The geography of cholera

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A.E. Collins

8.1 BACKGROUND TO SPATIAL PERSPECTIVES IN DISEASE INCIDENCE

Awareness of spatial differences in disease incidence has existed for thousands of years. In biblical times before the Exodus, the Israelite refugees witnessed how the plagues that afflicted Egypt avoided the land of Goshen but selectively attacked the people living in the other areas (Exodus 9). Work relating to geographical dimensions of disease pre-dates the laboratory orientation of scientific and clinical medicine which was emerging around the time that Robert Koch discovered the cholera vibrio. Distributions of diseases, of which cholera serves as an excellent example, have been utilized to explain disease occurrence by elucidating causal mechanisms, describing its natural history, or providing guidance in the administration of health services.

Studies of disease incidence with an essentially spatial perspective traditionally emphasize both the search for non-uniformity in disease distributions and the search for association with factors responsible for the pattern displayed. These approaches may be accredited with the titles of medical cartography and disease ecology respectively. Good examples of both are the early and well-known studies by John Snow who successfully isolated a contaminated hand pump water supply as the cause of a cholera epidemic in London in 1857. It was Snow in his publication, 'On the mode of communication of cholera' (1855) who illuminated the fact that those administrative areas served by the Southwark and Lambeth water-works were associated with the high rates of death from cholera. He had noted that five years on from the

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initial outbreak a change in pattern had come about in that the Southwark and Vauxhall Company water supply was still associated with high cholera mortality, but the Lambeth supply was not and that they had moved their waterworks to a point higher up the Thames, thus obtaining a supply of water free from the sewage of London. A less accurate correlation was made by William Farr in 1852, who made the mistake of postulating a direct relationship between cholera cases and altitude. The error of Farr in attributing cholera mortality directly to residence at low altitude illustrates in a simple way a fundamental problem in ecological associative studies in general, namely that concepts of cause and effect become extremely complex if disease distributions are shaped by an indeterminate range of factors. In this case there was correlation but no clear causative mechanism was identified. Individual chains of causation represent only a fraction of the reality and each component itself is the result of a complex genealogy or spatial history.

However, a theory of the natural tendency of zoonotic diseases to become localized in a specific habitat still carries much weight in modern epidemiology and may in particular help in explaining distributions of cholera. It is a perspective that has been referred to as 'landscape epidemiology' by Pavlosky *et al.* (1955) in Soviet work. This delimits the foci of infectious, zoonotic diseases by analysing the associations of factors such as vegetation, animal and insect life, soil type and acidity, precipitation regime, and other elements of the natural landscape. More well known (in western countries) is the similar perspective adopted by Jaques May (1950) who described the epidemiological constraints of various diseases as requiring the coincidence of two, three or four factors, identifying geographical elements, or 'geogens' as fundamental to determining their existence and distribution. Merson *et al.* (1978), in their epidemiological study of cholera and enterotoxigenic *Escherichia coli* diarrhoea in Bangladesh, asked the question, 'are we dealing with a phenomenon that is related to the biology of the organism or the host or simply to a difference in exposure to contaminated vehicles?' Interestingly, this echoes an early concept captured by Pasteur in the 19th century that 'the germ is nothing, the terrain is everything'. A geographical understanding of 'terrain' – somewhat different to Pasteur's principally biological context – includes factors pertaining to the physical and to the human environment and provides a good framework for understanding distributions of communicable diseases such as cholera.

Also particularly significant in the development of medical geographical thinking was the inclusion by May of the role of culture as a buffer between disease agents and human infection. Behaviour, which may be considered as the observable aspect of culture, often has spatial

expression and may create some of the environmental conditions which link to disease and health. Increased awareness of social and behavioural aspects of health therefore means that consideration must also be given to processes determining health, such as the location of health care, rather than simple descriptions of a particular disease and its distribution. It should also be emphasized that behavioural and socioeconomic factors often become confounding variables when carrying out studies in search of a straight environmental link. For example, investigations into links between water quality and incidence of cholera may be seriously flawed if consideration is not given to factors such as water storage, hygiene behaviour, socioeconomic status, and provision and use of health services.

Generally, the broader understanding of 'environment' must be included if our understanding of 'health' is to include the full parameters of the WHO's 1948 definition of 'a state of complete physical, mental and social well being and not merely the absence of disease or infirmity'. Something of the synthesis that is required in viewing the complexity of health outcomes is expressed by Learmonth (1988) who describes 'a holism that extends to consider community health as a whole, ultimately to put health and disease into a community and societal context, always – ideally at least – with respect for and conservation of the ecological balance of people, plants and animals in a particular setting' (Learmonth, 1988). The concept of balance is also echoed by Howe (1982) who has suggested that health equates with ecological equilibrium while ill-health may be considered as a state of maladjustment, disharmony or ecological disequilibrium. The main spatial perspective of this approach is that individual biomes or regions may broadly categorize the conditions under which a wide variety of well-being or ill-health may flourish. Changes in the balance of these ecological systems, whether in a physical environmental or socioeconomic sense, are influential factors in bringing about new patterns of disease. A simplified system approach to analysis of cholera geography is represented in Figure 8.1.

Because of its added emphasis on culture and environment, disease ecology requires contextual understanding, the term 'environment' taken as inclusive of external economic and social phenomena that influence the functioning of the local system. The 1992 World Bank Development Report in a section entitled Environmental Priorities for Development to some extent joins in with this perspective stating that 'too little is known about how risks and diseases are distributed and interact with each other, and uncertainty remains over the extent to which modest changes in infrastructure account for long-run health improvements'.

Disruption of ecosystems can result in new disease distributions and

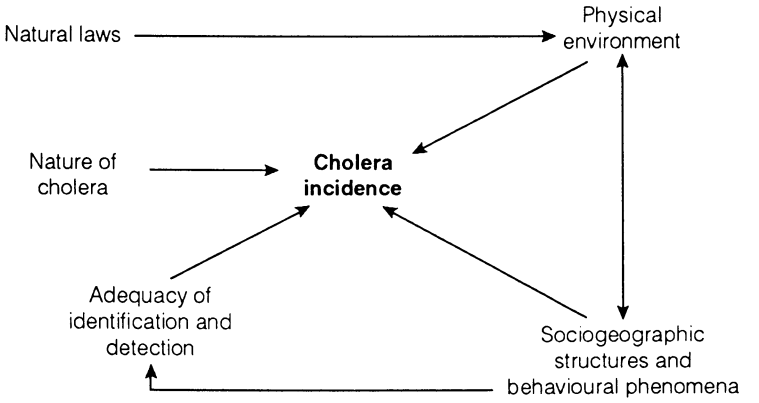

Fig. 8.1 A systems approach to cholera geography. (From Collins, 1993.)

higher rates of incidence for affected areas. Hughes and Hunter (1970) wrote about the 'hidden costs' of ecologically naïve development projects in Africa and how often ecological disruption had negative health outcomes. During the present decade this could be extended to the emergent issues of political and economic change, structural adjustment policies, a changing world order, and their impact on environment and health in many parts of the world. Stock (1986) describes a study strategy that involves looking at 'the political economic nature of ill-health occurring in particular ecological niches. ... In other words, a fully-developed holism, oriented toward understanding the underlying as well as immediate causes of ill-health'.

With these advances in medical geographical perspectives, spatial association remains fundamental. For example, the failed aspects of structural adjustment policies in many Third World countries have been expressed in the form of greater regionalization of resources and an accentuated urban to rural division of wealth (Timberlake, 1985; Reed, 1993; Rich, 1994). Additionally, the effects of changing emphases in development policy is apparent in terms of spatial differentiation of well-being within the urban areas of the same countries (Bergstrom and Ramalingaswami, 1992; Rich, 1994). While confirming the impact of physical and social factors on the health of the urban poor, the WHO (1991) confirm that our understanding of the way in which they interact with the urban development process is incomplete and imprecise, partly due to inadequate information. However, part of the explanation is contained in the 1995 World Health Report (WHO, 1995)

which maintains that increasingly the poor pay the price of social inequality with their health.

Variation in exposure to contaminated environments, often degraded through human poverty, forms the theme of many existing commentaries on the spatial distribution of cholera, though opinion as to the most significant cause is varied. Typically this type of associative environmental approach to cholera focuses on secondary transmission, correctly highlighting the importance of factors such as congestion, socioeconomic and behavioural disruption, and poor provision of appropriate health care. For example, Meade *et al.* (1987) comment on how diseases, particularly those found in the tropics, display an occurrence heavily modified by activities that promote economic development for some areas. Certainly, the 1991 spread of cholera through Latin America has cruelly exposed areas with deteriorating social conditions which were the legacy of widespread economic stagnation.

Connection has been made between cholera and 'policies of hard-nose foreign financiers' (Donovan, 1991), the breakdown of government infrastructure resulting in inadequate housing and sanitation (Robinson, 1991), lack of personal hygiene and education (Pan American Health Organization, 1991), overcrowding, lack of adequate and safe water supplies, and insanitary disposal of excreta (WHO, 1991). Other suggested links have been an over-burdened medical service and poor communications (Ferguson, 1977), and peoples' lack of commitment to maintaining a sanitary environment in post-colonial areas, the maintenance of which they consider to be the sole responsibility of the Government (Adesina, 1987). Rapid increase in incidence of gastro-intestinal infections, such as cholera, has also been linked to the importation of pathogens by migrants from rural areas where the disease is endemic (WHO, 1986), or among groups of newly arriving refugees to camps, such as has been described by Mulholland (1985) in an account of a cholera epidemic in a refugee camp in eastern Sudan in 1985.

However, the last few years have thrown up extensive new information on the nature of the disease and its terrain demanding a further extension of geographical perspectives on cholera. This is particularly the case regarding factors relating to the role of primary transmission of the pathogen from environmental reservoirs, now seen as a feature which may influence the distribution of the disease. Recent advancements in microbiological knowledge of *Vibrio cholerae*, a recent surge of incidence of cholera linked to the seventh pandemic during the early 1990s, of which South America and Africa particularly suffered, and the appearance of the new strain, *Vibrio cholerae* O139, in India are recent developments highly relevant to geographical aspects of disease and health and that require further investigation. Interest in the changing biology of cholera, the continued and widespread suffering it causes,

and its importance as a global issue has rightfully been reflected by a recent increase of academic papers published in a wide range of journals. With reference to these, and some original field investigation, the remainder of this chapter considers a number of aspects of the new geography of cholera and shows how geographical perspectives, more than ever, have a fundamental role to play in understanding incidence of the disease.

8.2 GEOECOLOGY OF CHOLERA

One of the more significant recent developments in the study of cholera relates to information derived from laboratory research carried out in the 1980s. This has pointed to the existence of aquatic environmental reservoirs in which *V. cholerae* survives for prolonged periods and from which a toxigenic form, under certain conditions of temperature, alkalinity and salinity, may emerge to support epidemic conditions (Miller *et al.*, 1984, 1985, 1986; Barua and Greenough, 1992). The need for attention to be paid to the possibility of these pools existing in nature was suggested after laboratory investigation into the impact of physico-chemical stress on *V. cholerae* O1 (Miller *et al.*, 1984, 1986). Work by Miyaki *et al.* (1967), Pandit *et al.* (1967) and Prescott and Bhattacharjee (1969) had earlier suggested survival times dependent on factors such as temperature, pH, osmotic pressure, moisture content, salt or carbohydrate concentration, and the presence of organic matter and bacterial flora as key factors in determining survival times in different foodstuffs. Experimental studies have also shown that gastric acid is one of the body's main lines of resistance against cholera (Cash *et al.*, 1984) and vibrios are known to be unable to survive in carbonated water due to its low pH (WHO, 1986). Other investigations carried out on water suggested the key factors to be temperature, pH, salt, bacterial and organic content (Singleton *et al.*, 1982; Colwell and Spira, 1992). Shellfish have often been suspected of spreading cholera and several recent studies in coastal areas of the USA have served to reawaken the possibility of the non-human animal reservoir (Kaysner *et al.*, 1987; Doran *et al.*, 1989). The aquatic reservoir and the non-human animal reservoir theories are open to convergence, in that the feature of a brackish environment can be considered common to both circumstances. This has recently been emphasized further by the isolation of *V. cholerae* O1 from intestines and skin of fish in polluted coastal waters along the coastline of Peru (Tamplin and Parodi, 1991).

However, survival in aquatic environments with favourable conditions has been only part of the accumulated findings from research on *V. cholerae*. It is now also suggested that, in unfavourable environmental conditions, toxigenic isolates of *V. cholerae* O1 and other vibrios are able

to enter a period of dormancy (Xu *et al.*, 1982; Colwell *et al.*, 1985; Colwell and Spira, 1992). If, in addition to nutrient depletion, the cells are subjected to reduction in temperature and/or elevation in salinity, the cells rapidly go non-culturable but remain viable and potentially pathogenic (Colwell *et al.*, 1985). This has meant that in the past potentially toxigenic pathogens capable of causing major epidemics of cholera may have remained hidden in the natural environment. New techniques of isolation which use fluorescent antibody or gene probes help overcome this problem of evasion, meaning that an entirely new appreciation of the space–time distribution of *V. cholerae* and incidence of cholera is possible. There are also possibly new implications for understanding the distribution and behaviour of many other bacterial enteric pathogens.

Linked to these developments, Martins *et al.* (1993) partly explain low numbers in positive samples of sewage water in Brazil between 1974 and 1983 in terms of the ability of *V. cholerae* O1 to undergo environmental adaptation and be non-culturable. Martins *et al.* conclude that *V. cholerae* O1 was therefore likely to be already present in the aquatic environment of São Paulo before the present outbreak of cholera in that country. However, Wachsmuth *et al.* (1993) state that there is still no real evidence of a non-toxigenic precursor for the toxigenic Latin American isolates and that the relatively nearby isolates found along the US Gulf Coast are not directly related to them. The Latin American isolates are considered more likely to be a clonal variant of the seventh pandemic that has been described elsewhere as being introduced by travellers. Wachsmuth draws attention to a shift from Inaba to Ogawa serotype within the Latin American clone. Possibly this helps to explain why the epidemic took off so rapidly, affecting so many people in that region.

The findings of Salazar-Lindo (1993) suggest that the Latin American isolates are clonal and distinct from the other three clones; the seventh pandemic, the US Gulf Coast, and the Australian isolates. He suggests that the toxigenic cholera vibrio organism was introduced into the aquatic environment of the Peruvian coast long before the outbreak flourished and long enough to evolve into a different clone. Instability in the *ctx* genes in the chromosomes of the recently appeared O139 isolates in Bengal and Bangladesh has been reported as unusual (Lida *et al.*, 1993) and 'could be key to understanding the genetic mechanism for the sudden appearance of O139 strain'. Questions of gradual evolution or genetic instability leading to 'spontaneous appearance' of the toxigenic form of the organism are likely to contribute to an ongoing debate on the biogeography of *V. cholerae* into the future.

A further topic of interest is environmental change that impacts on the nature of the organism. Drasar (1992) has indicated that 'survival is

only part of the story' and that the implication of an aquatic reservoir is that 'they form an essential component of the ecosystem'. Interaction takes place between the dormant/starved non-toxigenic vibrios and the environmental reservoir, and between hypertoxigenic strains and people who become cholera patients. He also draws attention to possible continuity in the action of cholera toxin (CT) in these reservoirs and the intestine. The ecosystem hypothis opens up much insight to distributions of *V. cholerae* at micro and macro scale and forms a good basis from which to begin an analysis of the possible implications of environmental change.

8.2.1 LOCALIZED ENVIRONMENTAL CHANGE AND EXPOSURE TO *V. CHOLERAE*

There now exists background information to indicate that different biotypes and serotypes of *V. cholerae* inhabit distinct zones determined by a combination of spatially defined environmental preferences and the relative immunity of the population that occupy an area.

Craig (1988) signalled caution in making generalizations in comparing epidemics of different biotypes when analysing time–space clustering of cholera in Matlab, Bangladesh. Spatial differentiation between biotypes has been demonstrated in Bangladesh during the epidemics of 1988–1989 (Siddique *et al.*, 1991) where there was clustering of the classical biotype in the southern region and of the El Tor biotype in all other regions. While the reason for the interplay between *V. cholerae* O1 biotypes in Bangladesh was not entirely clear, the ecological changes in various regions, caused by soil erosion and construction of barrages and dams in the river system, were thought to be possible associating factors. The appearance of the El Tor biotype coincided with increasingly severe flooding in the northeastern and middle-belt regions. Siddique reasons that since El Tor is hardier and more viable in water than the older Classical biotype, it may have found a more suitable habitat in those areas. Also, a drastic reduction of fresh water flow caused by the Farakka barrage in the catchment area changed the dry season hydrodynamics in southern Bangladesh and resulted in an increase in salinity and incursion of brackish water deeper inland. Siddique suggests that the Classical biotypes in the south may have become adapted to this changing environment.

Interestingly, *V. cholerae* O139 may be even hardier with a survival advantage over *V. cholerae* O1. Islam *et al.* (1993) note that whereas *V. cholerae* O1 is normally isolated from less than 1% of water samples during epidemics, 12% of water samples in his study of 92 water samples from ponds, lakes, rivers, and canals in rural Matlab and

urban Dhaka, Bangladesh yielded *V. cholerae* O139. Also, attention is drawn here to the much higher toxigeneity of the new serogroup (Islam *et al.*, 1993). A reciprocal seasonal pattern in prevalence of *V. cholerae* O139 with *V. cholerae* O1, identified by Jesudason and Jacob John (1993) also implies a tendency for one strain to fill the niche of the other in response to a controlling environmental factor. However, it should be remembered that *V. cholerae* O139 has been reported as having an overall similarity with *V. cholerae* O1 El Tor (Higa *et al.*, 1993).

Observation of the nature of previous pandemics of cholera should now warn us that the distribution of the more recent serogroup is unlikely to be explained solely in terms of the biology of the organism or the host but indeed also through differences in exposure to its habitat. Two factors stand out as particularly important. First, non-O1 serotypes are known to be widely prevalent in natural aquatic environments (Mandal, 1993) and secondly, previous infection with the El Tor serotypes does not provide immunity to infection from *V. cholerae* O139 (Bhattacharya *et al.*, 1993).

Reports from the cholera epidemic in Angola also present a situation of shifting serotypes (Colombo *et al.*, 1993). In 1988 all strains were Ogawa; by 1991, the prevalent epidemic strain was also Ogawa, but by 1992 this had changed to Inaba, identified both in patients and in the Bengo river which serves the Luanda piped water system. As in the case of Mozambique, which will now be explored in more detail, this pattern might relate to environmental and demographic change caused by continuous instability.

8.2.2 ENVIRONMENT AND CHOLERA IN MOZAMBIQUE

Work carried out by the present author in Quelimane, Mozambique in 1991 is of interest in that the serotype Ogawa of the biotype El Tor was identified, rather than Inaba which was being associated with the main epidemic spreading through Africa at that time. This lent substantial weight to the understanding that the situation in Quelimane was endemic (Collins, 1993). *V. cholerae* O1 El Tor serotype Ogawa, well adapted to the saline and alkaline aquatic reservoirs of Quelimane, may have become part of the indigenous fauna of that area, ready to strike in epidemic proportions should suitable circumstances arise. The larger estuarine city of Beira 300 km to the south also suffered a prolonged cholera epidemic in the early 1990s but serotype Ogawa generally did not occur. Also, environmental tests in that city has found the groundwater to be more acidic and less affected overall by a saline incursion than Quelimane.

The study on the distribution of incidence of cholera in Quelimane

suggested that **increased salinity** in the well-water supply of some parts of the city was associated with a higher morbidity rate in those areas during the course of a year-long epidemic. Evidence provided by environmental tests suggested that, along with population density, this may have been a key factor in explaining the pattern observed. It was also noted that degradation of the physical environment through devegetation and compaction of soil within a littoral region, may have led to the salinization and increased alkalinity considered preferable to the longevity and toxigeneity of *V. cholerae* in those areas. Saline water is generally described as having a chloride content in excess of 300 mg/l if relating it to acceptable drinking water levels. It therefore does not take much intrusion of seawater (with ca. 19 g/l chloride ions to cause deterioration. The actual movement of saline water into the freshwater environment is difficult to predict due to the complexity of mixing related to pumping rates and density variations between the two water types (Owen *et al.*, 1991). Freshwater, being less dense than saline will constitute the upper body of water. Provided the density difference can be maintained there will be little upward movement of saline water. However, over-pumping may destroy this balance, causing upconing and a resultant deterioration in quality.

The principal cause of a changed surface environment in those areas of Quelimane supporting unusually high rates of cholera incidence appeared to be the rapid population increase due to an influx of displaced people from war-torn rural areas. Change to natural environments which may impact on health, such as those suggested at Quelimane, represents a potentially fruitful area for research on communicable diseases in the future.

However, another part of the explanation for the observed distributions in Mozambique is likely to have been a lack of resistance of different communities to the different Ogawa and Inaba serotypes which produce only type-specific immunity (Preston, 1993). For example, in Quelimane, the flank of the city worst affected hosted the highest number of displaced persons from rural areas. Many of the areas of origin of these groups were both isolated and not known to have been cholera zones. The incomers would therefore have been especially susceptible to the cholera of Quelimane, while their reduced socioeconomic status from being displaced is likely to have also contributed to infection vulnerability.

The relationship between cholera and **malnutrition** is a further factor that should be considered in this context. Work by Mulholland (1985) in the May–June, 1985 cholera epidemic in a refugee camp in Eastern Sudan and that of Moren *et al.* (1991) investigating a cholera outbreak in a Mozambican refugee camp in Malawi in 1988 both point to its possible significance. Immunologic responses to infection in general are

modified by nutritional status (Scrimshaw *et al.*, 1968). Additionally, Rutherford and Mahanjane (1985) suggested that a large portion of diarrhoeal morbidity and mortality in the Mozambican famine of 1983 may have not been infectious but rather due to starvation-induced malabsorption. Hypochlorhydria through loss of gastric acids, which are one of the body's main lines of resistance against cholera, predisposes to higher incidence (Cash *et al.*, 1974). If the evidence of Thomason *et al.* (1981) that acute malnutrition predisposes to hypochlorhydria is correct, then it is reasonable to suspect that this is the mechanism by which cholera selectively attacks the malnourished (Nalin *et al.*, 1978). It can also be noted here that in Quelimane the three zones displaying the lowest expected rate of incidence were densely populated but historically established with a population largely indigenous to Quelimane. In Beira, the displaced were distributed more evenly around the city, or concentrated into special reception areas in more rural areas some distance away. It is reasonable to suggest that aquatic reservoirs and location-specific immunity played less of a role since the cholera there was associated with a more widespread epidemic situation affecting the region as a whole.

It should also be noted here that while both cities have extremely poor sanitation and have suffered the effects of virtual siege conditions during a war lasting years, Beira for the majority of the time was able to maintain some of its key function as an important strategic port at the end of the 'Beira Corridor'. Movement of people into and out of Beira was therefore much greater than in Quelimane which for long periods only received occasional internal flights. Beira's relatively greater contact with the outside world meant that it was more susceptible to the seventh pandemic *V. cholerae* O1 El Tor serotype Inaba which caused 153 367 cases and 13 998 deaths in Africa that year. By the end of 1992 the total for Mozambique was 30 802 cases with 726 deaths, the highest in Africa that year (WHO, 1993). To conclude here, the pattern of incidence between the two cities may show that the relative balance between endemicity and epidemicity for specific areas is expressed by different serotypes with a range determined by predisposing environmental and demographic processes.

Figures 8.2 and 8.3 show two types of environment in the Mozambican cities. Figure 8.2 is of a densely inhabited area where cholera is particularly rife during an epidemic. It is an area which suffers from inundations of salt water and where the soil has become devegetated, compacted and alkalinized. Figure 8.3 is taken in an area slightly further inland which also supports a high population density but where cholera incidence during an epidemic is much less. This area is well vegetated with palms and mango trees, is away from inundations of salt water and has a sandy acidic surface environment.

Fig. 8.2 Mozambican city environment. Caline, denuded and a focus of high cholera incidence. (Photograph courtesy of the author.)

Fig. 8.3 Mozambican city environment. A well site 7 km from that shown in Figure 8.2, with high population density, lower cholera incidence and a vegetated surface environment. (Photograph courtesy of the author.)

8.2.3 GLOBAL ENVIRONMENTAL CHANGE

Environmental change at the global scale may also relate to variation in disease incidence if, for example, organisms such as *V. cholerae* are considered as being sensitive to the physical parameters of temperature, alkalinity, and salinity as indicated by the laboratory research. Thus, if *V. cholerae* is able to survive in coastal waters, as do other salt water organisms such as algae and plankton, and if its successful multiplication is similarly dependent on temperature pH, salinity and available nutrients, then it is reasonable to postulate changes similar to that displayed by some oceanic algal blooms. Epstein (1992) has suggested that the recent pattern of cholera in the Americas may represent the first detectable impact of climatic change on the distribution of water-based and vector-borne diseases. Some evidence for this was that unusually large algae and plankton blooms were reported at sea at the same time as plankton in the harbour near Lima, Peru was found to be contaminated with *V. cholerae* (Tamplin and Parodi, 1991). Epstein points out that the unexpected intensity of the outbreak, which penetrated cities and towns along the Pacific coast in January and February 1991, was consistent with multiple entry points from marine life blooms, with fish, molluscs and crustacea as vectors.

Based on this hypothesis Epstein *et al.* (1993a) go on to suggest that an outbreak of water-borne disease which is a consequence of proliferating plankton and associated bacteria may be considered in part a consequence of sunlight, pH, currents, winds, and river run-offs that govern their location and timing. Major anthropogenic influences on algal blooms – apart from possible global warming – are caused by pollution, through excess nutrient from sewage and fertilizer effluents, soil erosion and acid rain, all of which affect the balance of nitrogen and phosphorus. Additionally attention might be given to over-harvesting of fish and shellfish which reduces algivorous grazing and loss of wetlands which filter nitrogen and phosphorus, store carbon, and support fish and seabirds. The complex nature of the world's climate and ocean circulation and the unpredictability of change caused by human inputs mean that predictions of the full implications of the changing distribution of associated bacteria remains difficult to assess.

Further impacts of climate change on cholera in some countries may eventually relate to sea-level rise, reduction of rainfall, and decreases in crop yields. Rising sea-levels could change the balance between salt and freshwater in the low-lying estuarine environments of cholera-prone regions such as parts of India, Bangladesh, Pakistan, Indonesia, Thailand, Egypt, Nigeria and Mozambique. In the event of further rising sea-levels, pumping stations would have to be located further inland and coastal well-water would become subject to more frequent

incursions of brackish ground water. Flooding by seawater would also leave more inland lagoons of water with physical conditions favourable to the longevity of *V. cholerae*. This would be intensified by the spread of unprotected sewage in flood waters.

Reduction of rainfall in the interiors of continents, another possible outcome of change to the global atmosphere–hydrosphere–cryosphere balance, could also increase incidence of inland brackish environments. The processes involved are two-fold. Firstly, through a shift in the freshwater and saltwater margin in coastal zones and secondly, through increased evaporation and capillary rise of saline groundwater. A warning of the effects of change in the margin where fresh and saline water meet was experienced in the estuarine cities of Beira and Quelimane during the drought of 1992 which affected most of Southern Africa. In the case of Beira the urban water source on the Pungwe river, was eventually turned off on the grounds of being too saline to drink. In the case of Quelimane, the artificial lagoons alongside the river Licuar, from which the city's water is pumped, dried up altogether. Though the pumping station is 40 km inland, there are now plans to resite the pumping station further upstream away from the low-lying and saline coastal plain. Desalination plants are generally expensive to maintain and are therefore only usually considered by countries with the combination of extreme freshwater shortages and extensive financial resources, such as Saudi Arabia.

Salinization and alkalinization are increasingly human-induced phenomena. Further examples of impact are provided by situations of high population density without access to an urban water network, such as in Jakarta where large quantities of private wells were sunk. This caused heavy over-pumping of the aquifer and a fall in the water-table to the extent that in northern Jakarta, seawater has contaminated the groundwater in a 5–10 km-wide continuous belt along the coastal plain (Briscoe, 1993). According to the Council on Environmental Quality (1981), about half the world's irrigated lands have been damaged to some extent by salinization or alkalinization. Kovda (1972) estimated that about 60–70% of all irrigated land was gradually being transformed into 'saline deserts'. This occurs particularly where continual addition of water, without adequate drainage, tends to cause a gradual raising of the general or local water-table. As a result of higher evaporation rates, excess compounds such as sodium chloride, magnesium and calcium carbonate, and sulphate are precipitated in the soil pores and on the soil surface and raised to ground level by capillary action. In time this process becomes evident in a whitish surface, characteristic of 'white alkali' soils (Tivy and O'Hare, 1989). Additionally, where there is a high concentration of free sodium chloride in the soil, downward leaching produces compounds of

sodium with either carbonates or hydroxides, both of which make the soil solution excessively alkaline. Since organic matter is dispersed and goes into solution during the same process, the soils become highly compacted and impermeable when they dry out. The surface becomes covered with a black surface scum of very alkaline organic matter, known as 'black alkalis', which is practically sterile (Tivy and O'Hare, 1989). A correlation between these zones, reservoirs of higher quantities of *V. cholerae* and incidence of cholera has not yet been fully investigated, but white and black alkalis are often a part of the landscape of urban and semi-urban environments in many of the endemic cholera zones of the world.

A further factor, which also relates to global climate and environmental change, is the link between nutritional well-being and communicable disease incidence in general. Estimates of the effects of climate change on the amount of food produced, world food prices, and people at risk from hunger in developing countries made by the Goddard Institute for Space Studies and the Environmental Change Unit in Oxford (Rosenzweig *et al.*, 1992) indicated that crop yields are likely to decline in low-latitude regions but could increase at mid-high latitudes. Greatest declines in world cereal production were predicted in the developing countries where there could be an average estimated reduction of between 8 and 12%. The number of people at risk from hunger was estimated to increase between 5% and 50% with the greatest absolute increase predicted to be in Africa (Haines and Parry, 1993). Additionally, a reduction in availability of drinking water in some regions equates with using inappropriate water sources. The outcome of these environmental pressures consistently occurring in the same parts of the world is likely to be further displacement of populations from those areas. Congestion of the displaced into fewer viable resettlement locations with inadequate water supply and sanitation further enhances the probability of communicable disease epidemics.

Macro scale environmental and demographic differences are likely to explain the changing distribution of non-O1 *V. cholerae*, which has recently taken on massive proportions in India and Bangladesh, though the full repercussions of this has not unfolded at the time of writing this chapter. This first recorded epidemic caused by a non-O1 *V. cholerae* accounted for over 15 000 cases and 230 deaths in Calcutta in its initial stages alone (Sarkar *et al.*, 1993). In Bangladesh the epidemic began in December, 1992, in the south and spread throughout the country with a total of 107 297 cases and 1473 deaths by the end of March 1992 (ICDDR,B, 1993). The first report of the dispersion of *V. cholerae* O139 outside of the region was to Bangkok (Chongsa-nguan *et al.*, 1993). Chongsa-nguan *et al.* point out that while the seventh pandemic strain of cholera, the El Tor, took 3 years to spread from

Celebes island in Indonesia through Bangkok to India from its first isolation in 1961, the O139 strain of *V. cholerae* has disseminated much faster. The organism is reported as causing local outbreaks in geographically distant sites and of having both the potential of pandemic spread and of virtually replacing *V. cholerae* O1, as happened in India and Bangladesh (Islam *et al.*, 1993; Jesudason and Jacob John, 1993). The spontaneity of occurrences of cholera cases may suggest a possible globalization of conditions required for the succession of new cholera strains. At this point in the disease's history we may be wise to consider the implications of a possible loss of diversity between regions as equating with a loss of protection against location-specific disease. The relative ease with which it was removed from some regions through changes to the human environment is mirrored by the relative ease new strains with a slightly different ecological range can return to the same regions. This is demonstrated by the disappearance of cholera from South America in 1867 and its dramatic reappearance in January 1991.

Also, immunity to the new strain of the disease is already known to be low. This is demonstrated by the fact that the first few years of *V. cholerae* O139 has revealed more adults to be suffering from it than children. Once widespread immunity has developed, most adults are protected and more cases are found in young children (Swerdlow and Ries, 1993). However, specific immunity to the O1 serotype does not provide immunity to the O139 serotype. Greater virulence of the organism during an age of increased travel and large population movements ensures that the disease can be efficiently spread. The phenomenon of forced population displacement, experienced by millions in recent times, provides a lethal combination of socially, economically and biologically vulnerable people, concentrated in zones where they may have little localized immunity to endemic strains of disease. The existence of new serotypes of *V. cholerae*, such as O139, among the predisposing conditions of poor sanitation, continued lack of clean water provision, and a deteriorating physical environment in many parts of the Third World will ensure that huge epidemics of cholera are likely to continue. Where there exists suitable environmental reservoirs for its survival, the long-term results will be the creation of further endemic zones and a new geography of cholera.

8.3 NEW THOUGHTS ON SEASONALITY

Geographical perspectives also contribute to understanding the ecology of cholera through concern with seasonality. Recent knowledge of cholera and *V. cholerae* provide us with some new insights on seasonal patterns of cholera incidence. Whereas the WHO reported in 1970 that

not much was known about seasonality (WHO, 1970), we are now more informed on the seasonal role of estuarine salinity, climate, water availability and quality, agricultural output, human mobility and other behavioural factors. Colwell and Spira (1992) suggested that the seasonality of cholera in Bengal may be explained by primary transmission controlled by environmental factors such as temperature, salinity, nutrient concentration, and zooplankton blooms, as well as by seasonal variations in seafood harvesting and consumption, and in direct water contact.

Salinity in estuarine zones is likely to relate to cholera incidence both directly and indirectly. Firstly, as a direct environmental control on survival times and toxigeneity of *V. cholerae*, as has already been described. Secondly, in affecting the availability of potable water supplies, as occurs when a freshwater pumping site becomes saline during a drought, or when wells are made inactive by a change in the balance of fresh and saline groundwater in a zone of wells. Miller *et al.* (1982) have shown how the salinity of estuaries fluctuates in accordance with seasonal variation in river flow and, with reference to Calcutta and London in the 19th-century, suggested this may explain the seasonality of cholera in estuarine cities.

Many studies on cholera incidence include the role of rainfall in seasonal variation. However, these have revealed a variety of patterns between the epidemic curve and monthly rainfall pattern and a variety of explanations are given of principal causal mechanisms. Two patterns of incidence in relation to patterns of rainfall are broadly: (i) the epidemic curve rising steeply during the rainy season and tailing off with the coming of the dry season; and (ii) the epidemic curve taking off in the driest period of the year and being sustained throughout the rains before tailing off. An example of the first pattern has been provided by Mbwette (1987) for Tanzania and of the second by Utsalo *et al.* (1992) in Calabar, Nigeria and Collins (1993) in Quelimane, Mozambique. The pattern has been reported as variable between different locations in Bangladesh by McCormack *et al.* (1969) who noted that in Dacca, the cholera season was during the dry winter months (December and January), but in nearby rural areas, a second epidemic occurred during May–July. Moe *et al.* (1991) explain their result of no significant seasonal difference of diarrhoea during the course of a 1-year study in the Philippines in terms of a lack of seasonal variation in rainfall.

An explanation for a surge in cholera with the onset of rains is that **faecal contamination** is washed into drinking water supplies, such as rivers and open wells. Old and leaky piped water supplies also become more susceptible to contamination at this time as pathogens become more readily diffused in the wet earth around underground pipes. The

deterioration of water quality during the wet season in rural Malawi has been quantified by Lindskog and Lindskog (1988) in terms of total coliforms, faecal coliforms and faecal streptococci in wells, rivers and springs. A similar pattern was recorded by Moore *et al.* (1965) in Costa Rica, Feachem *et al.* (1978) in Lesotho, and Barrell and Rowland (1979) in Gambia. However, Wright (1986) records a gradual increase in pollution during the dry season, interpreted as an increasing concentration of bacteria as water volumes decreased. Although Collins (1993) has shown that the cholera epidemic in Quelimane, Mozambique took off at the driest part of the year, just before the onset of rains, further research in Quelimane, Beira and Gorongosa has shown that faecal coliforms generally decrease as water levels lower during the dry season.

These differences may support the view that patterns of faecal contamination which increase during the wet season do not serve as definite indicators of cholera seasonality if *V. cholerae* is controlled by an additional range of environmental control factors. For example, in monitoring non-O1 *V. cholerae* in Lima sewage lagoons, Ventura *et al.* (1992) show that a seasonal variation in incidence was distinct but that there was no seasonal variation of faecal coliforms. Moe *et al.* (1991) conclude that indicator bacteria may mislead in that only beyond a certain threshold will they correlate well with incidence of diarrhoea, thus directing attention to important factors in transmission other than water contamination. It should also be remembered here that sampling of stored household water often reveals that contamination with bacteria continues to take place after collection. This has been shown by Lindskog and Lindskog (1988), Awad el Karim *et al.* (1985) and Swerdlow *et al.* (1992). The seasonal aspect of post-collection contamination might relate to varying care with personal hygiene dependent on the seasonal abundance or scarcity of water. With respect to rainfall and salinity, consideration might also be given to the implications of more favourable reservoirs for *V. cholerae* as wells become more saline but still potable during the dry season. This, combined with lower water levels and increased concentration of vibrios, might account for surges of cholera in coastal areas during a dry period.

Temperature has also been considered as a direct controlling factor. In the 19th century it was recognized that there were summer outbreaks of cholera between the isotherms at 60°F (16°C) and 80°F (27°C) and limits of 2–4 inches (5–10 cm) per month of rain (May, 1960). We are now able to consider the mechanisms behind this correlation, such as the possible role or synonymous behaviour of large algal and plankton blooms which increase with higher temperatures. The seasonal variation in nutrient levels in aquatic reservoirs caused by increased use of fertilizers and run-off from irrigation also play a role here. Seasonal differences in sunlight is a relevant factor if *V. cholerae* in drinking

water is inactivated by direct ultraviolet (UV) irradiation (Acra *et al.*, 1989). However, a study by MacKenzie *et al.* (1992) carried out in Ecuador found that there was only a reduction in vibrios for bottled water at the high-altitude site of Quito and little change at the low-altitude site of Santo Domingo. The affects of UV radiation in the natural cholera reservoirs of the world is a complex factor of not only season, but also of altitude and availability of shade. The complexity of patterns of sunlight might therefore render it only minor in relevance as an identifiable controlling factor.

Cholera in the early 1990s became so widespread that there arises the possibility of more general climatic differences between zones north and south of the equator providing a continuum of favourable background conditions the whole year round, such as between the affected zones stretching the length of South and Central America or Africa. Variation of strains between regions and the relative lack of serotype immunity of people occupying one area against that of the other are likely to be subject to a seasonable dimension if vibrio types maintain different environmental sensitivities. A hint of this occurring is presented by the reciprocal pattern in prevalence of *V. cholerae* O139 with *V. cholerae* O1 in Bangladesh reported by Jesudason and Jacob John (1993).

The patterns of environmental factors outlined so far also need to be considered against seasonal variation in human well-being and changes in human behaviour that affect the susceptibility of the host.

8.3.1 SEASONALITY OF THE HOST

The correlation of incidence of cholera with poverty has been well documented and is referenced in the earlier part of this chapter. Seasonal poverty that impacts on cholera incidence relates to direct factors such as predisposing conditions of malnutrition and insufficient access to clean water at certain times of year, and indirect factors caused by a reduced coping mechanism in times of crisis. Further behavioural factors that are not necessarily linked to poverty might also include seasonal changes in diet and cultural practices that occur at specific times of year. Many of these factors are well covered in the edited work by Chambers *et al.* (1981) writing on seasonal dimensions to rural poverty.

In addition to the link between malnutrition and cholera infection through the pathophysiology of the lower intestine, there are further environmental and socioeconomic factors to be considered. In a multivariate study of association of malnutrition and diarrhoea in children aged under 5 years in a rural Sudanese community, El Samani *et al.* (1988) found that factors such as rainy season and a general socioeconomic effect were also consistent with this link. Arnold (1993) has

illuminated how the seasonal onset of famine in 19th-century India resulted in the 'breakdown of normal social relations and produced a series of often dysfunctional behavioural responses', in terms of spreading epidemic diseases such as cholera. Survival strategies such as use of 'famine foods' and migration in search of food and work, facilitated epidemic diseases such as cholera in that the poor were further weakened. Weakening came about by the extra outlay of energy necessary to gather enough marginal foods and because these were coarse and unpalatable or poisonous unless thoroughly cooked. Interestingly, a rice-based diet, the indigenous staple diet of some of the world's cholera-prone regions is indicated as highly effective in the management of persistent diarrhoea in terms of improved nutrient absorption (Roy *et al.*, 1994). The optimum basis for this diet is rice powder, egg white, soya-bean oil, and glucose, with small additions of KCl, NaCl, $MgCl_2$ and $CaCl_2$. An extension of this discussion leads to a fundamental concept in holistic medicine in general, that the cause and remedies of sickness are found in the same place. Extraneous interference with this balance, such as occurred with the subsistence crises of 19th-century India, caused a breakdown of relative protection to certain communicable disease epidemics.

Non-availability of water is a major constraint in food hygiene and makes hand washing during food preparation and feeding a less frequent practice. During the dry season, contaminated surface streams and rivers often become the main sources of household water. This has been reported as a factor in Argentina near to the Bolivian Border (Chaudhary, 1992) and by Utsalo *et al.* (1992) in Calabar, Nigeria. Utsalo (1992) suggests an intensification in fishing and trade in fishery products carrying increased vibrio loads, occurs in the hot dry season when estuarine waters are shallow, and that this is a further factor in the seasonality of cholera. In Trujillo, Peru a multivariate study found that going to a fiesta was one of the associating factors as El Tor *V. cholerae* O1 grows rapidly in many cooked foods (Swerdlow *et al.*, 1992). Increased seasonal mobility at planting and at harvest time and religious ceremonies that attract large numbers of people into a small area have been further factors correlating with communicable disease transmission in general. Risks associated with seasonal ceremonies at spiritual sites on the River Ganges and migration to Mecca are well-known epidemic hazards of this type.

8.4 RECENT THOUGHTS ON DIFFUSION OF INCIDENCE OF CHOLERA

The spread of disease cannot be explained without understanding the spatial variation of any one moment. There are no simple diffusion

models that can be easily applied to communicable diseases, such as cholera, which spread across space and through people. Non-uniformity of space influencing the diffusion of cholera includes differences in environmental reservoirs of *V. cholerae*, climate, settlements, social and economic well-being, and culture. Biological differences between the people who are exposed to the pathogen constitute a further non-uniformity guiding cholera transmission. The distribution of susceptibles, infectives and immunes is complex. Biological differences which may be considered as risk factors in contracting cholera are now thought to include lowered levels of gastric acid, not breast feeding, and presence of O blood group (Glass *et al.*, 1985, 1991, 1992; Van Loom, 1993). The nature of the pathogen is a third variable determining the spread of cholera in that different serotypes display a varying degree of virulence.

8.4.1 LOCATIONAL VULNERABILITY AND THE ECOLOGY OF RISK

As the location and persistence of cholera is determined by a combination of physical environmental phenomena, people, and pathogenesis, change to any one of these elements is likely to alter the distribution of cases. Diffusion of the disease therefore occurs against a backdrop of spatially defined environmental risk factors, a dynamic distribution of susceptible, infective and immune people, and a changing biology of the organism responsible. As mobility and local disruption in the late 20th century has increased globally, potential opportunity for communicable disease transmission has become complex. Consequently, there may be more relevance in identifying the nature of the terrain that the disease becomes established in rather than individual cases of transmission.

The role of terrain factors in the diffusion of cholera incidence was observed in the Quelimane epidemic (Collins, 1993). In its initial stages the main focus of incidence moved from one side to the other of the main city area. The shift was to areas identified as environmentally preferable to the longevity of *V. cholerae* in terms of a higher salinity and away from its first appearance in the zone with the highest population density. The new focus area became the one with the highest rate of incidence throughout the rest of the epidemic. Further analysis recorded areas with significantly higher than expected numbers of cholera cases for each month based on a method formerly employed by Ferguson (1975). This revealed that the majority of localized peaks in incidence were non-consecutive and non-contiguous and that 87% of all significant peaks, subsequent to the initial one, were in areas recording significantly higher salinity in the aquatic environment from which people drink. The controlling effect of the aquatic environment on cholera diffusion has also been hinted at by Marsden (1992) commenting on the spread of cholera down the Amazon basin. He

suggests that the River Negro might be inimical to cholera as it has passed through large amounts of decomposed vegetable matter and is therefore acid in the range of pH 5–6, not suitable to *V. cholerae*. The importance of surface water in transmission in rural Bangladesh has been recorded by Hughes *et al.* (1982).

Susceptibility may be caused by factors such as hypochlorhydria in famine situations, as outlined above. However, it should be added here that it is not the only factor that involves changes to the human body. For example, alcoholism causes a loss of the resistant acids in the stomach. This has been suggested as an explanation of a particularly severe case of cholera in Belize (Hospedales, 1992). Baine *et al.* (1974) suggested that individuals with gastric hypoacidity from surgery, disease, or medication were particularly susceptible to cholera. Although investigations have shown that cholera can be transmitted by a variety of seafoods, a low pH in these same foods could inhibit transmission. St Louis *et al.* (1990) identified a lower risk of cholera in Conakry, Guinea when people ate the food with acidic tomato sauce (pH 3) rather than a neutral peanut-based sauce (pH 7). Breast-feeding in rural Bangladesh has been demonstrated as beneficial in protecting children up to the age of 36 months by Clemens *et al.* (1990). However, a study conducted by Bhattacharya *et al.* (1992) established that, in a cholera endemic area, about one-third of the admitted children up to the age of 2 years could have cholera and that even children below the age of 6 months were not spared, despite the fact that the average duration of predominant breast-feeding was about 4.7 months since birth.

Once established, there are numerous additional mechanisms through which **secondary transmission** may occur. They include factors such as drinking water contaminated during storage, going to festivals where food and beverages are prepared by multiple food-handlers, eating vegetables from farms which use untreated sewage to irrigate crops, and the consumption of raw seafood. Monitoring of diffusion of the disease through routes of secondary transmission is made difficult by the high proportion of symptom-free cases. This has been particularly prevalent with the El Tor strain. Symptom-free infections and mild to moderate cases of diarrhoea have been known to outnumber severe cases by as much as 100 to 1, particularly where the disease is endemic (Woodward and Mosley, 1971). Routine public health strategies aimed at controlling the diffusion of the disease via infected persons are not effective as most infected travellers are probably symptom-free.

8.4.2 HUMAN MOBILITY

The spread of cholera through and between nations by mobile populations is dependent on who, when and why people travel. For example,

travel by people from developed countries into and out of endemic areas in the Third World has been proven to be relatively insignificant in terms of cholera transmission, as travellers such as these are generally socially and economically not so susceptible. One US report puts the risk of cholera to nationals travelling to affected areas at 1 per 500 000 travellers (Snyder and Black, 1982). Among the people living in the suburbs of Quelimane, many of whom were newcomers from the rural areas, the rate was more typically 200 per 10 000 people.

A part of the increased susceptibility of forceably displaced people undoubtedly relates to a decreased socioeconomic status during a period of instability. People forced to migrate due to war or famine usually need several growing seasons to re-establish adequate levels of food production to become self-sufficient again. The association of large-scale population displacement and subsequent resettlement with serious outbreaks of communicable diseases such as cholera is well documented (Prothero, 1977, 1994; Dick, 1984; Simmonds, 1984; Shears and Lusty, 1987; Guglielmetti *et al.*, 1992). In the 1970s and 1980s, millions of Africans became refugees often in densely populated camps and cholera may be diffused further when the refugees move on. Processes of interaction and the combined effects of changed environmental circumstances and population displacement on health have only been briefly indicated by some accounts (Dick, 1984, 1985; Meade, 1987; Prothero, 1994). The need for greater attention to be paid to this has become particularly urgent as more rapid change occurs to the natural environment and population stability in several parts of the world, not least sub-Saharan Africa. More specifically, there is a need for more informed planning strategies aimed at risk reduction in vulnerable regions and among vulnerable communities. A first stage might be in the identification of the geographical risk areas. A second, in identifying the role of population movements in influencing incidence of cholera operating either through: (i) changes in the local environment caused by the resettling of displaced people; and (ii) changes in environmental circumstance experienced by displaced people which make them more susceptible to health problems.

8.5 THE ECOLOGY OF CHOLERA IN CONTEXT

In addition to the specific determinants of disease incidence, wider contextual factors need to be considered. Particular emphasis is made here of war, famine, population displacement, and changing economic circumstances in developing countries. These are phenomena not entirely independent of each other; what happens at one scale is not only relevant to what is going on at another, but is also reciprocal. Major change, such as that caused by increased mass displacement of

people from one zone to another and accelerated modifications to local environments through depletion of natural resources, often originates in structural developments occurring at national and international scale.

Structural phenomena determine the settlement patterns, congestion and environmental risk that impact on the distribution of cholera. The environmental factors of climate, soil, rainfall, temperature, altitude and seasonality that have been listed as possible proximate determinates of child mortality by Mosley and Chen (1984) and the added features of slope of terrain, population density and crowding within households listed by Blacker (1991) affect disease distributions in particular ecological settings, while simultaneously being affected by wider structural contexts.

Decisions of individuals to use clean water, observe basic **sanitational standards** and use appropriate health care – should these be available – are to a large part dependent on knowledge imparted through education. The rate of morbidity from cholera in any population may therefore be considered as the result of the interaction between hazards present in the environment and the ability of the population to defend itself against those hazards. Defences are generally those provided by the government or the community, such as provision of clean water and education, and those utilized by individuals, such as boiling drinking water and observing basic standards of hygiene. This also, however, depends on having the appropriate means and resources to take action, and therefore incidence of the disease is linked to wider-reaching economic considerations.

For example, if provision of basic infrastructures were good enough the world over, there would be little opportunity for the faecal–oral route of *V. cholerae* contamination, and incidence of cholera would be very minor or not occur at all. However, with a brief resume of the state of the world's water and sanitation supply, it can be quickly appreciated that contamination is not likely to be eradicated in the immediate future. In 1980, WHO estimated that only 20% of the world's population had access to totally safe drinking water, that 80% of all sick were suffering from diseases related to poor water and sanitation, and that 6 million children every year die from diarrhoeal diseases primarily associated with bad water, cholera being just one of the pathogens responsible.

During the United Nations Drinking Water and Sanitation Decade of the 1980s, access to uncontaminated water increased, with WHO figures suggesting that between 1980 and 1990 more than 1.6 million additional people were provided with access to water of reasonable quality. However, this barely kept pace with population growth and about 1 billion people still lack an adequate water supply with 1.7 billion people lacking adequate sanitation facilities (World Bank, 1992; Briscoe,

1993). There is also the harsh reality that many of those registered as officially having access to clean water still in fact drink polluted water. In short, the daunting scale of the effort required to eradicate the world's water and sanitation problems must mean that any additional preventative action that can be taken to reduce incidence should be explored with urgency. Greater appreciation of the ecological context of cholera, which is environmental, social, political and economic, is a step in the right direction for finding alternative and more sustainable solutions for controlling the disease.

Human conflict is a context of prime importance in understanding a proportion of today's cholera. Poignant demonstrations of its effects are the increased prevalence of refugee camps and associated cholera epidemics, as described by Mulholland (1985), Moren *et al.* (1991), Shears and Lusty (1987), and Sørenson and Dissler (1986), as with the cholera that has accompanied the aftermath of the Iraq war and among the survivors of the Rwandese genocide. The concentration of hundreds of thousands of Rwandan refugees into zones across the border in Tanzania and Zaire led to a rapid depletion of vegetation for firewood in those areas. Among the prevailing difficulties of environmental degradation, a continuous risk of cholera breaking out has been reported for the case of Tanzania. The long-term implications of this combination of disasters is not yet clear. Some 25 000 people a day arrived in Zaire from Rwanda. Among the over 1 million newcomers in the Goma area, Oxfam estimated that up to 3000 a day were dying of cholera. The total death toll by August 1994 was 13 000 (BBC, 1994). Conditions were so bad that it caused a return movement back across the border, despite continued security concerns. Many of those returning remained infected with cholera. Meanwhile, back in Rwanda other reports described a potentially good harvest, one of the best years for a while. Thus, disease and malnutrition relates specifically to human conflict in this region. In Angola, potentially one of the richest countries in Africa, harvests for 1994 would also have been good, but ongoing intensive fighting and displacement of peoples lives caused widespread malnutrition. Cholera and other communicable diseases abounded, in contrast to near disappearance of cholera in Mozambique during this period, and where a successful peace accord has been maintained since October 1992.

Thirdly, structural adjustment policies aimed at picking up the economies of some Third World countries have often been criticized as not giving priority to human well-being. UNICEF in Zimbabwe (1989) stated that 'adjustment programmes are rending the fabric of African society. Of the estimated half a million child deaths in 1988 which can be related to the reversal or slowing down of development, approximately two thirds were in Africa'. Loewenson (1993) argues that 'Struc-

tural Adjustment Programs have been associated with increasing food insecurity and undernutrition, rising ill-health, and decreasing access to health care in the two-thirds or more of the population of African countries that already lives below poverty levels'. The loss of a proactive health policy framework, a widening gap between the affected communities and policy makers, and the replacement of the underlying principle of equity in and social responsibility for health care are outlined in the same study.

Poorer countries' attempts to re-establish credit-worthiness with the International Monetary Fund, the World Bank and the international finance community after debt accumulation meant a tightening of public expenditure. Consequently, Peru's expenditure on health fell from $18.4 to $13.4 per head between 1980 and 1985 (Donovan, 1991). Average daily caloric intake dropped almost 30% since 1982, to well below accepted minimum standards, and in 1992 malnutrition rates approached 60% (Labonte, 1992). Meanwhile, the cost of cholera to Peru in 1991 was about 25% of its total budget. It has been suggested that cholera in the food and water of Peru found the population of that country to have little resistance as it was weakened by economic restructuring, and that policymakers had paid little attention to the public health impact of their policies.

At a minimum, socioeconomic factors can prove to be confounding variables when observing direct environmental links with cholera. This shortcoming in the general field of health and environment in urban areas of developing countries is highlighted by Stephens and Harpham (1992) who outline neglect of socioeconomic factors among household level studies. Outcomes determined by macroeconomics, settlement pattern, human connectivity, cost of transport, or concentrations of health care provision are generally visible and spatially definable phenomena and important in interpreting distributions of affected people and places. Intervention strategies therefore need to heed the relationship between the ecology of the areas and the social status of the inhabitants and this needs to be continuously monitored in the context of wider-reaching environmental changes and structural factors.

8.5.1 THE CASE OF STRUCTURAL CHANGE IN MOZAMBIQUE

The recent investigations carried out in Mozambique discovered that awareness of the causes, and ways of reducing the risk of getting cholera, among the inhabitants of Beira and Quelimane was generally good, but that people were unable to take action due to rising costs of living. Also, many interviewed said that on occasions they could not pay the 'nominal' fee that is charged for one bucket of water from the tap or protected well and were therefore forced to drink from the

heavily contaminated ones. Very few people were found to be boiling the water as most could not afford to pay for the additional fuelwood or charcoal which is having to be transported increasingly large distances as more localized stocks dwindle.

Soaring prices in Mozambique, a result of structural adjustment policies implemented in the second half of the 1980s, hit the poorest and most vulnerable to infection more. For example, the rising cost of living caused by the Economic Reform Programme forced the poorer of those who had moved into the former colonial cement areas in the years following independence to move out to wattle-and-grass housing in the environmentally marginal and congested zones of the city. The new occupiers of the cement areas are often expatriates or part of Mozambique's small minority of emergent *nouveau riche*.

The water supply has been in need of renovation for many years. The relative 'boom town' scenario that has been unfolding in the last 3 years created a sense of urgency for it to be improved. The piped water quality is now much better and further work will ensure a more continuous supply. But water must now be paid for, properties containing taps have become privately owned, and the supply of water to the areas where the masses live in conditions of extreme poverty has not been extended. In many of these areas the existing public water sources have continued to deteriorate. Since independence was gained from Portugal, thousands have benefited from a sporadic supply to former colonial mansions occupied by their compatriots. However, the order of change has meant that taps are disappearing behind high walls where guard dogs patrol. This has not occurred in all cases; consequently the remaining taps in properties not yet bought out or in those occupied by people who did not catch the 'all mine' syndrome, have become inundated with long queues which begin before the supply is connected each dawn. Many people do not have time for this, and therefore continue to drink the notoriously contaminated water from the city's open concrete and oil drum wells. Thus in Beira, for some, improvements in the infrastructure are creating a good quality of life, but for the majority things at the best remain the same, or have deteriorated. Improvements in water supply structure that only benefit one sector of a community is likely to be fed back into only limited reduction in water-related health problems. To use the economic metaphor, 'it doesn't trickle down'.

Impacts of structural adjustment may become increasingly observable through the distribution of well-being measured in terms of health, and more specifically here, incidence of cholera. Meanwhile in Quelimane the main development in water provision since economic reform begun has been in the provision of more wells and bore holes with hand pumps, assisted by several NGOs. Sadly, many of these stand idle due

to breaking down, there being a lack of adequate follow-up in pump maintenance. In some cases, and in particular with the bore-holes, bacterial contamination was reduced or removed, but the taste of the bore-hole water influenced by the pumping mechanism, is bad and people prefer to use the traditional wells, simple holes in the ground with 'sweet' water. Many of these are found to harbour high levels of contamination in terms of faecal coliforms. However, a few have been found to have low levels of contamination. More effort could be spent in determining how to make the best use of these. In Mozambique, as in many parts of the world, more effective strategies in reducing the amount of contaminated water that is actually consumed lies with the health and education sectors rather than solely the engineers. Unfortunately, in Mozambique, these are two sectors that have made only limited progress since their extensive disruption in the war of destabilization. Cliff and Noormahomed (1988) describe how after independence in 1975, Mozambique began successfully to implement a primary health care policy but how the preventative programmes became severely disrupted as units were attacked, transport destroyed and health workers kidnapped or killed. This report also records how the effects on health included an increase in mortality rates, famine and infectious disease epidemics including cholera.

8.6 A GEOGRAPHICAL RESEARCH STRATEGY

A recent increase in information on the epidemiology and ecology of cholera, improvements in the detection of *V. cholerae* in people and the environment, and the versatility of computerized information systems encourages a development in research approaches. This is coupled with a genuine need for surveillance of incidence of cholera, early warning systems, and a flexible preventative strategy appropriate to unique circumstances.

8.6.1 THE VALUE OF RECENT RESEARCH

Recent information on the ecology of *V. cholerae* assists in the identification of environmental zones with characteristics supporting higher disease incidence. This can aid implementation strategies for avoiding areas of primary transmission. Identification of processes of interaction leading to the creation of these unfavourable environmental conditions is necessary to avoid the development of further susceptible zones. With increased exposure of humans to varied environments caused by increased mobility and more rapidly changing local environments, the pattern of incidence of cholera will continue to alter. Understanding new patterns as they emerge may be particularly relevant in planning

risk-reduction strategies by determining the availability of more favourable zones or areas of avoidance for communities that suffer from recurring epidemics and in the resettlement of refugees and displaced populations. Where an environmental reservoir is believed to assist endemicity of cholera, consideration should be given to the consequences of geophysical changes that create conditions that increase the survival period and toxigeneity of *V. cholerae*. In already settled areas, the identification of, and intervention in, processes of environmental change leading to the creation of physical conditions favourable to *V. cholerae*, such as salinization and alkalinization, should be considered as a factor in preventing the primary transmission and subsequent persistence of cholera.

8.6.2 MONITORING CHOLERA

Monitoring levels of *V. cholerae* in the physical environment using improved methods of detection, which allow for the identification of vibrios maintained in a temporary state of dormancy, has the capacity to assist in delineating the distribution of possible zones of primary transmission. Deriving patterns of secondary transmission may be assisted by more rapid techniques for detecting *V. cholerae* in cholera patients by use of coagglutination assay (Abbott and Janda, 1993) and rapid diagnostic kits (Andersson *et al.*, 1992; Carillo *et al.*, 1994). The importance of epidemiological surveillance for communicable disease monitoring has been emphasized in several recent disaster situations. Toole and Waldman (1988) indicated its relevance among refugees in Somalia, Sudan and Thailand, and Moren *et al.* (1991) among Mozambican refugees in Malawi. Siddique *et al.* (1992) outline the absence of reliable surveillance as one of the factors responsible for more deaths during the cholera epidemics in Bangladesh between 1985 and 1991. They call for 'effective simple and representative surveillance in the country which could provide early warning signals for impending outbreaks'. Labonte (1992) has extended the concept of surveillance to include community-based approaches in an account of the spread of cholera in South America in 1991. Quick *et al.* (1993), on epidemic cholera in the Amazon, suggests a long-term strategy which includes 'an effort to provide health training to residents of every village, and to develop a coordinated system of communication to provide a means of disseminating information rapidly'.

Babille *et al.* (1994), in monitoring health trends among 25 000 displaced Kurds, call for international agencies and NGOs in the field to make use of available technology to monitor health and disease among refugees, returnees and the permanently displaced. With their experience from work with Iraqi–Kurdish refugees in Iran, limitations

are recognized in assessing changing risks and the proportion of risk attributable to the disaster and post-disaster experience. They suggest that more use should be made of existing information systems and complementary records so as to establish databases that could be used for epidemiological research, adding that 'Comparative data and data on trends from cross-sectional and prospective studies ... can help to identify and solve specific health problems when the international donors begin to lose interest'.

8.6.3 GEOGRAPHIC HEALTH INFORMATION SYSTEMS (GHIS)

Given the present status of health information systems what does a geographical approach have to offer? Firstly, cross-sectional and spatio-temporal techniques for environmental associative analyses are powerful tools of medical geographic research and their continued worth has been outlined in this chapter. The search for associations between variables using an essentially spatial dimension helps to reduce over simplified 'cause-and-effect' relationships.

Environmental zoning with indication of compatibility for human habitation with respect to health is a further development that could be applied in cholera-prone regions. Probability mapping indicating sublocations with significantly higher than expected numbers of cholera cases for individual periods of an epidemic has been included by Ferguson (1977) and Collins (1993). These can be used to indicate persistence of the disease in preferred environments and the movement of the epidemic focus to those areas. Analysis of combined factors or principal components includes use of what Jacquez and Kheifets (1993) refer to as 'synthetic variables' in their analysis of clustering of cancer; 'synthetic risk maps' can be generated from these. Residuals from multiple regression can also be spatially represented in sub-areas and then tested for contiguity. However, there are limitations in the use of sub-locations due to variation in disease clustering when the scale and size of sub-unit are altered. These are subjects explored in some detail by Openshaw (1977, 1984), Waller and Turnbull (1993) and Morris and Munasinghe (1993).

Spatial approaches such as those mentioned above currently benefit from the rapid development of Geographical Information Systems (GIS). These are data bases which have been combined with graphics software for mapping and spatial representation. There are many versions and space here does not allow a full discussion of their differences. However, in general, as a research tool one of their uses is in enabling integration of layers of spatially referenced and associated attribute data allowing analysis on phenomena where considerable amounts of disparate information is involved. For example, in the area

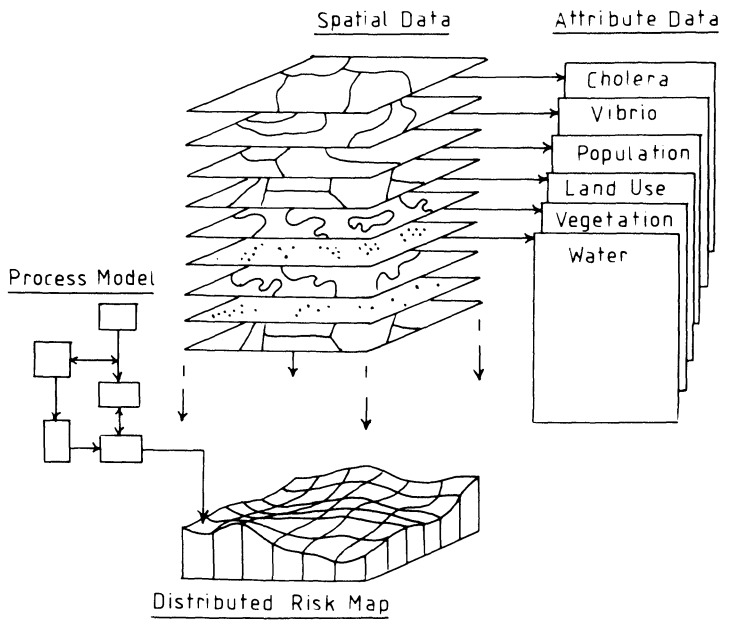

Fig. 8.4 Geographic Information System (GIS) overlay analysis producing risk map.

of environment and cholera, spatially distributed data can include attribute values such as rates of incidence in sublocations, levels of *V. cholerae* contamination and other indicator bacteria, population density, urbanization indexes, soils, water and more detailed geoecological measures of pH and salinity (Figure 8.4). Point positions and attributes, such as the location of individual households which are infected, can also be included. Wider investigations are able to use some of the same techniques to integrate empirical sociogeographic distributions, the GIS assisting as a tool for maximizing part of this procedure. The application of some developments in socioeconomic analysis using GIS to integrate conventional physical resource data with socioeconomic information in the context of benefiting land use planning is discussed by Martin and Bracken (1993).

Satellite imaging can also be integrated into GISs and, when combined with distribution maps of vector-borne diseases, has already been used. Examples are provided by Rogers and Randolph (1991), Rogers and Williams (1993) and Epstein *et al.* (1993b). A further aid in disease mapping is the use of Global Positioning Systems (GPS), such as that used by Snow *et al.* (1993) to map malaria cases on the coast of Kenya. This technology may be used rapidly to record the geographical

locations of events and the stored information can be used interactively with a GIS. 'The GPS receiver becomes a digitizing cursor and the earth is the digitizer's table' (Van Demark, 1992). Abler (1993) suggests that a great attraction will be in the ability to 'create new maps interactively, in real time, amid the real phenomena the maps represent, while at the same time referring to and revising the background maps for the area contained in portable GIS's carried into the field'. In this manner GIS/GPS combinations could be applied to improving disease surveillance systems, particularly in emergencies such as those outlined in this chapter.

GIS also facilitates manipulation of data sets to produce new layers of information, for example, the intersection of overlays (Figure 8.4) to produce new representations of distributions not immediately apparent previously. The ready availability of integrated information in time series enables zones of environmental constraint to be identified and a three-dimensional distributed risk map can be produced (Figure 8.4). The distributed cells of risk are derived from accumulated values generated by the layers of information. Cells most typically represent geographical space, but could equally be made to represent sectors of a community. In other areas of physical geography cells in such a map become part of a larger distributed model within which processes of change can be analysed, as with catchment run-off modelling. The degree to which processes of change in each cell can be accurately represented is the degree to which the overall model can predict. The system is deterministic and it remains to be evaluated what such an extension to Geographic Health Information Systems (GHIS) might benefit given the range of possibilistic considerations associated with health, as have been outlined in this chapter.

8.6.4 A NOTE ON PREVENTION

An essentially geographical and holistic outline of the ecology of cholera has been presented through discussion of the organism, its physical and human environment, and links to the wider world. While incidence of cholera may relate to changing environmental factors affecting the ecology of the disease pathogen, changes in infrastructure and the wider development process are influencing the nature of local environments.

This contemporary geographical perspective on cholera is valuable in that it provides understanding of the issues borne out of a multifaceted research strategy with due attention to circumstances unique in place and time. On the one hand it provides a framework for empirical investigations of patterns and processes associated with cholera, while on the other it is able to combine contextual understanding of the wider issues involved.

It is exactly this perspective that is required in tackling the ongoing challenge that a rapidly changing world ecology of communicable disease presents. The most appropriate preventative strategies and interventive action will arise out of a programme mindful of this approach.

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