CHAPTER 13

HUMAN IMPACTS ON THE ENVIRONMENT

High-rise buildings, fishing boats, and air pollution form the background of a garbage-littered beach in Mumbai, India.
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AP Learning Objectives

- Explain how major geographic concepts illustrate spatial relationships.
- Explain how population distribution and density affect society and the environment.
- Explain how agricultural practices have environmental and societal consequences.
- Explain challenges and debates related to the changing nature of contemporary agriculture and food production practices.
- Identify the different urban design initiatives and practices.
- Explain the effects of different urban design initiatives and practices.
- Describe the effectiveness of different attempts to address urban sustainability challenges.
- Explain how sustainability principles relate to and impact industrialization and spatial development.

When the daily tides come in, a surge of water high as a person's head moves up the rivers and creeks of the world's largest delta, formed where the Ganges and Brahmaputra rivers meet the Bay of Bengal in the South Asian country of Bangladesh. Within that Wisconsin-sized country that is one-fifth water, millions of people live on thousands of alluvial islands known as chars. These form from the silt of the rivers and are washed away by their currents and by the force of cyclones that roar upstream from the bay during the annual cyclone period. As the chars are swept away so, too, are thousands and tens of thousands of their land-hungry occupants who fiercely battled each other with knives and clubs to claim and cultivate them.

Late in April 1991, an atmospheric low-pressure area moved across the Malay Peninsula of Southeast Asia and gained strength in the Bay of Bengal, generating winds of nearly 240 kilometers (150 miles) per hour. As it moved northward, the storm sucked up and pushed a wall of water 6 meters (20 feet) high. With a full moon and highest tides, the cyclone and its battering ram of water slammed across the chars and the deltaic mainland. When it had passed, some of the richest rice fields in Asia were gray with the salt that ruined them, islands totally covered with paddies were left as giant sand dunes, others—densely populated—simply disappeared beneath the swirling waters. An estimated 138,000 lives were lost to the storm and hundreds of thousands more to subsequent starvation, disease, and exposure.

Each year, lesser variants of the tragedy are repeated; each year, survivors return to rebuild their lives on old land or new still left after the storms or created as the floods ease and some of the annual 2.5 billion tons of river-borne silt is deposited to form new chars. Deforestation in the Himalayan headwaters of the rivers increases erosion there and swells the volume of silt flowing into Bangladesh. Dams on the Ganges River in India alter normal flow patterns, releasing more water during floods and increasing silt deposits during seasonal droughts. Population growth adds to the number of desperate people seeking homes and fields on lands more safely left as the realm of river and sea. And global climate change already underway brings rising sea levels and stronger storm systems, increasing the vulnerability of places like the delta of the Ganges and Brahmaputra rivers.

13.1 Physical Environments and Human Impacts

The people of the chars live with an immediate environmental contact that is outside the experience of most of us in the highly developed, highly urbanized countries of the world. In fact, much of the content of the preceding chapters has detailed ways that humans isolate themselves from the physical environment and superimpose cultural landscapes on it to accommodate the growing needs of their growing numbers.

Many cultural landscape changes are minor in themselves. The forest clearing for swidden agriculture and the terracing of hillsides for subsistence farming are modest alterations of nature. Plowing and farming the prairies, harnessing major river systems by dams and reservoirs, building cities and their connecting highways, or opening vast open-pit mines are much more substantial modifications. In some cases, the new landscapes are apparently completely divorced from the natural ones that preceded them, as in enclosed, air-conditioned shopping malls and office towers. The original minor modifications have cumulatively become totally new cultural creations.

But suppression of the physical landscape does not mean eradication of human-environmental interactions. They continue, though in altered form, as humans increasingly become the dominant agents of environmental change. More often than not, the changes that we have set in motion create unplanned cultural landscapes and unwanted environmental conditions. We have altered our climates, polluted our air, water, and soil, destroyed natural vegetation and land contours while stripping ores and fuels from the Earth.

Environment is an overworked word that means the totality of things that in any way affect an organism. Humans exist within a natural environment—the sum of the physical world—that they have modified by their individual and collective actions. Human impacts on the environment can be summarized through the simple **IPAT equation:**

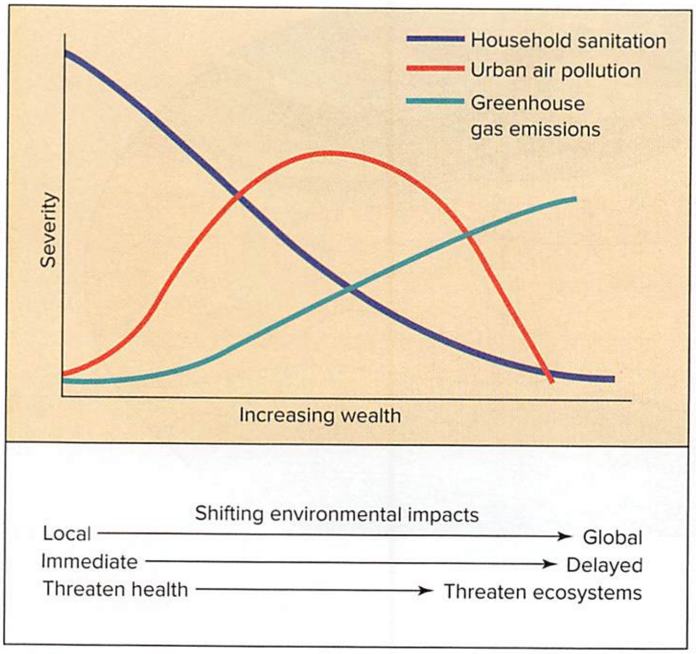
$$I = PAT$$

where:

I = Impact on the environment
P = Population
A = Affluence (often measured by per capita income)
T = Technology

As indicated by the IPAT equation, population growth and rising standards of living both lead to greater use of natural resources and greater waste production. However, the technology factor in the equation accounts for the very different impacts associated, for example, with various sources of energy such as coal, nuclear, or wind energy. Further, in many instances, increased standards of living have led to improvements in local air and water quality because rising prosperity has allowed societies to invest in pollution controls and cleaner technologies. Unfortunately, some changes aimed at improving the quality of the local environment, such as shifting to taller smokestacks or shipping toxic wastes overseas, come at the expense of the environment elsewhere or at the expense of the global environment (**Figure 13.1**). Each of the factors in the IPAT equation relate to topics in human geography—population geography, economic geography, and the various technologies that societies use to house, feed, and transport themselves. Thus, adverse consequences of human impact on the environment are the unforeseen creations of the cultural landscapes that we have been examining and analyzing, and their study highlights the unity of physical and human geography.

Awareness of the severity of human impacts on the environment has led to the concept of sustainable development. **Sustainable development** meets the needs of today without jeopardizing the ability of future generations to meet their needs. Sustainable development must work within the limits of natural systems. For example, sustainable groundwater use is limited by the amount of water replenished by rainfall and snowmelt, and sustainable



API **Figure 13.1** The geographic scale of environmental impacts shifts as incomes rise. For the world's poor, the primary environmental problems are disposing of human wastes and ensuring clean water supplies. As standards of living increase, communities can afford water and sewage treatment systems but also increase their consumption of raw materials, synthetic chemicals, and fossil fuel energy. This tends to shift environmental problems from local, immediate threats to human health to longer-term, delayed global impacts on ecosystems such as destruction of the ozone layer, acid precipitation, and global climate change.

Source: Graph from World Energy Assessment, UNDP, *2000, Figure 3.10, p. 95.*

fisheries limit the harvest of fish to a rate that maintains the long-term resilience, quantity, and diversity of the stock. Sustainable forestry harvests trees at a rate below that of natural forest regeneration. Sustainable agriculture loses soil at a rate below that of soil formation. Thus, a starting point for considering sustainable development is with a basic picture of the Earth's environmental systems.

Earth's Environmental Systems

The **ecosphere** is the thin zone of air, water, earth, and living matter that extends from the mountaintops to the bottom of the ocean, within which life is found. The ecosphere is composed of four overlapping, interrelated parts: the atmosphere, hydrosphere, lithosphere, and biosphere. The **atmosphere** is a thin blanket of air enveloping the Earth, with more than half of its mass within 6.5 kilometers (4 miles) of the surface and 98 percent within 26 kilometers (16 miles). The **hydrosphere** consists of the perpetually moving surface and subsurface waters in oceans, rivers, lakes, glaciers, groundwater, water vapor, and clouds. The **lithosphere,** the upper reaches of the Earth's crust, contains the soils that support plant life, the minerals that plants and animals require, and the fossil fuels and ores that humans exploit. The **biosphere** consists of the living matter of plants and animals. Cycles of energy in the atmosphere, water movement in the hydrologic cycle, the rock cycle, and the cycling of energy and chemical elements through the biosphere are all intricately linked. The ecosphere contains all that is needed for life, all that is available for life to use, and, presumably, all that ever will be available.

Geographic differences in climate, water availability, landforms, and biological communities generate a vast mosaic of environments on Earth. The most important components of climate are temperature and precipitation. Temperature is a measure of the air's energy, all of which comes from the sun. On an annual basis, tropical (equatorial) locations, where the sun is more directly overhead, receive the most energy from the sun. This uneven heating of the Earth's surface results in warm air in the tropics and cold air near the poles (**Figure 13.2**), The midlatitudes experience more seasonal variation, with less fluctuation near oceans and greater fluctuation in the middle of large landmasses. Summers become cooler and shorter farther toward the poles until finally, permanent ice cap conditions prevail. Temperature differences between the tropics and poles produce pressure differences that drive winds, storms, and ocean currents that redistribute the Earth's unevenly distributed energy.

The intense solar energy received in the tropics causes air to expand, rise, and eventually form clouds and precipitation. Some distance away from the equator, that air sinks, warms, and dries out. The rising and sinking air motions caused by uneven heating lead to a relatively consistent global pattern of atmospheric circulation cells (**Figure 13.3**). These circulation patterns create alternating bands of high precipitation and low precipitation areas on Earth (**Figure 13.4**). The Hadley cell, shown in Figure 13.3, is responsible for the wet tropical climates near the equator and dry, desert climates at about 30 degrees latitude north and south of the equator (**Figure 13.5**). In addition to the vertical air motions, the circulation cells interact with a spinning planet to produce the familiar surface winds such as the trade winds in the tropics and the westerlies in the midlatitudes.

Just as the rising and sinking air motions shown in Figure 13.3 create both rain forests and deserts, air that is forced up and over mountains creates wet climates on one side and persistent dryness on the other. A good example is the western United States, where prevailing winds from the west create areas of heavy snow or rainfall on the western slopes of the Cascade and Sierra Nevada mountain ranges and dry desert and steppe climates in the interior east of the mountains.

Water is essential to all life. Water covers about 71 percent of the Earth's surface, though only a small part of the hydrosphere is suitable or available for use by humans, plants, or animals. The total amount of water on the Earth remains constant as water moves through the **hydrologic cycle,** changing form from vapor to liquid to ice/snow and back again (**Figure 13.6**).

Water plays a critical role in moderating the Earth's climate, reducing temperature extremes, and making the planet habitable. Due to the diversity of Earth's climates, however, the availability of water varies widely across time and space. Ironically, the supply of water is most variable from year to year in the driest locations (**Figure 13.7**). Water, whether in the form of ice or liquid, weathers and erodes the Earth's crust, the lithosphere. As water erodes mountains and plateaus, carves valleys, and transports sediments to floodplains and deltas, it is a major force in the reshaping of the Earth's landforms.

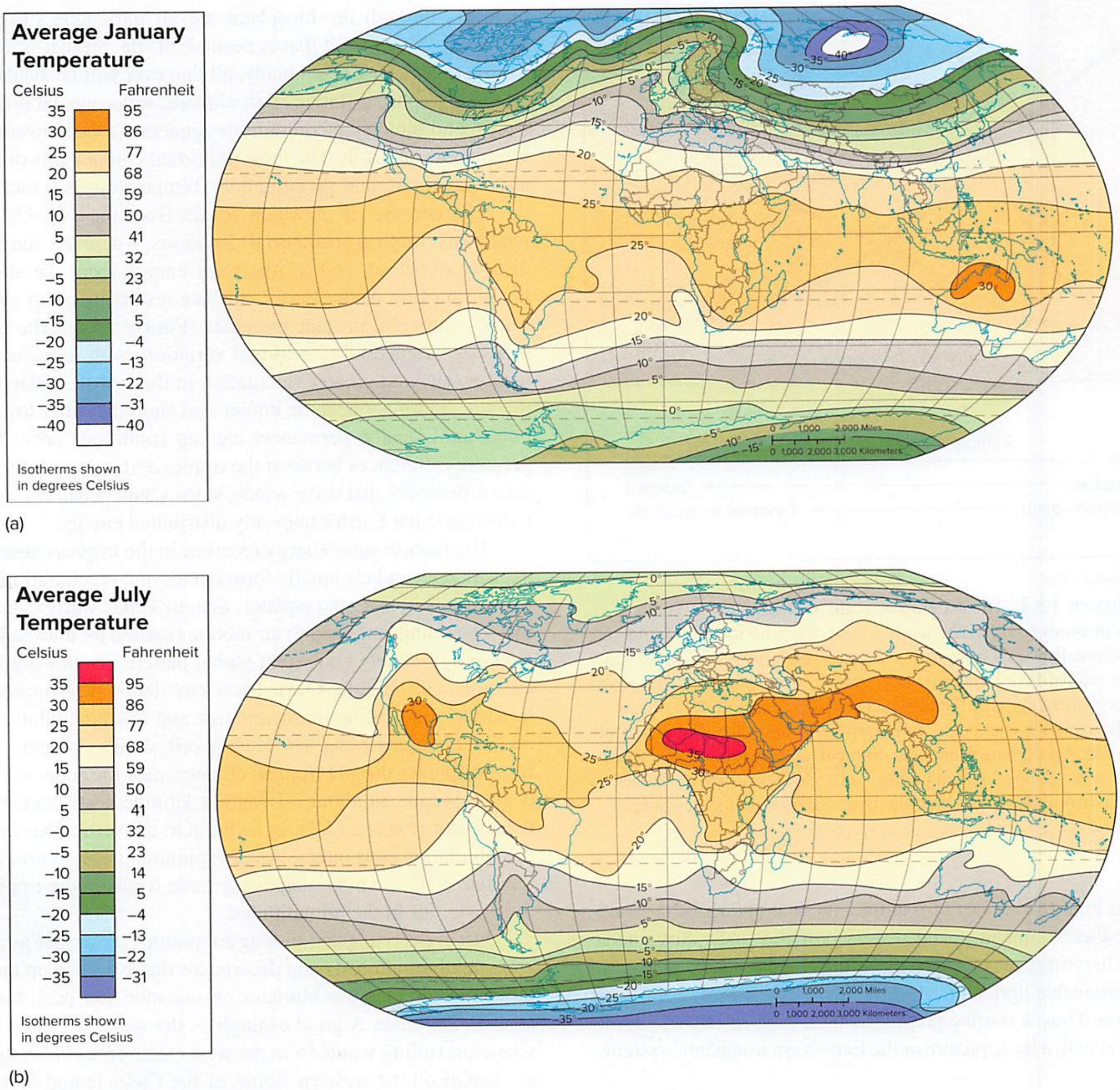


Figure 13.2 Average temperatures in (a) January and (b) July. The rotation of the Earth around the sun, along with the tilt of the Earth's axis, cause more direct solar energy to fall on the Northern Hemisphere in June and on the Southern Hemisphere in January. Note how over water, the temperatures decrease evenly with increased distance from the equator. The effect of land/water contrasts can be seen in the more dramatic temperature differences between January and July at continental locations in the midlatitudes compared to coastal locations.

Plants and animals are adapted to particular climate conditions. Thus, the biosphere is divided into separate groups of biological communities called **biomes,** which are established by the pattern of global climates. In fact, the original classification of global climates was based on observations of plant communities, not temperature and precipitation records, many of which did not exist at that time. In essence, plant communities served as weather stations, recording climate conditions by the ability of different species to survive. We know the Earth's biomes by such descriptive names as *desert, grassland,* or *steppe* or as the *tropical rain forest* and *northern coniferous forest* that were discussed in Chapter 8. Biomes, in turn, contain smaller, more specialized **ecosystems:** self-contained, self-regulating, and interacting communities adapted to local combinations of climate, topography, soil, and drainage conditions.

The structure of the ecosphere is not eternal and unchanging. On the contrary, alteration is the constant rule of the physical environment and would be so even in the absence of humans and their distorting impacts. Natural climatic change, year-to-year variations in weather conditions, fires, windstorms, floods, diseases, or the unexplained rise and fall of predator and prey populations all call for new environmental configurations and

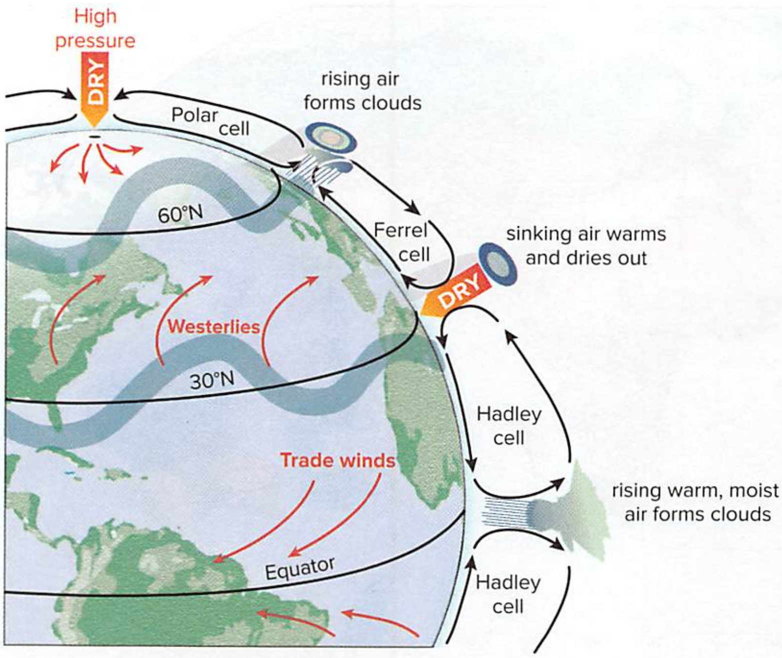


Figure 13.3 Uneven heating of the Earth's surface creates persistent air circulation patterns that move air, moisture, and energy around the Earth. One of those circulation patterns, the Hadley cell, creates wet climates near the tropics and deserts at about 30 degrees north and south.

forever prevent the establishment of a single, constant "balance of nature."

Remember that we began to track cultural geographic patterns from the end of the last continental glaciation, some 11,000 to 12,000 years ago. Our starting point, then, was a time of environmental change when humans were too few in number and primitive in technology to have had any impact on the larger structure of the ecosphere. Their numbers increased and their technologies became vastly more sophisticated and intrusive with the passage of time, but for nearly all of the period of cultural development to modern times, human impact on the world environment was absorbed and accommodated by it with no more than local distress. The rhythm and the regularity of larger global systems proceeded largely unaffected by people.

Impacts on the Atmosphere

Ecosystems have long felt the destructive hand of humans and the cultural landscapes they made. Chapter 2 explored the results of human abuse of the local environment in the Chaco Canyon and Easter Island deforestations. Forest removal, overgrazing, and ill-considered agriculture turned lush hillsides of the Mediterranean Basin into sterile and impoverished landscapes by the end of the Roman Empire. At a global scale, however, human impact was minimal. But slowly, unnoticed at first, human activity began to have a

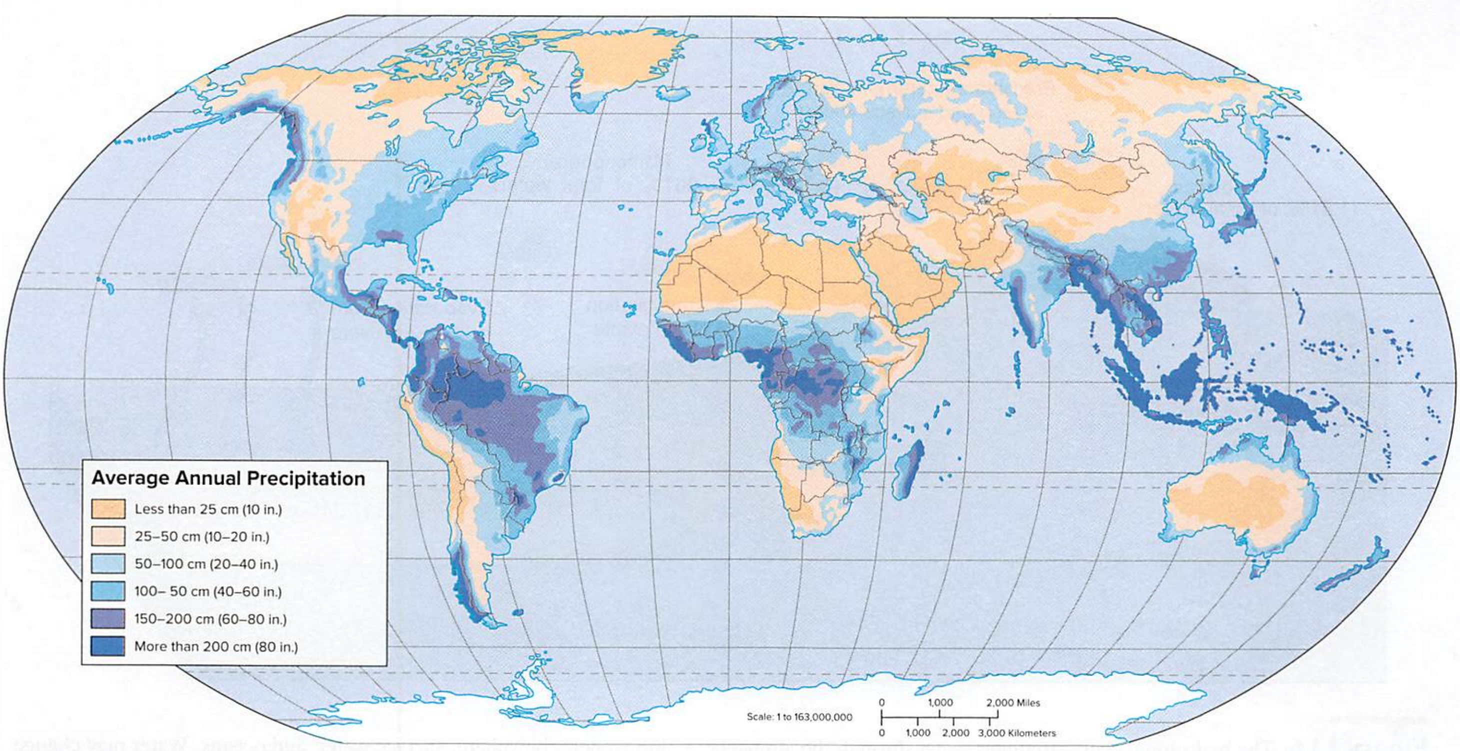


Figure 13.4 Average annual precipitation. Regional contrasts of precipitation clearly demonstrate the truism that natural phenomena are unequally distributed over the surface of the Earth. Global wind patterns create areas of high rainfall in equatorial and tropical areas of Central and South America, Africa, and South and Southeast Asia. A band of deserts is found at about 30 degrees from the equator. Proximity to large water bodies, and position with respect to prevailing winds and mountain ranges, also contribute to the patterns of annual precipitation.

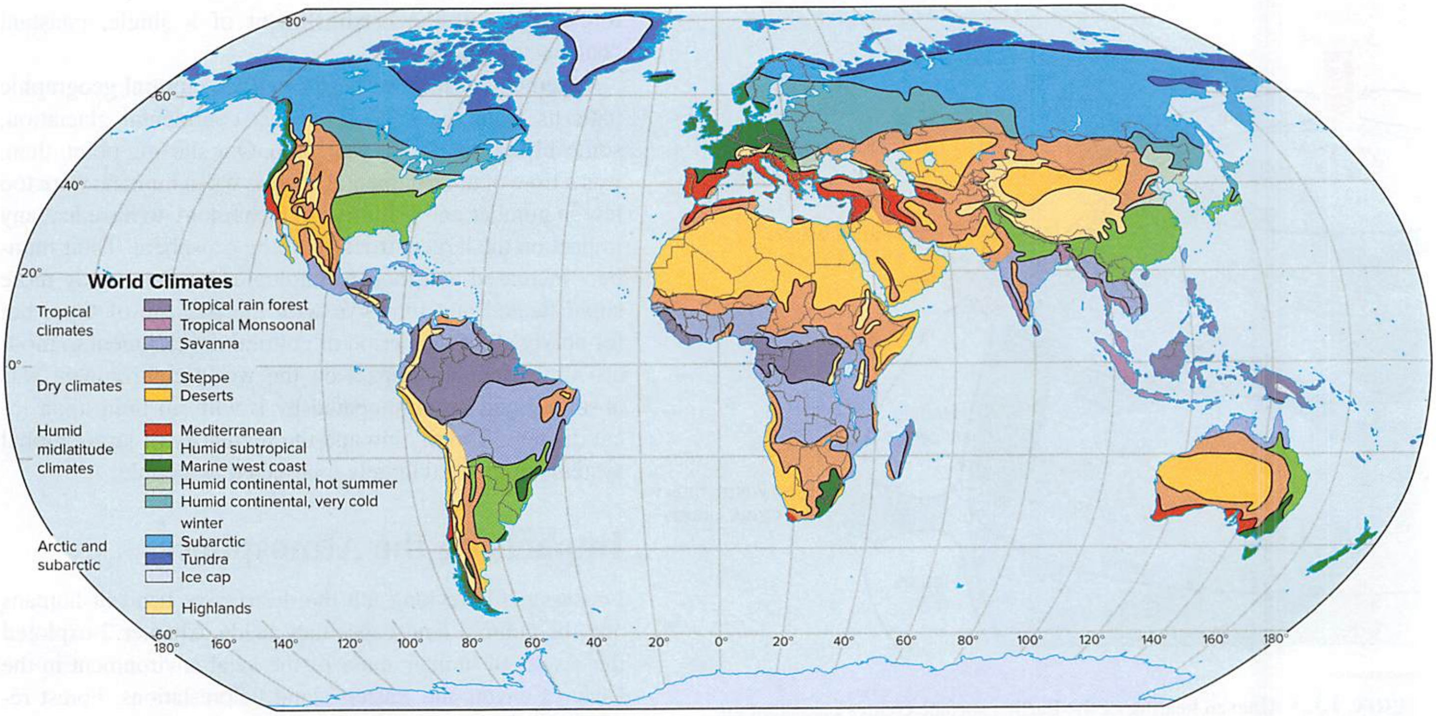


Figure 13.5 Climates of the world. Complex interrelationships of latitude, land and water contrasts, ocean currents, topography, and wind circulation create this generalized global pattern of climates.

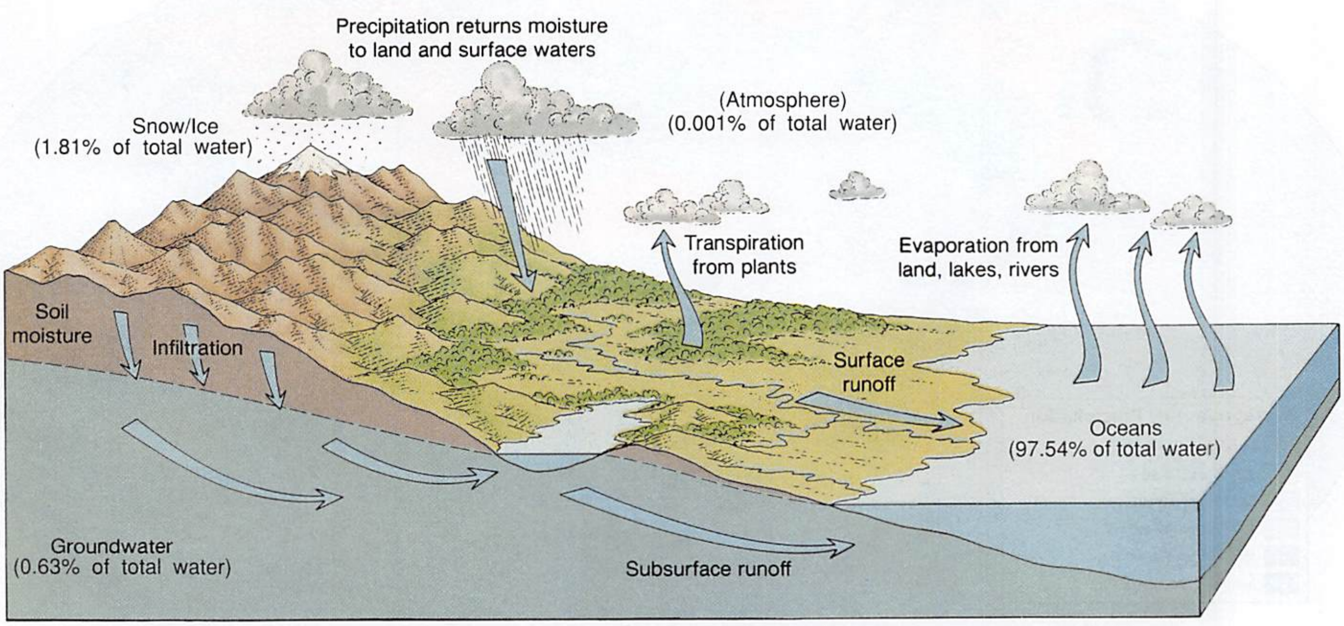


Figure 13.6 The hydrologic cycle circulates water through the atmosphere, lithosphere, biosphere, surface water, and oceans. Water may change form and composition, but under natural environmental circumstances, it is marvelously purified in the recycling process and is again made available with appropriate properties and purity to the ecosystems of the Earth. The sun provides energy for the evaporation of fresh and ocean water. The water is held as vapor until the air becomes supersaturated. Atmospheric moisture is returned to the Earth's surface as solid or liquid precipitation to complete the cycle. Precipitation is not uniformly distributed, and moisture is not necessarily returned to areas in the same quantity as it has evaporated from them. The continents receive more water than they lose; the excess returns to the seas as surface water or groundwater. A global water balance, however, is always maintained.

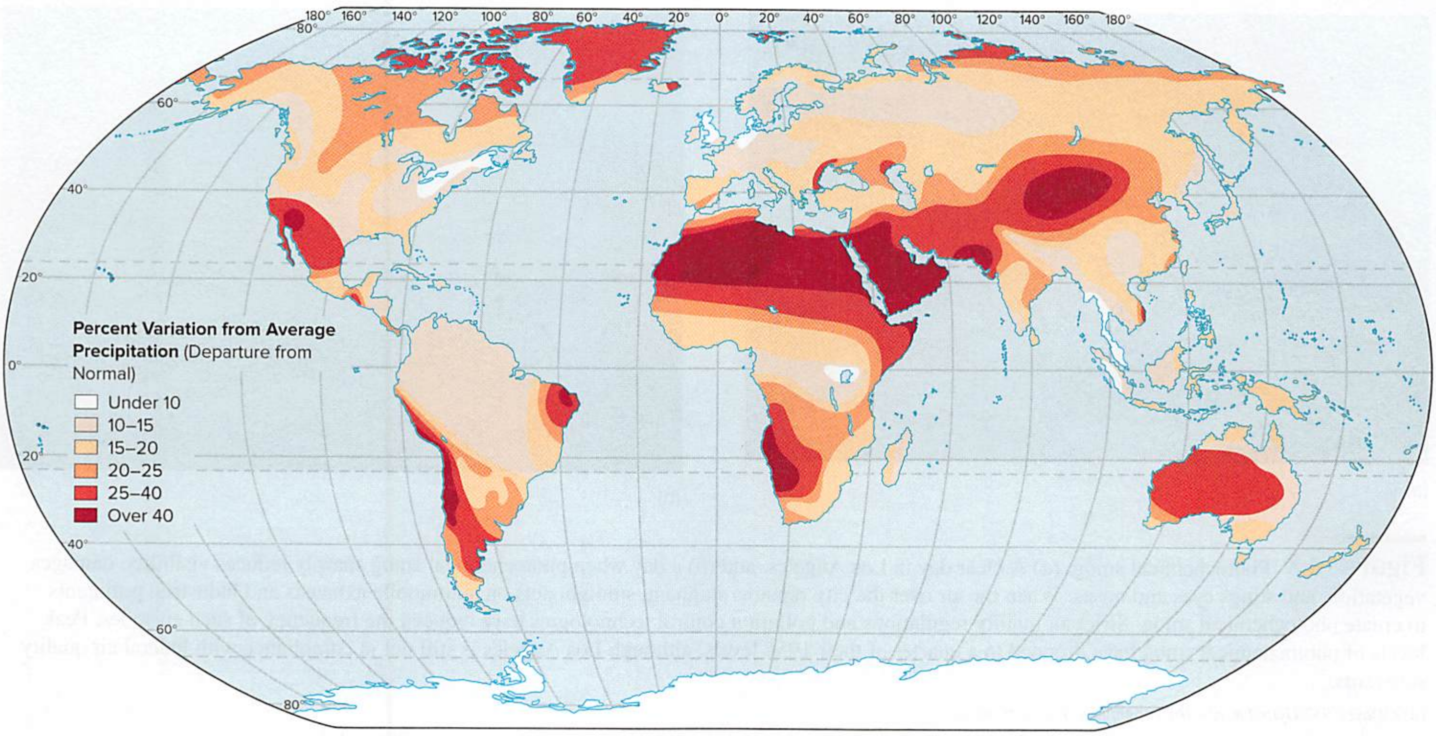


Figure 13.7 Precipitation variability. Note that steppe and desert climate regions have both low total precipitation and high variability. In general, the dryer the climate, the greater the variability. This creates vulnerability to shortages when humans develop agriculture or cities in these regions. Short-run variability in climatic conditions is the rule of nature and occurs independent of any human influence.

global impact, carrying the consequences of human abuse of the ecosphere far beyond the local scene. Air pollution was at first local, in the form of household air pollution and negative health effects from indoor cooking over open fires. However, the Industrial Revolution in the 18th century and continued increase in the use of fossil fuel energy sources has changed the scale of impacts on the atmosphere. At the metropolitan scale, urban air pollution episodes have rendered the air unsafe in many cities, at the continental scale, acid precipitation is carried across international borders, and at the global scale, destruction of the ozone layer and climate change threaten the entire planet's human and environmental systems.

Air Pollution and Acid Precipitation

Every day, thousands of tons of pollutants are discharged into the air by natural events and human actions. Air is polluted when it contains substances in sufficient amounts to have a harmful effect. Truly clean air has never existed, for atmospheric pollution can and does result in nature from ash from volcanic eruptions, marsh gases, smoke from naturally occurring forest fires, and windblown dust. Normally, these pollutants are of low volume, are widely dispersed in the atmosphere, and have no significant long-term effect on human health or ecosystems.

Far more damaging are the substances discharged into the atmosphere by human actions. These pollutants come primarily from burning fossil fuels—coal, oil, and natural gas—in power plants, factories, furnaces, and vehicles, and from fires deliberately set to clear forests and grasslands for agricultural expansion or **shifting cultivation** clearing and burning. In 1952, smoke from coal-burning factories and home fireplaces combined with fog to cause a four-day smog episode in London that blackened the skies in daytime and killed an estimated 4,000 people. By the 1950s, air pollution in Los Angeles from car exhausts and other sources stung people's eyes and noses and caused rubber tires to deteriorate rapidly (**Figure 13.8**). Since then, in London, Los Angeles, and other cities in the developed world, environmental regulations and pollution control technologies have dramatically cleared the air (although Los Angeles still does not meet some air quality standards).

Today, air pollution is a global problem; areas far from the polluting source may be adversely affected as atmospheric circulation moves pollutants freely without regard to political boundaries. Just as manufacturing activity has shifted to newly industrializing countries, so too has the world's worst air pollution. For example, current full-color satellite cameras regularly reveal a nearly continuous, 2-mile-thick blanket of soot, organic compounds, dust, ash, and other air debris stretching across much of India, Bangladesh, and Southeast Asia, reaching northward to the industrial heart of China. The pollution shroud in and around India, researchers find, reduces sunlight enough to cut rice yields across much of the country.

Although air quality is generally improving in high-income countries, it has worsened in the developing countries of South, Southeast, and East Asia. The World Health Organization (WHO) estimated that in 2015, air pollution caused 4.2 million premature deaths, mostly in low- and middle-income countries. The WHO reports that of India's 27 cities of more than 1 million people, not one meets the organization's air pollution standards.

In addition to the very serious human health consequences of air pollution, the interaction of pollutants with one another

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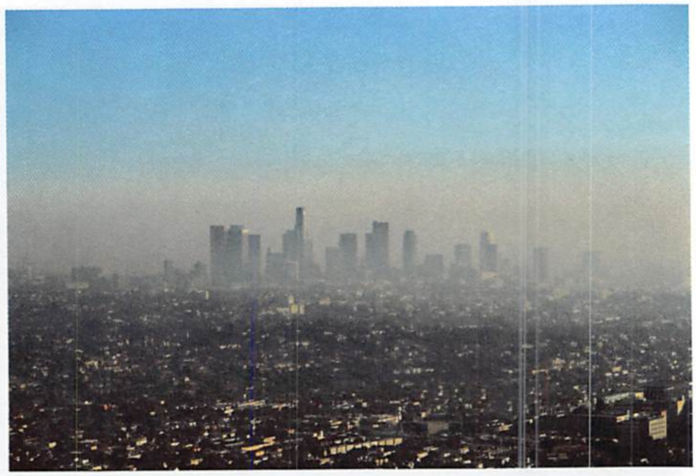
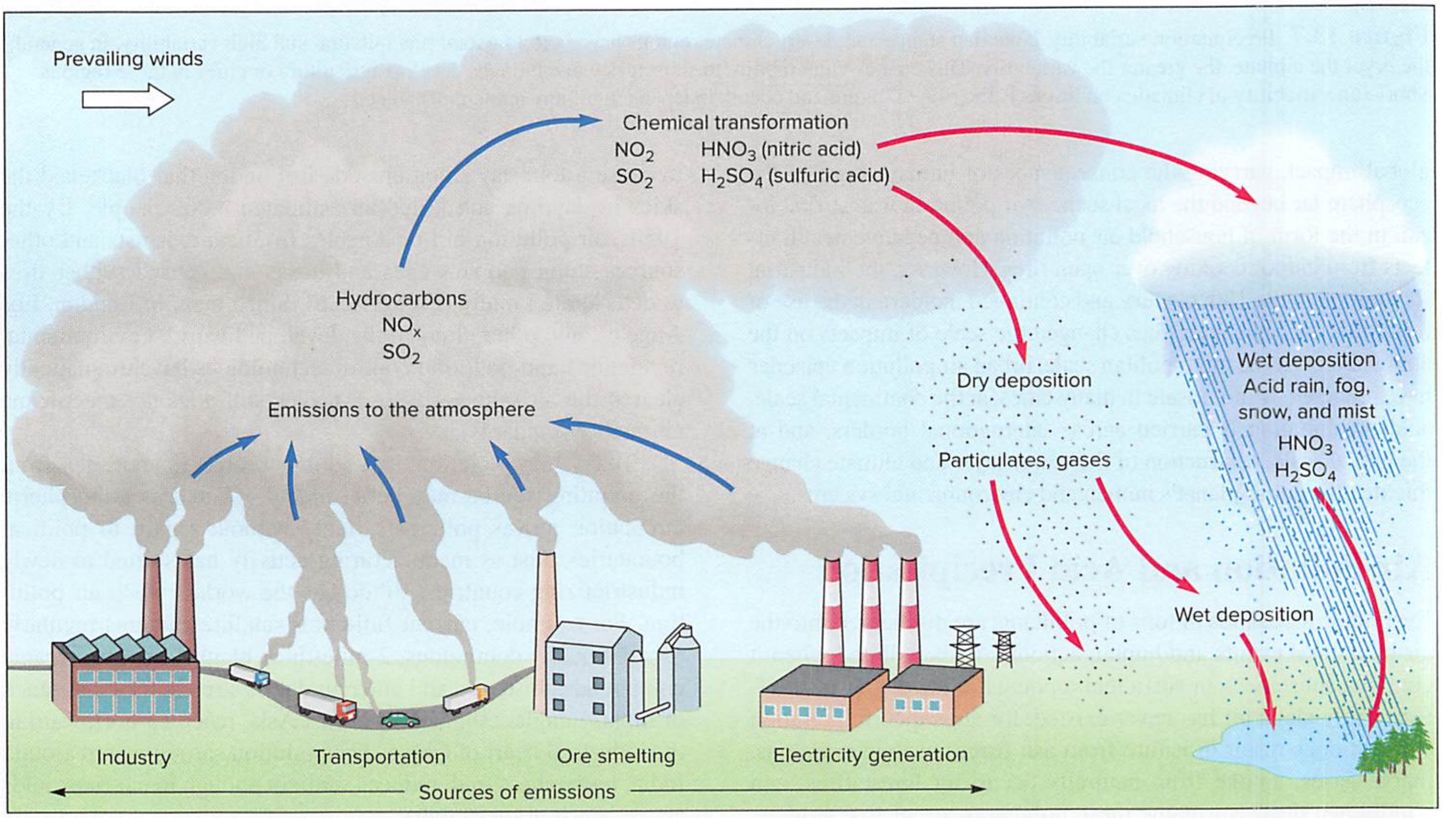


(b)

Figure 13.8 Photochemical smog. (*a*) A clear day in Los Angeles, and (*b*) a day when photochemical smog sharply reduces visibility, damages vegetation, and stings eyes and noses. When the air over the city remains stagnant, sunlight acts on automobile exhausts and industrial pollutants to create photochemical smog. Strict air quality regulations and pollution control technologies have reduced the frequency of such episodes. Peak levels of photochemical smog have dropped to a quarter of their 1955 levels, although Los Angeles is still not in compliance with federal air quality standards.

(a) ©Davel5957/Getty Images; (b) ©steinphoto/E+/Getty Images



AP **Figure 13.9** Acid precipitation forms as vehicle and industrial emissions are transformed in the atmosphere. Sulfur dioxide and nitrogen oxides produced by the combustion of fossil fuels are transformed into sulfate and nitrate particles; when the particles react with water vapor, they form sulfuric and nitric acids. Often carried long distances on prevailing winds, the acids are deposited on the surface in the form of fog, rain, snow, or particles.

or with natural substances such as water vapor may create secondary pollutants. Among these secondary pollutants is the acid precipitation that occurs when sulfur and nitrogen compounds in emissions from automobiles, coal-fired power plants, and industrial sources produce sulfuric acid and nitric acid in clouds (**Figure 13.9**). Acid precipitation is often carried long distances by prevailing winds to places where it is highly damaging to trees, lakes, and even structures.

Unexpectedly, acid precipitation is a condition in part traceable to actions taken in developed countries to alleviate the smoke and chemicals that poured into the skies from the chimneys of their power plants, mills, and factories. The clean air programs demanded by environmentalists usually incorporated prohibitions against the discharge of atmospheric pollutants damaging to areas near the discharge point. The response was to raise smokestacks to such a height that pollutants were diluted and dispersed far from their origin by higher-elevation winds (**Figure 13.10**).

But when power plants, smelters, and factories were fitted with tall smokestacks to free local areas from pollution, the sulfur dioxide and nitrogen oxides in the smoke were pumped high into the atmosphere instead of being deposited locally. There, they combined with water and other chemicals and turned into sulfuric and nitric acid that was carried to distant areas. They were joined in their impact by other sources of acid gases. Such as motor vehicle exhausts.

Once the pollutants are airborne, winds can carry them thousands of kilometers, depositing them far from their source. In North America, most of the prevailing winds are westerlies (see Figure 13.3), meaning that much of the acid precipitation that falls on the eastern seaboard and eastern Canada originated in the central and upper Midwest. Similarly, airborne pollutants from the United Kingdom, France, and Germany cause acidification problems in Scandinavia (**Figure 13.11**).

When acids from all sources are washed out of the air by rain, snow, or fog, the result is **acid precipitation.** Acidity levels are described by the *pH factor,* the measure of acidity/alkalinity on a scale of 0 to 14. The pH of normal rainfall is 5.6, slightly acidic, but acid rainfalls with a pH of 2.4—approximately the acidity of vinegar and lemon juice—have been recorded.

Figure 13.10 Dilution is not the solution to pollution. Before concern about acid rain became widespread, the U.S. Clean Air Act of 1970 set standards for ground-level air quality that could be met most easily by building tall smokestacks high enough to discharge pollutants into the upper atmosphere. Stacks 300 meters (1,000 feet) and higher became common at utility plants and factories, far exceeding the earlier norm of 60–90 meters (200–300 feet). What helped cleanse one area of pollution greatly increased damage elsewhere.

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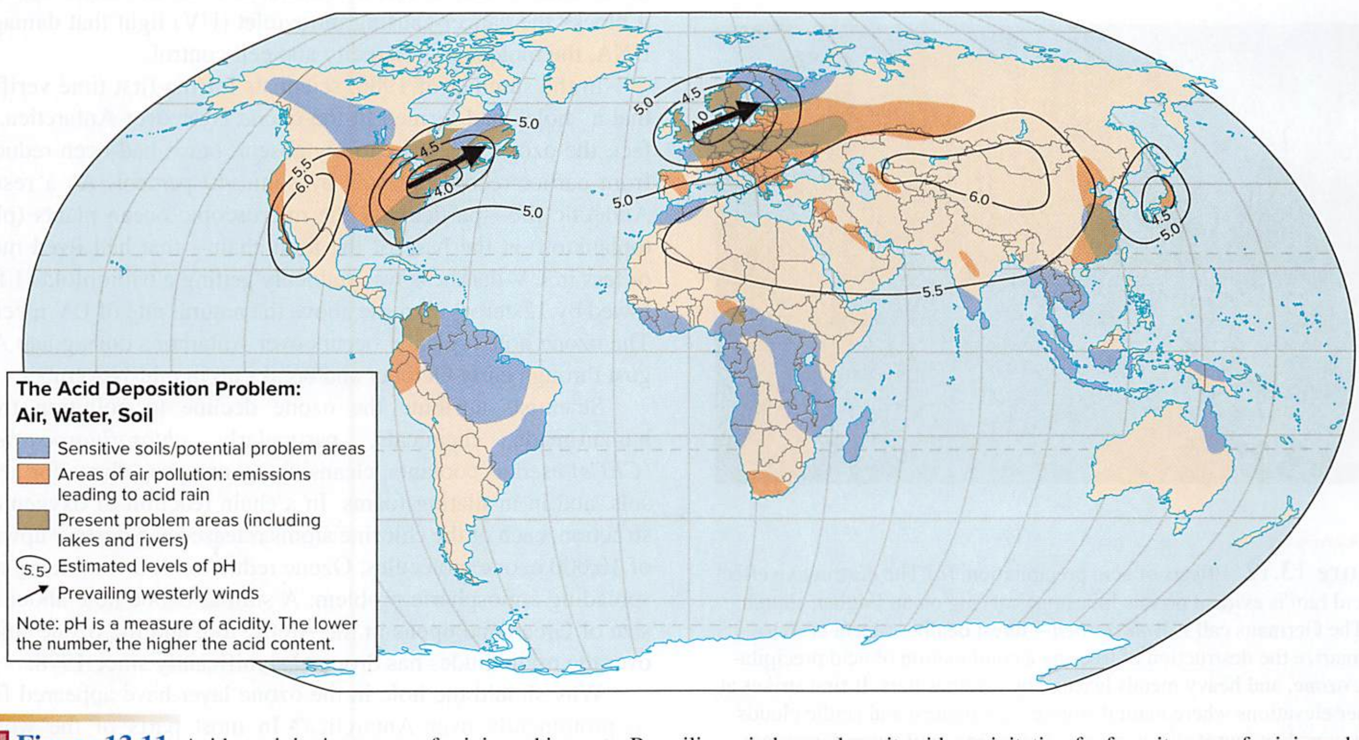

AP **Figure 13.11** Acid precipitation: areas of origin and impacts. Prevailing winds can deposit acid precipitation far from its area of origin and across international boundaries. Prevailing westerly winds carry acid precipitation east from the Ohio and Tennessee River valleys and from the industrial districts of Western Europe toward Scandinavia where it harms vegetation, lakes, and buildings. It is estimated that 90 percent of the sulfuric acid and 80 percent of the nitric acid falling on Norway is from outside the country. Compare this map with the centers of industrial production in Figure 9.20.

Source: Adapted from Student Atlas of World Geography, 4th ed. John Allen, Map 55, p. 70. McGraw-Hill/Dushkin, 2005.

Primarily occurring in industrialized nations, acid precipitation has become a serious problem in many parts of Europe, North America, and East Asia. It expresses itself in several forms, though the most visible are its corrosive effects on marble and limestone sculptures and buildings and on metals such as iron and bronze and in the destruction of forests (**Figure 13.12**). Trees at higher elevations are particularly susceptible, with widespread forest loss clearly apparent on the hillsides and mountain tops of New England, Scandinavia, and Eastern Europe.

(a)

(b)

Figure 13.12 Effects of acid precipitation. *(a)* The destructive effect of acid rain is evident on this limestone carving on an English church. *(b)* The Germans call it *Waldsterben*—forest death—a term used to summarize the destruction of trees by a combination of acid precipitation, ozone, and heavy metals leached by acidic waters. It first strikes at higher elevations where natural stresses are greatest and acidic clouds most prevalent, but it slowly moves downslope until entire forests are gone. Here, at Tatra National Park in Slovakia, *Waldsterben* is thought to result from pollution traveling eastward from industrial areas in Poland, Germany, and the Czech Republic. The forests will recover only in geologic time due to the extremely acidic soils.

(a) ©RMAX/Getty Images; (b) ©Branko Ostojic/123RF

Damage to lakes, fish, and soils is less immediately evident, but more widespread and equally serious. Acid precipitation has been linked to the disappearance of fish in thousands of streams and lakes in New England, Canada, and Scandinavia, and to a decline in fish populations elsewhere. It leaches toxic constituents (such as aluminum) from the soil and kills soil microorganisms that break down organic matter and recycle nutrients through the ecosystem. Acid precipitation has decreased in Europe and North America due to international agreements brokered by the United Nations, strict air emission standards, and deindustrialization—the closure of heavy industrial plants such as steel mills that were once major sources of emissions. The changing geography of industrial production means that the geographic patterns of acid precipitation are shifting toward Asia.

The Trouble with Ozone

The potential destruction of the Earth's ozone layer offers another example of the global nature of air pollution. However, it is also a success story of international cooperation and using science and technology to improve the environment. **Ozone** is a reactive molecule consisting of three oxygen atoms rather than the two of normal oxygen. Ozone can lead to confusion because high in the atmosphere, it offers essential protection against the sun's rays, but when it is near the surface, it is one of the main components in photochemical smog and highly damaging to plants and animals. Sunlight produces it from standard oxygen, and a continuous but thin layer of ozone accumulates at upper levels in the atmosphere. There, it is essential to all life forms because it blocks the cancer-causing ultraviolet (UV) light that damages DNA, the molecule of heredity and cell control.

In the summer of 1986, scientists for the first time verified that a "hole" had formed in the ozone layer over Antarctica. In fact, the ozone was not entirely absent, but it had been reduced from earlier recorded levels by some 40 percent. As a result, Antarctic life—particularly the microscopic ocean plants (phytoplankton) at the base of the food chain—that had lived more or less in UV darkness was suddenly getting a trillionfold (1 followed by 12 zeros) increase above the natural rate of UV receipt. The ozone hole typically occurs over Antarctica during late August through early October and breaks up in mid-November.

Scientists attribute the ozone decline to pollution from human-made chemicals, particularly *chlorofluorocarbons (CFCs)* used as coolants, cleansing agents, propellants for aerosols, and in insulating foams. In a chain reaction of oxygen destruction, each of the chlorine atoms released can destroy upward of 10,000 ozone molecules. Ozone reduction is a continuing and spreading atmospheric problem. A similar ozone hole about the size of Greenland opens in the Arctic, too, and the ozone shield over the midlatitudes has dropped significantly since 1978.

Why should the hole in the ozone layer have appeared first so prominently over Antarctica? In most parts of the world, horizontal winds tend to keep chemicals in the air well mixed. But circulation patterns are such that the freezing whirlpool of air over the south polar continent in winter is not penetrated by air currents from warmer regions of the Earth. In the absence of sunlight and atmospheric mixing, the CFCs work to destroy the ozone. During the Southern Hemisphere summer, sunlight works to replenish it. In either hemisphere, ozone depletion has identical adverse effects. Among other things, greater exposure to UV radiation increases the incidence of skin cancer and, by suppressing bodily defense mechanisms, increases risk from a variety of infectious diseases. Many crop plants are sensitive to UV radiation, and the very existence of the microscopic plankton at the base of the marine food chain is threatened by it.

Production and use of CFCs has been phased out under the Montreal Protocol, a 1987 international agreement made effective in 1992. The developing countries were given a grace period before they began their phaseout schedule for ending use of CFCs. Industries involved in the production or use of CFCs initially resisted the agreement but have since responded by finding substitute chemicals. The Montreal Protocol is an encouraging example of the ability of international agreements to address a global environmental problem successfully. Because of those restrictions, ozone depletion has been slowed or even stopped.

Recent oscillations in the extent of the ozone hole suggest its peak may have been reached by 2003 to 2006 and mending may be complete by the year 2070. The good news has been tempered by recent discovery of rising levels of other ozone-depleting industrial chemicals that are not regulated by the Montreal Protocol.

Global Climate Change

Scientists agree that humans have significantly altered the chemical composition of the atmosphere since the advent of the Industrial Revolution in the 1700s. Human activities have increased the concentrations of three greenhouse gases—carbon dioxide, methane, and nitrous oxide—intensifying the natural **greenhouse effect,** leading to **global climate change.** The greenhouse effect is caused by a group of atmospheric gases that partially capture the heat energy radiated from the Earth back toward space. Without the greenhouse effect, the Earth would be substantially colder and its temperatures would fluctuate wildly. What is of concern today is that human activities have significantly increased the concentrations of greenhouse gases, intensifying the greenhouse effect and causing anthropogenic (human-caused) climate change (**Figure 13.13**). Humankind's

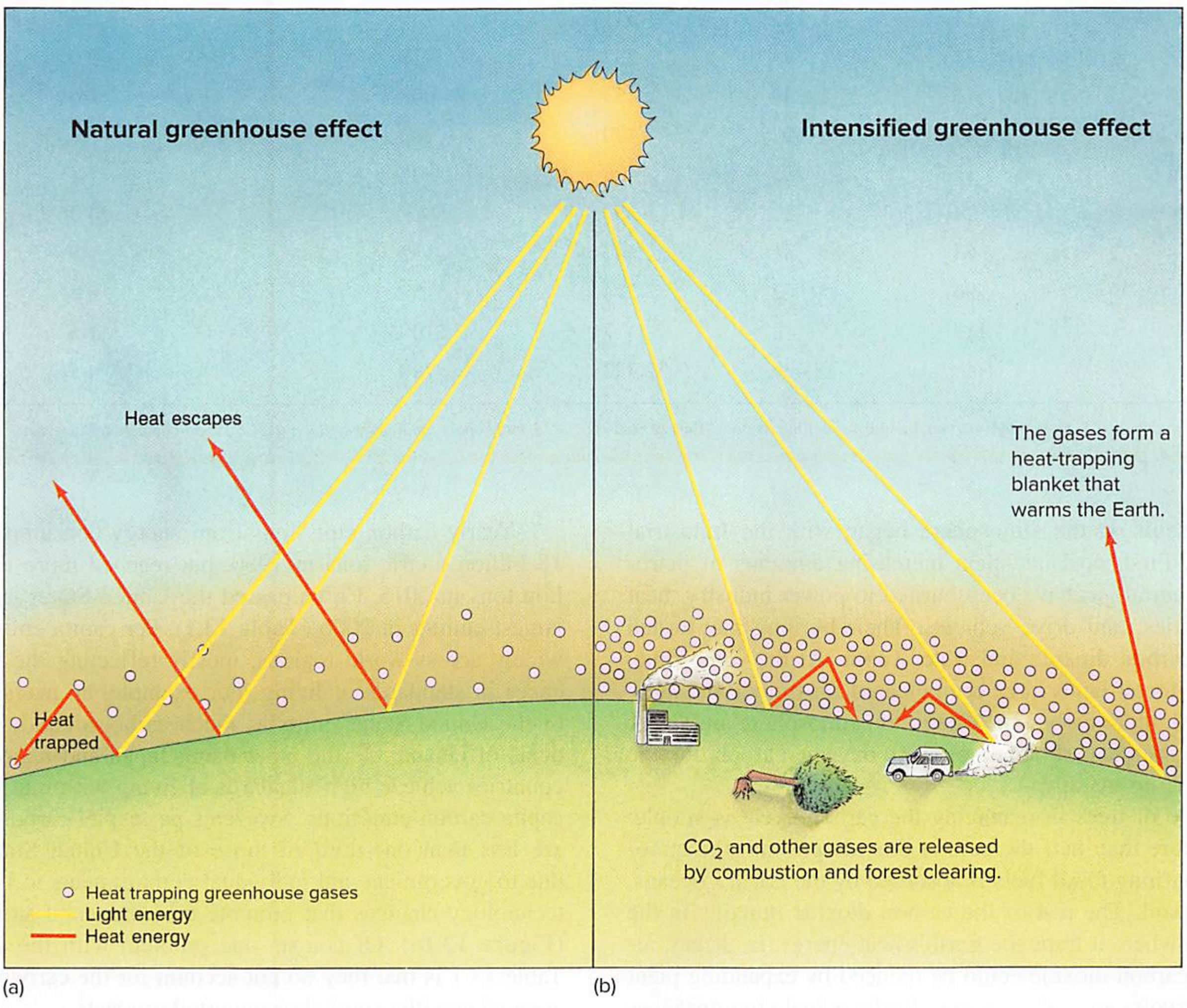

Figure 13.13 Anthropogenic climate change occurs when human activities intensify the natural greenhouse effect. When the level of carbon dioxide (CO_2) in the air is low, as in (*a*), incoming solar radiation strikes the Earth's surface, heating it up, and the Earth radiates the energy back into space as heat. Some of the heat energy is captured by naturally occurring greenhouse gases, thereby heating the atmosphere. The intensified greenhouse effect depicted in (*b*) is the result of the higher levels of CO_2 in the atmosphere due to burning of fossil fuels and forest clearing.

Table 13.1

Carbon Dioxide Emissions from Energy Consumption

		Total Emissions (Millions of Metric Tons/Year)			Per Capita Emissions (Metric Tons/Year/Person)
	Rank, 2015	**1980**	**2015**	**Change (1980–2015)**	**2015**
China	1	1,486	8,866	497%	6.5
United States	2	4,680	5,269	13%	16.4
India	3	263	1,894	621%	1.4
Russia	4	N/A	1,687	N/A	11.7
Japan	5	939	1,126	20%	8.9
Germany	6	1,056	743	–30%	9.2
Iran	7	118	654	455%	8.3
Korea, South	8	138	644	369%	12.7
Saudi Arabia	9	177	606	242%	19.2
Canada	10	430	600	40%	16.8
Brazil	11	185	541	193%	2.6
Indonesia	12	85	502	492%	2.0
Mexico	13	239	453	90%	3.6
United Kingdom	14	597	430	–28%	6.6
South Africa	15	225	406	80%	7.4
United Arab Emirates	24	30	237	682%	24.7
Sweden	63	81	47	–43%	4.8
Ghana	96	2	14	515%	0.5
Costa Rica	119	2	7	210%	1.5
WORLD	N/A	18,430	32,722	78%	4.5

Source: *calculated from U.S. Energy Information Administration,* International Energy Statistics, *2018, and Population Reference Bureau* 2015 World Population Datasheet.

massive assault on the atmosphere began with the Industrial Revolution. First, coal and then increasing amounts of petroleum and natural gas have been burned to power industry, heat and cool cities, and drive vehicles. Their burning has turned fuels into carbon dioxide and water vapor. At the same time, the world's forest lands have been cleared for timber and agriculture. With more carbon dioxide in the atmosphere and fewer trees to capture the carbon and produce oxygen, carbon dioxide levels have risen steadily.

The role of trees in managing the carbon cycle is simple: Probably more than half the carbon dioxide put into the atmosphere by burning fossil fuels is absorbed by the Earth's oceans, plants, and soil. The rest of the carbon dioxide remains in the atmosphere where it traps the Earth's heat energy. In theory, atmospheric carbon dioxide could be reduced by expanding plant carbon reservoirs, or *sinks,* on land. Under actual circumstances of expanded combustion of fuels and reduction of forest cover, atmospheric carbon dioxide levels have increased from about 280 parts per million (ppm) at the start of the Industrial Revolution to 403 ppm in 2016.

Yearly carbon emissions from energy consumption totaled 18 billion metric tons in 1980, but reached more than 30 billion tons in 2015. China passed the United States as the single largest emitter in 2006 (**Table 13.1**). Per capita emissions vary widely across world regions, mostly reflecting the vast differences in standards of living. For example, an average resident of the United States emits as much carbon dioxide as 33 residents of Ghana. On the other hand, Japan and many European countries achieve high standards of living with much lower per capita carbon emissions. Sweden's per capita carbon emissions are less than one-third of those of the United States, largely due to government and individual commitments to lifestyle and technology changes that promote environmental **sustainability** (**Figure 13.14**). Of course, one problem with the statistics in Table 13.1 is that they do not account for the carbon emissions associated with exported or imported products.

Carbon dioxide gets most of the media coverage, but other greenhouse gas concentrations are also increasing (**Figure 13.15**). Methane levels have increased largely due to agricultural expansion to feed a growing world population. Methane is formed by

Figure 13.14 Technologies for reducing greenhouse gas emissions are part of the solution as suggested by the IPAT equation. Many European countries maintain high standards of living with per capita carbon emissions half or one-third that of U.S. residents. Denmark is a world leader in wind energy, generating more than 40 percent of its electricity with renewable wind power, mostly in offshore turbine installations. The Beddington Zero Energy Development (BedZed) is one of many examples of an eco-community. At BedZed in South London, passive solar heating, solar panels to generate electricity, a car-sharing club, and rooftop gardens allow residents to reduce significantly or even eliminate their emissions of greenhouse gases.

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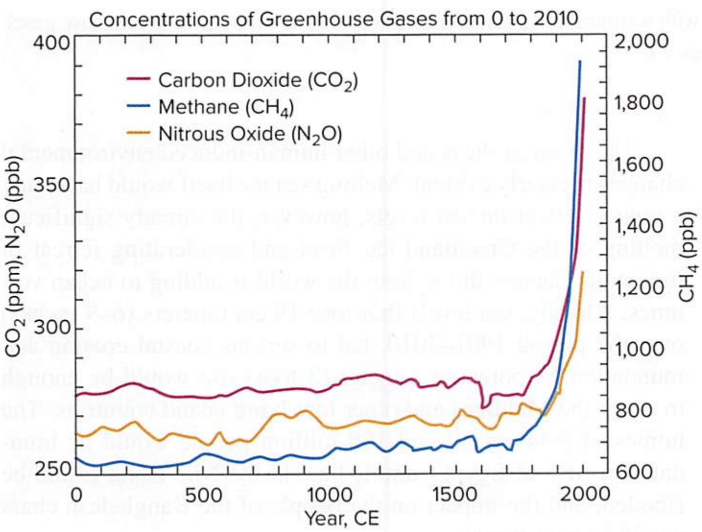


Figure 13.15 Trends in greenhouse gases are upward, and this trend is due to human activities.

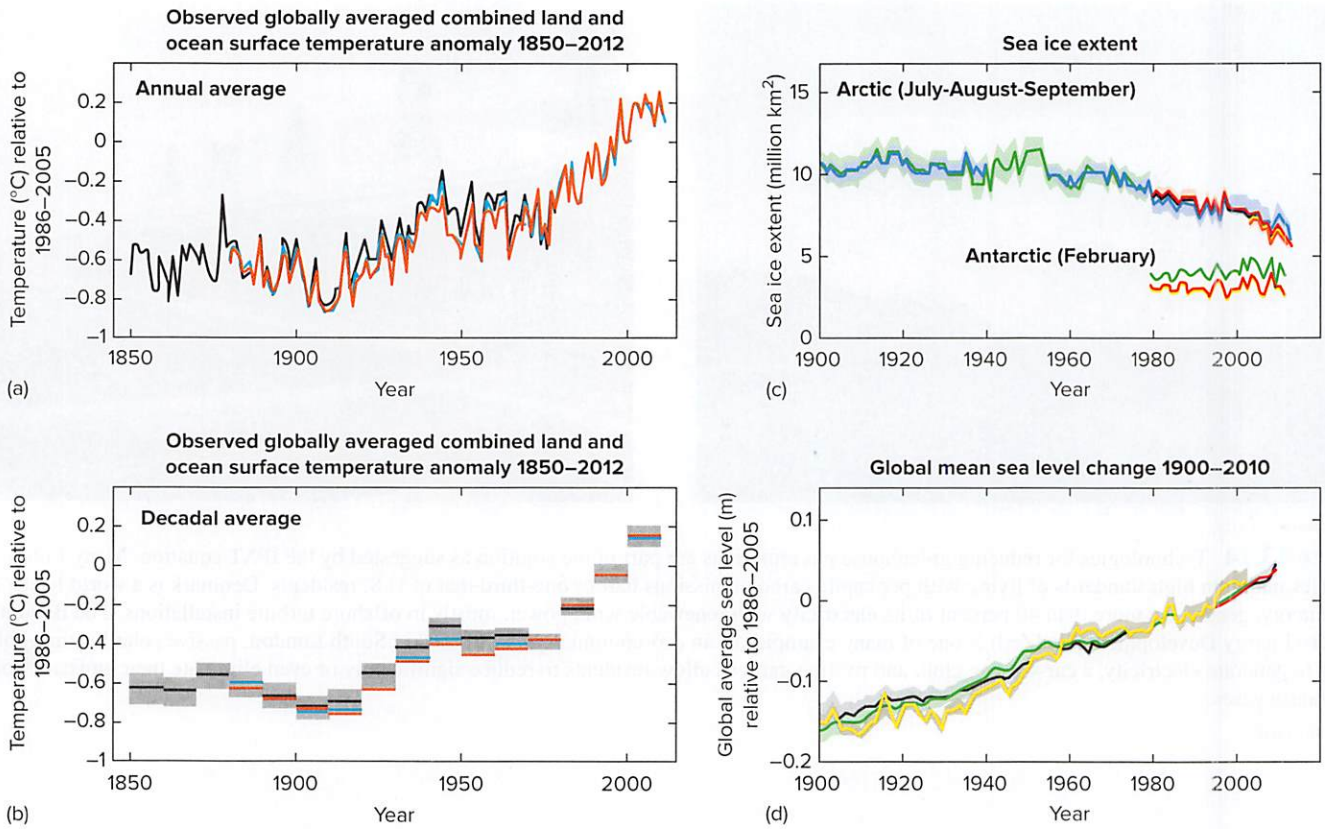
Source: Adapted from Intergovernmental Panel on Climate Change, Climate Change 2007. The Physical Science Basis, Figure 6-4, 2007 and Climate Change 2014, Synthesis Report, *Figure SPM.1.*

decomposition processes and is emitted from the intestinal tracts of livestock and from flooded rice paddies. Nitrous oxide emissions are a byproduct of increased fertilizer use, again a consequence of agricultural expansion and intensification.

Warming of the climate system during the 20th and early 21st centuries was unequivocal. The global average temperature increased 0.6 to 0.7°C from 1951 to 2010 (**Figure 13.16a**). The pattern of increasing temperatures has meant that every decade since the 1980s has been warmer than the previous one (**Figure 13.16b**). The global mean temperature evidence is supported by shrinking glaciers and ice caps, shrinking sea ice (**Figure 13.16c**), rising sea levels (**Figure 13.16d**), rising ocean temperatures, and satellite and weather balloon measurements of temperatures above the Earth's surface.

The most complete assessment of global climate change is done by the United Nations Intergovernmental Panel on Climate Change (IPCC). The panel and reviewers, a group of almost 4,000 scientists from around the world that is affiliated with the United Nations and the World Meteorological Organization, was established in 1988 to assess the science of climate change, determine the impact of any changes on the environment and society, and formulate strategies to respond. In 2014, the IPCC issued results of predictions assuming no major efforts were made to to reduce emissions. They predicted a global temperature increase of 1.4° to 4.8°C (2.5° to 8.6°F) over the 21st century. The effects of such an increase on world climates would be profound.

Although past climates have fluctuated apart from human influence, the IPPC's 2014 report concluded that it was "extremely likely" that human emissions of greenhouse gases rather than natural variations were responsible for the majority of observed warming. They noted that greenhouse gas concentrations are higher today than at any time in the last 800,000 years. Warming that cannot be explained by natural causes has been observed in global oceans and on every continent except Antarctica (**Figure 13.17**). In addition, global rainfall patterns have shifted and extreme rainfall events have become more common.



AP Figure 13.16 Indicators of a changing global climate are all consistent with warming and point to the influence of anthropogenic greenhouse gases.
Source: Intergovernmental Panel on Climate Change, Climate Change 2014 Synthesis Report, *Figure 1.1.*

Climatologists agree on certain of its general consequences in addition to—and the result of—increasing temperatures:

- Arctic summer sea ice is likely to disappear in the second half of the century.
- Sea levels will rise by 28 to 43 cm (11 to 17 in.) by 2100, with an additional 10 to 20 cm (4 to 8 in.) possible if recent accelerated melting of polar ice continues.
- Islands and coastal areas—including densely settled river deltas such as in Bangladesh—will be inundated, affecting the livelihoods and existence of millions.
- Rivers fed by snow or glacier melt will see dramatically altered flows, affecting irrigation.
- There will be spreading droughts in southern Europe, the Middle East, sub-Saharan Africa, the American Southwest, and Mexico. This will impact agriculture and also lead to increased forest fires.
- Many world regions facing the greatest risk or certainty of adverse environmental change are among the world's poorest; damage and misery will not be evenly shared.
- Many parts of the world will see an increase in the number of heat waves and an increase in the intensity of tropical storms.
- If climate change proceeds as the IPPC projects, there will be mass extinctions of perhaps one-fourth of the world's species within 100 years.

The onset of these and other human-induced environmental changes is clearly evident. Melting sea ice itself would have only a modest effect on sea levels; however, the already significant melting of the Greenland ice sheet and accelerating retreat of mountain glaciers throughout the world is adding to ocean volumes. Already, sea levels that rose 19 centimeters (6–9 inches) over the period 1901–2010, led to serious coastal erosion and inundation. A potential 1-meter (3-foot) rise would be enough to cover the Maldives and other low-lying island countries. The homes of between 50 and 100 million people would be inundated, a fifth of Egypt's arable land in the Nile Delta would be flooded, and the impact on the people of the Bangladesh chars would be catastrophic.

Two major interrelated impacts of global climate change will be on water resources and agriculture. Warmer temperatures will increase evaporation, precipitation, and the demand for water, intensifying the movement of water through the hydrologic cycle. In all drought-prone areas of the world, droughts have become more intense and enduring since the 1970s. Earlier IPCC assessments warned that much of the continental interiors of middle latitudes would receive less precipitation than they do now and suffer at least periodic drought, if not absolute aridity. More frequent droughts are likely in the U.S. Corn and Wheat Belts, drastically reducing agricultural productivity and altering world patterns of food supply and trade. Higher temperatures and less snowpack would translate into significantly reduced flows of

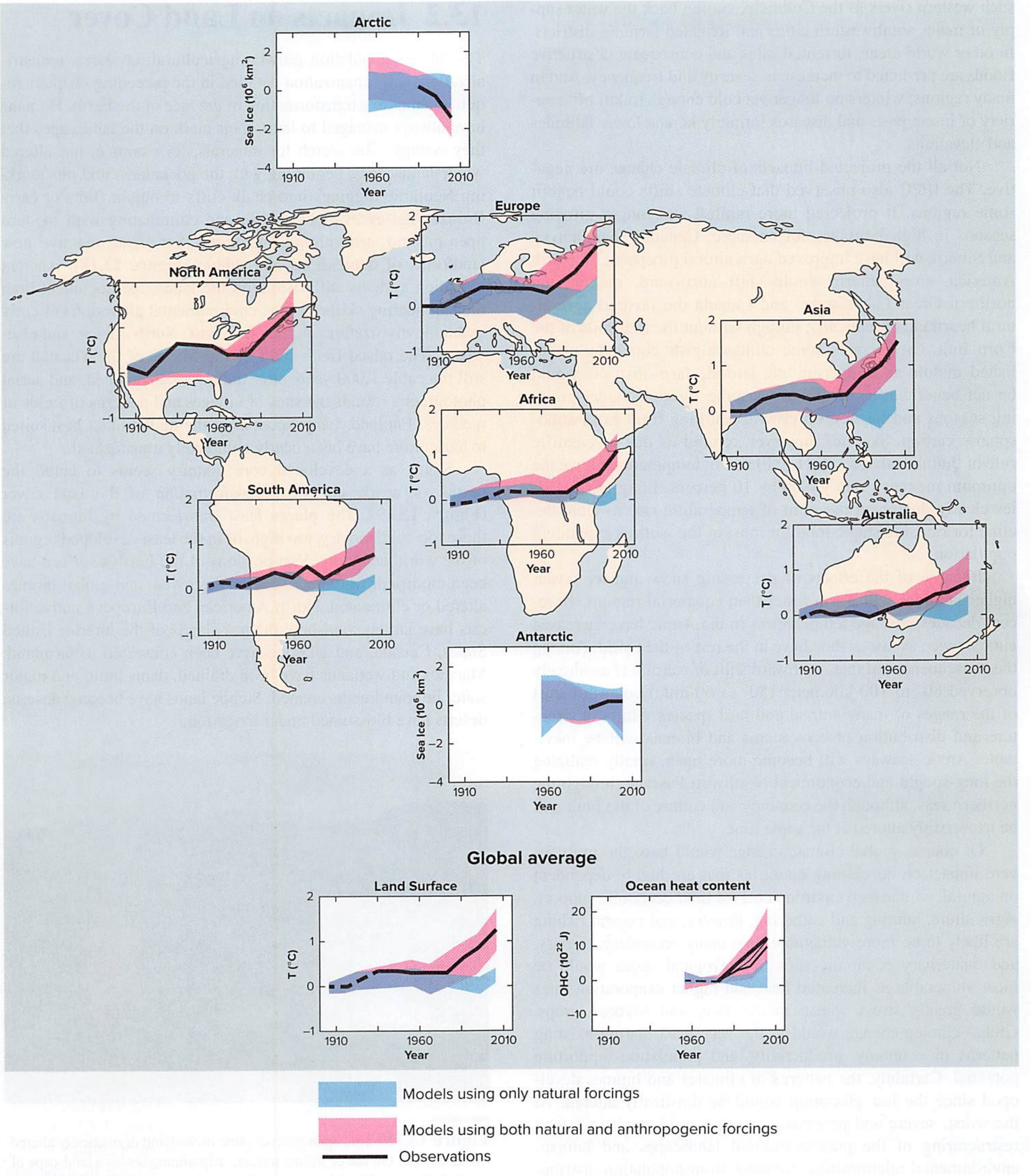


Figure 13.17 Changes in sea ice, global, continental, and ocean temperatures are consistent with predictions for a warming planet. Climate models using only natural causes cannot account for the observed sea ice loss in the Arctic and temperature increases experienced on every continent over the past century. Only by incorporating human influences can the models agree with the observed warming and loss of sea ice. The thickness of the blue and pink bands shows the range of results in different computer simulations using different models.

Source: Intergovernmental Panel on Climate Change, Climate Change 2014 Synthesis Report, *Figure 1.10.*

such western rivers as the Colorado, cutting back the water supply of major southwestern cities and irrigated farming districts. In other world areas, torrential rains and consequent destructive floods are predicted to increase in severity and frequency. And in many regions, winters no longer get cold enough to kill off a variety of insect pests and diseases formerly kept at lower latitudes and elevations.

Not all the projected impacts of climate change are negative. The IPPC also observed that climate shifts could benefit some regions. It projected more rainfall and longer growing seasons in high latitudes, for example; Canada, Scandinavia, and Siberia will have improved agricultural prospects. In North America, crop patterns could shift northward, making the northern Great Lakes states and Canada the favored agricultural heartland climatically, though without the rich soils of the Corn Belt. On average, some climatologists conclude, established middle and upper-middle latitude farm districts would be net beneficiaries of global warming through longer growing seasons and faster crop growth resulting from extra atmospheric carbon. Skeptics, however, remind us that a scientific rule of thumb is that a 1°C (1.8°F) rise in temperature above the optimum reduces grain yields by 10 percent. Long-term studies clearly document the ratio of temperature rise to yield decline for rice, the staple food for most of the world's expanding population.

Because of the effects of decreasing snow and ice cover, higher latitudes will warm faster than equatorial regions. In recent decades, average temperatures in the Arctic have increased almost twice as fast as they have in the rest of the world. Among the consequences of that northward shift of warmth is an already observed 80- to 100-kilometer (50- to 60-mile) poleward shift of the ranges of many animal and bird species. Shifts in structure and distribution of ecosystems and biomes will be inevitable. Arctic seaways will become more open, finally realizing the long-sought and economical Northwest Passage through the northern seas, although the economy and culture of the Inuit will be irreversibly altered at the same time.

Of course, global climate change would have the most severe impact on developing countries that are highly dependent on natural, unmanaged environments for their economic support. Agriculture, hunting and gathering, forestry, and coastal fishing are likely to be more vulnerable than many secondary, tertiary, and quaternary economic activities. Tropical states would be most vulnerable as increased heat and higher evaporation rates would greatly stress wheat, maize, rice, and soybean crops. Global climate change would at the very least disrupt existing patterns of economy, productivity, and population-supporting potential. Certainly, the patterns of climates and biomes developed since the last glaciation would be drastically altered. At the worst, severe and pervasive changes could result in a total restructuring of the present cultural landscapes and human-environmental relationships. Nothing, from population distributions to the relative strength of countries, would ever be quite the same again. Such dire predictions were the background for major international conferences and treaty proposals on global climate change (see the feature "From Kyoto to Paris: Global Climate Change Treaties").

13.2 Impacts on Land Cover

The human population growth, agricultural advances, industrialization, and urbanization detailed in the preceding chapters required a massive transformation of the face of the Earth. Humans have always managed to leave their mark on the landscapes that they occupy. The search for minerals, for example, has altered whole landscapes, beginning with the pockmarks and pits marking Neolithic diggings into chalk cliffs to obtain flints or early Bronze Age excavations for tin and culminating with modern open-pit and strip-mining operations that create massive new landforms of depressions and rubble (**Figure 13.18**). Ancient irrigation systems still visible on the landscape document both the engineering skills and the environmental alterations of early hydraulic civilizations in the Near East, North Africa, and elsewhere. The raised fields built by the Mayas of the Yucatán are still traceable 1,000 years after they were abandoned, and aerial photography reveals the sites of villages and patterns of fields of medieval England. Large sections of the midlatitudes best suited to agriculture have been nearly completely transformed.

Status as a developed core country seems to entail the partial or nearly complete transformation of the land cover (**Figure 13.19**). The places least transformed by humans are those too cold, too dry, too high, or in the least developed regions of the world economy. Vast portions of the Earth's surface have been modified, whole ecosystems destroyed, and global biomes altered or eliminated. North American and European native forests have largely vanished; the grasslands of the interior United States, Canada, and Ukraine have been converted to farmland. Marshes and wetlands have been drained, dams built, and major water impoundments created. Steppe lands have become deserts; deserts have blossomed under irrigation.

Figure 13.18 This open-pit coal mine in Scotland dramatically altered the landscape. On flat or rolling terrain, strip mining leaves a landscape of parallel ridges and trenches, the result of stripping away—overburden—the unwanted surface material. Besides altering the topography, open-pit mining interrupts surface and subsurface drainage patterns, destroys vegetation, and places sterile and frequently highly acidic subsoil and rock on top of the new ground surface.

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From Kyoto to Paris: Global Climate Change Treaties

Our understanding of global climate change depends upon the cooperative work of scientists from around the world. The IPCC, a group of scientists who review and assess the latest scientific, technical, and socioeconomic data on climate change and impacts, is a model of international cooperation on scientific issues of climate change. The IPCC doesn't do the actual research; rather, it reviews thousands of published scientific papers and reports. Working groups within the IPCC take on different tasks such as reviewing the scientific data, assessing vulnerability to climate change, or developing strategies for combatting climate change. The IPCC issued its first assessment report in 1990 and in 2014 released its fifth assessment report.

In 1994, the United Nations established a Framework Convention on Climate Change (UNFCCC) that set up arrangements for sharing data on climate, developing national plans for controlling greenhouse gas emissions, and for adapting to climate change. Three years later in Kyoto, Japan, 191 countries signed and ratified a protocol for combatting global climate change. The Kyoto Protocol called for stabilization of greenhouse gases at levels that would not harm the climate system. The agreement assigned different levels of responsibility to countries based on their level of economic development. Arguing that the developed countries had contributed the largest share to the historic increase in greenhouse gases and were the major emitters, the Kyoto Protocol required more of them. The developed countries committed to reducing their greenhouse gas emissions to below 1990 levels by the year 2012. Developing countries were allowed to increase their emissions to meet social and economic needs. The United States signed the protocol but never ratified the treaty. Meanwhile, countries in the European Union made significant progress in honoring their Kyoto commitments.

World leaders met again in Copenhagen (2009), Cancún, Mexico (2010), Durban, South Africa (2011), and Paris (2015). The major complicating factor was the highly uneven geographic distributions of both responsibility and vulnerability. As indicated in Table 13.1, the carbon dioxide emissions of a typical American equal those of 30 sub-Saharan Africans. On the other hand, many of the places most vulnerable to climate change, such as Bangladesh and the Sahel of Africa, are in the developing world. Meanwhile, some high-latitude regions, mostly in developed countries, will benefit from a longer growing season in a warmer climate.

The 2015 Paris meeting led to a new international climate change agreement to replace the Kyoto Protocol. The centerpiece of the Paris Agreement was a commitment to limit global warming to well below 2°C (3.6°F) above pre-industrial levels. At the request of vulnerable low-lying island states, language was added about working to keep temperature increases below 1.5°C above pre-industrial levels, if feasible. The developed countries also agreed to contribute $100 billion to help countries transition to renewable energy sources and to adapt to the effects of climate change. Each country agreed to submit their own targets for emission reductions called "Nationally Determined Contributions" and begin implementing those reductions in 2020. The Paris Agreement went into effect in 2016 when countries accounting for at least 55 percent of global greenhouse gas emissions had ratified the agreement. On June 1, 2017, President Trump withdrew the United States from the agreement, leaving it the only country to reject the climate accord.

Tropical Deforestation

Forests, we saw in Chapter 8, still cover some 30 percent of the Earth's land surface, though the forest biomes have suffered mightily as human pressures on them have increased. Forest clearing accompanied the development of agriculture and spread of people throughout Europe, Central Asia, the Middle East, and India. European colonization had much the same impact on the temperate forests of eastern North America and Australasia. In most midlatitude developed countries, although original forest cover is largely gone, replanting and reversion of cropland to timber has tended to replenish woodlands at about their rate of cutting.

Now it is the tropical rain forest biome that is feeling the pressure of growing populations, the need for more agricultural land, and expanded demand for fuel and commercial wood. These disappearing forests—covering no more than 6 percent of the planet's land surface—extend across parts of Asia, Africa, and Latin America, and are the world's most diverse and least understood biome.

Tropical forest removal raises three principal global concerns and a host of local ones. First, on a worldwide basis, all forests play a major role in maintaining the oxygen and carbon balance of the Earth. This is particularly true of tropical forests because of their total area and volume. Humans and their industries consume oxygen; vegetation replenishes it through photosynthesis and the release of oxygen back into the atmosphere as a by-product. At the same time, plants extract carbon dioxide from the atmosphere, regulating the levels of this important greenhouse gas. Each year, each hectare (2.5 acres) of Amazon rain forest absorbs one ton of carbon dioxide. When the tropical rain forest is cleared, not only is its role as a carbon sink lost but the act of destruction itself through decomposition or burning releases as carbon dioxide the vast quantities of carbon the forest had stored.

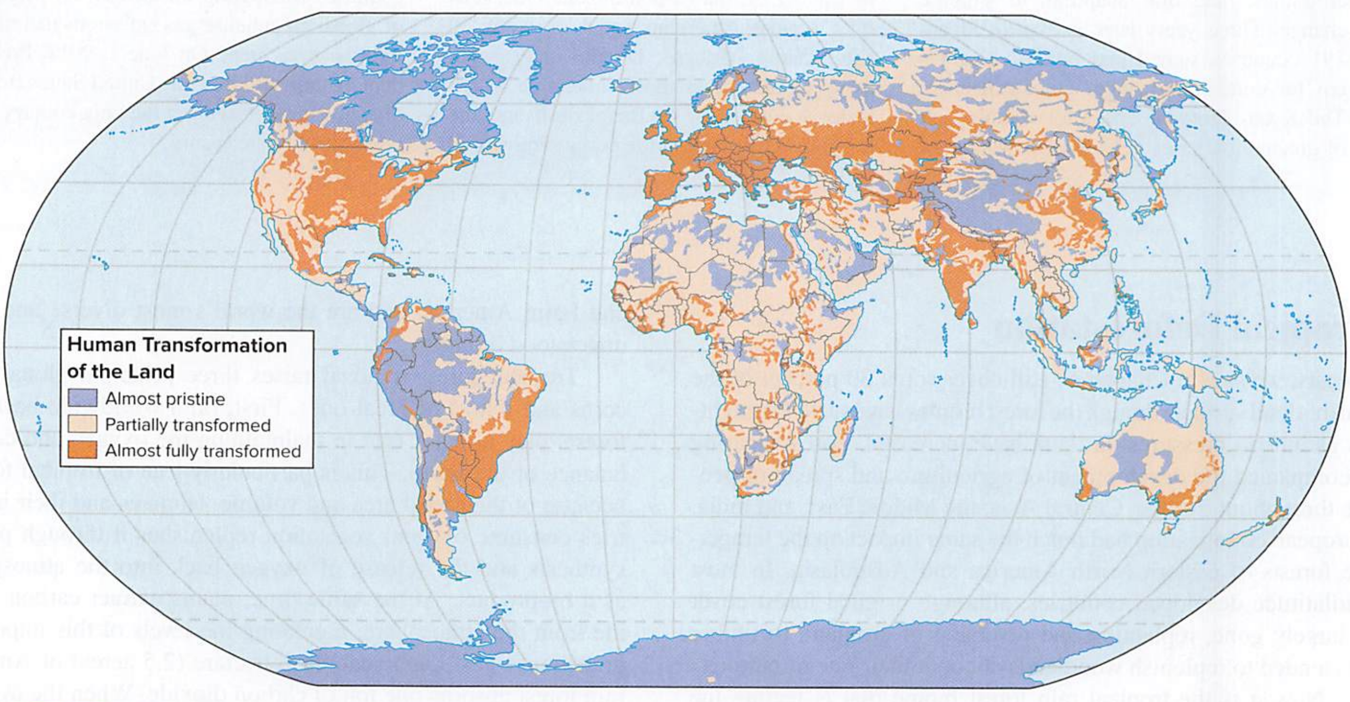
A second global concern is also climate related. Forest destruction changes surface and air temperatures, moisture content, and reflectivity. It is calculated that cutting the forests of South America on a wide scale could raise regional temperatures from 3°C to 5°C (5.5° to 9°F), which in turn would extend the dry season and greatly disrupt not only regional but global climates.

In some ways, the most serious long-term global consequence of the eradication of tropical rain forests will be the loss of a major part of the biological diversity of the planet. Of the estimated 5–10 million plant and animal species believed to exist on Earth, a minimum of 40 percent to 50 percent—and possibly 70 percent or more—are native to the tropical rain forest biome. Many of the plants have become important world staple food crops: rice, millet, cassava, yam, taro, banana, coconut, pineapple, and sugarcane, to name but a few well-known ones. Unknown additional potential food species remain as yet unexploited. Reports from Indonesia suggest that in that country's forests alone, some 4,000 plant species have proved useful to native peoples as foodstuffs of one sort or another, though less than one-tenth have come into wide use. The rain forests are, in addition, the world's main storehouse of drug-yielding plants and insects, including thousands with proven or prospective anticancer properties and many widely used as sources of antibiotics, antivirals, analgesics, tranquilizers, diuretics, and laxatives, among a host of other items. The loss of the zoological and botanical storehouse that the rain forests represent would deprive humans of untold potential benefits that might never be realized.

On a more local basis, tropical forests play for their inhabitants and neighbors the same role taken by forests everywhere. They protect watersheds and regulate water flow. After forest cutting, unregulated flow accentuates the problems of high and low water variations, increases the severity of valley flooding, and makes more serious and prolonged the impact of low water flow on irrigation agriculture, navigation, and urban and rural water supply. Accelerated **soil erosion**—the process of removal of soil particles from the ecosystem, usually by wind or running water—quickly removes the always thin, infertile tropical forest soils from deforested areas. Lands cleared for agriculture almost immediately become unsuitable for that use partially because of soil loss. The surface material removed is transported and deposited downstream, changing valley contours, extending the area subject to flooding, and filling irrigation and drainage channels; or it may be deposited in the reservoirs behind the increasing number of major dams on rivers within the tropical rain forests or rising there (see the feature "Dam Trouble in the Developing World").

Desertification

With no intent to destroy or alter the environment, humans are also negatively affecting the arid and semiarid regions of the world. The process is called **desertification,** the expansion or intensification of areas of degraded or destroyed soil and vegetation cover. While the Earth Summit of 1992 defined desertification broadly as "land degradation in arid, semiarid, and dry subhumid areas, resulting from climatic variations and human activities," the process is often blamed on increasing human pressures exerted through overgrazing, **deforestation** for fuel wood, clearing of original vegetation for cultivation, and burning.



AP **Figure 13.19** Human transformation of the land. Humans have altered much of the Earth's surface in some way. The "almost pristine" areas, covered with original vegetation, tend to be too high, dry, cold, or otherwise unsuitable for human habitation in large numbers. They generally have very low population densities. "Partially transformed" describes areas of secondary vegetation, grown after removal of the original cover. Most are used for agriculture or livestock grazing. "Almost fully transformed" areas are those of permanent and intensive agriculture and urban settlement.

Dam Trouble in the Developing World

By the 1970s, the construction of large dams in the developed countries such as the United States had slowed to a trickle, as the best sites had already been dammed and environmental groups protested the loss of wild rivers. Thus, the focus of dam building shifted to the developing countries. The developing countries have a sizable percentage of the world's undeveloped power potential. The lure of that power and its promise for economic development and national prestige have proved nearly irresistible. China is now the world's leader in large dams and its immense Three Gorges Dam on the Yangtze River is the world's largest hydropower project. China's engineering companies and banks are also actively involved in building large dams in many other developing countries, primarily in Africa and Southeast Asia. The dams (and their reservoirs) often carry a heavy ecological price, and the clearing and development of the areas that they are meant to serve often ensure a shortened life of the dam projects themselves.

The creation of Lake Brokopondo in Suriname in 1964 marked the first large reservoir in a rain forest locale. Without being cleared of their potentially valuable timber, 1,480 square kilometers (570 square miles) of dense tropical forest disappeared underwater. As the trees decomposed, producing hydrogen sulfide, an intolerable stench polluted the atmosphere for scores of miles downwind. For more than two years, employees at the dam wore gas masks at work. Decomposition of vegetation produced acids that corroded the dam's cooling system, leading to costly continuing repairs and upkeep. Identical problems have occurred at the Tucuruí Dam and Reservoir in Brazil, started in 1984 and covering 2,850 square kilometers (1,100 square miles) of uncleared rain forest.

Water hyacinth spreads rapidly in tropical impoundments, its growth hastened by the rich nutrients released by tree decomposition. Within a year of the reservoir's completion, a 130-square-kilometer (50-square-mile) blanket of the weed was afloat on Lake Brokopondo, and after another year, almost half the reservoir was covered. Another 440 square kilometers (170 square miles) were

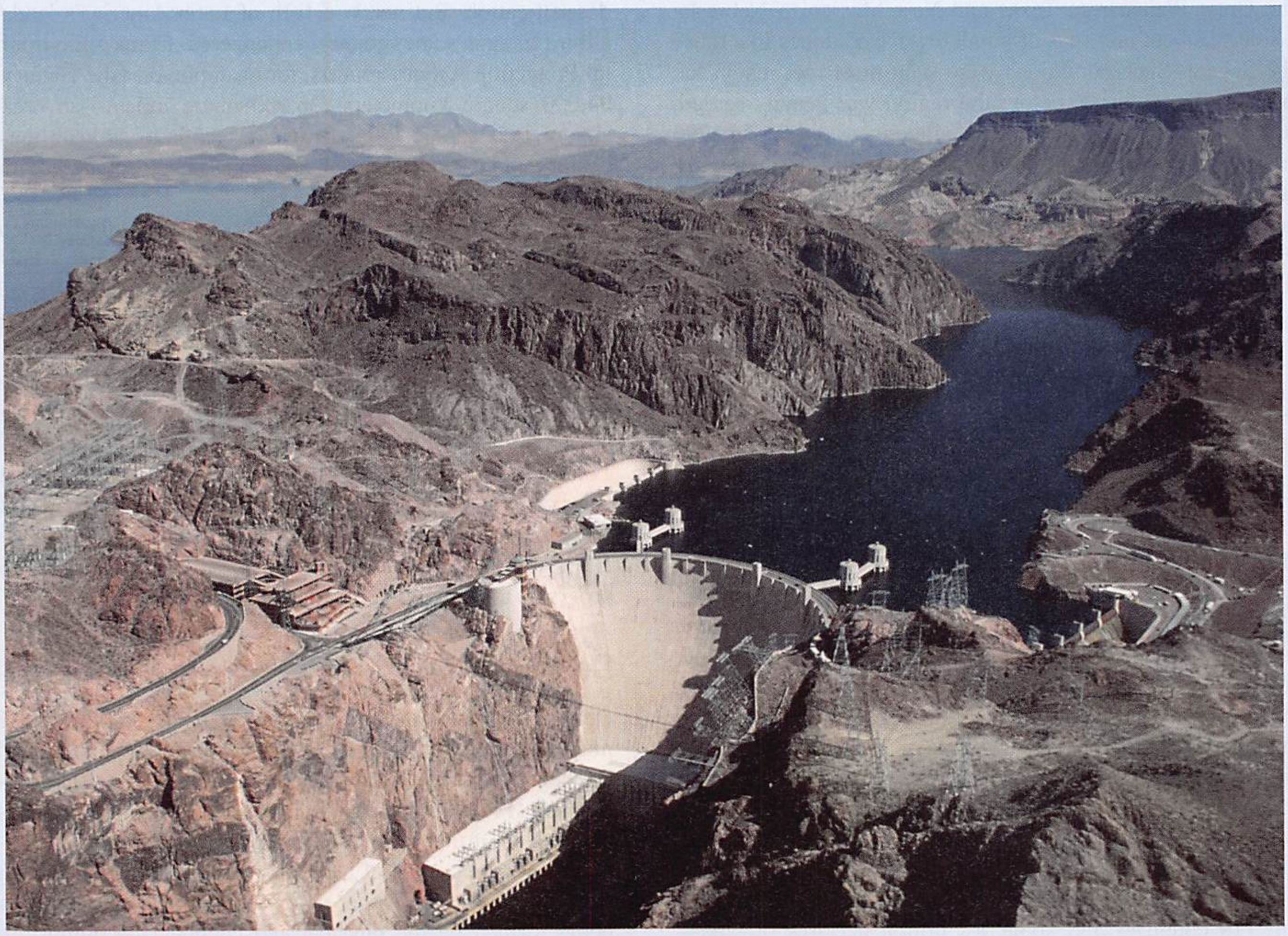


Figure 13A Hoover Dam on the Colorado River, completed in 1935, created a model for the construction of large, hydroelectric dams.
Source: Natural Resources Conservation Service/U.S. Department of Agriculture (USDA)

(Continued)

claimed by a floating fern, *Ceratopteris.* Identical problems plague most rain forest hydropower projects.

The expense, the disruption of the lives of valley residents whose homes are to be flooded, and the environmental damage of dam projects in the rain forest all may be in vain. Deforestation of river banks and clearing of vegetation for permanent agriculture usually results in accelerated erosion, rapid sedimentation of reservoirs, and drastic reduction of electrical generating capacity. The Ambuklao Reservoir in the Philippines, built with an expected payback period of 60 years, now appears certain to silt up in half that time. The Anchicaya Reservoir in Colombia lost 25 percent of its storage capacity only 2 years after it was completed and was almost totally filled with silt within 10 years. The Peligre Dam in Haiti was completed in 1956, with a life expectancy of at least 50 years; siltation reduced its usefulness by some 15 years. El Cajón Dam in Honduras, Arenal in Costa Rica, Chixoy in Guatemala, and many others—all built to last decades or even centuries—have, because of premature siltation, failed to repay their costs or fulfill their promise. The price of deforestation in wet tropics is high indeed.

Certainly much of past desertification has been induced by nature rather than by humans. Over the past 10,000 years, for example, several prolonged and severe droughts far more damaging than the *Dust Bowl* period of the 1930s converted vast stretches of the Great Plains from Texas and New Mexico to Nebraska and South Dakota into seas of windblown sand dunes like those of the Sahara. Such conditions were seen most recently in the 18th and 19th centuries, before the region was heavily settled, but after many explorers and travelers noted—as did one in 1796 in present-day Nebraska—"a great desert of drifting sand, without trees, soil, rock, water, or animals of any kind." Today, those same areas in the Great Plains are covered only thinly by vegetation and could revert to shifting desert—as they almost did in the 1930s—with a prolonged drought of the type that might accompany global climate change.

Whether natural or anthropogenic, every year desertification makes 12 million hectares (46,000 square miles) useless for cultivation. Regardless of its causes, it begins in the same fashion: the disruption or removal of the native cover of grasses and shrubs through farming or overgrazing. If the disruption is severe enough, the original vegetation cannot reestablish itself and the exposed soil is made susceptible to erosion during the brief, heavy rains that dominate precipitation patterns in semiarid regions. Water runs off the land surface instead of seeping in, carrying soil particles with it and leaving behind an *erosion pavement.* When the water is lost through surface flow rather than seepage downward, the water table is lowered. Eventually, even deep-rooted bushes are unable to reach groundwater, and all natural vegetation is lost. The process is accentuated when too many grazing animals pack the dirt down with their hooves, blocking the passage of air and water through the soil. When both plant cover and soil moisture are lost, desertification has occurred.

Worldwide, desertification affects about 1 billion people in 110 countries and about 1.2 billion hectares of land—about the size of China and India combined. According to the United Nations—which declared 2006 the "International Year of Deserts and Desertification" to address their problems and solutions—between one-quarter and one-third of the planet's land surface now qualifies as degraded semidesert. Africa is most at risk; the United Nations has estimated that 40 percent of that continent's nondesert land is in danger of human-induced desertification. But nearly a fifth of Latin America's lands and a third of Asia's are similarly endangered. China's Environmental Protection Agency reports, for example, that the country lost 94,000 square kilometers (36,000 square miles)—an area the size of Indiana—to desert from the 1950s to early in the 21st century and each year has an additional 3,900 square kilometers (1,500 square miles) buried by sand.

In countries where desertification is particularly extensive and severe (Algeria, Ethiopia, Iraq, Jordan, Lebanon, Mali, and Niger) per capita food production has declined. The resulting threat of starvation spurs populations of the affected areas to increase their farming and livestock pressures on the denuded land, further contributing to desertification. It has been suggested that Mali may be the first country in the world rendered uninhabitable by environmental destruction. Many of its more than 11 million inhabitants begin their day by shoveling their doorways clear of the night's accumulation of sand (**Figure 13.20a**). The United Nations has identified desertification as a major barrier to poverty elimination in arid regions and has established programs to fight desertification (**Figure 13.20b**).

Soil Erosion

Desertification is but one example of land deterioration. Over much of the Earth's surface, the thin layer of topsoil upon which life depends is only a few inches deep, usually less than 30 centimeters (1 foot). Below it, the lithosphere is nearly as lifeless as the surface of the moon. **Soil** is a complex mixture of rock particles, inorganic mineral matter, organic material, living organisms, air, and water. Under natural conditions, soil is constantly being formed by the physical and chemical decomposition of rock material and by the decay of organic matter. It is simultaneously being eroded, for soil erosion is as natural a process as soil formation and occurs even when land is totally covered by forests

(a)

(b)

Figure 13.20 Desertification is the advance of the world's deserts into adjacent lands. *(a)* In this scene, windblown dust engulfs a scrub forest in a drought-stricken area of Mali, near Timbuktu. This region is part of the Sahel of Africa where desertification is accelerated by climate fluctuations and human pressures on the land. Here, the margins of the Sahara ebb and flow. *(b)* This windbreak and garden in Mali are attempts to combat desertification.

(a) ©Lissa Harrison; (b) ©Jose Azel/Getty Images

or grass. Under most natural conditions, however, the rate of soil formation equals or exceeds the rate of soil erosion, so soil depth and fertility tend to increase with time.

When land is cleared and planted to crops or when the vegetative cover is broken by overgrazing, deforestation, or other disturbances, the process of erosion inevitably accelerates. When its rate exceeds that of soil formation, the life-sustaining veneer of topsoil becomes thinner and eventually disappears, leaving behind only sterile subsoil or barren rock. At that point the renewable soil resource has been converted through human impact into a nonrenewable and dissipated asset. Carried to the extreme of bare rock hillsides or wind-denuded plains, erosion spells the total end of agricultural use of the land. Throughout history, such extreme human-induced destruction has occurred and been observed with dismay.

Any massive destruction of the soil resource could spell the end of the civilization it had supported. For the most part, however, farmers—even those in difficult climatic and topographic circumstances—devised ingenious ways to preserve and even improve the soil resource on which their lives and livelihoods depended. Particularly when farming was carried on outside of fertile, level valley lands, farmers' practices were routinely based on some combination of crop rotation, fallowing, and terracing.

Rotation involves the planting of two or more crops simultaneously or successively on the same area to preserve fertility or to provide a plant cover to protect the soil. **Fallowing** leaves a field idle (uncropped) for one year or more to achieve one of two outcomes. In semiarid areas, the purpose is to accumulate soil moisture from one year to apply to the next year's crop; in tropical wet regions, as we saw in Chapter 8, the purpose is to renew soil fertility of the swidden plot. **Terracing** replaces steep slopes with a series of narrow-layered, level fields, providing cropland where little or none existed previously. In addition, because water moving rapidly down-slope has great erosive power, breaking the speed of flow by terracing reduces the amount of soil lost. Field trials in Nigeria indicate that cultivation on a 1 percent slope (a drop of 1 foot in elevation over 100 feet of horizontal distance) results in soil loss at or below the rate of soil formation; farming there on a 15 percent slope would totally strip a field of its soil cover in only 10 years.

Pressures on farmlands have increased with population growth and the intensification of agriculture. Farming has been forced higher up on steeper slopes, more forest land has been converted to cultivation, grazing and crops have been pushed farther and more intensively into semiarid areas, and existing fields have had to be worked more intensively and less carefully. Many traditional agricultural systems and areas that were ecologically stable and secure as recently as 1950, when world population stood at 2.5 billion and subsistence agriculture was the rule, are disintegrating under the pressures of 7.5 billion people and an integrated global economy.

The evidence of that deterioration is found in all parts of the world (**Figure 13.21**). Soil deterioration expresses itself in two ways: through decreasing yields of cultivated fields themselves and in increased stream sediment loads and downstream deposition of silt. In Guatemala, for example, some 40 percent of the productive capacity of the land has been lost through erosion, and several areas of the country have been abandoned because agriculture has become economically impracticable; the figure is 50 percent in El Salvador. In Turkey, a reported 75 percent of the land is affected, and more than half is severely eroded. Haiti has no high-value soil left at all. A full one-quarter of India's total land area has been significantly eroded. Between 1960 and 2000, China lost more than 15 percent of its total arable land to erosion, desertification, or conversion to nonagricultural use. Its Huang River is the most sediment-laden of any waterway on Earth; in its middle course it is about 50 percent silt by weight, just under the point of liquid mud. Sediment washed into waterways results in reduced reservoir capacity, fish kills, and dredging costs (see the feature "Dam Trouble in the Developing World").

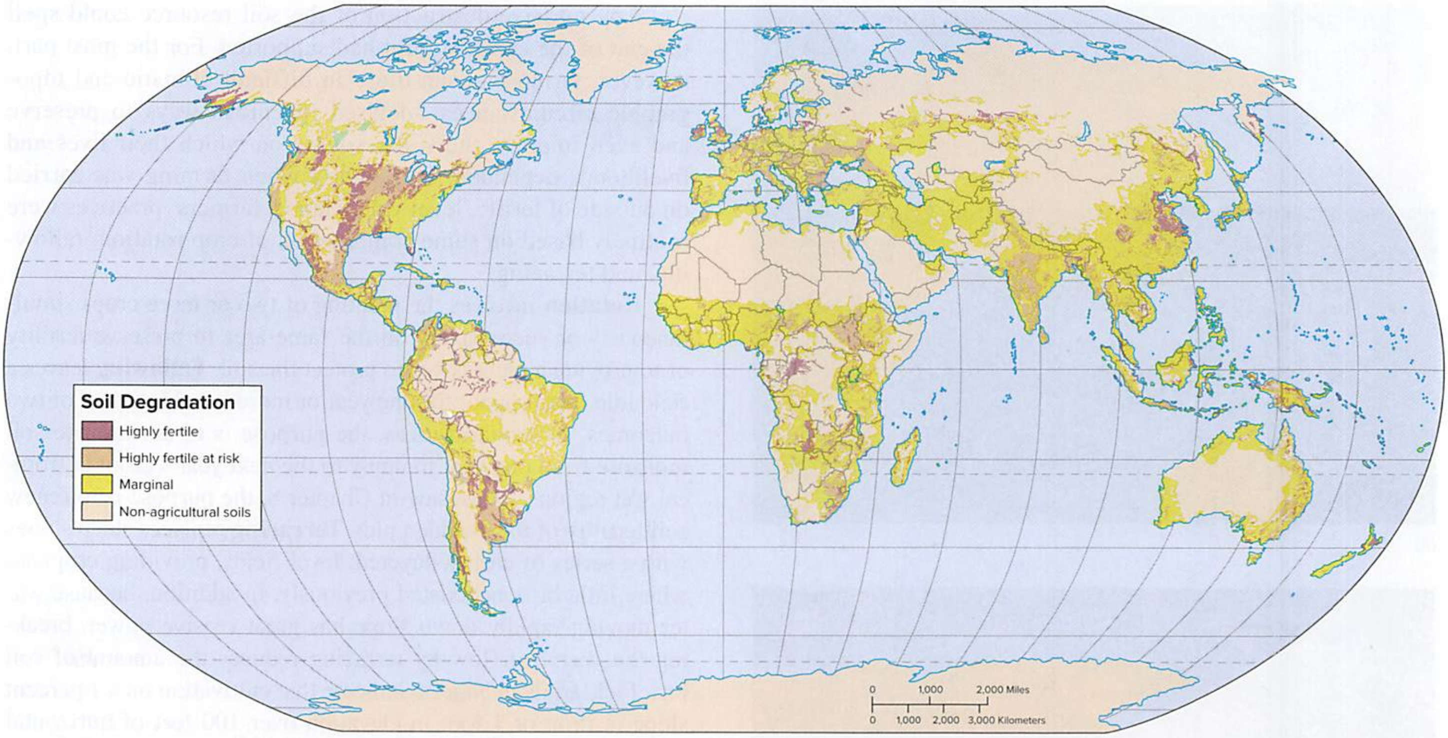


Figure 13.21 Soil fertility and vulnerability to degradation. Between 1945 and 2000, nearly 2 billion hectares (almost 5 billion acres) of the world's 8.7 billion hectares (21.5 billion acres) of cropland, pastures, and forests used in agriculture—an area as large as Russia and India combined— were added to the existing total of degraded soils. Globally, about 18 percent of forest area, 21 percent of pastures, and 37 percent of cropland have undergone moderate to severe degradation. The causes for soil degradation, in order of importance, are water erosion, wind erosion, chemical deterioration due to salinization or nutrient loss, and physical degradation due to compaction or waterlogging.

Map: John L. Allen, Student Atlas of World Geography, 7th edition, McGraw-Hill, p. 124. Data: World Resources Institute and International Soil Reference and Information Center.

Agricultural soil depletion through erosion—and through salt accumulation and desertification—has been called "the quiet crisis." It continues inexorably and unfolds gradually, without the abrupt attention attracted by an earthquake or volcanic explosion. Unfortunately, silent or not, productive soil loss is a crisis of growing importance and immediacy, not just in the countries of its occurrence but—because of international markets and relief programs—throughout the world. Conservation measures, however, can make a difference. In the United States, soil erosion decreased by almost half between 1982 and 2007. In sub-Saharan Africa, natural soil regeneration and agro-forestry projects have succeeded in reducing erosion and restoring soils to productive uses.

13.3 Impacts on Water Resources

Water is essential to all life on Earth. Our bodies are about 60 percent water and about 70 percent of the Earth's surface is covered by water. The supply of water is essentially constant, but highly uneven in its distribution. Careful management of water resources, often for irrigation, has been essential to many early human civilizations such as those of Egypt, Mesopotamia, the Indus Valley, and Mesoamerica (see Figure 2.15). Ancient civilizations that failed to properly manage water resources such as the Anasazi of the American Southwest were subject to collapse (see the feature "Chaco Canyon Desolation" in Chapter 2). Today, managing water resources is critical because rising human populations and increased agricultural, urban, and industrial development have stressed water resources in many regions.

Water Availability

The problem is not with the global amount of water, but with its distribution, its availability, and its quality. The vast majority of water on Earth (96.5 percent) is saltwater found in oceans, seas, and bays, and most freshwater is in ice caps and glaciers. Only about 1 percent of all water is available as liquid fresh water, and most of that is beneath the surface in groundwater **aquifers** that may be difficult and expensive to pump to the surface. Even so, enough rain and snow fall on the continents each year to cover the Earth's total land area with 83 centimeters (33 inches) of water. Observations about global supplies of fresh water ignore the ever-present geographic reality: things are not uniformly distributed over the surface of the Earth. Populations are rising in many regions where water supplies are limited. For example, the Middle East and North Africa are home to 6.3 percent of the world's population but contain only 1.4 percent of the world's renewable fresh water. Idaho, Nevada, and Utah were the three fastest-growing U.S. states in recent years and are all in arid/semiarid climates. Compounding matters, the demand for water by natural processes of evaporation and transpiration varies spatially as well. In hot, dry subtropical deserts annual evaporation may equal 250 centimeters (100 inches) of water per year or more.

For thousands of years, human cultures have responded to the uneven distribution of water in both time and space by constructing small dams and diversion canals for irrigation. During the height of the Depression, the United States built the Hoover Dam (1931–1936) and Grand Coulee Dam (1933–1942); they were bold engineering feats that raised dams to unprecedented heights and impounded enormous volumes of water. These dams generate large quantities of low-cost, renewable, hydroelectric power for cities and industry, and their reservoirs provide a reliable supply of water for cities and agriculture. Perhaps more significantly, these dams established a model for economic development of arid regions based on large water engineering projects. That model has diffused globally, promoted by international aid agencies and seen as prestigious symbols of development by developing countries. There are many economic, social, and environmental costs of large dams, but they are still being built in developing countries (see the feature "Dam Trouble in the Developing World" earlier in this chapter). Today, the flow in more than half the world's major rivers has been altered significantly by dams.

Within the hydrologic cycle, surface runoff takes place within basins or watersheds that are determined by topography; ridgelines divide the waters flowing toward different streams and rivers. Thus, river basins are the primary areal unit to use when studying water. We can then calculate and compare the quantity of renewable water available per person within different river basins. Areas of high water stress are defined as those with less than 1,000 cubic meters of water per person per year. Of course, not all of this water is needed for human consumption. Rather, it is needed for producing food, sanitation, industry, and other essential uses. It is projected that with current patterns of population growth and climate change, by 2050 half the world's population will live in water-stressed areas. (**Figure 13.22**).

In North America, two large river basins with potential water stress are the Colorado and the Rio Grande, both in the Southwest and both reduced to a trickle at times by diversions for agriculture and cities. Complicating management of the limited water supplies of the Colorado and the Rio Grande is the fact that they are international rivers shared by the United States and Mexico. International treaties govern the obligations of each country with respect to quantity and quality of the river's waters. **Transboundary river basins**—basins straddling two or more countries—cover an estimated 40 percent of the Earth's land area and contain more than 60 percent of the world's population.

Water conflict is a distinct possibility when a substance so essential to life is shared by more than one country. Notable transboundary rivers with potential conflicts include the Indus, Jordan, Nile, and Tigris-Euphrates. The Indus has its source in India but provides irrigation water essential to Pakistan's food supply. Despite a series of wars between India and Pakistan, the two countries continue to observe a negotiated treaty regarding the waters of the Indus. The Jordan River basin takes in parts of Israel, Jordan, Lebanon, the Palestinian Territories, and Syria and has major issues related to scarcity and international security. In fact, the amount of renewable water available per person is below recommended minimums in Israel, Jordan, and Palestine. The Nile River drains 10 countries in Africa and is subject to colonial-era treaties that some believe favor Egypt over the upstream countries such as Ethiopia. The Tigris-Euphrates was among the birthplaces of civilization and today is shared by Turkey, Syria, and Iraq, each with their own water development objectives. Yet, despite the very real possibility of water wars, international cooperation has been more common than hostilities.

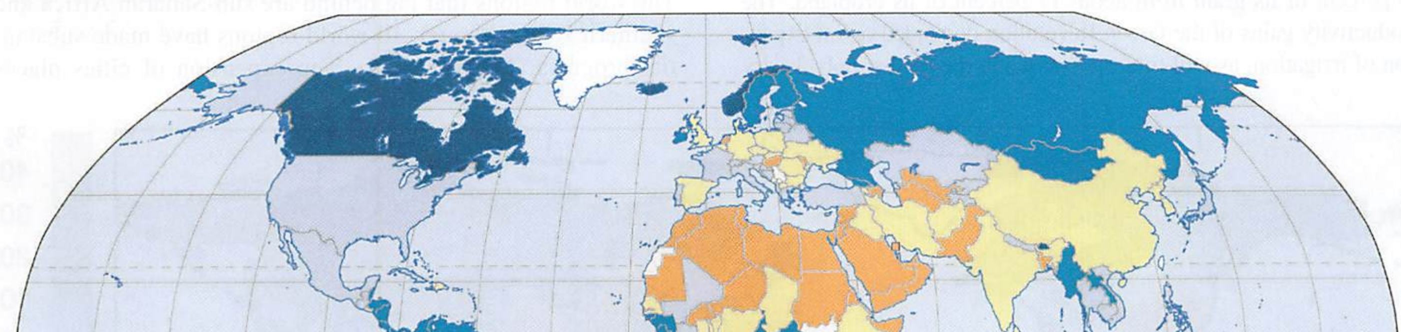


Figure 13.22 Freshwater availability, 2007. Highly stressed areas are those with less than 1,000 cubic meters of water per person per year. In North America, the Rio Grande basin is predicted to be highly stressed and the Colorado River basin stressed.

Source: Sutton C. Student Atlas of World Geography, *8th edition, 2014, based on World Bank,* World Development Indicators, *2012.*

The climate system and hydrosphere are intimately connected. Climate change is likely to alter the hydrologic cycle, increasing both the demand for water and annual precipitation in many areas. Climate models forecast altered patterns of water availability with increased dryness in many areas already subject to water scarcity (**Figure 13.23**). Of particular concern is the American Southwest and Indus Basin, where growing populations will need to adapt to declining water supplies. In both regions, declining snowpack in the mountains will lead to decreased river flow in the dry season.

Water supplies and energy supplies are intimately connected. If energy supplies were unlimited, so too would be water supplies. The ocean offers almost unlimited water supplies but making that water drinkable requires expensive, energy-intensive desalination. The world's largest desalination plants are in the Middle East, where water is scarce and energy supplies are abundant. Wastewater reclamation, also quite expensive, is the treatment of sewage so that it can be reused for irrigation or as a drinking water source. For cities in desert regions, their own sewage is often the last remaining untapped water resource. Australia, Israel, Singapore, Florida, and Southern California are leaders in the use of reclaimed water. Use of reclaimed sewage for drinking water was used in the space program and is now growing in acceptance for city supplies. Water reclamation for drinking water uses ultrafiltration technologies and reinjection into aquifers to address health concerns.

Water Use and Abuse

Water supplies and food supplies are intimately connected. Irrigation uses about three-fourths of all water used by humans and a higher percentage in the least developed countries. Irrigation agriculture produces some 40 percent of the world's total harvest and 60 percent of its grain from about 17 percent of its cropland. The productivity gains of the Green Revolution depended on an expansion of irrigation, as will future increases in the food supply. In dry climates, rivers and lakes have shrunk or even disappeared due to irrigation demands. The Aral Sea in Kazakhstan and Uzbekistan was once the world's fourth-largest lake by area before irrigation diversions caused it to shrink by 90 percent (**Figure 13.24**). Groundwater can be used unsustainably if it is pumped faster than it is replenished by natural infiltration. In the United States, a major concern is the dropping groundwater levels in the Ogallala Aquifer, which provides irrigation water for agriculture in eight Great Plains states.

When humans introduce wastes into the biosphere in kinds and amounts that the natural system cannot neutralize or recycle, the result is **environmental pollution.** In the case of water, pollution exists when water composition has been so modified by the presence of one or more substances that either it cannot be used for a specific purpose or it is less suitable for that use than it was in its natural state. In both developed and developing countries, human pressures on freshwater supplies are now serious and pervasive concerns (see the feature "A World of Water Woes").

Water pollution can come in a variety of forms. Human wastes often contain infectious agents that cause waterborne diseases such as cholera, dysentery, and typhoid fever. Waterborne diseases kill an estimated 1.5 million persons each year, largely due to lack of sanitation, sewage treatment, and/or access to safe drinking water supplies. An estimated 2.4 billion people around the world lack basic sanitation such as a latrine or toilet and 1.8 billion use drinking water sources containing fecal contamination. Thus, one of the United Nations' Millennium Development Goals (MDGs) was to cut in half the proportion of the population without access to safe drinking water and basic sanitation between 1990 and 2015. The United Nations' Sustainable Development Goals call for ensuring safe drinking water and basic sanitation for all people by 2030. The world regions that lag behind are sub-Saharan Africa and southern Asia, although all world regions have made substantial progress (**Figure 13.25**). The expansion of cities places

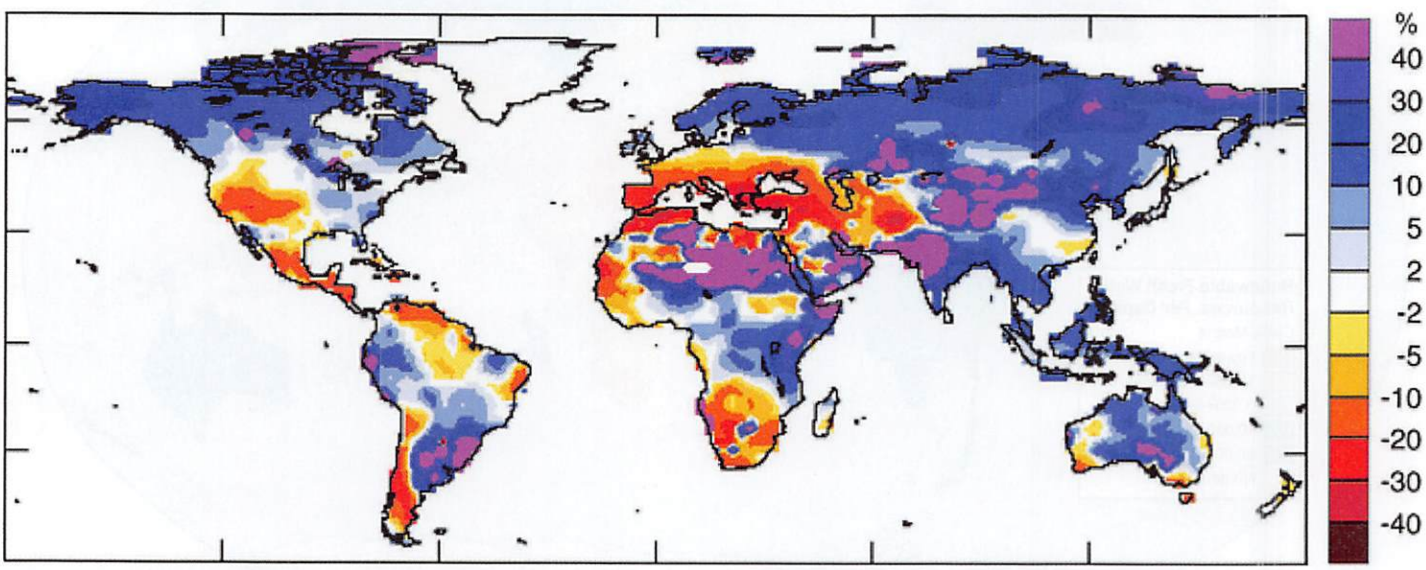
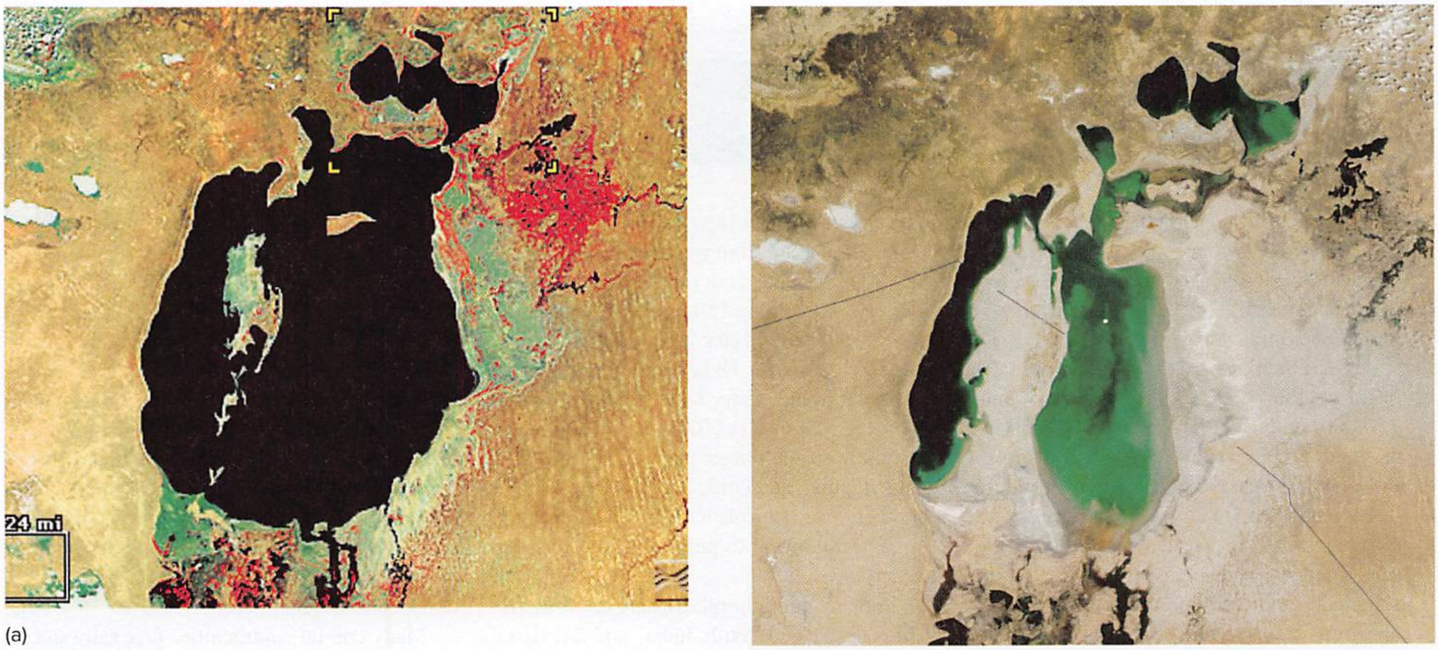


Figure 13.23 Predicted change in annual runoff by the mid-21st century compared to 1900–1970. This map from the IPCC report is based on 12 global climate model simulations using middle-range assumptions about greenhouse gas emissions. A substantial reduction in water availability is predicted for a number of already dry regions such as the American Southwest, Mexico, southern Africa, southern Europe, northern Africa, and the Middle East.

Source: Intergovernmental Panel on Climate Change, 2007. Climate Change 2007: Working Group II: Impacts, Adaptation, and Vulnerability, *Figure 3.4.*



(a)

(b)

Figure 13.24 The Aral Sea has dramatically declined in size and depth. *(a)* This map from 1975 shows the original extent of the sea when it was the fourth-largest inland sea in the world. *(b)* In this satellite image from 2005, the Aral Sea has shrunk due to diversions of water for irrigated agriculture. Water levels have declined by 18 meters (59 feet), causing the lake to split into two parts. Fishing, port, and resort towns are now 80 kilometers (49.6 miles) or farther from the water. The remaining flow into the sea is contaminated by agricultural runoff, yielding a toxic, salty brine. Dust storms whip up particulates and toxic chemicals from the dry lake bed. Restoration work is being done on the Little Aral Sea in the north in Kazakhstan.

Source: EROS Data Center USGS

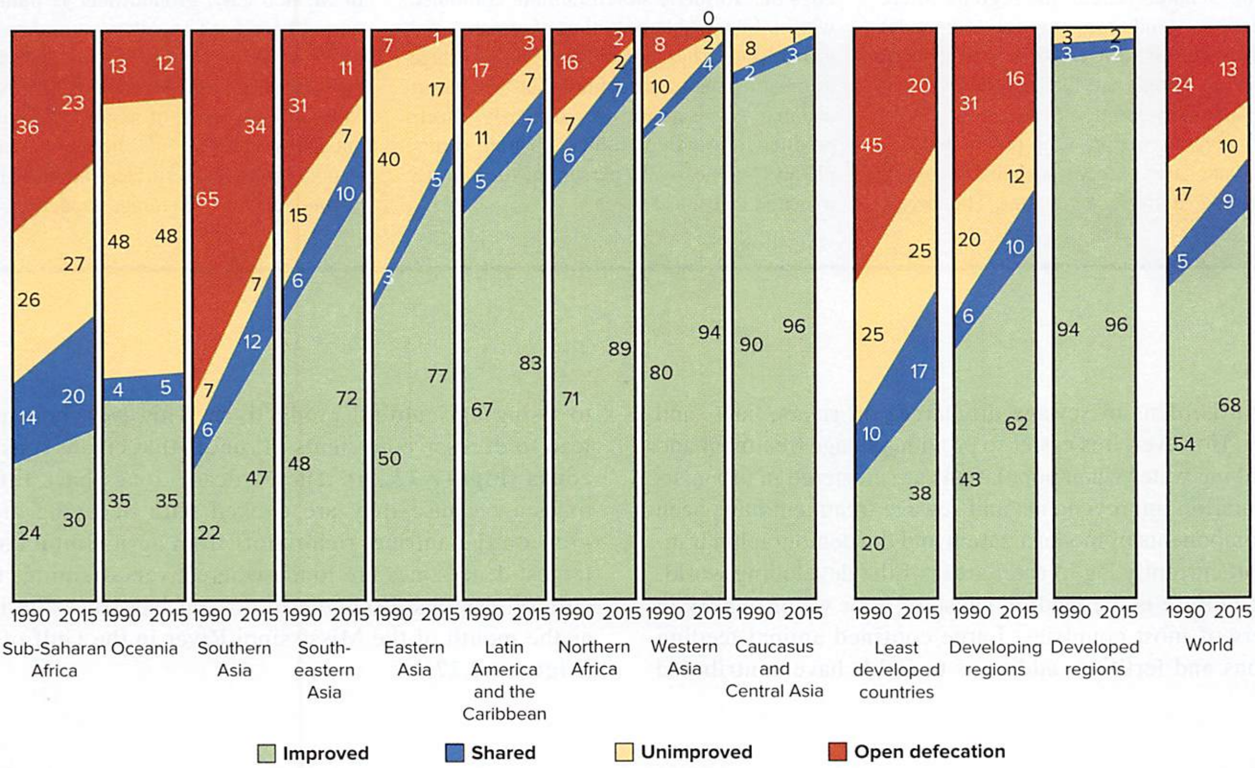


Figure 13.25 The availability of sanitation in each world region improved between 1990 and 2015. While improved facilities (flush toilets and sewage disposal systems) are the norm in developed countries, only 62 percent of people in developing regions had access to this level of sanitation in 2015. The United Nations Millennium Development Goals called for cutting in half the proportion without improved sanitation. Substantial progress on sanitation was made between 1990 and 2015, promising major benefits for human health.

A World of Water Woes

Water covers almost three-quarters of the surface of the globe, yet *scarcity* is the word increasingly used to describe water-related concerns in both the developed and developing world. Globally, fresh water is abundant. Each year, an average of more than 7,000 cubic meters (some 250,000 cubic feet) per person enters rivers and underground reserves. But rainfall does not always occur when or where it is needed. Already, 80 countries with 40 percent of the world's population have serious water shortages that threaten to cripple agriculture and industry; 22 of them have renewable water resources of less than 1,000 cubic meters (35,000 cubic feet) per person—a level generally understood to mean that water scarcity is a severe constraint on the economy and public health. Another 18 countries have less than 2,000 cubic meters per capita on average, a dangerously low figure in years of rainfall shortage. Most of the water-short countries are in the Middle East, North Africa, and sub-Saharan Africa, the regions where populations (and consumption demands) are growing fastest. By 2025, two-thirds of the world's people are likely to be living in areas of acute water stress.

In several major crop-producing regions, water use exceeds sustainable levels, threatening future food supplies. The largest underground water reserve in the United States, stretching from west Texas northward into South Dakota, is drying up, partially depleted by more than 150,000 wells pumping water for irrigation, city supply, and industry. In parts of Texas, Oklahoma, and Kansas, the underground water table has dropped by more than 30 meters (100 feet). In some areas, the wells no longer yield enough to permit irrigation, and farmed land is decreasing; in others, water levels have fallen so far that it is uneconomical to pump it to the surface for any use.

In many agricultural districts of northern China, west and south India, and Mexico, water scarcity limits agriculture even though national supplies are adequate. In Uzbekistan and adjacent sections of Central Asia and Kazakhstan, virtually the entire flow of the area's two primary rivers—the Amu Darya and the Syr Darya—is used for often wasteful irrigation, with little left to maintain the Aral Sea or supply growing urban populations. In Poland, the draining of bogs that formerly stored rainfall, combined with unimaginable pollution of streams and groundwater, has created a water shortage as great as that of any Middle Eastern desert country. And salinity now seriously affects productivity—or prohibits farming completely—on nearly 10 percent of the world's irrigated lands.

Water scarcity is often a regionwide concern. More than 200 river systems draining more than half the Earth's land surface are shared by two or more countries. Egypt draws on the Nile for 86 percent of its domestic consumption, but virtually all that water originates in eight upstream countries. Turkey, Iraq, and Syria have frequently been in dispute over the management of the Tigris and Euphrates rivers, and the downstream states fear the effect on them of Turkish impoundments and diversions. Mexico is angered at the U.S. depletion of the Colorado River before it reaches the international border.

Many coastal communities face saltwater intrusions into their drinking water supplies as they draw down their underlying freshwater aquifers, while both coastal and inland cities dependent on groundwater may be seriously depleting their underground supplies. In China, 110 mostly large cities face acute water shortages; for at least 50 of them, the problem is groundwater levels dropping on average 1 to 2 meters (3 to 6 feet) each year. In Mexico City, groundwater is pumped at rates 40 percent faster than natural recharge; the city has responded to those withdrawals by sinking 30 feet during the 20th century. Millions of citizens of major cities throughout the world have had their water rationed as underground and surface supplies are used beyond recharge or storage capacity.

additional burdens of sewage discharges on rivers, bays, and estuaries. However, it is easier to provide sewage treatment and safe drinking water when populations are clustered in urban areas. Sanitation improvements and sewage treatment have been major components of modernization and the demographic transition, but currently lag in rural areas of the developing world.

Agriculture is the leading cause of poor water quality in the rivers of most countries. Large confined animal feeding operations and fertilizer additions to fields have contributed to rising agricultural productivity. However, both practices lead to excessive nutrients in runoff that create coastal **dead zones** (**Figure 13.26**). These "dead" zones have little or no oxygen because they are choked with decaying algae that grew on the nutrient rich runoff from agricultural lands. The largest dead zones are found where rivers draining rich agricultural regions discharge to coastal bays or estuaries, such as the mouth of the Mississippi River in the Gulf of Mexico (**Figure 13.27**).

Figure 13.26 This slum in Mumbai, India, sits atop a drainage channel and lacks access to clean water and sanitation. Waterborne diseases, mostly stemming from water supplies contaminated with human wastes, are estimated to cause 1.5 million deaths a year.
©McGraw-Hill Education/Barry Barker, Photographer

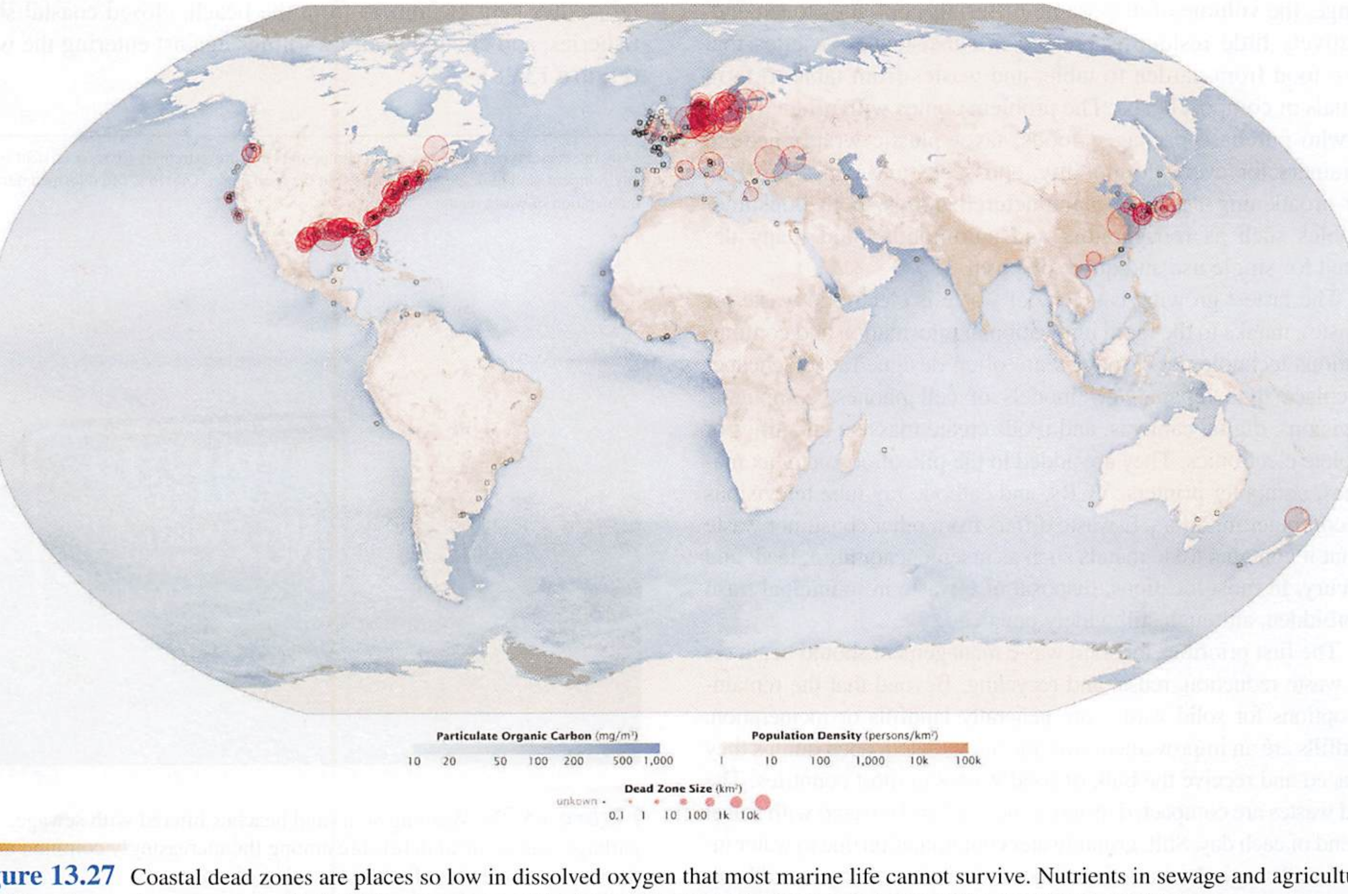


Figure 13.27 Coastal dead zones are places so low in dissolved oxygen that most marine life cannot survive. Nutrients in sewage and agricultural runoff are the most common culprit. Note the prevalence of dead zones where populations are highest in the developed countries.

13.4 Wastes

Humans have always managed to leave their mark on the landscapes that they occupy. Among the most enduring of landscape evidences of human occupancy is the garbage produced and discarded by every society. Prehistoric dwelling sites are located and analyzed by their *middens,* the refuse piles containing the kitchen wastes, broken tools, and other debris of human settlement. We have learned much about Roman and medieval European urban life by examination of the refuse mounds that grew as man-made hills in their vicinities. In the Near East, whole cities gradually rose on the mounds of debris accumulating under them (see Figure 11.9).

Modern cultures differ from their predecessors by the volume and character of their wastes, not by their habits of discard. Generally, the greater the society's population and standard of living, the greater the quantity of its garbage. Developed countries are increasingly discovering that their material wealth and technological advancements are submerging them in a volume and variety of wastes—solid and liquid, harmless and toxic—that threaten both their environments and their established ways of life.

Solid Wastes

Americans produce rubbish, garbage, and other municipal waste at a rate of about 2 kilograms (4.5 pounds) per person per day. As populations grow, incomes rise, and consumption patterns change, the volume of disposable materials continues to expand. Relatively little residue is created in subsistence societies that move food from garden to table, and wastes from table to farm animals or compost heaps. The problem comes with urban dwellers who purchase packaged foods, favor plastic wrappings and containers for every commodity, and seek (and can afford) an ever-broadening array of manufactured goods, both consumer durables such as refrigerators and automobiles and many designed for single use and quick disposal.

The fastest growing category of waste is electronic waste (or e-waste), thanks to the rapid innovation in information and communications technologies. Products are often designed to be cheaper to replace than repair. New models of cell phones, computers, televisions, digital cameras, and iPods create massive quantities of obsolete electronics. They are added to the pile of obsolete fax machines, computer printers, VCRs, and cathode ray tube televisions and computer monitors. E-waste differs from other consumer waste in that it contains toxic metals such as arsenic, cadmium, lead, and mercury. In most locations, disposal of e-waste in municipal trash is forbidden, although still widely practiced.

The first priorities for solid waste management should be, in order, waste reduction, reuse, and recycling. Beyond that the remaining options for solid wastes are generally landfills or incineration. Landfills are an improvement over the unregulated, open dumps they replaced and receive the bulk of solid wastes in most countries. The solid wastes are compacted inside a lined cell and covered with soil at the end of each day. Still, groundwater contamination due to water infiltration through the waste is a major technical challenge to address. Beyond technical details, an increasing problem is where to locate a landfill because most communities will protest, expressing **Not in My Backyard (NIMBY)** sentiments.

Over the years, of course, many filled dumps have posed problems for the cities that gave rise to them. New York City, for example, for years placed all of its daily 14,000 tons of residential waste into the world's largest dump, Fresh Kills on Staten Island. Opened in 1947 as a three-year "temporary" 500-acre facility, it became a malodorous 1,214 hectares (3,000 acres) of decomposing garbage rising 15 stories above the former ground level. Generating 140,000 cubic meters (5 million cubic feet) of methane gas annually and illegally exuding contaminated water, Fresh Kills—finally closed in 2001 at a cost of more than $1 billion—symbolized the rising tide of waste engulfing cities and endangering the environment.

Incineration recovers some of the energy in waste by burning it to produce steam or electricity. Incinerators produce air pollution, including highly toxic metals and organic compounds such as dioxin,[1] so pollution control equipment is required. As with landfills, proposing a location for a solid waste incinerator often leads to community resistance.

For coastal communities around the world the ocean has long been the preferred sink for not only municipal garbage, but for (frequently untreated) sewage, industrial waste, and all the detritus of an advanced urban society. Along the Atlantic coast of North America from Massachusetts to Chesapeake Bay, reports of dead dolphins, raw sewage, tar balls, used syringes, vials of contaminated blood and hospital waste, diapers, plastic products in unimagined amounts and varieties, and other foul refuse has kept swimmers from the beach, closed coastal shellfisheries, and elicited health warnings against entering the water (**Figure 13.28**).

[1]Any of several types of hydrocarbon compounds that are extremely toxic, persistent in the environment, and biologically magnified in the food chain. Dioxin is often formed during incineration of waste matter.

Figure 13.28 Warning signs and beaches littered with sewage, garbage, and medical debris are among the increasingly common and distressing evidences of ocean dumping of wastes.
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AP Geography and Citizenship

Environmental Justice

In Houston, a city of some 2 million people, about 25 percent of the population is African American. Yet, when researchers examined the placement of garbage facilities in the city, they found that 11 of 13 solid waste disposal facilities owned by the city were in mostly black areas and all five of the city's garbage incinerators were in black and Hispanic neighborhoods. Thus, when the city proposed establishing a new dump in a primarily black neighborhood in 1979, near houses and a high school, local residents protested and brought the waste management company to court, charging it with racial discrimination in the selection of the landfill site. The court decided in favor of the company, and the landfill was built.

In 1982, a few states away, in Warren County, North Carolina, the rural, mostly African American residents were shocked to learn that the state was proposing their county as the site of a hazardous waste landfill for disposing of polychlorinated biphenyls (PCBs). Their protests resulted in more than 500 arrests, and the effort to block the landfill failed. The Warren County activists were the first to use the term *environmental racism.*

Environmental racism refers to any policy or practice that differentially affects or harms individuals, groups, or communities because of their race or color. The harm may be intentional or unintentional. **Environmental justice** is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. No group of people should bear a disproportionate share of negative environmental consequences. In many cases, environmental racism and injustice result from long-established and unexamined structural inequality: those who have a reduced political voice compared to the dominant groups in society live in the worst environments because authorities and companies have faced little opposition in placing hazardous facilities, such as landfills, in their vicinity.

The problem is not confined to the United States. In most countries, poorer people and minorities tend to live in areas that are disproportionately exposed to polluting industries, waste disposal facilities, toxic soils, and polluted air and water, in. In Kagiso township, southwest of Johannesburg, South Africa, poor African residents live near a gold mine. In the past, when the gold was extracted from the ore, the waste product was pumped into a waste pile a distance from the residential area. However, the pile was eventually expanded to the extent that it now lies less than 27.4 meters (30 yards)—or less than half the length of a typical city block—from some of the houses. The drying waste produces dust that is high in alpha quartz particles, or silica, which cause silicosis. The inhalation of silica causes lung disease characterized by shortness of breath, fever, and cyanosis, and it also leaves its victims susceptible to tuberculosis. The condition is irreversible. The township is dominated by *informal* housing, which has few city services, is overcrowded, and has poor sanitation; it includes areas that were set aside for black Africans during apartheid.

The United States has taken some steps to rectify the wrongs of environmental injustice. Following the Warren County, North Carolina, protests, President Bill Clinton signed an executive order that made environmental justice a national priority and directed all federal agencies to develop policies to reduce environmental inequity, in 1992, the EPA established an Office of Environmental Equity (now called the Office of Environmental Justice). The agency, however, has had an uneven record since its founding. Organizations outside the government continue to call attention to disturbing conditions often using a geographic information systems (GIS) to identify inequalities.

Consider Louisiana's Chemical Corridor, or Cancer Alley, a 130-kilometer (80-mile) stretch of the Mississippi River that is home to a chemical plant every half mile and a predominantly poor, African American population. While community groups protested a proposed new polyvinyl chloride (PVC) plant, the state government gave the owners tax exemptions. The EPA delayed the new plant's permit until the state addressed the citizens' environmental justice concerns. In the end, the owners bowed to community opposition and built the new plant 48 kilometers (30 miles) upstream, which may represent a Pyrrhic victory because the plant will still contaminate the air and water nearby.

Environmental injustice has its origins both in neglect and overt discrimination.

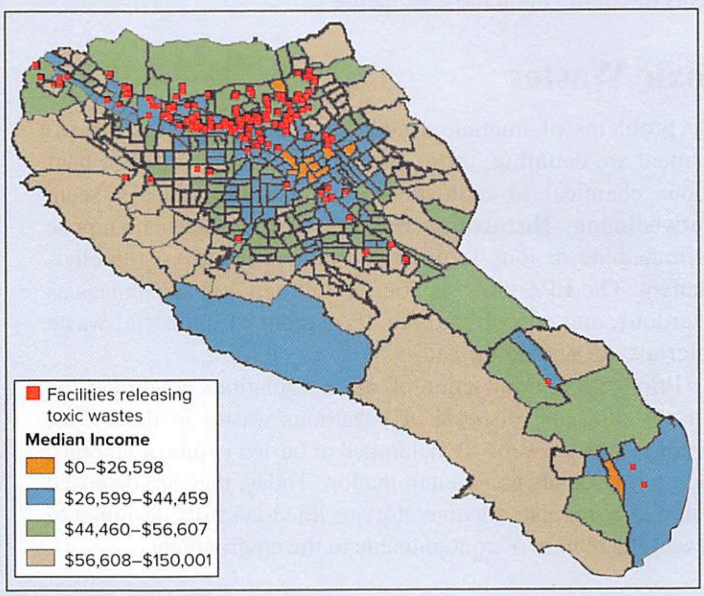


Figure 13B Poverty and Environmental Risk. The distribution of household income and facilities that release toxic materials in Santa Clara County, California. Black lines represent census tracts. (Source: Data from M.R. Meusar and A. Szosz "Environmental Inequality in Silicon Valley." www.mapcnjzin .com/EI/index.hmi.)

(Continued)

There are many instances of intentional placement of environmentally hazardous plants and waste sites in areas already home to minorities and the poor. Government attempts to address the issue of environmental injustice have had an uneven track record. A body of case law regarding environmental justice in the United States has not developed yet, and some scholars contend that, because the issue falls between civil rights law and environmental law, development will continue only slowly.

Thinking Geographically

1. Environmentally hazardous structures—landfills, chemical plants, factories—have to be placed somewhere. How should communities and governments make decisions among different sites? Should the activism of local populations affect government decisions? Write a one-page position paper to summarize your thoughts.
2. Where are landfills, polluting industries, and other environmental hazards located in your town or city? Are low-income residents and minorities exposed to greater-than-average amounts of pollution, and thus bearing greater health risks than the rest of the population? Conduct research about this issue and share your findings in an oral presentation.

Adapted from: *Getis and Getis,* Introduction to Geography, *12th ed., McGraw-Hill, 2008, 326–327.*

Whether the solution to solid waste disposal is sought by land, by fire, or by sea, humanity's rising tide of refuse threatens to overwhelm the environments that must deal with it. The problems that continue to surface remind us that the Earth's environmental systems are interrelated, so that all too often, our solutions simply move the problem from the land to the sea or air or groundwater. The problem is present, growing, and increasingly costly to manage. Solutions are still to be found, a constant reminder for the future of the threatening impact of the environments of culture upon those of nature.

Toxic Wastes

The problems of municipal and household solid-waste management are daunting; those of treatment and disposal of hazardous chemical or radioactive wastes from industry seem overwhelming. **Hazardous wastes** are substances that pose an immediate or long-term risk to human health or the environment. The EPA has classified more than 400 substances as hazardous, and currently about 10 percent of industrial waste materials are so categorized.

Prior to the introduction of strict regulations governing the transportation and disposal of hazardous wastes in the 1970s, hazardous wastes were often dumped or buried in pits or lagoons, leading to groundwater contamination. Today, they are disposed of in highly regulated incinerators or lined landfills designed to prevent the release of contaminants to the environment.

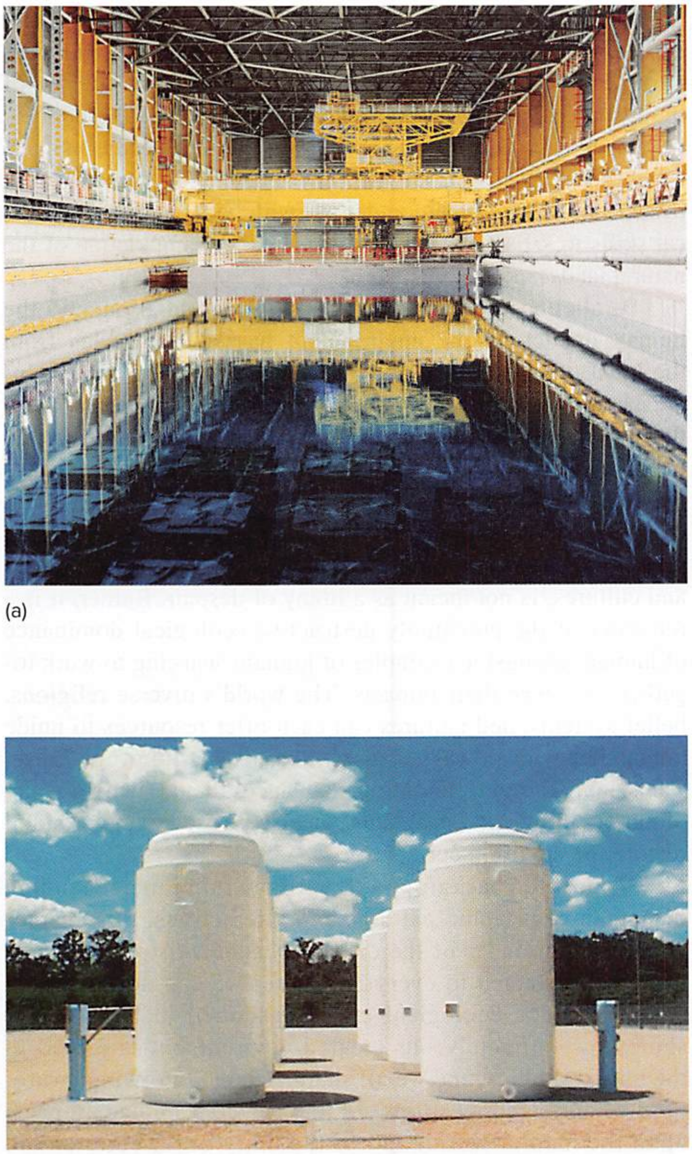
Radioactive Wastes

Every facility that either uses or produces radioactive materials generates at least *low-level waste,* material whose radioactivity will decay to safe levels in 100 years or less. Nuclear power plants, industries that manufacture radiopharmaceuticals, smoke alarms, and other consumer goods, and research establishments, universities, and hospitals also produce low-level radioactive waste materials.

High-level waste can remain radioactive for 10,000 years and more; plutonium stays dangerously radioactive for 240,000 years. It consists primarily of spent fuel assemblies of nuclear power reactors—termed *civilian waste*—and such *military waste* as the by-products of nuclear weapons manufacture. The volume of civilian waste accumulates rapidly because approximately one-third of a reactor's rods need to be disposed of every year.

Spent fuel is a misleading term: the assemblies are removed from commercial reactors not because their radiation is spent, but because they have become too radioactive for further use. The assemblies will remain radioactively "hot" for thousands of years. By 2018, 90,000 metric tons of accumulated nuclear waste (spent fuel) was in storage in the containment pools or above ground in dry casks at 80 commercial nuclear power reactors, awaiting a more permanent solution (**Figure 13.29**). Stored spent fuel rods were among the most serious concerns and sources of radiation releases when the Fukushima nuclear power plant in Japan was hit by an earthquake and tsunami in 2011. Spent fuel is not contained as well as the fuel rods inside reactors, so they must be constantly covered in cool water to prevent overheating. When the earthquake and tsunami knocked out power to the water pumping systems, the spent fuel ponds overheated, contributing to radiation releases.

The U.S. Department of Energy spent two decades developing plans for a centralized nuclear waste depository inside Yucca Mountain in the desert 90 miles from Las Vegas, Nevada. The plan was to encase the radioactive waste in extremely strong glass inside steel canisters beneath 300 meters (1,000 feet) of volcanic rock. Local opponents to the plan pointed out the potential for accidents in shipment or earthquakes in the area and succeeded in having the project scrapped. No alternative, permanent disposal method has been devised. Much low-level radioactive waste has been placed in tanks and buried in the ground at 13 sites operated by the U.S. Department of Energy and three sites run by private firms. Millions of cubic feet of high-level military



(a)

(b)

Figure 13.29 Spent nuclear fuel from nuclear power plants continues to generate heat and emit radiation long after it is removed from the reactor. *(a)* Initially after it is removed, spent fuel is stored in water-filled pools equipped with continuously circulating water baths to keep it from overheating. Spent fuel remains in the cooling water a year or longer before it can be transferred to *(b)* aboveground dry casks stored at the nuclear reactor site. The lack of a permanent disposal solution in the United States means spent fuel continues to accumulate at nuclear power plants.

(a) ©Steve Allen/DigitalVision/Getty Images; (b) Source: Office of Civilian Waste Management. Department of Energy

waste are temporarily stored in underground tanks at four sites: Hanford, Washington; Savannah River, South Carolina; Idaho Falls, Idaho; and West Valley, New York. Several of these storage areas have experienced leaks, with seepage of waste into the surrounding soil and groundwater. Nuclear power plants continue to store spent fuel on site.

Exporting Wastes

The problem with throwing away wastes is that on Earth, there is no true "away." The Earth's atmosphere, hydrosphere, lithosphere, and biosphere are all interrelated, and every place is somebody's backyard. Almost everywhere that governments or industries have proposed to build landfills, hazardous waste incinerators, or nuclear waste repositories, communities and NIMBY movements have arisen in opposition. As a consequence, unwanted facilities such as these tend to be located in places where there is the least community resistance and least political power, often low-income, minority communities (see the feature "Geography and Citizenship: Environmental Justice").

In a leaked 1991 memorandum, World Bank chief economist Larry Summers shared his opinion that it made perfect economic sense to encourage the movement of dirty industries to poor countries. He argued that residents of less-developed countries were less likely to be concerned about the environment, and if they suffered negative health effects from pollution, the economic cost would be lower because their wages were so much lower. He wrote, "I think the economic logic behind dumping a load of toxic waste in the lowest-wage country is impeccable, and we should face up to that."[2]

Regulations, community resistance, and steeply rising costs of disposal of hazardous wastes in the developed countries encouraged producers of those unwanted commodities to seek alternate areas for their disposal. Transboundary shipments of dangerous wastes became an increasingly attractive option for producers, continuing the globalization of the world economy. In total, such cross-border movement amounted to tens of thousands of shipments annually by the early 1990s, with destinations including debt-ridden Eastern European countries and impoverished developing ones outside of Europe that were willing to trade a hole in the ground for hard currency. It was a trade, however, that increasingly aroused the ire and resistance of destination countries and, ultimately, elicited international agreements among both generating and receiving countries to cease the practice.

The Organization of African Unity (OAU) adopted a 1988 resolution condemning the dumping of all foreign wastes on that continent. Under the sponsorship of the United Nations, 117 countries adopted a treaty—the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes—aimed at regulating the international trade in wastes. That regulation was to be achieved by requiring exporters to obtain consent from receiving countries before shipping waste and by requiring both exporter and importer countries to ensure that the waste would be disposed of in an environmentally sound manner. The Basel Convention came into force in 1992, but the United States has not yet ratified it.

The European Union allows its members to export hazardous wastes only to developed countries that are assumed to have satisfactory treatment capabilities. However, the lack of global

[2]Quoted from David Harvey, *Justice, Nature, and the Geography of Difference*, 366, 2006.

ratification of the Basel Convention means that export of hazardous wastes to developing countries continues.

The line between reusable products and wastes is often fuzzy and depends on local standards of living and costs of labor. Thus, obsolete manufactured goods and recyclable materials are often shipped from high-income countries to low-income developing countries for the labor-intensive and potentially dangerous tasks of sorting, disassembly, and recycling. An estimated 80 percent of e-waste collected in the United States for recycling is exported to areas such as China, India, Pakistan, Nigeria, and Mexico. Reports warn of environmental pollution and accidental toxic exposures due to the unregulated recycling of e-waste in low-income countries.

13.5 Future Prospects and Perspectives

Not surprisingly, the realities of the human impacts upon the environment that we have looked at in this chapter bring us directly back to ideas first presented in Chapter 2, at the start of our examination of culture and the development of human geographic patterns on the surface of the Earth. Humans, in their increasing numbers, growing technical sophistication, rising standards of living, and expanding global reach, have transformed the Earth's landscapes since the end of the last glaciation. Humans have adopted a domineering role in the human-environment relationship, all too often forgetting that they depend upon the environment for their very existence.

That dominance is reflected in the growing divergence of human societies as they distance themselves from common hunting-gathering origins. In creating their differing cultural solutions to common concerns of sustenance and growth, societies altered the environments they occupied. Diverse systems of exploitation of the environment were developed in and diffused from distinctive culture hearths. They were modified by the ever-expanding numbers of people occupying Earth areas of differing carrying capacities and available resources. Spatial interaction among regions did not halt the creation of distinctive regional subsystems of culture or assure common methods of utilization of Earth resources. Sharp contrasts in levels of economic development and well-being emerged and persisted even as cultural convergence through shared technology began to unite societies throughout the world.

Each culture placed its imprint on the environment it occupied. In many cases—Chaco Canyon and Easter Island were our earlier examples—that imprint was ultimately destructive of the resources and local environments upon which the cultures developed and depended. To satisfy their felt needs, humans have learned to manipulate their environment. The greater those needs and the larger the populations with both needs and technical skills to satisfy them, the greater is the manipulation of the natural landscape.

Paralleling the global reach of the world economy, the human impact on the environment has shifted scales from the local or regional to the continental and global scales. Increasingly, the most pressing environmental issues are those that cross international boundaries, such as depletion of the ozone layer, acid precipitation, global climate change, managing transboundary river basins, and transboundary shipment of wastes. This final chapter, detailing a few of the damaging pressures placed upon the environment by today's economies and cultures, is not meant as a litany of despair. Rather, it is a reminder of the potentially destructive ecological dominance of humans alongside examples of humans learning to work together to reduce their impacts. The world's diverse religions, belief systems, and cultures can each offer resources to guide human behavior in ways that are more respectful of the Earth. The scientific and technological advances that lie behind many of our environmental problems can also be used to monitor and restore the environment.

Against the background of our now fuller understanding of human geographic patterns and interactions, this chapter is another reminder of the often repeated truism that everything is connected to everything else; we can never do just *one* thing. The ecological crises described in this chapter show how intimately our created environment is joined to the physical landscape we all share. There is growing awareness of those connections, of the adverse human impacts upon the natural world, and of the unity of all cultural and physical landscapes. Climate change, air and water pollution, soil loss and desertification, toxic wastes, and a host of other environmental problems are all matters of contemporary public debate and international compacts, and treaties. Acceptance of the interconnectedness and indivisibility of cultural and natural environments—the human creation and the physical endowment—is now more the rule than the exception.

AP KEY WORDS

Use the terms below with a ▮ to focus your study of AP Human Geography key words in this chapter.

acid precipitation
▮ aquaculture
aquifer
atmosphere
biome
biosphere
▮ brownfield
▮ carrying capacity
dead zones
▮ deforestation
▮ desertification
ecosphere
ecosystem
▮ ecotourism
environment
▮ environmental determinism
environmental justice
environmental pollution
fallowing
▮ genetically modified organism (GMO)
▮ greenbelts
▮ global climate change
greenhouse effect
hazardous waste
hydrologic cycle
hydrosphere
IPAT equation
lithosphere
▮ natural resource
▮ New Urbanism
Not In My Backyard (NIMBY)
ozone
▮ pastoral nomadism
▮ possibilism
rotation
▮ shifting cultivation
soil
soil erosion
▮ soil salinization
▮ sprawl
▮ sustainability
sustainable development
terracing
transboundary river basins
▮ urban growth boundary

AP TEST PRACTICE

Multiple Choice Questions

1. **People practicing sustainable development should**
   (A) use only the water available to them through groundwater that is replenished from rainfall and snowmelt.
   (B) harvest large amounts of fish to avoid overgrazing of their land caused by raising livestock.
   (C) practice slash and burn agriculture to gain as many resources from the land as possible in a short amount of time.
   (D) use aquafarming techniques to raise only the species of fish that are the most profitable.
   (E) use fossil fuels and plastics instead of renewable resources.

2. **According to the maps in Figure 13.2 on page 434, because of the rotation of the earth and the tilt of its axis,**
   (A) it is always warmer in the sea than on the land.
   (B) the temperature in January is warmer in the southern hemisphere, while the temperature in July is warmer in the northern hemisphere.
   (C) the temperature fluctuates randomly between hot and cold in both hemispheres.
   (D) the temperature in January in the northern hemisphere does not get as cold as it does in July in the southern hemisphere.
   (E) people living in Australia experience winter in January and summer in July like everyone else in the world.

3. **The problem of air pollution is evident in all of the following situations EXCEPT**
   (A) indoor pollutants from using cook fires inside the house cause lung ailments and death in developing countries.
   (B) industrial pollution of air and rivers as developing countries industrialize cause death and illness of people and livestock.
   (C) cities experience days of bad air quality due to the burning of fossil fuels in power plants and cars.
   (D) the dumping of tons of trash in landfills and in the oceans causes fish and marine mammals to become ill and die.
   (E) forests are devastated, and waterways are contaminated worldwide due to pollutants in the atmosphere that are brought to earth by acid rain.

4. **According to Table 13.1 on p. 443, the countries that have the most impact on climate change are**
   (A) rapidly industrializing countries with large populations like China and India.
   (B) countries with a high standard of living like the United States, which has not curbed its usage of fossil fuels.
   (C) countries with cold climates like Russia and Canada that can burn fossil fuels for heat.
   (D) developing countries with small populations like Ghana and Costa Rica.
   (E) European countries like the United Kingdom and Germany.

5. **Major concerns raised by tropical deforestation include all of the following EXCEPT**
   (A) forests help maintain the oxygen and carbon balance of the planet.
   (B) loss of habitat will affect biodiversity of species by causing mass extinctions.
   (C) land used for farming provides food for millions of people.
   (D) erosion of soil is rapid once trees are cut down, and the land quickly becomes infertile.
   (E) the rise in temperature due to lack of groundcover leads to heatwaves and other climate related events.

6. **The expansion or intensification of areas of degraded or destroyed soil and vegetation in arid and semi-arid regions of the world is called**
   (A) global climate change.
   (B) desertification.
   (C) erosion.
   (D) slash and burn agriculture.
   (E) transhumance.

7. **The building of dams in developing countries is made more problematic by**
   (A) retaliation by people whose homes were flooded.
   (B) environmental groups protesting the loss of animal habitats.
   (C) quick growth of tropical plants such as water hyacinth that clogs reservoirs.
   (D) deforestation of river banks and excessive rains that cause dams to burst.
   (E) lack of infrastructure to transport electricity produced to the people who need it.

8. **The use of irrigation**
   (A) causes areas downstream to experience drought conditions.
   (B) has allowed the production of 90% of the world's crops on just 17% of the land.
   (C) means that in many places groundwater is being pumped out sustainably, at a lower rate than it is being replenished.
   (D) is unnecessary except in the driest areas of the world.
   (E) is an inexpensive way for farmers to expand the arable portion of their land.

9. **Coastal dead zones are caused by**
   (A) rivers drying up due to overuse of groundwater by irrigation projects upstream.
   (B) die offs of birds, fish, and marine mammals.
   (C) red tides made up of toxic algae.
   (D) runoff of chemicals used by farmers and animal waste from feedlots.
   (E) industrial waste dumped into waterways.

10. **Radioactive and other hazardous wastes**
   (A) are disposed of in lagoons or pits to keep them from contaminating groundwater.
   (B) are not dangerous to humans or the environment as long as they are disposed of in the ocean where the large amount of water disperses the waste.
   (C) come from military and nuclear facilities, not from civilian sources.
   (D) are rarely exported to developing countries, which do not have the facilities to deal with them.
   (E) are incinerated or disposed of today in facilities in the desert or in lined landfills to keep contamination out of groundwater sources.

Free Response Questions

1. **Answer Parts A and B below.**
   (A) Identify and explain three geographic effects of global climate change.
   (B) Explain one cause of climate change and one solution to the problem.

2. **Explain three methods farmers can use to combat soil erosion.**

3. **Define the concepts of *environmental racism* and *environmental justice* and explain them using examples from the United States and two other countries.**