CHAPTER 18

When geography of health meets health ecology

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18.1 Introduction

Human deteriorations of the ecosystems have long been recognized as influencing health status by favouring the emergence of diseases as well as risk conditions for chronic diseases (Chivian and Berstein 2004; Patz et al. 2004). Furthermore, recent sudden awareness of the drastic and irreversible environmental changes, surpassing former predictions, has raised a serious anxiety regarding the consequences of emerging diseases worldwide. The swine flu pandemic that emerged in April 2009 with a new strain of influenza A virus subtype H1N1 (Shetty 2009) was a spectacular example of rapid spread in an interconnected world, and was furthermore a real health threat for people who could follow a near real-time report of suspected or confirmed cases with modern information technologies. A few years earlier, the SARS (Severe Acute Respiratory Syndrome) epidemic in 2002, then avian influenza epidemics in 2003, both emerging from South-east Asia, had also been spectacular disease outbreaks. With high fatality rates (contrary to the H1N1 pandemic), they generated a real ‘psychosis’ for people travelling in the epidemic areas. They caused a considerable reduction in tourism and economic activities, which consequently affected South-east Asia. Despite the actual risk of an influenza pandemic, the word ‘psychosis’ can be used if we consider the profile of human cases that were highly exposed to the viruses, and the magnitude of the epidemics that caused 774 deaths for the SARS-associated coronavirus and 256 deaths for the H5N1 virus, according to the World Health Organization (WHO) data as of April 2009 (http://www.who.int). These figures are far from the about 880,000 people killed by malaria in 2006, or the 1.9 to 2.4 million people who died after HIV infection in 2007 (also reported from the WHO in April 2009). Epidemics are now reported to the world and examples of rapid transmission through space and time have awakened the consciousness of possible sudden exposure to unexpected pathogens.

On the one hand, understanding health patterns, and especially the dynamic of diseases, requires an ecological approach to assess the interaction of humans with their environment. On the other hand, a geographical approach is also essential in a world facing increasing movements of people, transport of goods, animal, and agricultural products, that contribute to the transmission of pathogens worldwide. It is also an answer to understanding health patterns when observing similar pathologies in different places, being now boosted by increasing surveillance and reporting of disease incidences.

In this chapter, I propose to describe the methodologies used in both health geography and health ecology and see how these approaches complement each other. Then, I attempt to review the global human-induced pressures on the environment and their impact on health. I illustrate these patterns with major illnesses in the light of ecology and geography.
18.2 From microsatellites to satellites: the contribution of geography to health ecology

Health ecology considers individuals or populations in their environment, working on the assumption that health status is conditioned by the physical, biological, and social environments. Ecosystems are governed by a dynamic equilibrium between these environments. Any perturbation can induce cascading effects on the ecology of living organisms. In this frame, humans, also causing stress on ecosystems, can suffer from ecological imbalance threatening health. This approach takes into account every factor working on individual conditions, from the contact with parasites, pathogens, or pollutants in the physical and biological environments, to sanitary or working conditions in the social environment. Health ecology differs from traditional medical approaches that focus on symptoms of individual cases, and from epidemiology that focuses on the characterization of specific diseases. Epidemiological studies usually target the identification of the causes and mechanisms of the emergence of chronic or infectious diseases, while health ecology tackles the general processes of individuals and population interactions with the environment that can result in the emergence of pathologies. It takes into consideration the complexity of ecosystems and interactions between living organisms and usually proposes a conceptual approach to disease, where observed disease occurrences are used to build or validate models.

A fundamental ecological approach of health patterns is to consider the ecological niche of pathogens and vectors in the case of infectious diseases. The concept of niche was first described as a spatial unit by Grinnell (1917). It represents the space where conditions are suitable for a given species to live, in terms of food, refuge, and breeding site availability (Grinnell 1917). Another definition, presenting a niche as a functional unit, was proposed by Elton in 1927 and refined the spatial unit by considering the ecological position of the organism in the community or ecosystem (Elton 2001). Gause (1934) also put forward another definition with the ‘competitive exclusion principle’: two species cannot co-exist at the same locality if they have identical ecological requirements (Gause 1934; Hardin 1960). Finally, Hutchinson (1957) proposed considering a niche as an abstract multidimensional space, where each dimension represents the range of the environmental conditions (abiotic or biotic factors) that are required by the species. In health ecology, populations of pathogens are studied through their niche, and the dynamics of diseases through the overlaps in space and time of the niche of pathogens, with the niches of possible animal vectors and the introduction of humans. This approach requires a precise knowledge of species distribution and is enhanced by information of the pathogen and/or vector ecology that could allow their environmental niche modelling. Indeed, different organisms can have similar niches while one species can occupy different niches. Also, when organisms are introduced into a new environment, they can potentially invade an occupied niche and repress or reduce native organisms (Matthews 2004). This approach has been used to describe the invasion and emergence of zoonotic diseases.

Therefore, health ecology is a difficult challenge requiring researchers to assess the status and dynamics of ecosystems. Multidisciplinary approaches help to gather suitable information, including climate changes studies, land cover studies (using remote sensing techniques on earth observation satellites images), without neglecting primary inventories of faunal and floral diversities. Advances in genetics have also contributed to a better identification of living organisms and assessment of biodiversity. Regarding the transmission of vector-borne diseases, genetics help not just to find the limits between species and describe the niche of animals and parasites, but also to discover their evolutionary history and possible coevolution with phylogeny (and co-phylogeny) and explain their actual distribution with phylogeography (Despommier et al. 2007).

Health geography proposes a complementary approach to health ecology for studying infectious or non-infectious diseases and also health and healthcaresystems. It considers the interconnections
between socio-economic and ecological components that define the patterns of disease, the health status, or the needs for healthcare. It puts forward a spatial analysis of health from individuals to populations, at different scales, from a local to a regional and global point of view. Mapping techniques have been progressively integrated with epidemiological studies, first as tools to display information, as suggested by the legendary example of John Snow during the nineteenth century, then as new ways to explain disease patterns in space and time. The first steps in health geography were illustrated by Edmund Cooper with the cholera epidemic in London in 1854 (Brody et al. 2000). His maps showing the location of cholera deaths together with water pumps were later attributed to John Snow, who used them to support the hypothesis of a water contamination rather than an air contamination. Maps have been widely used in epidemiology to display incidence or prevalence of disease, and remain the major ‘geographical’ basic application of health studies. Moreover, health geography proposes techniques for spatial analysis to foresee ecological niche patterns at different scales and confront ecological observations in remote spaces. The geography of health has developed with the increasing power of computers and Geographic Information Systems (GIS) that allow us nowadays to deal with large datasets and integrate as many ecological variables as available to explain health patterns in space and time. Local observations and records are computed together to view environment and health from a global perspective (Gatrell 2002).

The geographical approach can be proposed as a synthetic tool to zoom out from the largest scale, each individual living organism, to the smallest, the globe, or vice versa. In other words, we suggest this metaphor of the magnification: from microsatellites, used as molecular markers in the field of genetics, to satellites used as ecological observers in the field of remote sensing.

Considering the relevance of such a multidisciplinary integrated approach of health study, we propose in this review to consider the global drivers of health patterns from a geographical and an ecological point of view.

18.3 From geography to ecology: an integrated approach of major health patterns

18.3.1 Human pressure, spatial inequalities, and implications for ecosystems and human health

Global population increase: the main pressure on ecosystems

The earth is currently being degraded at an increasing pace, under the pressure of a growing population gaining ground on wild biotopes and threatening ecosystem balance. This global tendency has been recorded through history, since the world population was estimated at about 1 million in year 10,000 BC, 170 million in year 1, and is now over 6.5 billion (US Census Bureau 2008a).

Nevertheless, the growth rate dramatically increased during the nineteenth (1 billion people in 1804) and twentieth centuries (2 billion in 1927 and 6 billion in 1999), with the growth peaking in 1962 and 1963 at 2.20 per cent per annum (that represents a doubling time of 35 years) (US Census Bureau 2008a). This exponential growth can be compared in its overpowering acceleration to the spread of epidemics or pandemics, with a latency phase preceding an outbreak. We can also see that population growth has rarely encountered a noticeable slowdown except in the middle of the fourteenth century, with one of the deadliest pandemics, the Black Death (Morens et al. 2008). Since 1963, the world growth rate has been decreasing and is currently about 1.14 per cent, representing a doubling time of 61 years. The world population is expected to stabilize at over 10 billion after 2200 if current growth continues and projections are validated (United Nations 1999). Medical advances associated with a better agricultural productivity may explain the recent rapid population growth.

However, this global tendency masks regional and local differences in demographic dynamics revealing a world divide in population and health. The world’s population growth occurs mostly in the poorest countries. During the second half of the twentieth century, the proportion of population living in developing countries has raised from 68 per cent to more than 80 per cent (United Nations 1999). The highest population natural increases (without
regard for migration, i.e. the difference between the birth rate and death rate) are recorded in Western Africa, Central Africa, Eastern Africa, and the Middle East, as well as in Madagascar, Afghanistan, French Guiana, and Guatemala, with growth rates ranging from 2.4 per cent to 3.6 per cent, according to the Population Reference Bureau (2008) (Fig. 18.1a). Africa is growing faster than any other region and is projected to represent a fifth of the world’s population in 2050, whereas it was less than a tenth in 1950. Unlike this trend, the Russian Federation and Eastern European countries have a negative growth rate. This spatial divide at a world scale also masks local divides between cities and countryside. Since 2008, more than one half of the world’s population lives in urban areas (having more than 2,000 inhabitants), whereas it was less than a third in 1950 (US Census Bureau 2008b). However, most of the urban population lives in small cities or villages. Figure 18.1b reveals a spatial fracture between urbanized and rural countries. The most urbanized countries (over 75 per cent of the population living in urban areas) are located in the Americas, Oceania, and Europe, while the most rural countries (less than 25 per cent) are in Africa and Asia.

These spatial heterogeneities in the population dynamics imply local difficulties for the high-growth areas in dealing with the consecutive need for food, infrastructure, and services. In the poorest countries, this results in a concentration of poverty and induces sanitation and health problems. It is finally interesting to notice a significant negative correlation between the life expectancy and the natural population growth for the world countries (−0.56 with p<0.05), without getting into the complex relations between the populations dynamics and health patterns, but considered from a spatial point of view, that some regions are again distinguished by a very low life expectancy. Figure 18.1a illustrates that the lowest life expectancy is encountered in Central and Southern Africa (the lowest in Swaziland, at 33 years old), as well as Afghanistan, which also presents a less urbanized populations with high natural growth.

These population dynamics are also considered a major driving pressure on ecosystems, with possible return effects on health. A major implication of population growth is the need for agricultural products and land. The most visible consequence is the conversion of forests to agricultural lands (about 13 million hectares per year, according to FAO in 2008) that has risen as the main environmental issue since the twentieth century.

Indeed, the natural population growth is significantly correlated to the annual rate of forest cover change between 1990 and 2000 (−0.35 with p<0.05; Table 18.1 and between 2000 and 2005; −0.35 with p<0.05; Table 18.1), when compared to the forestry statistics from the Global Forest Resources Assessment 2005 (FAO 2006). The annual rate of forest change shows a latitudinal pattern, with the highest net loss of forests in equatorial and tropical countries (mainly Central Africa and South America) and an extension of forest areas in temperate countries, with China recently conducting large-scale afforestation activities.

On top of human-induced deforestation, forests can also be affected by natural disasters (or occasionally from human origin): fire, drought, storms, floods, and pests (animals or diseases). This global pressure of humans on ecosystems has direct and indirect negative consequences on human health, which can be first related to the introduction of people in wild biotopes.

**Increasing proximity with wildlife: a threat for a rapid disease outbreak**

By moving deeper into dense forests humans have been exposed to virulent pathogens. The first human infections of Ebola hemorrhagic fever were attributed to the handling of wild animals, chimpanzees, gorillas, monkeys, and antelopes in tropical African ecosystems (Gonzalez et al. 2005). Recent cases of Sylvatic Yellow Fever in Brazil (23 confirmed cases, 13 of whom died, from December 2007 to January 2008) have also shown the risk of exposure to harmful pathogens in wild environments (World Health Organization 2008). In all cases, the victims became sick after a stay in forests where they were bitten by infected mosquitoes (‘jungle’ yellow fever is a disease of monkeys, spread with mosquitoes). The number of yellow fever epidemics has risen during the last 20 years, affecting more countries in Western and Central Africa and South America (World Health Organization 2001). Yellow fever is enzootic in the Amazonian forest and
Figure 18.1 World distribution of (a) life expectancy at birth (data source: Population Reference Bureau 2008); (b) percentage of population living in urban areas (towns with more than 2,000 inhabitants; data source: Population Reference Bureau 2008); (c) incidence of malaria in 2004 for 100,000 inhabitants (data source: GIDEON database 2009); (d) incidence of H1N1 on June 11th 2009 for 1,000,000 inhabitants (data source: WHO 2009).
human cases are regularly reported in the neighbouring countries (Brazil, French Guiana, Suriname, Guyana, Venezuela, Colombia, Ecuador, Peru, Bolivia and even in the South, in Paraguay and Argentina). Infections have occurred following migrations of population in enzootic areas, illustrating the increasing proximity between humans and mosquitoes.

Forest-related activities, including logging, mining, hunting, and increasingly recreational activities expose people to unexpected pathogens for which they are not immunized. These activities are also connected, while logging or mining requires the construction of roads this later favours hunting and other recreational practices. These have been associated with cases of yellow fever, but also malaria and leishmaniasis (Chivian 2003; Patz et al. 2004). In these cases, humans are ‘active’ for transmission as they make contact with pathogens by entering wild biotopes. Therefore, the profiles of human cases correspond to people involved with activities in forests.

Further infections can occur when the circulation of the pathogens moves from wild to anthropized environments, typically brought out of forests by an animal vector. Humans are relatively passive in the transmission as they can be affected in close proximity to their living place. Consequently, people from any age or sex are likely to be affected. The development of livestock and the extent of grazing areas close to forests have been shown to attract pathogens out of the forest and cause epidemics. This was first illustrated in 1957 with the identification of the Kyasanur virus (Flavivirus) from a forested region in the Shimoga district of Karnataka, south-west India (Pattnaik 2006). Since then, the Kyasanur forest disease has been increasingly but exclusively reported from this region, probably as a result of the population growth and development of cattle (Gould and Solomon 2008). The Kyasanur virus is transmitted by ticks (Haemaphysalis spp.), involves mammals as reservoirs, and can accidentally infect humans. Deforestation and the introduction of humans and cattle in proximity to wild habitats have helped the transmission of Kyasanur virus. Ticks are brought out of the forests by wild mammals and then feed on cattle or humans in these fragmented habitats that are now composed of dense forest alternating with agricultural lands.

Since 2000, increasing cases have been detected from Karnataka (Pattnaik 2006), and serological surveys have revealed the existence of another major silent focus, in the Nicobar and Andaman islands in India (Padbidri et al. 2002; Pattnaik 2006). Genetically close viruses causing similar tick-borne viral hemorrhagic fevers have been described in other countries. The Nanjianyin virus, isolated in Yunnan (China) during human serological investigations in 1989, is now described as a variant of the Kyasanur virus (Wang et al. 2009). Another variant is the Alkhurma virus that was first reported in 1992 in the Arabian Peninsula (Charrel et al. 2005) and has caused increasing human cases (Pattnaik 2006; Gould and Solomon, 2008). These variants have emerged in foci presenting very different biotopes.

Table 18.1 Summary of statistically significant correlations between the rate of forest cover changes and demographic indicators or disease incidences (correlation coefficient with \(p<0.05\)).

<table>
<thead>
<tr>
<th>Rate of forest cover change between</th>
<th>1990 and 2000</th>
<th>2000 and 2005</th>
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<tr>
<td>Demographic indicators (Source: Population Reference Bureau 2008)</td>
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<tr>
<td>Rate of natural increase</td>
<td>(-0.35)</td>
<td>(-0.35)</td>
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<tr>
<td>Percentage of population living in urban areas</td>
<td>0.33</td>
<td>0.27</td>
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<tr>
<td>Life expectancy at birth</td>
<td>0.35</td>
<td>0.29</td>
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<tr>
<td>Diseases prevalences</td>
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<tr>
<td>Malaria incidence in 2004 (GIDEON database)</td>
<td>(-0.28)</td>
<td>(-0.24)</td>
</tr>
<tr>
<td>Dengue incidence in 2007 (GIDEON database)</td>
<td>(-0.35)</td>
<td>(-0.30)</td>
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than those of Karnataka, higher in latitude in China with a colder climate, and under a dry and hot climate in the Arabian Peninsula.

Another example of the transmission of pathogens following the expansion of human settlements on forested areas is the spread of the Lyme disease. This infection is the most common tick-borne disease in North America and Europe, increasingly affecting the United States, with a very high prevalence (9.1 cases per 100,000 persons in 2007) (Centers for Disease Control and Prevention 2009). Lyme disease, caused by bacteria from the genus *Borrelia*, is transmitted to humans through the bites of ticks (mostly *Ixodes scapularis* in the United States). Tick larvae can get infected while feeding on forest rodents that are the main reservoir of the disease. Adult ticks take the final bloodmeal on larger vertebrates, such as deer in the United States. The circulation of these rodents and deer at the border or out of their natural habitat contributes to the spread of ticks close to humans that can then be accidentally bitten.

Wild animals and ticks have also been responsible for the recent transmission of the Crimean-Congo hemorrhagic fever (CCHF) virus to domestic and human populations in Turkey. CCHF has emerged since 2002, with seasonal epidemics (Yilmaz et al. 2009). Here again, increasing pullulations of wild animals and a closer proximity between domestic animals and humans may explain the emergence.

Beyond the global driving force induced by the increase of the human population on earth, several global changes (long-term) affecting ecosystems have been observed and are suspected to have negative effects on human health.

### 18.3.2 Global changes, alteration of ecosystems, and expanding sources of infection

*Deforestation, habitat fragmentation: consequences on the environmental niches of animal vectors and contacts with humans*

The consequences for human health of the damage caused by anthropogenic actions on ecosystems are difficult to assess. However, at a worldwide scale, we can already observe some links between these ecological changes and some health patterns. For instance, there is a significant correlation between the incidence of malaria in 2004 (source: GIDEON database, http://www.GIDEONonline.com) and the annual rate of forest cover change between 1990 and 2000 (−0.28 with p<0.05, for 147 countries; Table 18.1) and between 2000 and 2005 (−0.24 with p<0.05), using the forestry statistics from the Global Forest Resources Assessment 2005 (FAO 2006). The countries that have the highest rate of forest loss during these two periods are also the countries where the incidence of malaria was highest in 2004. This relationship should be interpreted carefully with regards to the complexity of ecological and societal factors involved in the transmission of malaria. Malaria occurs in equatorial and tropical countries where forests are denser, and we might have expected a geographical link between forest extent and the incidence of malaria. Nevertheless, there is no statistically significant correlation between the surface of forested areas or the annual changes in surface and the incidence of malaria. The role of deforestation in the emergence of malaria has been explained by the consecutive increase of ecological niches for the *Anopheles* mosquito vectors of malaria, and higher numbers of humans getting into these uninhabited areas for contact (Patz et al. 2004). Changes in ecological niches have been interpreted in different ways. First, it could be the increase of water reservoirs in space and time, when the soil is compacted and used for agriculture or constructions, that allows mosquitoes to breed. Also, in the Amazon, deforestation has decreased the acidity of soils and water reservoirs for *Anopheles darlingi*, the main vector of malaria, which has consequently proliferated (Chivian 2003; Vittor et al. 2006). In West Africa, the loss of savannah and riverine forests has contributed to expand the *Anopheles* population that preferentially breeds in arid areas (Chivian 2003).

At a worldwide scale, the map showing the incidence of malaria in 2004 (Fig. 18.1c) emphasizes the very high rates of malaria in African tropical countries. These countries are also characterized by important deforestation. However, such important forest changes are observed in other countries, like South America and South-east Asia, without such high malaria incidence. Demographic variables (such as natural increase, the percentage of
population living in urban areas, or life expectancy at birth) help us to understand the specificities of these African countries with high rates of malaria: their population is mostly rural, increases rapidly, and still has a low life expectancy (these three variables correlate significantly with the malaria incidence; Table 18.1), and that reflects the lack of healthcare and difficulties in living conditions. A multiple regression between the incidence of malaria in 2004 (as a dependent variable) and these three demographic variables and the annual rate of forest extent changes between 2000 and 2005 (pairwise deletion, i.e. a minimum of 150 pairs) shows that life expectancy is the best predictor. This example illustrates how a geographical approach can complete an environmental study to explain health patterns with further social variables.

Deforestation usually occurs within small patches, creating either isolated clearings in large forests or isolated small forests surrounded by agricultural fields. This is described as forest fragmentation, which leads to an increase in the border contact between humans and vector-dense areas and consequently the risk of transmission of vector-borne diseases. Wild animals living in the remaining forests have their ecological niche altered and experience changes in their density with the possible extinction or invasion of species.

Biodiversity changes: consequences on the diversity and density of vectors and pathogens
Cutting down trees radically modifies every component of the ecosystem starting with microclimate variables (local temperature, air humidity), then water and soil reserves, soil composition, soil humidity, and later the biodiversity and structure of plant and animal communities. The anthropization of the ecosystems damages habitats and affects plants and animals species, which can finally disappear. Species diversity generally decreases from rural to peri-urban to then urban ecosystems, as was calculated for mosquitoes in the Peru (Johnson et al. 2008). The inexorable loss of biodiversity may have different effects on the pathogenicity of infectious vector-borne agents. An intuitive understanding could be that a decrease in the diversity of animals leads to a decrease in the diversity of pathogens and consequently a lower risk of infection. This idea may be illustrated by the greater threat of infectious diseases in tropical areas compared with regions in higher latitudes that present a general lower biodiversity (Chivian 2003). However, the diversity of animal hosts has been proved to have a diluting effect on the pathogenicity of some infectious agents. In the case of Lyme disease, an increase in the diversity of hosts has the effect of lowering the nymphal infection prevalence of ticks (LoGiudice et al. 2003). In epidemic areas, human encroachment, leading to a decrease in biodiversity, has contributed to higher densities of rodent population and the concentration of the bacteria responsible for Lyme disease in a few host species. The dilution effect applies to diseases transmitted by vectors (typically mosquitoes or ticks) that can feed and get infected on different hosts.

This dilution effect also concerns the density of populations and depends on the size of habitats. A local absence of deer may increase tick feeding on rodents and create a higher risk of Lyme disease transmission (Perkins et al. 2006). Therefore, pushing deer away from villages may have adverse effects on the risk of transmission.

From a geographical point of view, these observations can be comprehended at different scales: 1—on a global scale, a greater diversity of hosts and vectors in the tropics could be associated to a higher risk of infection; 2—on a regional scale, a decrease of biodiversity has a concentration effect on pathogens in fewer hosts for a higher pathogenicity; and 3—on a local scale, the absence of a host may also increase the prevalence in alternative hosts and induces the emergence of tick-borne or other vector-borne disease hotspots. Further observations could be proposed on the diversity of parasites and pathogens themselves regarding biodiversity and global changes.

The decrease of animal species diversity should be considered within the frame of the equilibrium between species, the species competing for food, shelter, or some species being predators of others. The extinction of one species is a break in the ecological chain that will result in major changes in the diversity and densities of remaining species. Animal species are moved and balanced following changes in their biotopes. A radical action, such as cutting down forests, makes associated wild animal species
disappear, and offers a new empty niche to opportunistic animals. A few species may rapidly invade this space, as can be observed with rodent invasions in agricultural fields gained on forests. These species may also bring pathogens and cause new disease outbreaks. The lower diversity of species in peri-urban and urban environments also explains some invasions of species that cause high rates of pathogen transmission in urban areas, as has been described for Culex species in the United States (Kutz et al. 2003, Johnson et al. 2008).

Agricultural practices and resource management: consequences for pathogen dynamics

One of the major impacts of agriculture on the environment is the hydrological change brought about by the use of water to grow plants. Irrigation and drainage require the construction of canals, reservoirs, or dams that artificially maintain water during long periods within these infrastructures as well as in the irrigated fields. Watering systems also contribute to a smaller extent to the presence of puddles on compacted soils.

Water can be a direct vector of parasites and pathogens, rapidly contaminate different areas, and create large epidemics. Several diseases are associated with water, mainly from bacterial origin (leptospirosis, cholera, botulism, dysentery, legionellosis, typhoid fever, cryptosporidiosis, colibacillosis, i.e. infection with Escherichia coli, etc.) and parasitic origin (schistosomiasis also known as bilharzia, dracunculiasis, echinococcosis, amebiasis, enterobiasis, etc.) but also from viral origin (poliomyelitis, i.e. polio, hepatitis A and E, gastroenteritis, etc.). All these diseases may be amplified as soon as agriculture favours conditions to maintain water. Water-related diseases can be classified in three groups. First, water-borne diseases result from the consumption of water contaminated by human or animal ejections with bacteria, parasites, or viruses (in the case of cholera, hepatitis A and E). Second, water-based diseases are caused by parasites or pathogens having part of their life-cycle in water and another part in an intermediate animal vector, such as molluscs or snails (in the case of schistosomiasis and dracunculiasis) and mammals (case of leptospirosis). Third, vector-borne diseases can be linked with water without any direct connection, but using vectors breeding or living in or near water, in particular mosquitoes, midges, and flies. Mosquitoes, which represent the most extensive family of vector insects, can transmit malaria, filariasis, dengue fever, yellow fever, Japanese encephalitis, West Nile virus, Rift Valley fever, and chikungunya fever. For vector-borne diseases, hydrological changes affect the ecology of the vectors. On the one hand, some animals, like mammals, can respond radially to the presence of water, for example deciding whether they are attracted or not and migrate or not. On the other hand, mosquitoes or snails may find more places for breeding and their population may increase in space and density consecutively. Indeed malaria, which is the most important parasitic infectious disease in terms of prevalence, and schistosomiasis, which is the second most important parasitic disease, are particularly associated with hydrological conditions. Malaria is caused by a protozoan parasite of the genus Plasmodium transmitted by mosquitoes that breed in fresh or occasionally brackish water. Schistosomiasis is a chronic parasitic disease that uses freshwater snails as an intermediate host and humans as a definitive host. Leonardo et al. (2005) used a GIS and the analysis of satellite images with remote sensing to demonstrate the importance of the proximity to water to the incidence of malaria and schistosomiasis in the Philippines. Their study is an example of the potential of these technologies in health geography to assess prevalences and help decision-making on intervention and treatment.

Beyond the consequences of individual agricultural practices on human health, water management projects have had serious effects on ecosystems and as a result on human health. They have developed throughout the world as an answer to the increasing population and need for food during the twentieth century. They allow farmers to produce twice or three times more than the non-irrigated fields that are limited to a single harvest per year in tropical countries. At the end of the twentieth century, there were over 45,000 large dams (impoundments over 15 m high or storing at least 3 million m³ of water) in 140 countries and over 800,000 small dams (World Commission on Dams 2000; Keiser et al. 2005). Since the 1980s, irrigated fields have accounted for more than half of the increase in food
production (World Commission on Dams 2000). Nevertheless, these water management projects have also had considerable consequences for ecosystems, by modifying the natural flow of streams and rivers, by drying fields with drainage, or maintaining water with artificial flooding (especially for rice production). They have had direct adverse consequences on human health, by causing several noticeable epidemics worldwide. Schistosomiasis has been the major threat following the construction of dams. It has emerged since the building of the first large dams, Aswan High Dam in Egypt, Kariba Dam in Zambia, and Mozambique and Akosombo Dam in Ghana, all operating in the 1960s (Malek 1975; World Commission on Dams 2000).

Rift Valley Fever, a viral zoonosis transmitted by mosquitoes (typically *Aedes* or *Culex* genera), has also spread after the building of the Aswan and Kariba dams (World Commission on Dams 2000). However, in a comprehensive study of the effects of irrigation and large dams on the incidence of malaria, Keiser *et al.* (2005) noted that research assessing health impacts must be used with care, as surveys are generally conducted after the construction of the dams and they deal with confounding factors. This study listed from the literature the surveys of malaria in relation to dam construction, but failed to relevantly quantify a global health impact due to the heterogeneity of data. It also noted that the impact of small dams on malaria is underestimated because of the lack of studies, even though their total shoreline is greater when compared with large dams.

Agricultural practices create local hydrological conditions that disrupt the continuum of the biotope in space and time. The alternation of different crops and the introduction of new species are also radical ecological changes in a biotope, since their production requires different use of water, fertilizer, or pesticides. The spread of maize production throughout the world has caused such changes. Maize has been introduced in tropical countries alternately with rice, and does not require the flooding of paddies during its growth. The use of water to grow crops (such as flooding rice fields, or watering crops) and the alternation of different crop species, condition not only the presence and absence of animal species but also their ecology. Animals living in agricultural fields may adapt their reproduction to the presence of food and possibilities of shelter. Rodents are one such very reactive animal, moving to different fields according to the stage of crops and increasing in density during harvest. Cavia *et al.* (2005) showed the effect of corn and wheat harvest on the *Akodon azarae* population in Argentina and their ability to maximize fitness in periodically disturbed habitats. By conditioning the structure of animal populations, these agricultural practices also indirectly determine the transmission of vector-borne diseases.

Over-exploitation of natural resources for agriculture has already shown dramatic effects beyond the loss of vegetal cover and biodiversity. Agricultural fields are exposed to wind and water erosion, which is increased by agricultural practices. Irrigation also accelerates soil salination leading to unfertile lands. The loss of soil and increasing desertification (in low-rainfall areas) forces farmers to move and find more fertile agricultural spaces: this issue has also emerged as a major challenge with regard to the lack of agricultural space, famine, poverty, and health. The United Nations Convention to Combat Desertification (UNCCD) was adopted in 1994, and has been signed by 191 countries (as at September 2005). It estimates that 250 million people are affected by desertification, and about one billion people are at risk in over one hundred countries, which are also among the world’s poorest.

The conversion of forests to agricultural lands has also led to dramatic soil and water pollution. A spectacular example is the pollution of the Amazon with mercury, formally found in rainforest soils, and increasingly accumulating in fishes (Passos and Mergler 2008; Patz *et al.* 2004). Agricultural practices, and especially intensive farming, also generate pollution by nitrates, pesticides, and heavy metals (lead, mercury, etc.), that cause poisoning in humans. However, health systems still fail to detect the extent of the effect of these pollutions on human health, due to the technical difficulty and high cost of investigation for such poisoning in bodies. Pesticides may cause about 10,000 deaths out of 2 million poisonings each year, according to the United Nations, and three quarters occur in developing countries with inappropriate protective measures (Quijano *et al.* 1993;
Pesticides also have long-term effects through increasing the risk of cancer and disrupting the immune, nervous, reproductive, and endocrine systems (Horrigan et al. 2002). Moreover, growth enhancers used in factory farms are found in manure and pollute ground and surface water. They may cause breast and testicular cancers in humans (Horrigan et al. 2002; Soto et al. 2004). The use of antibiotics for animal growth may also be responsible for increasing antibiotic resistance in humans and jeopardize the effectiveness of similar antibiotics in human medicine (Horrigan et al. 2002). Here again, the effects on humans are difficult to assess but may be dramatic if confirmed when we consider the increasing use in developing countries. Another means of pollution from intensive agriculture is air transmission, which has local effects. Substances may be released in the air from confinement buildings or while spreading manure (Horrigan et al. 2002).

Some indirect impacts of agriculture on human health are linked to changes in livestock management. The intensification of livestock farming with animal husbandry has been pointed to as contributing to the development of human diseases (Chivian 2003). Animals are raised in confinement at high stocking density, to reduce space and costs, and become incubators of pathogens and parasites that can be harmful not only to their health but also to other animals and humans.

Disruption of the ecological chains in livestock management has raised serious concerns with the emergence of the bovine spongiform encephalopathy (also known as mad cow disease), first detected in 1986 in the United Kingdom (Richt and Hall 2008). Hypotheses about its origin include bad farming practices, with the administration of animal contaminated proteins in meal. Richt and Hall (2008) have recently shown that an atypical form of bovine spongiform encephalopathy had the same type of prion protein gene mutation as found in a human patient affected by the Creutzfeldt-Jakob disease, which potentially explains cattle to human transmission when eating contaminated meat.

Illnesses caused by food consumption are preponderant in public health, with more than 200 diseases described, caused by viruses, bacteria, parasites, toxins, metals, and prions (Mead et al. 1999). Common food-borne infections are caused by the bacteria Campylobacter and Salmonella and with a lower extent but higher mortality Escherichia coli and Listeria (Horrigan et al. 2002).

Transmission of pathogens from livestock to humans can occur directly, being favoured by unhealthy working conditions in farms and slaughterhouses. One example is Streptococcus suis serotype 2, an enzootic bacteria affecting pigs and present in countries with extensive pig farming (Tang et al. 2006). Infections in humans can be associated with meningitis (about 80 per cent of all cases), septicemia, endocarditis, and deafness (Sriskandan and Slater 2006; Tang et al. 2006). Human cases have been increasingly reported from Asia, with an important outbreak in 2005 in China, which caused 38 deaths out of 204 human cases (Tang et al. 2006). This emergence follows growth in livestock production, and probably better surveillance of infectious diseases after the H5N1 epidemics.

Livestock can act as reservoir of parasites and pathogens, which can be amplified with the density of animals. Livestock can serve as intermediate host in a complex life-cycle and present a great risk for human health because of their proximity to villages or cities. This is illustrated by Japanese encephalitis epidemics, whose responsible virus is transmitted by mosquitoes (belonging to the Culex tritaeniorhynchus and Culex vishnui groups) and also circulates in water birds and pigs (Gould and Solomon 2008). The virus reproduces and is amplified in pigs, through which mosquitoes get infected. Japanese encephalitis is widespread over South-east Asia and Australasia, where it has expanded with the development of agriculture. The annual human incidence is very high but fluctuating (between 30,000 and 50,000 cases), with about 10,000–15,000 fatal cases [C1] (Erlanger et al. 2009). The proximity of pig farms with irrigated rice fields creates favourable conditions for the disease emergence. The rapid population increase in South and South-east Asia, associated with the development of irrigated rice farming and pig rearing, explains the emergence and spread of Japanese encephalitis in these regions.

Other viruses have benefited from the concentration of animals in husbandry, and mutate before spilling over to other animal vectors or humans.
A major example for animal and human health is the case of influenza virus, with the frequent emergence of new strains. Intensive poultry rearing in Asia has been shown to be a major incubator of new strains of viruses causing several outbreaks (Mayer 2000). Avian influenza viruses infecting poultry and a great variety of birds are divided into two groups: subtypes H5 and H7 potentially causing the highly pathogenic avian influenza (HPAI) and the other subtypes causing the low-pathogenic avian influenza (LPAI) (Alexander 2007). Avian influenza is an ancient disease that has caused epidemics through history with a catastrophic pandemic in 1918 with the Spanish flu (Webster et al. 2006). However, infections have been expanding worldwide in poultry since the 1990s with the highly pathogenic H5N1 strain that has affected over 433 persons, mostly in Asia, and has killed 262 (60 per cent) from 2003 to 2009 (WHO 2009). Alexander (2007) suggests the increasing densities in poultry production, the possible changes in wild bird movements, but also higher surveillance and diagnostic capabilities, as explanations for such emergences.

Urbanization: the consequences of inadequate planning on health situation
The rapid population increase and global migration from rural to urban centres (with over one half of the total population living in urban areas, see Subsection 18.3.1) raises major health issues (Sutherst 2004). These changes have mostly occurred in developing countries, and the health consequences can be particularly dramatic in the poorest countries as the urbanization is usually not controlled and not planned. Possible consequences relevant to public health, including inadequate housing, deteriorated water, sewage, and waste management, offer favourable conditions for the emergence of water-borne, mosquito-borne, and rodent-borne diseases (Gubler 1998).

Rapid urbanization poses sanitary problems when not accompanied by infrastructures to ensure environmental health. In tropical and equatorial countries with heavy rainfall, inadequate drainage of water along roads and pavements favours the transmission of water-borne diseases. These diseases rapidly spread with insufficient sanitation and poor water treatment systems when pollution on the surface water percolates into drinking water wells. Together with inadequate waste collection and treatment it also offers habitats for different animal vectors, such as mosquito larvae that develop in standing water or used tires and containers, before the adults spread and potentially transmit dengue fever, chikungunya, West Nile fever, yellow fever, and lymphatic filariasis (Gubler 1998; Sutherst 2004; Estallo et al. 2008), other arthropods, such as the ticks that are potential vectors of Lyme disease (LoGiudice et al. 2003), small mammals, and especially rodents that look for a refuge and food in human garbage, and that are potential hosts of fleas and reservoirs of plague, leptospirosis and hantaviral, and arenaviral infections (Jittapalapong et al. 2009).

As soon as animal vectors and reservoirs find a suitable habitat (including shelter, a place to reproduce and protect themselves from predators and food), their population may increase rapidly in space and density, and may constitute a threat to human health. The management of waste water and garbage is a determinant of health in urban areas.

Dengue fever is the most important arboviral disease with about 2.5 billion people at risk in over 100 countries worldwide (Guha-Sapir and Schimmer 2005). Dengue fever, which has essentially caused epidemics in urban areas, is increasingly reported from peri-urban and rural areas, following a spread of its vectors (Aedes mosquitoes) in association with environmental changes (Chareonsook et al. 1999; Guha-Sapir and Schimmer 2005; Ellis and Wilcox 2009). Chareonsook et al. (1999) stated that Thailand, regularly affected by dengue epidemics, recorded higher dengue incidence in rural (102.2 per 100,000) than urban areas (95.4 per 100,000) in 1997. Indeed, we found a statistically significant negative correlation between dengue incidence per country in 2007 and the variable measuring the rate of forest changes, (−0.35 with forest cover change between 1990 and 2000, and -0.30 with forest cover change between 2000 and 2005; Table 18.1). This reflects again the link between population pressure, the consequences for ecosystems, and the global negative impact on human health.
Global climate changes

Evidence of a global climate change has only risen recently in the public consciousness and its irreversibility arouses great concern when considering the possible negative impacts on health. The Intergovernmental Panel on Climate Change (2007) has recognized the responsibility of human activities in most climate change, with an increase in the atmospheric concentration of greenhouse gases and aerosols and land surface changes. Causes include deforestation (reduction of the absorption of carbon dioxide and emission of gases with fires), urbanization (increase of the albedo), and agricultural practices (such as irrigation modifying the hydrological cycles, or livestock production causing large emissions of methane and nitrous oxides) (Chivian 2003; IPCC 2007; Bates et al. 2008). The increase of troposphere carbon dioxide (CO₂) from 280 parts per million by volume (ppmv) 420,000 years ago to 370 ppmv today has largely contributed to the global increase of temperatures, referred to as global warming (Chivian 2003). Some global trends in climate change are observed: oceans absorb almost all the energy from global warming; temperatures are increasing faster at higher latitudes; heat waves increase in intensity and extent with more elevated night temperatures; fresh water resources decrease; and weather extremes (especially responsible for droughts and floods) increase in intensity, higher winds accelerate and make the climate more unstable (Relman et al. 2008). Solomon et al. (2009) outlined that the CO₂ emissions responsible for climate change cause a long term increase of temperatures that could not be significantly reduced 1,000 years after the emissions stopped. Even if drastic actions are taken to reduce the human impact on CO₂ emissions, the patterns of temperatures and rainfall will evolve in a negative way for earth health and human health. Several researchers have tried to assess the consequences of climate changes on the incidence of diseases.

First, the role played by oceans as heat sinks may have direct consequences on the diseases linked to ocean temperatures. Lobitz et al. (2000) showed the relationship between cholera epidemics and climatic variations in Bangladesh by using remote sensing techniques. Cholera, caused by the bacterium *Vibrio cholerae*, frequently affects Bangladesh and India and occasionally some other developing countries. It attaches preferentially to zooplankton, and especially copepods, to spread (Lobitz et al. 2000). The authors compared the 1992–1995 cholera epidemics to measurements of the Sea Surface Temperatures (SST) that present a similar yearly cycle. A global increase of the SST may lead to a higher risk of cholera transmission in this area.

Second, global warming, with rising temperatures and more variable precipitations, may have diverse consequences on human health. Heat waves may directly increase human mortality, as happened in Europe in 2003 when over 30,000 people died (Kosatsky 2005). Variation in rainfall may affect the supply of fresh water and the production of agricultural food that could be critical for the poorest populations. Increased atmospheric and surface temperatures and their impact on hydrological cycles necessarily disrupt the ecology of infectious diseases. They modify the distribution of the animal vectors and reservoirs with an expansion of their range, especially to higher elevations and higher temperatures (Relman et al. 2008). Indeed, climatic variables such as temperature, humidity, and rainfall significantly influence the development and survival of mosquitoes (Estallo et al. 2008). Mosquito-borne diseases that nowadays affect tropical areas (such as malaria or dengue fever) may consequently expand to higher latitudes. This was illustrated by the chikungunya epidemics transmitted by *Aedes albopictus* in northern Italy after an accidental introduction by traveller coming from India (Beltrame et al. 2007). The chikungunya virus first emerged in Africa before outbreaks were recorded in Central Asia, South-east Asia, and other parts of the World (Chevillon et al. 2008). It is transmitted by two major species of mosquitoes, *Aedes albopictus* and *Aedes aegypti*, which are also vectors of dengue virus (Chevillon et al. 2008). *Aedes albopictus* was first recorded in 1990 in Italy and seems to have quickly spread across the country since then (Beltrame et al. 2007). This expansion has already shown health consequences and highlights the threat of having these two species spread, with regards to chikungunya and dengue fever, but also yellow fever and Rift Valley fever for *Aedes aegypti* (Gould and Higgs 2009).
Third, extreme weather events linked to the El Niño Southern Oscillation (ENSO) have been associated with incidences of malaria, dengue, and Rift Valley fever (Chivian 2003). ENSO generates climate variability with warm (El Niño) and cool (La Niña) phases of surface water temperatures that cause heat waves and droughts in Africa and Asia, as well as heavy rain and floods in South America (Chivian 2003). These events occur irregularly. Different studies have shown an increase in the incidence of dengue fever with ENSO (Hales et al. 1996; Keating 2001). However, Guha-Sapir and Schimmer (2005) interestingly have doubts about relating the incidence of dengue epidemics with climatic changes, as regards the complexity of relations and the scarcity of data and models that have been used to make such correlations.

Climate changes were also proved to affect the distribution and the density of rodent populations. Engelthaler et al. (1999) relate that several hantaviral epidemics (Hantavirus Pulmonary Syndrome (HPS) outbreak in the Four Corners region in 1993, HPS outbreak in western Paraguay in 1995 and 1996) were associated with an increase in rodent populations following increasing rainfall and El Niño events. They argue that higher precipitations contributed to abundant food resources and a consequent increase in the density of rodents.

There is no linear effect between climate change and disease patterns, since climate impacts on different factors involved in the transmission of diseases. Predicting future climatic conditions and assessing their consequences to human health is also challenging with regard to the complexity of these relations and the difficulty in measuring the consequences of human activities on global climate changes. This may explain why past scenarios are regularly and radically revisited.

### 18.3.3 Mobility, species introduction, and environmental contaminations of pathogens

International trade, professional travel, and tourism are globally increasing following economic development and the decreasing time needed to reach remote locations. These movements have contributed to the spread of pathogens and parasites with eventually their animal vectors moved with people or products. Mobility poses a complex challenge in the assessment of health patterns since pathogens can be spread around the world within a few days or hours, and can rapidly infect people far from the ecological area where they have been maintained and have evolved for years. Historically, the importance of transport in the emergence of epidemics has been well documented. One of the deadliest pandemics, the Black Plague also known as the Black Death, probably originated in China in the 1330s before progressing to central Asia and Europe along caravan and shipping routes (Morens et al. 2008). It killed about 34 million humans in Europe and 16 million humans in Asia and was scarcely confined, owing to lack of knowledge about transmission and medical care (Morens et al. 2008). However, a precursory quarantine (40 days) was applied to ships on arrival at port to limit the spread (Morens et al. 2008).

Regarding health, the question of mobility is first related to the voluntary, but most often accidental, spread of invasive alien species, which is now recognized as one of the greatest threat to ecology, economy, and health, with irreversible consequences (Matthews 2004). Species are carried with the growing transport of goods and people worldwide, and a few have become invasive. Invasive species belong to all major taxonomic groups, including viruses, fungi, algae, mosses, ferns, higher plants, invertebrates, fish, amphibians, reptiles, birds, and mammals (Matthews 2004). Some examples of alien species introduction to an ecosystem are spectacular. Among the worst, the Nile perch (Lates niloticus) introduced in 1954 to Lake Victoria has contributed to the extinction of more than 200 endemic fish species (Lowe et al. 2001). Water hyacinth (Eichhornia crassipes) has spread to over 50 countries, invading lakes and rivers, and with a very fast doubling time (about 12 days) has damaged fresh water ecosystems by limiting sunlight and oxygen (Lowe et al. 2001). Rodents are also worthy examples of invasive species. Rodents, which represent 40 per cent of mammalian species, are present worldwide on all continents other than Antarctica and inhabit most ecosystems (Wilson and Reeder 2005; Carleton 1984). They can breed rapidly, eat a large variety of food, and can adapt to fast environmental changes (Carleton 1984).
prising to see their population increasing rapidly and spreading before reaching a new equilibrium in the biotope.

Introduced and invasive species also bring into the ecosystem their parasites and pathogens, and these may possibly cause epidemics in humans. This was oddly illustrated with the occurrence of malaria in the neighbourhood of several international airports in Geneva, New York, and Paris, brought to these non-endemic areas with infected mosquitoes (Mayer 2000). Also, the long history of trading in the Middle East may explain the presence of two variants of flavivirus, the Kyasanur virus in India and the Alkhurma virus in the Arabian Peninsula. Exchanges of sheep or camels have probably favoured the transmission of infected ticks (Gould and Solomon 2008). So far, only a few cases of Alkhurma haemorrhagic fever have been reported in only two provinces of Saudi Arabia, Makkah and Najran, since its first isolation in 1994. Nevertheless, at the beginning of 2009, four cases were reported from the Najran province, raising awareness of this disease which has shown high lethality (25 to 30 per cent). As the ecology of the Alkhurma virus, also transmitted by ticks, remains unknown, comparisons with the other variants within the family of Flaviridae is informative, with regards to the risk of outbreak and preventative actions that could be undertaken. Further studies are needed to confirm the hypothesis of an imported infection through ticks carried on animals exchanged in the region.

Invasive species also impact vector-borne diseases through regulating the biodiversity of indigenous species and their pathogens. In addition, if transported pathogens find suitable living conditions in the place where they are introduced, they can maintain themselves, infect other animal vectors and may cause epidemics.

Rapid mobility can also allow a direct (human to human) transmission of pathogens: people travelling serving as vectors of diseases (Mayer 2000). This was recently highlighted by the worldwide diffusion of severe acute respiratory syndrome (SARS) that first appeared in southern China in November 2002 (Matthews 2004). The respiratory disease, caused by a coronavirus, rapidly spread to Asia, Europe, North and South America, causing more than 8,000 cases and over 774 deaths (WHO, data as of April 2009, www.who.int). The illness is believed to have originated in animals traded in the region’s markets (Field 2009). The virus, which originated from factory farms and animal trade, was transmitted through the air by travellers remaining infective during and after their trip. Another spectacular example is the H1N1 pandemic that started in April 2009 and rapidly spread from Mexico to countries directly connected, especially the United States, Canada, Chile and Australia. Figure 18.1d, displaying the incidence of H1N1 (for 1 million inhabitants) on 11 June 2009 (the day when the WHO declared phase 6 of the pandemic, after a rapid increase in incidence and worldwide distribution), shows these countries as severely affected, while the poorest countries, in Africa, remain economically isolated and unaffected. A comparison with the map showing the level of urbanization (Fig. 18.1b) also illustrates the higher transmission linked to higher population densities. Nevertheless, we note that unaffected countries may also have insufficient resources to detect the virus in the population.

Environmental contamination of infectious disease agents is a major health risk. A potential threat for human health with regards to yellow fever is the occurrence of an urban cycle if the flavivirus is imported with mosquitoes (*Haemagogus* and *Sabethes* spp.) from wild then rural areas and transmitted to the urban vector *Aedes aegypti*. The high densities of populations and *Aedes* mosquitoes in cities could then favour large epidemics and would have dramatic consequences if we consider the high lethality (20 to 50 per cent).

This problem of mobility and the threat of the potential introduction of pathogens, parasites, and/or their vectors has been now realized by most of countries following recent epidemics and pandemics (SARS, H5N1 avian influenza, and H1N1 swine flu), which may now be better prepared to curb transmission.

### 18.3.4 Inequalities in health offer and access to healthcare

Access to healthcare and the quality of the health systems are also determinants of the health status of populations. On one side, social inequalities result
in different vulnerabilities to diseases, exacerbated by inadequate living conditions, inadequate water and waste management, hard working conditions, poverty, and the limited recourse to health services. Populations may not have sufficient resources to access healthcare (when social security is not provided, or when transport is needed to reach suitable structures: for example, specialists doctors who are unevenly distributed on the territories). Van Donk (2006) assigned poverty, unemployment, lack of secure income, and income inequality to vulnerability to HIV infection. This vulnerability is increased with difficulties in accessing healthcare and affordable prevention (Van Donk 2006). Furthermore, socio-economic disturbances such as wars, economic crises, and unemployment worsen inequalities. During the war in Nicaragua between 1983 and 1987, malaria epidemics increased in war zones where populations migrated and could not benefit from an adequate health system, while they decreased in non-war zones (Garfield 1989; Sutherst 2004).

On the other hand, health depends on the resources invested by the society in response to global change (Sutherst 2004). For instance, rapid urbanization poses sanitary problems when not accompanied by the construction of public health infrastructures with the difficulty of responding to heterogeneous needs in space and time. The use of health structures differs from rural to urban areas (Guha-Sapir and Schimmer 2005), and with regard to social status.

This problem of allocation of health resources has also been exemplified by water management projects. The construction of large infrastructures implies the resettlement of downstream communities and the development of health services and structures that condition health status. Smaller water management projects, such as drainage and irrigation, may also be accompanied by local migrations of populations. The World Commission on Dams (2000) reported different cases of such resettlements that have caused food shortage and famine in Africa and Asia. In Zimbabwe, the construction of the Kariba Dam between 1955 and 59 constrained about 57,000 people to move to lower-fertility areas and was responsible for malnutrition, as well as schistosomiasis epidemics (2000).

Similar emergences of schistosomiasis, malaria, or adverse effects on public health through resettlement have followed different dam constructions over the world. An increase in poverty may also be accompanied by the emergence of non-infectious diseases. The building of the Akosombo Dam in Ghana in the 1960s and the failures of the resettlement programme prompted migrations, especially to Côte d’Ivoire, driven by poverty and increasing infections by HIV, leading to a disproportionate prevalence (Sauvé et al. 2002). The World Commission on Dams (2000) concluded that there was a general lack of health impact assessment in the design of dams and infrastructures, as was already reported by Malek (1975) regarding the Aswan High Dam. These examples illustrate again the multiple consequences of man-made changes on health and how ecological and geographical (i.e. social) factors can impact upon human health. A geographical approach to health is necessary to forecast health issues for resettled populations and plan action based on former cases.

Therefore, assessment of public health needs (where and how to allocate health facilities) constitutes a fundamental task in urban planning that is unfortunately often guided by political decisions, instead of a health geography approach that would consider social, economic, and health conditions with a spatial perspective.

### 18.4 Conclusions

Health ecology has played a great role in the study of diseases in linking emergences or pathologies with environmental changes that have particularly accelerated since the industrialization era. In a complementary approach, health geography has contributed to a spatial understanding of local and global dynamics by multiplying scales and broadening the analysis of causative factors. Illnesses are considered globally in the geographical environment beyond traditional approaches limited to individuals. Indeed, human health status is observed within a society undergoing rapid transformations and drastically impacting on an unbalanced environment. Understanding the causes and consequences of disease is of course a
very difficult task when considering the complexity of both human-induced changes and disease patterns, but some general driving forces or local mechanisms have been described and tackled in this chapter.

The risk of an epidemic or pandemic, that could be the consequence of ecological changes as well as increasing mobility and exchanges, remains a major threat for populations and an essential concern for public health. SARS and the avian influenza epidemics have shown such spectacular worldwide spread that they have positively alerted health administrations in several countries to organize surveillance and inform rapidly on human cases and on the possible emergence of diseases. The avian influenza epidemics that have been recorded in South-east Asia from 2003 may have also demonstrated that hiding an outbreak (through fear of economic impact) could have the worst economic consequences when other countries or populations lose confidence in the local health administrations and public health situation. Since then, information on epidemics is increasingly reported in a shorter time and publicly made available in journals or instantly through the Internet, in breaking news, or newsletters. Rapid reporting has also benefited from technological developments in geographic information systems with the possible management of large datasets with remote but controlled access allowing the addition and consultation of records. In 2009, the H1N1 epidemic was exemplary in the transmission of information with near real-time records and a web-based mapping of the disease incidence per country.

Other priorities are the vaccination of populations exposed to pathogens and the awareness of the risk of epidemics and general recommendations in such situations. The three epidemics cited above (SARS, H5N1, and H1N1) may have changed the global perception of the real health threat of the emergence of a highly virulent strain of H5N1 directly transmitted to humans. As mentioned in the introduction, SARS and H5N1 created a kind of psychosis for Western populations, while H1N1 may have reassured populations that a pandemic can occur with a limited number of cases and deaths.

An interdisciplinary approach to health, based on ecology and geography, appears fundamental and urgent, when noting the considerable impact on health of human-induced local and global environmental changes and facing the health threat of rapid emergence of diseases worldwide. This is a challenge on a degraded planet, since the ecological interactions involved in health patterns are complex and still remain elusive for scientists.

References


