a significant role in mineral and land resource monitoring, agriculture, forestry, water resources, natural disasters, and other environmental fields.

It is worth noting that in recent years, there has been substantial investment in the global market for environmental goods and services (5), a list of some companies is given in Table 1. The Organization for Economic Cooperation and Development (*OECD*) estimates that the global market for environmental services, combined with pollution control and waste management equipment and goods, stood at about US$300 billion in 2000.

The most general and important strategies to lessen environmental impacts of technology center on improving land, energy, and labor productivity. Governments, individuals, firms, and society at large spend resources on innovation, experimentation, and continual improvement. Other strategies center on specific technologies to reduce particular environmental impacts by fitting them with cleanup technologies. Still other strategies focus on radically redesigning the production process and the entire product cycle.

International Cooperation on Environmental Issues. Attempts at international cooperation on environmental and resource management issues began in the late nineteenth century, mainly on regional rather than global issues. Many dealt with regional fisheries or ocean pollution, or international waterways. Today, there is a very wide scope of activities relating to environmental management in which cooperative action is effective, beneficial, and even essential for control or solution of environmental problems on national and international levels, as illustrated in Fig. 5. These activities, conducted within local areas, nations, and regions and globally, include information collection and dissemination, regulation setting and control, collaborative research, and monitoring to protect the environment and preserve natural resources. Organizations such as the United Nations (*UN*), the OECD, Council of Mutual Economic Assistance (*CMEA*), the European Community (*EC*), the Association of South East Asian (*ASEAN*), and the Organization of African Unity (*OAU*) have branches to look after environmental concerns. Established nongovernmental organizations, including the International Union for the Conservation of Nature and Natural Resources (*IUCN*) and the International Council of Scientific Unions (*ICSU*), also play a major role in environmental concerns.

The UN Conference on the Human Environment, held in Stockholm in 1972, was the first international conference to have a broad agenda covering virtually all aspects of environmental concerns. One of the most important outcomes of this conference was the establishment of the United Nations Environment Program (*UNEP*) in 1974. Its major tasks were to act as a source of environmental data, assessment, and reporting on a global scale, and to become a principal advocate and agent for change and international cooperation.

UNEP has been working in close collaboration with the UN and outside organizations to establish and promote a large number of programs covering such topics as desertification, climate change, hazardous wastes, oceans, and global environmental monitoring. In 1980, UNEP, in conjunction with the World Conservation

Table 1: Suppliers of Environment Products and Services[a]

Advanced Environmental Systems 32 Harris Circle Newark, DE 19711 Tel: 800-220-5330 Fax: 302-234-5335	CSM Environmental Systems, Inc. Brooklyn Navy Road, Building 12 Brooklyn, NY 11205 Tel: 718-522-7000 Fax: 718-852-1686
Aquamagnetics International, Inc. 910 Harbor Lake Drive Safety Harbor, FL 34695 Tel: 813-447-2575 Fax: 813-726-8888	Davies Water Treatment Group 1828 Metcalf Avenue Thomasville, GA 31792 Tel: 1-800-226-5775 Fax: 912-228-0312
Aquamatic, Inc. 22737 Granite Way, Unit C, Laguna Hills, CA 92653 Tel: 714-472-8166 Fax: 714-472-9315	Ducon Environmental Systems 110 BI-County Blvd., Farmingdale, NY 11735 Tel: 516-420-4900 Fax: 516-420-4985
Bayliss Technologies, Inc. 9631-D Liberty Road Randallstown, MD 21133 Tel: 410-521-4700 Fax: 410-521-4799	Elexor Associates, Inc. 283 Myrtle Ave., Boonton, NJ 07950 Tel: 201-299-1615 Fax: 201-299-8513
Bios International 230 West Parkway, Unit 1 Pompton Plains, NJ 07444-1060 Tel: 1-800-663-4977 Fax: 201-839-7445	Enviro-Comp Consultants, Inc. P.O. Box 91 Laurel, NY 11948 Tel: 1-800-969-8445 Fax: 516-369-8492
Comprehensive Environmental Serv. 457 River Drive Garfield, NJ 07026 Tel: 201-478-5755 Fax: 201-478-5551	Environmental Diagnostics, Inc. 612 Orrington Court Lake Zurich, IL 60047 Tel: 800-540-9588 Fax: 708-540-9589
Clean-Flo Laboratories, Inc. 2525 Xenium Lne North Plymouth, MN 55441 Tel: 612-557-6773 Fax: 612-557-6723	Eps ECO Purification Sys. USA, Inc. 8813 Waltham Wood Rd., Suit 304 Baltimore, MD 21234 Tel: 410-882-1566 Fax: 410-882-2910
Compliance Systems International 6353 El Camino Real Suite M-T Carsbad, CA 92009 Tel: 1 800-220-1128 Fax: 619-431-7936	Earth Media Technologies 214-T S. W. Walnut Ankeny, IA 50021 Tel: 515-965-8272 Fax: 515-965-8208
Hach Company P.O. Box 389 Loveland, Colorado 80539 Tel: 303-669-3050 Fax: 303-669-2932	Nucon international, Inc. P.O. Box 29151-T Columbus, OH 43229 Tel: 614-846-5710 Fax: 614-431-0858
Interel Env. Technology, Inc. P.O. Box 4676-T Englewood, CO 80155 Fax: 303-792-0931	Peroxidation Systems, Inc. 5151 E Broadway, Suite 600 Tuscon, AZ 85711 Tel: 1-800-775-0857
INX Corporation 7137 Bernville Rd., Bernville, PA 19506 Tel: 717-933-8192 Fax: 717-933-9190	Purified MicroEnvironments A Div. of Germfree Laboratories, Inc. 7435 N.W. 41st Street Miami, FL 33166 Tel: 305-592-1780 Fax: 305-591-7280
Lamotte Dept. TR-9, P.O. Box 329 Chestertown, MD 21620 Tel: 410-778-3100 Fax: 410-778-6394	OSPRA Spectogram Corporation 385-T State Street North Haven, CT 06473 Tel: 1-800-839-9050 Fax: 203-248-8887
McNeill International 7041 Hodgson Road Mentor, OH 44060 Tel: 216-953-0005 Fax: 216-953-1933	Ozone Pure Water, Inc. 5330 Ashton Court Sarasota, FL 34233 Tel: 813-923-8528 Fax: 813-923-8231
Monroe Environmental Corporation 11 Port avenue P.O. Drawer 806-P Monroe. MI 48161 Tel: 313-242-7654 Fax: 313-242-5275	Testo, Inc. 230 Rt. 206 Flanders, NJ 07836 Tel: 800-227-0729 Fax: 201-252-1729
Monsanto Enviro-Chem Systems, Inc. Avenue de Tervuren 270-272 B-1150 Brussels, Belgium Tel: Int+32-2-776-4655 Fax: Int+32-2-776-4040	Unified Safety Corporation 8530 Wilshire Blvd., Suite 301 Beverly Hills, CA 90211 Tel: 800-394-5776 Fax: 800-394-5504
NAO Inc, 1284 East Sedgley Avenue., Philadelphia, PA 19134 Tel: 215-743-5300 Fax: 215-743-3018	United Industries Group P.O. Box 8009, Dept. TR Newport Beach, CA 92658-8009 Tel: 714-476-1006 Fax: 714-476-2913
	Water Group System 290 Trousdale DR., Suite 1-TR Chula Vista, CA 91910 Tel: 800-739-9072 Fax: 619-476-7807

[a]Environmental products have a large worldwide market. Many companies are offering consultancy on environmental issues, pollution preventive products, and pollution control and monitoring equipment. The environmental market is expected to rise sharply in the next 10 to 20 years.

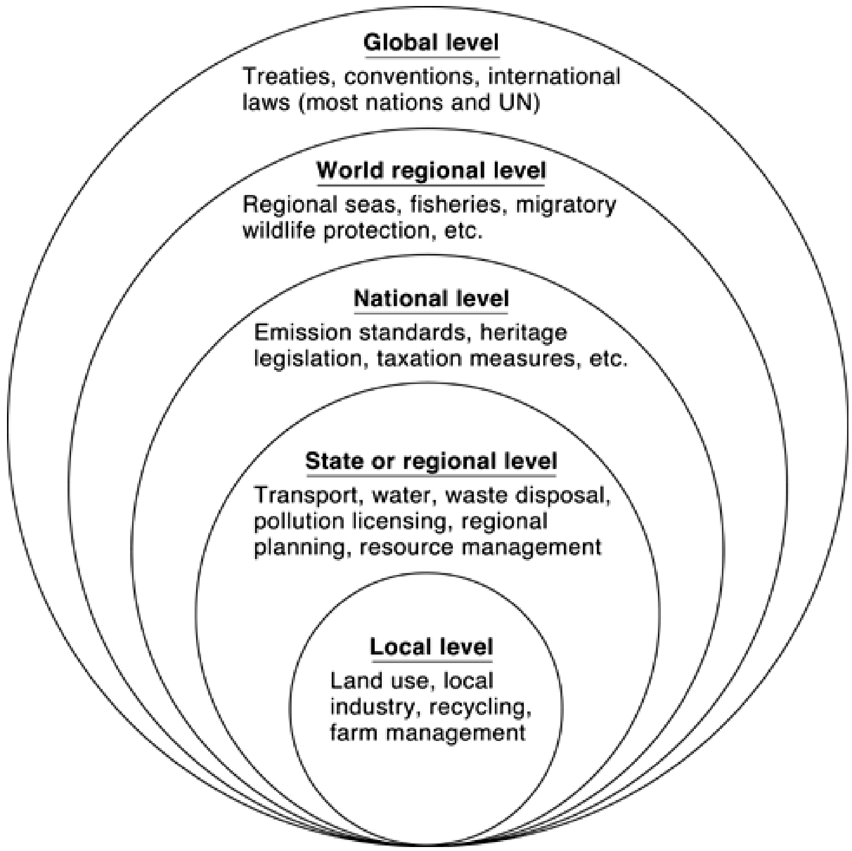

Fig. 5. Today, humans realize that the environment is fragile and can no longer be used in the traditional way. Therefore, many organizations at various levels are looking into environmental problems and means of sustainable development.

Union (*IUCN*) and the World Wildlife Fund (*WWF*), produced a World Conservation Strategy that contained key features for sustainable development. The United Nations Conference on Environment and Development (*UNCED*), held in Rio de Janeiro in 1992, was a comprehensive meeting and a major media event that focused worldwide public attention on environmental issues; its agenda is given in Fig. 6. Although there was disagreement on many issues, UNCED initiated many international actions to be taken and organizations to be set up concerning regional and global environmental problems. The Montreal Protocol of 1994, the Convention on the Law of the Sea (1994), the Desertification Convention, and the Biodiversity Convention are some of the important milestones in international cooperation on environmental issues (8).

Since 1957, a network of data centers, operating under the auspices of ICSU, has provided facilities for archiving, exchange, and dissemination of data sets, which now encompass all disciplines related tor the earth, its environment, and the sun. Currently there are 27 World Data Centers (*WDC*s) active, each tending to specialize in one discipline. The United States maintains nine WDCs, Russia two, and 16 other centers operate in various countries. There are other important organizations such as International Environmental System (known as INFOTERRA) and the International Register of Potentially Toxic Chemicals (*IRPTC*). Nowadays, environmental data are obtained from a wide variety of sources and in many formats, including satellite observations, using advanced computer technology. The data entered in the Global Resource Information

UNCED AGENDA 21 (Rio de Janeiro, 1992)

SECTION A	SECTION B	SECTION C	SECTION D
Social and economic	***Conservation and management of resources***	***Strengthening the roles of major groups***	***Means of implementation***
• Sustainable development • Demography • Health • Poverty • Consumption patterns • Human settlements • Integrated decision making	• Atmosphere • Natural resources • Deforestation • Toxic chemicals • Hazardous wastes • Solid wastes • Radioactive wastes • Desertification • Mountain regions • Agriculture • Biological diversity • Biotechnology • Oceans and seas • Freshwater resources	• Major groups • Women • Children and youth • Indigenous people • Business and industry • Science and technology • Farmers • Non-governmental organizations • Local authorities • Trade unions and workers	• Financial resources and mechanisms • Science for sustainable development • Education, public awareness, and training • Capacity building • International institutions • International legal instruments • Information for decision making

Fig. 6. The United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, was very significant in bringing people of the world together on environmental issues. As can be seen, the conference agenda included many important economic, social, management, and implementation issues, thus providing the basis for a good understanding of environmental problems.

Database (*GRID*), maintained by the UN, are analyzed and integrated using Geographic Information System and image-processing technologies to describe complex environmental issues.

Specific Effects of Technology

Land Use. Three major cultivation centers are recognized historically: in southeast Asia as early as 13,000 B.C., the Middle East about 11,000 B.C. with irrigation about 7000 B.C., and Central America about 9000 B.C. Since then, human-induced land degradation has been taking place in many forms, such as soil erosion, salination, desertification, waterlogging, soil acidification, soil contamination, and range-land degradation. Throughout history, man has substantially altered much of the world's land cover by clearing forests and draining wetlands for agriculture and livestock, burning grasslands to promote desirable forage crops, and building villages, towns, and cities for human habitation. Generally, the impact on land and the changes in land use have presented problems when the decisions of a sufficient number of users or owners coincided. Thus land usage has been a cumulative phenomenon (12).

Land use can be divided into three broad categories: agricultural lands, forests and woodlands, and other lands (cities, unmanaged rangelands, wetlands, etc.). We will briefly discuss them here.

Agriculture. Since the 1930s, global agriculture has been transformed from a resource-based industry to a technology-based industry. Mechanization, synthetic factor inputs in the form of fertilizers and pesticides, new production techniques, biological innovations, and new crops have pushed agricultural output to large scales, thus requiring fewer farmers. The reduced demand for farmers is followed by migration from rural to urban areas. At the same time, progress in agricultural technologies and techniques has progressively decreased the need for expansion of arable land to be able to supply food for increasing population. Initially,

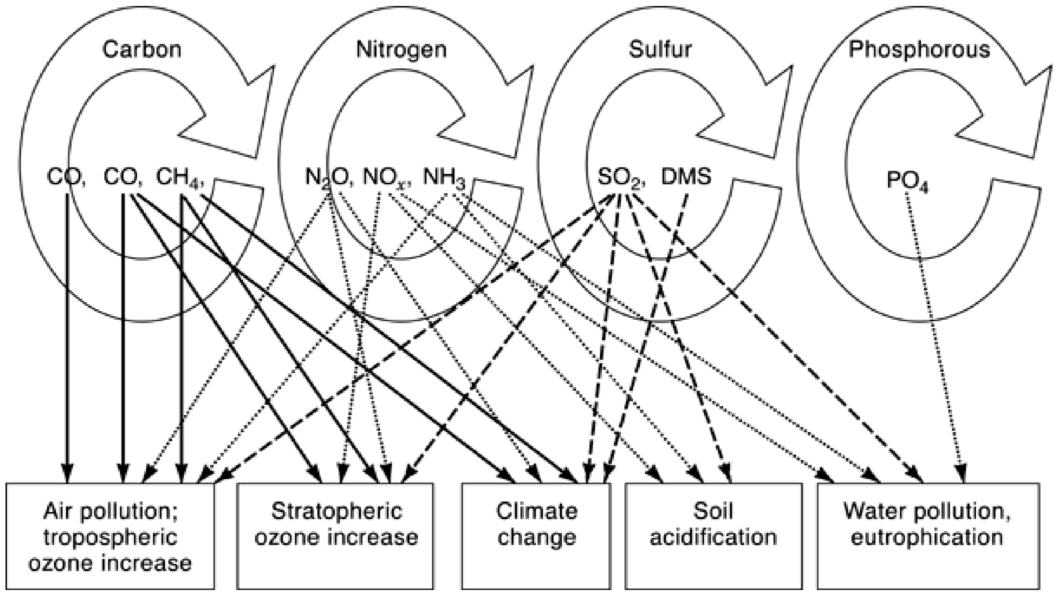

Fig. 7. Carbon, nitrogen, sulfur, and phosphorus are naturally cycled in the ecosystem. However, man's activities accelerate and upset this natural cycle, thus adversely affecting air, soil, and water.

this decrease slowed down the expansion of agricultural land in some countries, transferring the expansion to others. Particularly in European countries and the United States, agricultural productivity increased to such an extent that some agricultural land could be converted to other uses. In recent years, agricultural mass production, combined with saturation of the demand for food, has translated into absolute reductions in the overall agricultural land requirements around the globe. Here, technology has tended to spare nature and the environment. But, in parallel with the decreased land requirements, the overall expansion of agricultural production had other effects, such as putting pressure on water resources and affecting global nutrient and geochemical cycles (12).

Important factors in agriculture are land, labor, energy, water, and nutrients. In some areas agricultural systems are highly land-productive and labor-intensive, as in Asia; in others, labor-productive and land-intensive, as in North America and Australia.

In land-intensive areas, in order to raise land productivity, many synthetic fertilizers (e.g., superphosphates and nitrogen fertilizers) have been widely used. For example, after the Second World War ammonia synthesis became the dominant source of nitrogen fertilizers, and since then global nitrogen use has risen from 3 million tons to over 80 million tons. The use of phosphates has risen to over 150 million tons. Today, artificial nitrogen and phosphate cycles affect nearly every major biospheric flow of nitrogen and phosphorus nutrients on the planet (Fig. 7).

Pesticide use has also grown significantly, to a production level of over 3 million tons of formulated pesticides per year. The adverse environmental effect of long-lived pesticides, such as DDT, has been significant globally. Nevertheless, there has been important progress in the development of degradable pesticides.

Innovations in food preservation have proved to be very important. These began with tin cans, concentrated milk, and refrigeration. The refrigeration technology remained cumbersome until the 1930s, suffering from frequent leaks of reactive ammonia. To solve that problem, chemically inert chlorofluorocarbons (*CFC*s) were substituted, which contributed significantly to the depletion of the earth's stratospheric ozone layer (3).

Agricultural production suffers from crop pests and diseases. Adverse impacts are caused directly, such as by insect defoliation or by competition for space, light, and nutrients by weed species, or indirectly, by vector organisms carrying crop diseases. The use of pesticides has helped to reduce crop losses. However, adverse environmental effects, such as pest resistance and food-chain accumulation, have forced us to phase out several of the more toxic and persistent chemicals.

Apart from crops, livestock are maintained for meat, milk, eggs, wool, leather, and transportation. Worldwide, the numbers of some livestock have increased significantly while others have declined. In many dryland areas, irrigation has been essential to maintain adequate grassland for livestock. However, badly managed irrigation has caused salt accumulation on the soil surface as water evaporated, leading to salinization, which has become a significant environmental hazard and a chronic problem in many parts of the world, as in the case of Australia.

Forests and Woodlands. Forests are perhaps the most important biomass on the earth; they play vital role in the planet's biophysical system. They are reservoirs of biodiversity and habitats for endangered plant and animal species. Yet, they are also among the most threatened environments, being depleted at rate that could reduce them to impoverished remnants within decades. Technology in the form of powerful machinery and easy transportation, together with increase in the human population and demand for forest products such as paper and timber for housing and fuel, accelerates deforestation (10).

Forests and woodlands account for more than one-fifth of the world total land area (8). Forests are under pressure on account of many human uses: agricultural land, firewood, marketable timber, and land for settlements. The loss of forests and woodlands has varied considerably between countries, and the recent data indicate a general increase in clearing of forests for cropland or pasture in developing countries since the 1960s. However, many developed countries have increased their forested area and reduced the area of cropland (12).

The first complete assessment of forest cover was estimated in 1990 by the Food and Agricultural Organization (*FAO*). According to various sources (e.g., Ref. 4), the green areas of the planet in 1980 were as follows: 51 million km^2 (38%) covered with forests, close to 70 million km^2 (51%) with grass, and 15 million km^2 (11%) with crops. In the forest land, there was estimated to be 34 million km^2 of native tree species and plantation forests, and the remaining 17 million km^2 consisted of other woody vegetation such as open woodland, scrubland, and bushland.

Increase in land use and deforestation has had significant effects on the environment through altered ecosystems, destroyed wildlife habitats, changed regional climates, and the release of an estimated 150 billion tons of carbon into the atmosphere. The FAO defines deforestation as the conversion of forest to other uses such as cropland. By this definition, the forests declined by 2% between 1980 and 1990. But in the same period, new plantation cover totaling to about 630,000 km^2 offset the loss of natural forest. At this point credit must be given to China for her massive forestation programs.

The land use changes associated with forests are the ones of greatest significance to the global climate system. Deforestation for agricultural and other uses is one of the major causes of increased atmospheric carbon concentration and the ecological problems facing the planet (2). The ecological environmental consequences of deforestation include soil erosion, incapacity of soil to retain water, loss of biological diversity, and loss of cultural diversity. Loss of forests and change in land use for other purposes results in significant emissions of CO_2 and other greenhouse gases.

Deserts. Deserts are arid areas with sparse or absent vegetation and a low population density. Together with semiarid regions, they constitute more than one-third of the earth's surface. However, only 5% of the earth's land surface can be described as extremely arid. Such regions include the central Sahara and the Nabib deserts of Africa, the Takla Makan desert in central Asia, the Atacama Desert in Peru and Chile, parts of the southwestern United States and northern Mexico, the Gobi desert in northeastern China, and the Grate desert of Australia (12). It has been observed that more than 100 countries are suffering the consequences of desertification, or land degradation in dry areas.

In addition, the ice deserts of the Antarctic continent and the Arctic region should be mentioned. They are fairly barren with respect to fauna and flora. A vast ice sheet, averaging about 2000 m deep, covers Antarctica's 14,200,000 km^2 surface. The cold climate of Antarctica supports only a small community of plants, but the coasts provide havens for seabird rookeries, penguins, and Antarctic petrels. Research findings indicate that there has been a large-scale retreat of Antarctic Peninsula ice shelves during the past 50 years due to local and global warming.

Land Use for Human Occupation and Residence. Reference to technology's impact on land use usually calls up misleading images of land covered by cities, sprawling suburbs, factories, roads, dams, pipelines, and other human artifacts. In reality, the area covered by these is most likely less than 1% of the earth's total land area. It is estimated that globally 1.3 million km^2 of land (1%) is built up. Physical structures like buildings and infrastructures are estimated to cover not more that 0.25 million km^2, or less than 0.2% of the global land area. However, these small percentages mask potentially serious land-use conflict over usable land, as settlements impinge on agricultural and forested areas (10). Also, the land that urban structures occupy is almost permanently excluded from alternative uses.

Urban infrastructures such as water systems offer greater efficiency, thus improving environmental conditions. Nonetheless, there is substantial urban poverty around the world and, with it, urban environmental stress. Large urban population concentrations also create environmental stress, such as smog, and serious health hazards. Urban poverty remains widespread; over the globe, more than 1 billion urban people have no access to a safe water supply. Some 2 billion people lack adequate sanitation. These constitute a prime example of environmental problems arising from too little technology rather than too much. Urban environmental problems due to high population concentrations are most noticeable in air and water pollution. The large appetite of cities for water strains resources significantly (12). This strain is felt differently in different places. For instance, in Mexico City water comes almost exclusively from a local aquifer, and its depletion causes significant land subsidence. Another example is Venice, where heavy groundwater withdrawal for industry has led to subsidence of nearby areas and flooding of the city.

Soil Contamination. Soil contamination refers to addition of soil constituents, due to domestic, industrial, and agricultural activities, that were originally absent in the system. Soil contamination is of two different kinds. One is the slow but steady degradation of soil quality (e.g., organic matter, nutrients, water-holding capacity, porosity, purity) due to contaminants such as domestic and industrial wastes or chemical inputs from agriculture. The other is the concentrated pollution of smaller areas, mainly through dumping or leakage of wastes. The sources of contamination include the weathering of geological parent materials, where element concentrations exceed the natural abundances in wet or dry deposition forms (2).

Soils are prone to degradation due to human influences in a number of ways: (1) crops remove nutrients from soils, leading to chemical deterioration, (2) management practices influence soil quality through waste dumping, silting, and salinization, and (3) erosion removes soil. There are many examples of such degradation, and the impacts that it inflicts on the environment have been witnessed around the globe since antiquity. For instance, silting of soil due to bad irrigation practices destroyed the agricultural base of the large empires of Mesopotamia. Recently, in the United States in the 1930s, due to destructive agricultural practices, drought and dust storms caused dust bowls carrying millions of tons of fertile topsoil hundreds of miles, thus forcing millions of farmers to abandon their lands.

A number of metals and chemicals are commonly regarded as contaminants of soil. They notably include heavy metals, but also include metalloids and nonmetals. The main elements implicated as contaminants are arsenic, cadmium, chromium, copper, fluorine, lead, mercury, nickel, and zinc. In addition, beryllium, bismuth, selenium, and vanadium may also be dangerous (2).

Acid deposition arises largely through complex chemical transformation of sulfur and nitrogen oxides in the atmosphere and the resulting acidification of the environment. Many environmental effects of it, including soil and freshwater acidification, injury to vegetation, and materials damage, are well documented. Until recently, recognition of the problem of acidification has been confined to acid-sensitive regions of North America and Europe. However, many other regions are likely to be affected if trends in population growth, urbanization, and energy consumption continue.

At this point acid rain must be elaborated on, as it is one of the prime cases of acid land degradation. Acid rain refers to the acidification of rain associated with the combustion of fossil fuels: coal, oil, and natural gas. The constituents of flue gases that contribute to the acidity of rain are oxides of sulfur and of nitrogen. These chemical compounds react with the water vapor to form acids. Some acids may adhere to particulates in the air to form acid soot; most are absorbed by rain, snow, or hail and carried far from the source of pollution. Significantly affected areas are the northeastern United States; Onterio, Canada; Scandinavia; and the Black Forest in Germany.

Sediments provide an integrated assessment of contamination within a body of water. The levels of contaminants in sediments are often higher than in the water itself and thus easier to analyze. Sediments in lakes, in particular, are suitable for contaminant monitoring, as they often remain undisturbed for many years and represent an accumulation of suspended material from the whole lake basin. They can therefore reflect the integrated effects of human activity in the surrounding area. Since many metals and organic substances have an affinity for organic matter or mineral particles, both soils and sediments are suitable media for the accumulation of contaminants from the aqueous sources and atmospheric deposition. Studies, particularly in lake sediments, enable historical records of many contaminants to be obtained.

Waste materials are one of the major factors in degradation of soil. Nowadays, many environmental problems come from population concentrations generating large amounts of solid, liquid, and gaseous waste, exceeding the assimilative capacity of the environment. Globally, total solid and liquid urban wastes amount to approximately 1 billion tons per year. Over the 200 years since the beginning of industrialization, massive changes in the global budget of wastes and critical chemicals at the earth's surface have occurred, challenging natural regulatory systems that took millions of years to evolve.

Waste products can be classified as municipal wastes, wastewater, wastes dumped at sea, oil and oil products, hazardous waste, and radioactive effluent. Municipal wastes and wastewater originate from domestic and industrial sources as well as urban runoff. There are still a few countries and cities that dump wastes into the sea, in violation of the London and Oslo conventions. Waste and spilled oil often end up in surface waters and the sea. The total input of petroleum hydrocarbons to the marine environment is difficult to estimate; the main contributors are from river runoff, the atmosphere, and spills from oil tankers.

Production of toxic and other wastes continues to grow in most countries, and data indicate that disposal of these wastes is already a significant problem or will become one in the near future. However, implementation of educational programs, collection schemes, and new technologies has caused an increase in the quantities and variety of materials being recycled. Increased public awareness of waste issues has also resulted in some governments funding research into new methods of waste reclamation, recycling, and disposal, and of implementation of regulatory measures (2).

Toxic and Hazardous Wastes. Toxic materials (some heavy metals, pesticides, chlorinated hydrocarbons, etc.) are chemicals that are harmful or fatal when consumed by organisms even in small amounts. Some toxic materials may be deadly even at concentrations in parts per trillion or less. The toxic pathways through the living organisms are governed by absorption, distribution, metabolism, storage, and excretion (3). Toxic effects can be *acute*, causing immediate harm, or *chronic*, or long-term harm. For example, pesticides (e.g., DDT) can cause cancer, liver damage, and embryo and bird egg damage; petrochemicals (e.g., benzene, vinyl chloride) cause headaches, nausea, loss of muscle coordination, leukemia, lung and liver cancer, and depression; heavy metals (e.g., lead, cadmium) can cause mental impairment, irritability, cancer, damage to brain, liver, and kidneys; and other organic chemicals such as dioxin and polychlorinated biphenil (PCBs) can cause cancer, birth defects, and skin disease.

Toxic substances are generated mainly by industry, either as primary products or as wastes (2). Over the times, technologies have drawn on different principal raw materials and different energy sources, ranging from iron and coal in the nineteenth century to plastics, petrochemicals, oil, and natural gas in the twentieth. Hence the amounts and compositions of wastes have varied in time. For example, in 1990 the US chemical industry produced some 90 million tons of organic and inorganic chemicals. To produce these chemicals it generated 350 million tons of wet hazardous wastes.

It must be mentioned here that the term "hazardous materials" has different definitions in different countries. Depending on the definition, estimates for the United States vary from 100 million tons to 350 million tons, including 329 chemicals.

Hazardous wastes are generated in great amounts. Important hazardous wastes are: waste oil, acids, alkalis, solvents, organic chemicals, heavy metals, mercury, arsenic, cyanides, pesticide wastes, paints and dyes, pharmaceutical, and others. Landfill, incineration, and dumping at sea are currently the most used disposal methods for hazardous wastes. Elimination, transportation, and dumping of hazardous wastes can be a socially and politically sensitive issue; therefore complete worldwide data are not available. In some cases, these wastes are internationally traded. International transportation of hazardous waste can be divided into two classes: transportation to a recognized location for authorized treatment or disposal, and importation to be dumped illegally.

US laws regulating hazardous wastes are very strong compared to most countries'. While many European countries have laws similar to the Resource Conservation and Recovery Act (*RCRA*) of the United States, none is as restrictive and comprehensive. For example, the United States lists approximately 500 wastes as hazardous; the United Kingdom, 31; France, 100; and Germany, 348. One estimate suggests that only 20% of Italian toxic waste is disposed of properly, with the rest either stockpiled, dumped illegally, or exported. The difference between the US hazardous waste laws and those in developing countries is even greater. Few of the latter have significant laws regulating hazardous wastes.

Another hazardous waste of importance is the radioactive waste that is generated by the reprocessing of nuclear fuel and discharged in liquid effluent. Contamination levels of discharges are measured in terms of the long-lived nuclides ^{90}Sr, ^{137}Cs, and ^{106}Ru, and selected isotopes of transuranic elements.

Water Pollution. Water is a resource fundamental to all life, and it is important in both quantity and quality, particularly for humans. Fresh water is essential for life, and clean, unpolluted water is necessary to human health and the preservation of nature. Water usage varies from one country to another. In 1940, total global water use was about 200 m^3/capita·yr. The global use of water doubled in the 1960s and doubled again in the 1990s to about 800 m^3/capita·yr. According to the World Bank, the United States uses 1870 m^3 of water per person per year, Canada 1602 m^3, and other developed countries about 205 m^3 on the average. In last 20 years, growth of water use has flattened in developed countries because of technology improvement in response to water laws.

Water is used for many purposes besides human consumption, and in arid and semiarid countries large quantities are used for irrigation. The water availability varies from one country to another; for example availability is 110 thousand m^3/capita·yr in large and sparsely populated Canada, and 0.04 thousand m^3/capita·yr in Egypt, which receives most of its water from other countries. The internal renewable water resources in Bahrain are practically nil. Also, countries with rivers that have already passed through other countries may suffer from reduced quantity and quality as a result of prior use upstream.

Throughout the world, agriculture uses approximately 2000 km^3 of water annually for irrigation and livestock. Households, services, and industry use about 1000 km^3. Since the industrial revolution, irrigation water usage has increased by a factor of 30, causing significant environmental impacts. Irrigation is the key technology for increasing agricultural productivity and yields. Only about 16% of the global cultivated land is irrigated, but that 16% produces approximately 33% of all crops. The central components of irrigation systems are the reservoirs, which are just over 30,000 in number, covering 800,000 km^3 and holding 6000 km^3 (6000 billion tons) of water worldwide. Prior to 1900, reservoirs globally held only about 14 km^3 of water. This increase in the volume of water captured in reservoirs, which is about 450 times within a century, has been the largest material-handling effort of mankind.

Water withdrawal for irrigation purposes can have a number of ecological impacts far beyond the agricultural ones. Perhaps the most dramatic illustration in this century is the disappearance of the Aral Sea, resulting in severe ecological consequences such as salinity, destruction of the fish population, and serious health problems for the local population, including an increase in infant mortality.

Water Quality Problems. Different standards of water quality are acceptable for different uses. Water for human consumption should be free of disease-causing microorganisms, harmful chemicals, objectionable taste and odor, unacceptable color, and suspended materials. In contrast, stock can tolerate saltier water, irrigation water can carry some sediments, and so on. As a general principle, water quality problems fall into two categories, biological and chemical (2):

- Biological agents such as bacteria, viruses, and some higher organisms can exist naturally or can be human-induced. They can cause infections and outbreaks of acute diseases. Microbiological contamination of water is responsible for many widespread and persistent diseases in the world. Globally, around 250 million new cases of waterborne diseases are reported each year, resulting about 10 million deaths, 60% of which are of children.
- Chemical agents such as suspended sediments, toxins, and nutrients are generated by various forms of land use, industrial and agricultural activities, wastes, and air pollution.

Many pollutants, through terrestrial runoff, direct discharge, or atmospheric deposition, end up in surface waters. In turn, rivers carry many of these pollutants to the sea. However, water quality varies from one location to the next depending on local geology, climate, biological activity, and human impact. Several basic measurements of natural water quality need to be made before the additional impact from artificial sources could be assessed. With increasing numbers of chemicals being released into the environment by man, the number of variables that may have to be monitored in both fresh and marine water is growing all the time, and is currently in the hundreds. Nonetheless, subnational governments set the standards on water pollution; therefore it is difficult to obtain data and compare water regulations between nations. Also, water controls in many jurisdictions are very weak.

One of the major causes of water pollution is due to cycles of nitrogen and phosphorus, as shown in Fig. 7. The first inorganic nitrogen fertilizer was introduced in the nineteenth century in the form of Chilean nitrates and guano, but the real breakthrough came early in the twentieth century with ammonia synthesis using the Haber–Bosch process. Overall, human activity has doubled the rate of global nitrogen fixation since preindustrial times, and farming has largely become dependent on assuring adequate nitrogen supplies. The resulting large increase in nitrogen mobility creates environmental concerns. Nitrates can pollute underground water resources, and NO_x emissions from combustion are a major cause of urban photochemical smog. Ammonia (NH_3) emissions from fertilizer application and from dense livestock populations add to nitrogen oxides as an additional source of acidification. In the mid-1990s, European nitrogen emissions totaled some 13 million tons of elemental nitrogen. About half of this came from agriculture, 4 million tons were emitted from mobile sources such as vehicles, and 3 million tons from stationary sources. Also, nitrogen in the form of N_2O contributes substantially to the global greenhouse effect (3). The N_2O is highly absorptive in the infrared, and its atmospheric residence time is approximately 120 years.

Rivers, lakes, underground waters, and marine waters around the globe face somewhat different threats from technology and human activities. The most important pollutant in rivers are eroded soil, salt, nutrients, wastewater with high organic content, metals, acids, and other chemical pollutants. As far as lakes are concerned, an important environmental concern is the problem of *eutrophication*, that is, enrichment in nutrients. In the recent decades, extensive use of fertilizers that run off from agricultural land and the discharge of wastewater into rivers have aggravated this problem.

The underground waters, on the other hand, suffer from dumping of wastes and from agricultural activities. Underground water is an important source of drinking water in both developing and developed countries.

It accounts for 95% of the earth's usable fresh-water resources and plays an important part in maintaining soil moisture, stream flow, and wetlands. Over half of the world's population depends on underground water for drinking.

As a result of the long retention time and natural filtering capacity of aquifers, these waters are often unpolluted. Nevertheless, recently, there has been evidence of pollution from certain chemicals, particularly pesticides. In some countries the use of pit latrines has led to bacterial contamination of drinking-water wells through underground water movement. Increased nitrate levels in ground waters cause concern in many developed countries. One of the most widespread forms of groundwater pollution is an increase in salinity, often as a result of irrigation or saline intrusion in coastal areas and islands.

Water quality in seas is particularly important in regard to the contamination of fisheries. There is evidence that a general deterioration of water quality in highly exploited seas is taking place, causing serious concerns. There are many examples showing the adverse effects of technology and human behavior on water quality, affecting vast areas and vast volumes of water. In addition to the Aral Sea, one may mention the Baltic Sea and the Caspian Sea.

The Baltic Sea. The Baltic Sea covers 420,000 km^2 and is fed by four major rivers. It is the largest area of almost fresh water in the world. Today it borders countries that are home to more than 80 million people conducting about 15% of the world's industrial production. Hence, the waters of the Baltic are becoming turbid due to increased nutrient flows from the land and from the atmosphere. The bottom mud is becoming loaded with phosphorus. Toxic wastes from industry and transportation systems have greatly reduced the population of seals, otters, and sea eagles.

The Caspian Sea. The Caspian sea covers an area of 370,000 km^2 and is fed by many rivers. There are some 850 fauna and more than 500 plant species in the Caspian. Due to industrial activities and petrol production, the fragile Caspian ecosystem is buckling under increasing exploitation, one possible result being that the world will lose 90% of its caviar production.

Resource Depletion. A resource is a source of raw materials used by society. These materials include all types of matter and energy that are used to build and run society. Minerals, trees, soil, water, coal, and all other naturally occurring materials are resources. There are renewable resources (e.g., timber, food, hydropower, and biomass) that can be replaced within a few human generations, and nonrenewable resources (e.g., ore deposit metals, and fossil fuels) that cannot (13).

Man is the greatest user of natural resources and consequently presents a major threat to their future availability. Table 2 illustrates the intensity of common mineral mining and production. Population growth and rapid development around the world are placing constantly increasing demands on many resources. In addition, overexploitation and poor management in some areas have led to serious degradation or depletion of the natural resources on which many lives depend. For example, increased industrial development has placed continuing demand on the world's mineral resources. These resources are nonrenewable, and as extraction continues to increase, methods of recycling have to be investigated to ensure availability of certain essential minerals for future generations. Consumption of all materials, except mercury and arsenic, has been increasing steadily. However, some have been replaced by new materials, as in the substitution of plastics for aluminum.

Worldwide, industrial activities with easy availability of supporting technology, such as heavy machinery, mobilize vast amounts of materials. In 1990s, close to 10 billion tons of coal, oil, and gas were mined as fuel; more than 5 billion tons of mineral ores were extracted; and over 5 billion tons of renewable materials were produced for food, fuel, and structural materials. Actual material flows were even higher, because all the materials mentioned above had to be extracted, processed, transformed and upgraded, converted to the final goods, and finally disposed of as wastes by the consumers. Globally, metal production generates 13 billion tons of waste materials per year in the form of waste rock, overburden, and processing wastes. Nevertheless, if managed properly, most of these materials do not pose environmental problems (13). The overburden, waste rock, or water is generally not toxic or hazardous.

Table 2. Mineral Reserves and Production[a]

Mineral	Estimated Viable Reserves (10^3 metric tons)	Estimated World Production (10^3 metric tons)	Uses	Est. Static Reserve (yr)	Max. Reserve (yr)
Iron ore	65,000,000	552,000	Iron and steel	167	236
Bauxite	21,500,000	18,100 (Al)	Ore of aluminum	224	2238
Manganese	813,000	8,600	Iron and steel production	95	
Chromium	419,000	3,784	Alloys, electroplating	111	
Copper	321,000	8,920	Alloys, electric wires	41	66
Titanium	288,600	102	Alloys, paints, paper, plastics	2830	
Zinc	143,910	7,300	Iron and steel, rubber, medicine	21	42
Lead	70,440	3,350	Batteries, solder, pipes	22	37
Nickel	48,660	949	Stainless steel	65	144
Tin	5,930	216	Metal coating, cans, solder	21	21
Gold	42	0.2	Jewelry, circuits, dentistry	210	

[a]Many common mineral resources are being rapidly exhausted. Titanium, zinc, lead, tin, and many other resources may diminish appreciably within our lifetimes. Other minerals have longer estimated lives, but they still are exhaustible. The rate of exhaustion of these minerals depends on economic growth of countries and possible substitutions.

Technology-dependent metal production and waste-material handling (material mobilization) can significantly disturb the land, require infrastructures and settlements to be relocated, and substantially alter the flow of surface and ground waters. The long-term impacts of metal production and waste-material handling can be remedied through land reclamation and appropriate water management. The extent of environmental impact depends on the *material mobilization ratio* (*MMR*), which is defined as the ratio of final to primary material (a kind of efficiency). The MMR is nearly 1 in the case of crude oil and petroleum products, but 1 in 150,000 in the case of gold. It can approach to 1 in a million in the case of drugs and medicine.

Metals and hydrocarbons appear to be abundant in the earth's crust. Accessibility and concentration (both being functions of technology and price) determine if a particular deposit is minable. The amount of material input to economies of different countries is difficult to obtain. It is estimated that the total material input to the US economy in 1994 was about 6 billion tons, or 20 tons/capita·yr. This figure is largely accounted for by 2 billion tons of fuel and 1 billion tons of forestry and agricultural materials, the rest being material imports, crude oil, etc. In addition, 15 billion tons of extractive wastes are generated, and 130 billion tons of water is used. The materials used in the United States are mostly hydrocarbons (87%) and silicon dioxide (9%); metals, nitrogen, sulfur, and other materials constitute the remaining 4%.

Enormous expansion of metal production worldwide has led to emission of copper, lead, zinc, arsenic, and so on into the environment (13). However, with regard to impacts on the environment, such quantitative data have to be supplemented with qualitative characteristics of different wastes, most prominently toxicity. For example, total US dioxin and furan emissions amount only to one metric ton per year, but they cause serious environmental concern.

As far as resource depletion (Table 2) is concerned, there are several technology-dependent strategies in place, which can be attributed to environmental impacts. These are (1) dematerialization, (2) material substitution, and (3) recycling and waste mining. They are briefly discussed below:

(1) *Dematerialization* is a decrease in the quantity of materials used per unit of output. Computers can be mentioned as an example; the first electronic computer filled several rooms; today their functions can easily be performed by small pocket computers. Dematerialization is achieved by radical design changes and technological change. However, dematerialization of individual items does not indicate decline in the total consumption of the material that it is made from, since that depends on the volume of production and consumption.

(2) *Material substitution* is a core phenomenon of industrialization. It is possible to show key substitutions that made technological revolutions throughout the history. In the mass-production–consumption period the replacement of coal by oil and gas, and of natural materials by synthetic fibers, plastics, and fertilizers, are good examples. Material substitution overcomes the resource constraints and diversifies key supplies; it introduces materials with new properties, thus opening new applications and in some cases improving the functionality of use. In many cases, environmentally harmful materials can be replaced by less harmful ones.

(3) *Recycling and waste mining* depend on the technology of separation of mixed materials. Many materials such as aluminum, copper, glass, lead, paper, steel, zinc, arsenic, plastics, and coal ash are recycled for economic and environmental reasons.

Air Pollution. Air pollution may be defined as unwanted change in the quality of the earth's atmosphere caused by the emission of gases and solid or liquid particulates. It is considered to be one of the major causes of climatic change (greenhouse effect) and ozone depletion, which may have series consequences for all living things in the world. Polluted air is carried everywhere by winds and air currents and is not confined by national boundaries (3). Therefore air pollution is a concern for everybody irrespective of what and where the sources are. Due to the seriousness of air pollution, this article concentrates more on that topic than on others.

The seriousness of air pollution was realized when 4000 people died in London in 1952 due to smog. In Britain, the Clean Air Act of 1956 marked the beginning of the environmental era, which spread to the United States and Europe soon after (14). The Global Environmental Monitoring System (*GEMS*), established in 1974, has various monitoring networks around the globe for observing pollution, climate, ecology, and oceans. Concentrations of atmospheric pollutants are monitored routinely in many parts of the world at remote background sites and regional stations, as well as urban centers. Since the establishment of GEMS, some interesting findings have been reported. Some examples are as follows: It is found that overall only 20% of people live in cities where air quality is acceptable. More than 1.2 billion people are exposed to excessive levels of sulfur dioxide, and 1.4 billion people to excessive particulate emission and smoke. In 1996, there were over 64,000 deaths in the United States that could be traced to air pollution.

The most widely available data on ambient standards concern air quality, particularly for sulfur dioxide (SO_2), total suspended particulate matter (*TSP*), and nitrogen oxides (NO_x). Different countries have different standards on air quality (2). The US Clean Air Act regulates 189 toxic pollutants and criteria pollutants, whereas Japan's Air Pollution Control Law designates only 10 regulated pollutants.

Air pollutants can be classified according to their physical and chemical composition as follows:

Inorganic Gases. Sulfur dioxide, hydrogen sulfide, nitrogen oxides, hydrochloric acid, silicon tetrafluoride, carbon monoxide, carbon dioxide, ammonia, ozone, and others (14).

Organic Gases. Hydrocarbons, terpenes, mercaptans, formaldehyde, dioxin, fluorocarbons, and others.

Inorganic Particulates. Lime, metal oxides, silica, antimony, zinc radioactive isotopes, and others.

Organic Particulates. Pollen, smuts, fly ash, and others.

CO and CO_2. Carbon monoxide is a colorless, odorless, poisonous gas produced by incomplete combustion of fossil fuels. In the detection of carbon monoxide, the most commonly used methods are indicator tubes, iodine pentoxide, spectrometry, and gas chromatography.

NO_x. In industrialized countries nitrogen compounds are common pollutants. Nitrogen oxides are produced when fuel is burned at very high temperatures. Colorless nitric oxide (NO) gas tends to combine further with O_2 in the air to form poisonous brown nitrogen dioxide. In the presence of sunlight, NO_2 absorbs ultraviolet radiation to break down into NO and atomic O, which reacts with O_2 to form ozone (O_3). Measurements of NO can be made by nonautomatic or automatic methods.

SO_x. Sulfur compounds are among the main contaminants in air pollution. They are produced when materials containing sulfur as impurity are heated or burned. In industrialized nations, burning of bituminous coal produces 60%, fuel oil 14%, and metallic ore smelting, steel, and acid plants 22% of the SO_x emission. The other 4% comes from many diverse sources. The main compound, SO_2, is a colorless gas with a sharp choking odor. Some sulfur oxides are formed in air as secondary pollutants by the action of oxygen, ozone, and nitrogen oxides on hydrogen sulfide (H_2S). SO_2 combines with oxygen to make sulfur trioxide (SO_3). When the atmospheric conditions are ripe, a highly corrosive sulfuric acid mist can form by reaction of SO_3 and water vapor.

Many automatic and nonautomatic devices are manufactured to measure sulfur compounds in the atmosphere. The most frequently used methods are flame photometric detectors, West and Gaeke colorimetric and *p*-rosaniline methods, electrolytic methods, hydrogen peroxide methods, and amperimetric methods.

Hydrocarbons. Most hydrocarbons are not poisonous gases at the concentrations found in air; nevertheless, they are pollutants because, when sunlight is present, they combine with nitrogen oxide to form complex variety of secondary pollutants that are known to be the main causes of smog. Concentrations of hydrocarbons are determined by many methods: filtration; extraction; and chromatographic, adsorption, and fluorescence spectrophotometry. Dispersive and nondispersive infrared analyzers are also used to measure low concentrations of hydrocarbons and other organic compounds, as well as carbon monoxide and carbon dioxide.

Particulates. Pollutant particulates are carbon particles, ash, oil, grease, asbestos, metals, liquids, and SiO_2 dusts, particularly in remote areas. Heavy particles in the atmosphere tend to settle quickly. However, small particles are the main pollutants, and they are permanently suspended in air as aerosols. Therefore, collection of settled particles is not necessarily representative of all types of particles in the air. The size of particulates suspended in air as aerosols may vary from 30 μm to 0.01 μm or less.

Aerosols exist in individual particles or in condensed agglomerated form as coarse particles. Their stability in the atmosphere influenced by gravity settling, coagulation, sedimentation, impaction, Brownian movement, electric charge, and other phenomena. The identification and measurement of particles in air may be made by a number of methods, such as settling and sedimentation, filtration, impingement methods, electrostatic precipitation, thermal precipitation, and centrifugal methods.

Measurement of Air Pollution. Accurate measurements of air pollution are necessary to establish acceptable levels and to establish control mechanisms against offending sources (2). Accurate prediction of pollution helps in setting policies and regulations, as well as in observing the effect on humans, plants, vegetation, animals, environment, and properties. Nevertheless, precise estimation of substances responsible for air pollution is difficult due to geographical, physical, and seasonal variations. Currently many studies are taking place to understand the processes involving the formation, accumulation, diffusion, dispersion, and decay of air pollution and the individual pollutants causing it. Effective national and international control programs depend very much on this understanding.

A fundamental requirement for an air pollution survey is the collection of representative samples of homogeneous air mixtures. The data must include the content of particulate and gaseous contaminants and their fluctuations in space and time. Geographical factors—horizontal and vertical distribution of pollutants, locations of the sources of contaminants, air flow directions and velocities, intensity of sunlight, time of day—and the half-lives of contaminants must be considered to be able to determine level of pollution in a given location. The sampling must be done by proven and effective methods and supported by appropriate mathematical and statistical analysis (14).

Two basic types of sampling methods are used in determining of air pollution: spot sampling (sometimes termed grab sampling) and continuous sampling. These techniques can be implemented by a variety of instruments. *Automatic* samplers are based on one or more of methods such as electrolytic conductivity, electrolytic titrimetry, electrolytic current or potential, colorimetry, turbidimetry, photometry, fluorimetry, infrared or ultraviolet absorption, and gas chromatography. *Nonautomatic* samplers are based on absorption, adsorption, condensation, or the like.

Causes of Air Pollution. Gaseous and particulate pollutants are emitted into the atmosphere from a variety of both natural and man-made sources. Man-made pollutant emissions, predominantly from combustion sources, have given rise to a range of environmental problems on global, regional, and local scales. Most important air pollutants can be attributed primarily to five major sources: transportation, industry, power generation, space heating, and refuse burning (2). Approximately 90% by weight of this pollution is found to be gaseous, and the remaining 10% is the particulate matter.

Energy Usage. The consumption of energy is governed by the laws of thermodynamics. When energy is used, it is not lost or destroyed, but simply transformed to some other form of energy. In terms of energy flows, earth is an open system with energy inputs entering and outputs leaving. Virtually all the flows are driven by solar energy that enters biophysical systems by being absorbed, stored, and transported from place to place. Humans gain most of their nonfood energy from burning fossil fuels (10).

An adequate supply of energy is essential for the survival and development of all humans. Yet energy production and consumption affect the environment in a variety of ways. Consumption patterns in commercially traded energy sources indicate continued growth. The long-term prospects for traditional energy sources seem adequate despite the warnings put forward in the 1970s. Identified energy reserves have increased, but renewable energy sources such as firewood continue to be scarce—an increasingly serious issue for people in developing countries. The percentage worldwide uses of natural energy sources in the 1990s are as follows: 32% oil, 26% coal, 17% gas, 14% biomass, 6% hydro, and 5% nuclear.

More than half of the world population rely on the biomass fuels such as firewood, charcoal, and other traditional but not commercial fuels for their energy sources. Some 300 million people in Africa alone rely on biomass for cooking, heating, and lighting. The use of wood fuel for cooking and space heating presents environmental and social problems because the wood is being used up faster than it is being replaced. Scarcity of wood fuel is currently thought to affect about 1.5 billion people.

Over the next 100 years, energy demand is likely to increase substantially. But, in general, our knowledge of future demands for energy, raw materials, food, and environmental amenities is extremely uncertain. There is also little knowledge about the basic drivers, such as the world's future population.

Industry. Different industrial plants emit different types of air pollutants. Thermal power plants emit soot, ash, and SO_2; metallurgical plants emit soot, dust, gaseous iron oxide, SO_2, and fluorides; cement plants emit dust; plants of the heavy inorganic chemical industries emit waste gases such as SO_2, SiF_4, HF, NO, and NO_2; plants emit malodorous waste gases; and so on. These pollutants may be due to incomplete conversion of products, or due to discharge of secondary components and impurities. In general, industrial plants create the greatest diversity of pollutants; they emit SO_2 (33%), particulate matter (26%), HC (16%), CO (11%), NO_x (8%), and others (6%). However, as the nature and technology of industrial operations change in time, the amounts and proportions of the pollutants change too.

Even in industrialized nations, industry accounts for only about 17% of the total pollution. The other major contributors are transportation (60%), power generation (15%), space heating (6%), and refuse burning (3%).

Transportation. Transport activities affect the environment by the use of land and fuel resources and by emission of noise and pollutants. Environmental impacts from transportation systems have reached global dimensions in energy use and CO_2 emission. Traffic-related CO_2 emissions are estimated at 1.3 billion tons of carbon, rivaling the 1.6 billion tons due to land use. At the local level, traffic pollutants in the form of solid particulates, nitrogen oxides, and sulfur compounds are the principle precursors of acid rain.

In recent years, strict environmental regulations on the level of emissions has reduced the emission per vehicle; however, growth in the number of vehicles has more than canceled that achievement, and emissions have increased by about 20% since the 1970s. Also, the ownership of road vehicles is increasing worldwide. The number of vehicles per 1000 persons varies from one country to another; in the United States it is about 700, in the OECD countries 400, and in India and some African countries 1 or 2. It is estimated that there are about 550 million vehicles in the world, and this figure is likely to double in the next 30 years. For prevailing emission trends demand growth must be slowed, technology must improve for zero emission, and alternative non-emission-based systems must be developed. It is becoming apparent that incremental innovations are not enough to reverse emission trends and reduce the environmental impacts of transport systems (10).

Other important sources of air pollution are maritime and air traffic, both of which are increasing worldwide. Over the past 10 years the number aircraft-kilometers flown by scheduled airlines has increased rapidly in many countries.

Greenhouse Effect. The greenhouse effect is a natural phenomenon due to presence in the atmosphere of so-called greenhouse gases such as CO_x, CH_4, and N_2O (as shown in Table 3), which absorb outgoing terrestrial radiation while permitting incoming solar radiation to pass through the atmosphere relatively unhindered. The natural greenhouse effect warms the earth by about 33°C. The enhanced greenhouse effect, brought about by the release of additional gases, results in an average increase in the warming of the earth's surface. The consensus in the early 1990s was that the human-induced greenhouse effect had already warmed the earth by about 0.5°C, and a further warming of about 2.0°C is expected by 2030 (3). The primary cause of the human-induced greenhouse effect is burning of fossil fuel for energy, but land use is also a source of harmful gases (2).

Carbon Dioxide. Carbon dioxide is currently increasing at 0.5% per annum in the atmosphere and now constitutes approximately 360 parts per million by volume (*ppmv*), compared to 280 ppmv in preindustrial times. CO_2 is increasing by 1.5 ppmv each year, or 4% per decade. In the mid-1990s people put 6.7 to 9.3 gigatons (Gt) of carbon into the atmosphere each year. This is made up of about 5.5 Gt/year from fossil-fuel

Table 3. Principal Greenhouse Gases[a]

Compound	Source	Annual Production	Fraction of Effect
CO_2	Industrial	5.6 Gt C	
	Biotic	2.0–2.8 Gt C	50%
	Deforestation	2.0–2.8 Gt C	
CH_4	Industrial	50–100 Mt C	
	Biotic	320–780 Mt C	20%
	Deforestation	155–340 Mt C	
N_2O	Industrial	$<$1 Mt N	
	Biotic	3–9 Mt N	5%
	Deforestation	1–3 Mt N	
CFC	Industrial	700,000 tons	
	Biotic	0	20%
	Deforestation	0	

[a]The most important greenhouse gases are CO_2, CH_4, N_2O, and CFCs. They are generated by industrial activities, biotic processes, and deforestation, except for CFC, which does not occur naturally.

burning, and about 1.6 Gt/year from deforestation and land use. CO_2 has a residence of 50 to 200 years in the atmosphere.

Methane. Methane (CH_4) accounts for 8% to 15% of the total greenhouse effect. The atmospheric concentration of CH_4 has been rising steadily in the last 300 years. The current concentration of 1.72 ppmv (the preindustrial level was 0.7 ppmv) corresponds to an atmospheric reservoir of around 4900 million tons (Mt) of CH_4, which is increasing by around 30 Mt CH_4 per year. The largest emission of greenhouse methane gas is completely independent of human intervention and comes from natural wetlands. However, human action continues to intervene in the natural balance by altering the areas of wetland, primarily by draining it for agricultural and other uses. The mean atmospheric life cycle of methane is 12 years.

Nitrous Oxide. Atmospheric N_2O emissions are currently rising at a rate of 0.8 ppbv per year, so the concentration is likely to be 320 ppbv within 50 years (the preindustrial level was 275 ppbv). Total production of nitric oxides is estimated to be about 0.01 Gt/year, approximately 60% coming from natural emissions from land and sea, 15% from fossil-fuel burning, 10% from biomass burning, and the remainder from the application of nitrogen fertilizers. The principal sink of N_2O is destruction by ultraviolet light in the stratosphere; it thus has a long atmospheric residence time of approximately 150 years.

Halocarbons. There is a whole family of carbon compounds in the atmosphere, collectively known as *halocarbons*, that contain chlorine, fluorine, iodine, or bromine. Halocarbons, including CHCs and hydrochlorofluorocarbons (HCFCs), are among the main causes of ozone-layer destruction and the greenhouse effect. The preindustrial CFC level was 0; today, the combined CFC and HCFC level is about 370 pptv.

Agricultural and cropland expansion have interfered substantially with global flows of carbon dioxide and methane, which are the most important greenhouse gases. Agriculture dominates anthropogenic methane emission. For carbon, the impact of agriculture and land use is secondary to other industrial activities and energy use. Current biotic carbon emission occurs largely in the tropics, where most biomass burning and land-use changes are concentrated. Annual biotic carbon emission is estimated to be 1.1 Gt of elemental carbon. It is estimated that from 1800 to 1990 about 190 Gt of greenhouse gases were released globally into atmosphere as a result of land-use change, while approximately 200 Gt were released from fossil-fuel consumption in the same period.

Biodiversity. Biodiversity, or biological diversity, is an umbrella term to describe collectively the variety and variability of living things. It encompasses three basic levels of organization in living systems: the genetic, species, and ecosystem levels. Plant and animal species are the most commonly recognized units of biological diversity. Extinction of many species is caused by human activities through habitat disruption, introducing diseases and predators, overhunting, and environmental changes such as climatic changes, destruction of forests, and water and air pollution. The best way to save species is to preserve their natural habitat, and most countries have taken legal and physical measures to protect endangered species from extinction. Also, the idea of protecting outstanding scenic and scientific resources, wildlife, and vegetation has taken root in many countries and developed into national policies, embracing both terrestrial and marine parks.

Biodiversity can be estimated and measured in a variety of ways, but species richness, or species diversity, is one of the most practical and common measures (15). It is estimated that there are grave threats to many species; up to 5% to 50% in some genera of animals and plants are threatened with extinction in the foreseeable future (1). In 1996, the *Red List of Threatened Animals* issued by the World Conservation Union identifies 5205 species in danger of extinction. It has been estimated by biologists that three species are being eliminated every hour in tropical forests alone. Much of the decline is caused by habitat destruction, especially logging. Only 6% of the world's forests were formally protected, leaving 33.6 million km^2 vulnerable to exploitation.

Surveys of concentrations of contaminants in organisms and measurements of their biological effects reflect exposure to contaminants in the organisms' habitats. The main measured parameters are concentrations of organochlorin residues and radionuclides. There are many examples of traces of pollutants in organisms. Some examples are migratory birds (waterfowl), which have been found to have accumulated considerable amounts of polychlorinated biphenyl (*PCB*) residues. Similarly, intensive accumulation of DDT, PCB, chlordane, and toxaphene residues in freshwater fish have been noted. Concentrations of heavy metals such as mercury, cadmium, and lead in fish muscle and shellfish are reported. There are not many reports of monitoring data on concentrations of contaminants in plants on regional, national, or global scales. Mosses and lichens have high capacity for interception and retention of airborne and waterborne contaminants such as lead, sulfur, and their compounds.

The worldwide diffusion of agricultural crops and animals has been taking place for centuries. The pervasive diffusion of crops is accompanied by the diffusion of new pests and of species that became nuisances in new ecosystems where their growth is unchecked by natural predators. Some typical examples of human-induced shifts in the ecosystem will be dealt with next.

Fish Catch. Fish is an important source of protein in the human diet, and three-quarters of the world catch is used directly for human consumption. The increasing adoption of production quotas for managing fish stocks has contributed to overexploitation of certain fish stocks for the last century, and several fisheries remain severely depleted. Nevertheless, aquaculture has the potential to supplement fish catches and help offset the declining stocks of some fish species. It is estimated that aquaculture production may be about 7 Mt to 8 Mt worldwide; thus this technology helping to preserve the natural environment.

Marine Mammals. World catches of many species of marine mammals have declined, in part because populations have been significantly reduced, or because of legal restrictions placed on killing or capture. For example, in the case of whales, permits have been granted only for scientific purposes. Catches of most whales have diminished very substantially, and there is continual pressure to stop whaling altogether.

Protected Areas and Wildlife. Conserving the diversity of wildlife and plant genetic stocks is essential to maintain the potential for the development of new and improved varieties, which may benefit both man and environment. The protection of wildlife resources has developed at both the species and the ecosystem level.

Both developing and developed countries around the world have perceived certain natural areas to be worth preserving and therefore have designated thousands of protected areas. There are five categories of protected areas: strict nature reserves; national parks and their equivalent; natural monuments; managed nature reserves and wildlife sanctuaries; and protected landscapes and seascapes.

Although significant advances in the establishment and management of protected areas have been made over the last few decades, networks are not complete, and management suffers from a range of significant problems, particularly in the Tropics. There are many actions that can be recommended for improvement of the coverage and management of the protected area systems.

There are organizations in place that prohibit commercial international trade in currently endangered species and closely monitor trade in species that may become endangered. Trade is prohibited for about 600 endangered species and regulated for about 30,000 species, which are not yet in jeopardy of extinction, but soon may be. Trade restrictions and prohibitions have been credited with rescuing several species, such as American alligators, from the brink of extinction; but other species adversely affected by trade, such as the African elephant and the rhinoceros, continue to suffer disastrous population declines, largely brought about by illegal poaching and trade.

Some populations of endangered animals have been making a comeback, such as the fur seal, the short-tail albatross, and the whooping crane. Others have remained stable or fluctuated slightly. In some species or subspecies there have been marked or even drastic declines. Examples are the black and northern white rhinoceroses, the Tana River red colobus, the Riddle turtle, the Atilan grebe, the Californian condor, and the pink pigeon.

Noise and Electromagnetic Pollution.

Noise. Noise is often defined as unwanted sound. Usually it is unwanted because it is either too loud for comfort or is an annoying mixture that distracts us. Thus, the notion of noise is partly subjective and depends on one's state of mind and hearing sensitivity.

Noise is the most ubiquitous of all environmental pollutants. Excessive noise can affect humans physiologically, psychologically, and pathologically in the forms of loss of hearing, disturbed sleep, stress, anxiety, headaches, emotional trauma, nausea, and high blood pressure.

Loudness increases with intensity, which is measured on a decibel (dB) scale, illustrated in Table 4. Daily noises in a busy building or city street average 50 dB to 60 dB; in a quiet room, about 30 dB to 40 dB. Hearing damage begins around 70 dB for long exposure to sound such as a loud vacuum cleaner. At about 130 dB, irreversible hearing loss can occur almost instantaneously.

In terms of population exposure, transportation is the major source of environmental noise. Recent estimates from OECD countries show that approximately 15% of the population is exposed to road traffic noise. About 1% of the population is exposed to aircraft noise in excess of 65 dB, which is the proposed guideline for maximum daytime exposure to noise for populations living near main roadways. Despite advance in noise reduction technology and the adoption of environmental quantity standards in a number of countries, exposure to noise appears to an increasing problem, particularly in urban areas.

Electromagnetic Pollution. Another important environmental pollution is likely to be electromagnetic pollution, at low frequencies in the vicinity of power lines and at high frequencies in mobile communication systems and near transmitters. The flow of electricity through the wires produces an electromagnetic field that extends through air, vacuum, and some materials. Concerns over the health effects of such fields, in particular cancer, have been growing since the late 1960s. Numerous studies have yielded conflicting results, so the question is controversial.

Table 4. Sound Intensity Scale[a]

Sound Intensity			
mW/cm^2	dB	Sound Source	Effect
10^0	0	Threshold of hearing	Barely audible
10^1	10	Rustling leaf	
10^2	20	Radio studio	Very quiet
10^3	30	Library, soft whisper	Quiet
10^4	40	Average living room	
10^5	50	Light traffic (30 m)	Moderately loud
10^6	60	Normal conversation	
10^7	70	Vacuum cleaner	
10^8	80	Truck	Very loud (damage after long exposure)
10^9	90	Motorcycle (8 m), food blender	
10^{10}	100	Newspaper press	Uncomfortable (danger of loss of hearing)
10^{11}	110	Jet-plane flyover (300 m)	
		Auto horn (1m)	
10^{12}	120	Rock music	
10^{13}	150	Jet-plane takeoff	Painful (irreversible damage)
10^{20}	200	Rocket engine	

[a]Noise pollution is a serious problem in urban areas and near airports. Sounds louder than 70 dB to 80 dB can cause permanent damage to human hearing.

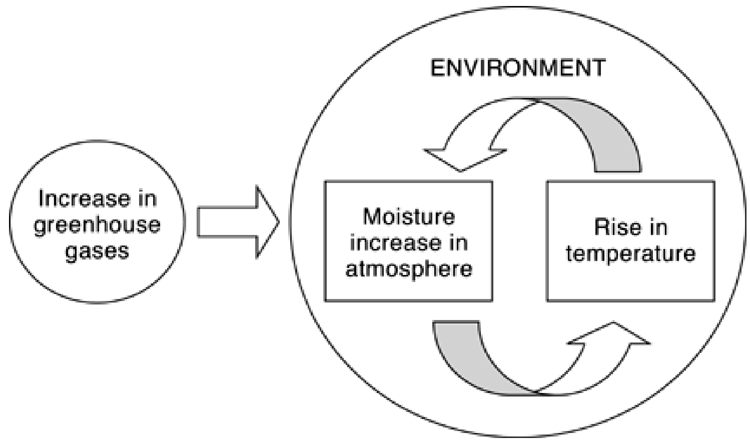

Fig. 8. Man-induced increases in greenhouse gases cause the temperature to rise, which in turn puts more moisture in the atmosphere. This leads to a cause-and-effect cycle.

Climate Change. It is generally accepted that increases in atmospheric concentrations of greenhouse gases, such as carbon dioxide, methane, nitrous oxide, CFCs, and ozone, lead to increases in surface temperature and global climatic change, as shown in Fig. 8. Calculations using climate models predict that increases of CO_2 and other greenhouse gases will result in an increase in the global mean equilibrium surface temperature in the range of 1.5° to 5.5°C. If present trends continue, the combined concentration increases of atmospheric greenhouse gases will be equivalent to doubling of the CO_2 concentration, possibly by as early as the year 2030. Models are currently unable to predict regional-scale changes in climate with any degree of certainty, but there are indications that warming will be enhanced at high latitudes and summer dryness is likely to become more frequent in midcontinental, midlatitude regions of the northern hemisphere. Increases in global sea levels are also forecast; it is estimated that a warming of 1.5° to 5.5°C can produce a seal-evel rise of between 20 cm and 165 cm (3).

A variety of data sources are available for analysis of long-term trends in climate variables such as surface and upper air temperatures, precipitation, cloud cover, sea ice extent, snow cover, and sea level (4, 7, 10).

Indicators of Climatic Change. For comparison with the results of model calculations, large-scale average changes in climatic indicators in regional, hemispheric, and global trends are needed. Changes in the surface air temperature give the most direct and reliable predicted effect of greenhouse-gas-induced climatic changes. Global land-based surface temperature data sets have been compiled since 1927 by various authorities (e.g., the Smithsonian Institution). Data analysis indicate that since the turn of the twentieth century global temperatures have increased by 0.3° to 0.7°C. Using data collected over land and sea, publications indicate that greater warming occurred over land areas in the southern hemisphere and that some regions in the northern hemisphere showed signs of cooling.

Large-scale trends of air temperature change in the troposphere and the stratosphere have also been assessed. A warming trend of 0.09°C per decade is indicated at the 95% confidence level in the tropospheric (850 mb to 300 mb) layer. A cooling of 0.62°C per decade is indicated in the stratospheric (100 mb to 50 mb) layer.

Precipitation has high spatial and temporal variability. However, analysis of historical and current data indicates an increase in the higher latitudes (35° to 70°N) over the last 40 to 50 years, but a decrease in the lower latitudes.

Cloud cover plays an important, but complex role in determining the earth's radiation budget and climate. Clouds reflect incoming short-wave radiation from the sun back in the space, but also absorb thermal long-wave radiation emitted by the earth. The net effect of clouds depends on the cloud type, height, and structure. Results obtained from the analysis of cloud coverage indicate that average total cloud coverage has increased over the last 90 years in the United States.

Fluctuations of glaciers and sea levels are sensitive indicators of climatic change. Information on the glaciers consists of the location, surface area, width, orientation, elevation, and morphological characteristics of individual ice masses. Recent studies indicate that the mass of glaciers in wet maritime environments has tended to increase, whereas the mass of glaciers in dry, continental areas is decreasing.

Sea levels also appear to be changing, by about 1.0 cm/yr. This figure is arrived at from the historical data obtained from tide-gauge measurements and current data obtained from devices such as Late Holocene sea-level indicators.

Ozone Depletion. People have had a number of impacts on the atmosphere, ranging from the local to the regional and global scales. Arguably, the most important impacts on the global atmosphere are the enhanced greenhouse effect and the depletion of the ozone layer, both of which have the potential to affect many other aspects of the Earth's physical, chemical, and biological systems. Particularly in recent years, research and development on the measurement of ozone depletion has attracted considerable attention due to its implications for the earth's temperature and for human health (10). World ozone levels have been monitored continuously by NASA, and information is updated daily on its Web site. The ozone level on the day of submission of this article is given in Fig. 9 (16). The accurate measurement of ozone and the ozone layer is important; therefore, in this article some detailed treatment of the measurements methods will be given.

Ozone (O_3) is naturally occurring gas concentrated in the stratosphere at about 10 km to 50 km above the earth's surface. It is formed in a reaction of molecular oxygen (O_2) caused by ultraviolet radiation of wavelengths less than 0.19 μm, in which the oxygen is split in the presence of catalysts and recombines to produce ozone. Ozone plays a major role in absorbing virtually all UV radiation entering the atmosphere from the sun. Ozone is destroyed in the atmosphere in three ways: it reacts with UV radiation at wavelengths of 0.23 μm to 0.29 μm to produce oxygen molecules; it reacts with nitric oxide (NO); and it reacts with atomic chlorine (Cl). The natural ozone cycle has been interfered with by the release of chemicals such as CFCs. CFCs do not break down in the lower atmosphere, but gradually diffuse into the stratosphere, where strong UV breaks then down to their monomers, releasing atomic chlorine. Initially, the chlorine reacts with ozone in a photolytic reaction to produce chlorine monoxide (ClO) and oxygen:

$$\mathrm{Cl} + \mathrm{O_3} \rightarrow \mathrm{ClO} + \mathrm{O_2}$$

The ClO then reacts with atomic oxygen to produce atomic chlorine and oxygen:

$$\mathrm{ClO} + \mathrm{O} \rightarrow \mathrm{Cl} + \mathrm{O_2}$$

These two reactions act as a catalytic cycle leading to a chain reaction, which effectively removes two molecules of ozone in each cycle, thus causing large-scale ozone destruction in the ozone layer.

Depletion of the ozone layer was first noticed in Antarctica, but is not restricted to that area. It is estimated that there has been about 14% reduction in the ozone levels of the world. Depletion of the ozone layer affects both the energy cycle in the upper atmosphere and the amount of UV radiation reaching the earth's surface.

Many devices are available for ozone measurements. There are six main methods to determine the ozone in air: electrolytic titrimetry, coulometric titrimetry, reaction with nitric oxide, ultraviolet spectrometry, and ultraviolet photometry. For stratospheric ozone determinations ultraviolet methods are mainly used.

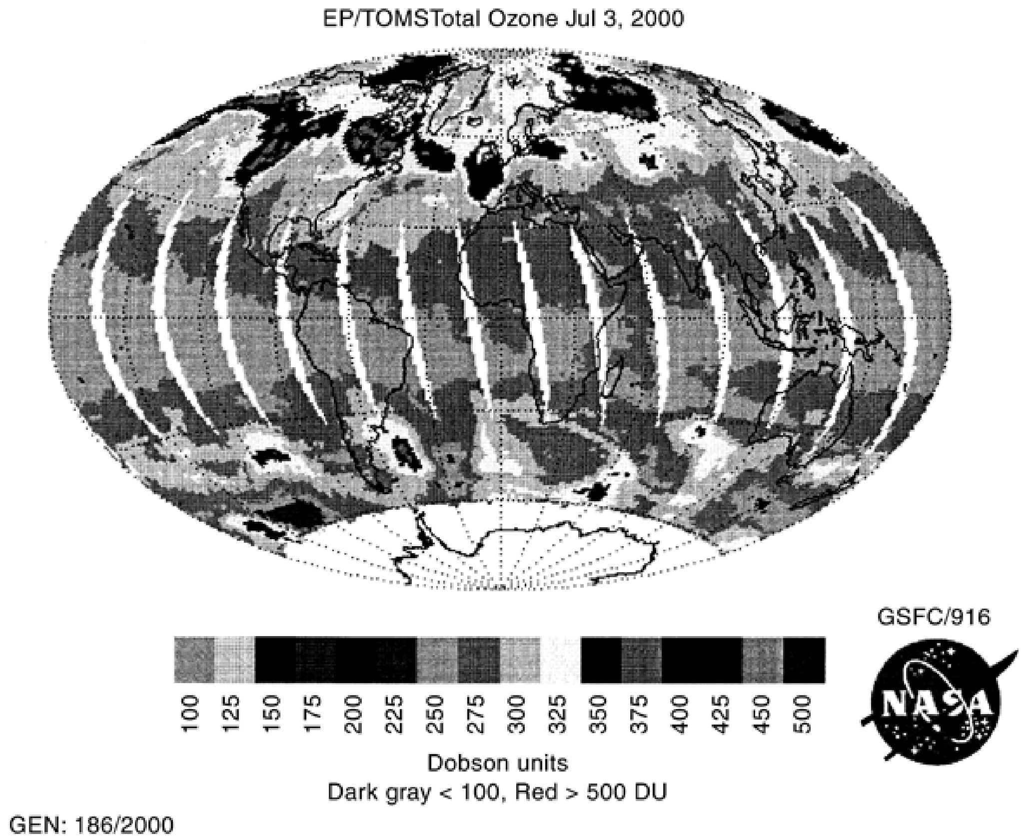

Fig. 9. Ozone levels round the globe are monitored by satellites, and the information is updated daily by NASA (16).

Conclusions

Global warming, soil contamination, ozone depletion, hazardous wastes, acid rain, radioactive hazards, climate change, desertification, deforestation, noise, and diminishing biodiversity are illustrations of current environmental problems that are common to nations worldwide. The growth in human population and rising or deteriorating living standards due to use or misuse of technology are intensifying these problems. If the existing human–environment interaction continues and if the human population increases with the current trends, the evidence shows that irreversible environmental damage may be inflicted on this fragile planet. However, the knowledge gained by science and clever use of technology, coupled with the willingness and positive attitude of people as individuals and as nations, can navigate a sustainable path to save the world from possible man-created disasters. Although not sufficient, there is evidence of understanding of the fragility of the environment by individuals and nations. There are also positive signs of development in the international cooperation.

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