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Mapping Disease Patterns

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Abstract: Cartograms make a distinctive contribution to disease mapping. By resizing areas of a map, not by land area but instead by another variable of interest, maps become humanized. In a cartogram concerned with health, population, morbidity, mortality, prevention, or control measures take the central role of determining the dimensions of the map. Map reading changes in nature; what is striking to the map reader when area is distorted by disease prevalence is not the larger land area, or a bolder color, but those expanded areas where the most is happening with regards to the map topic. This article showcases several instances of disease mapping with cartograms. Focusing on the Haitian cholera epidemic, which began in 2010 and which was continuing at the time of writing, other forms of mapping are introduced for comparison to show the value of using several map forms in conjunction with one another.

For as long as disease patterns have been mapped, there has been skepticism over the value of the pictures that are drawn. For instance, a map of the geography of the 1832 influenza epidemic in Glasgow (Scotland) was produced by the inmates of a lunatic asylum, a task given to them mainly to occupy their time[1]. Later, in the nineteenth century, the value of mapping disease patterns was recognized as specific epidemiologic breakthroughs were attributed to the insight gained from mapping. Often cited is a map of the distribution of deaths from the 1848 cholera epidemic in London (England), which, so the tale goes, inspired the removal of the handle of the water pump at the center of a cluster of dots on the map, resulting in the curtailing of the epidemic[2]. However, the map was actually drawn after the pump handle had been removed and was centered on the pump suggesting that it had been identified as being central before the map was drawn.

Maps of diseases are like news pictures of crowd trouble. Viewers should always ask themselves what is not being shown in the map while looking at what is there. They should also ask how the map came to drawn as it is. In particular, look around the edge of the map. Ask why it ends where it does. For instance,
Q1 maps of diseases are often centered on the point the author thinks is most important. Figure 1 shows the central section of John Snow's map of deaths from cholera in Soho. Note how the eye is drawn to the pump in the center, particularly by the very high number of deaths at the intersection of Cambridge and Broad Streets. Had Snow drawn his map of all of London he would have discovered a greater density of deaths

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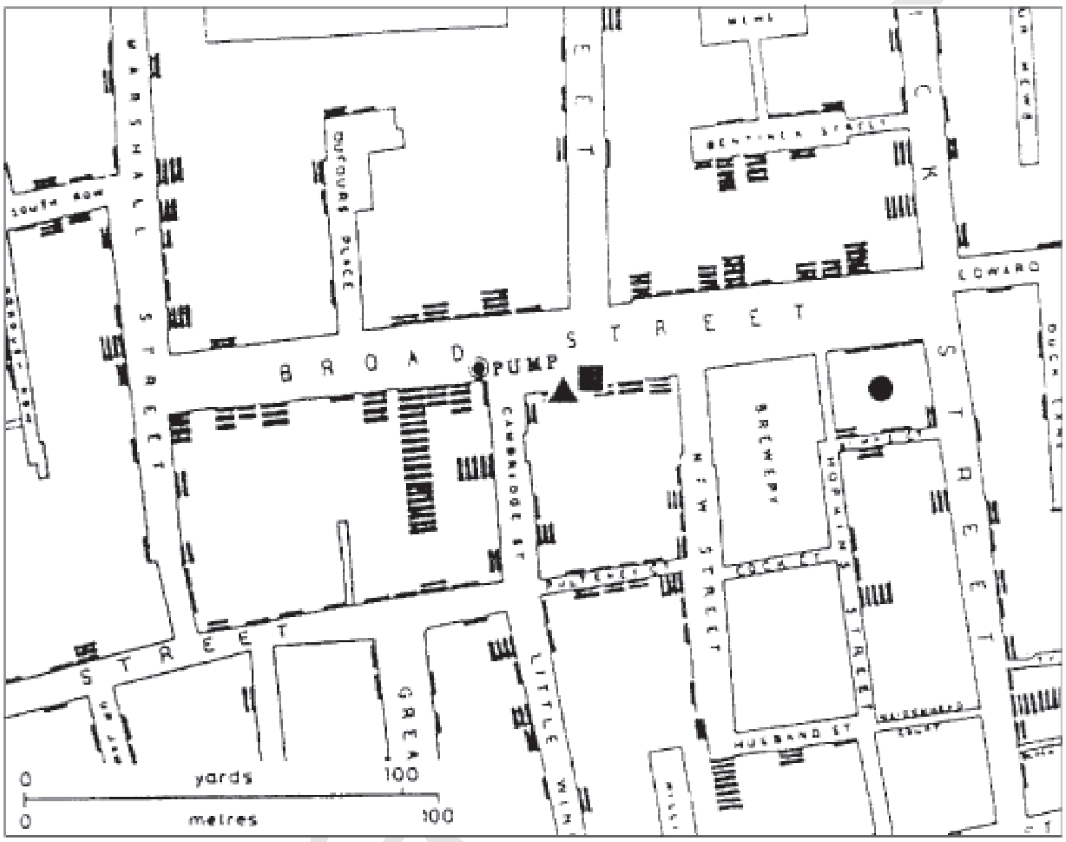

Figure 1. John Snow's map of cholera deaths in Soho, London, 1854. This map shows just the central section of Snow's original map and the Broad Street Pump with Snow identified as the source of cholera. The mean, median, and mode geographical centers of the epidemic have been added. The triangle shows the mean; the square shows the median; and the circle shows the mode. The authors note that the mean and median are quite stable measures and are located within a few yards of each other [1, p. 51]. *Source*: Taken from Cliff and Haggett [1, Figure 1.15D].

just south of the river Thames, as shown in Figure 2. This concentration would have changed location again had Snow had recourse to an isodemographic base map, as shown in Figure 3. As our picture of a disease pans out, as we include more cases and as we change the way we view the picture, the patterns on our maps show change too.

Disease mapping has been most strongly influenced by the history of diseases. Figure 4 shows the prevalence of 12 major causes of death in England and Wales since the publication of Snow's map of cholera. Infectious diseases now account for a tiny fraction of deaths in developed countries (which can afford most disease mapping and research), we later turn our attention to an infectious disease in a poorer country: the case of cholera in Haiti. The causes of death, which are not declining in affluent countries, such as suicide, and those which are rising in importance, such as cancers and dementia, increasingly interest researchers. For these causes of illness and death, the analysis of point patterns around particular sites is still a frequently used approach, but the patterns are usually far less clearly spatially defined than were outbreaks of cholera. More importantly, it is increasingly being accepted that more abstract factors, such as social inequality, can lie behind particular patterns of disease, and these require more abstract mappings for their study.

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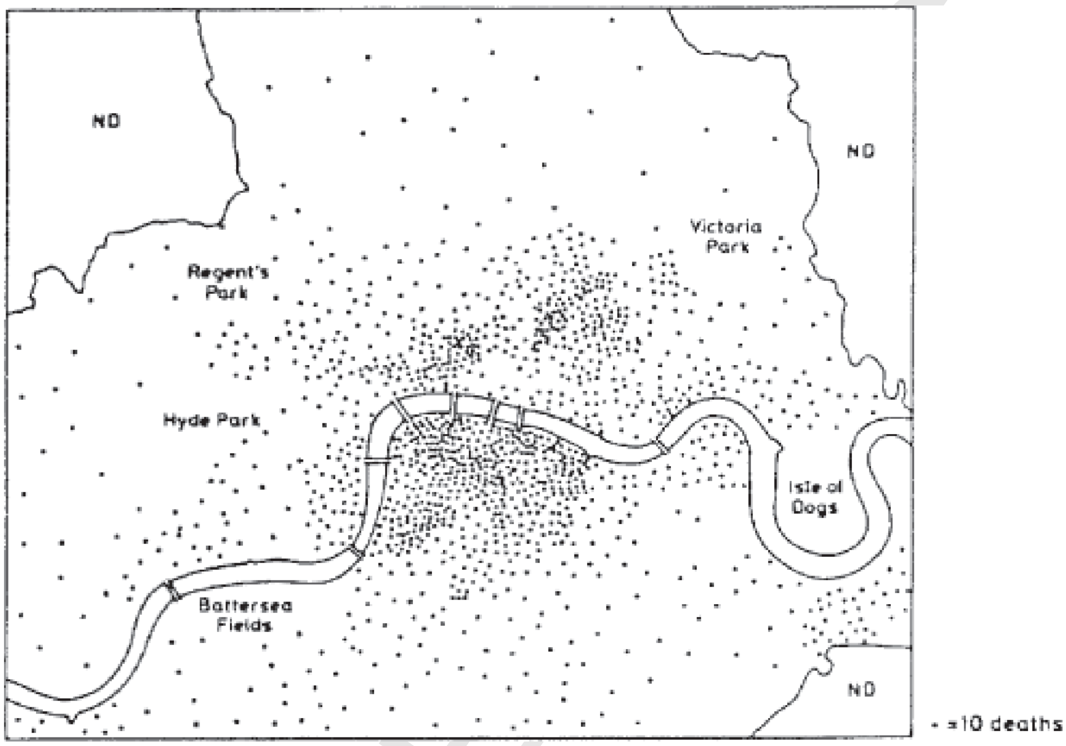

Figure 2. Cholera deaths in London in 1849. A dot map showing the spatial distribution of cholera deaths. Each dot represents 10 deaths, and the location of each dot is determined by the population distribution within the registration district. *Source*: This Taken from Cliff and Haggett [1, Figure 1.3B].

There are many different ways of mapping disease but here there is only space to explore a few alternatives. The alternatives include traditional choropleth mapping, where areas on a map are shaded according to statistics about the population. Most common in epidemiology is the mapping of areas colored by their
06116 standardized mortality ratios (*see* **Standardization Methods**). Another common form of mapping is to map points or the incidences of disease, and often color is also used here to highlight different types of disease. Various different point symbols can be used in mapping, particularly common is the use of proportional circles that are colored or segmented to highlight different features of a disease. The size of the circles is often made proportional to the population at risk of contracting a disease, at which point this type of cartography begins to merge into isodemographic mapping[4,5]. Mapping can also chart the spread of disease over time, enabling the identification of likely vectors and corridors of infectious diseases. This technique benefits from being plotted onto a topographic land area map for those instances when the physical environment influences the way in which a disease spreads.

Diseases occur across a population as much as across land. That is not to say that geographic distributions are not important but that we should take account of the distribution of the population at risk to a particular disease, or cause, before mapping its pattern. One way in which this can be done is to use a map projection that draws every area in proportion to the number of people at risk living in that area—hence the term *isodemographic* (equal people)[4,5]. Isodemographic maps, more commonly called *cartograms*, are used for many purposes, mostly obviously in mapping the geography of elections. However, their most established use has been in disease mapping. Figure 5 shows one of the earliest examples of a cartogram designed for epidemiologic purposes [6, p. 1023].

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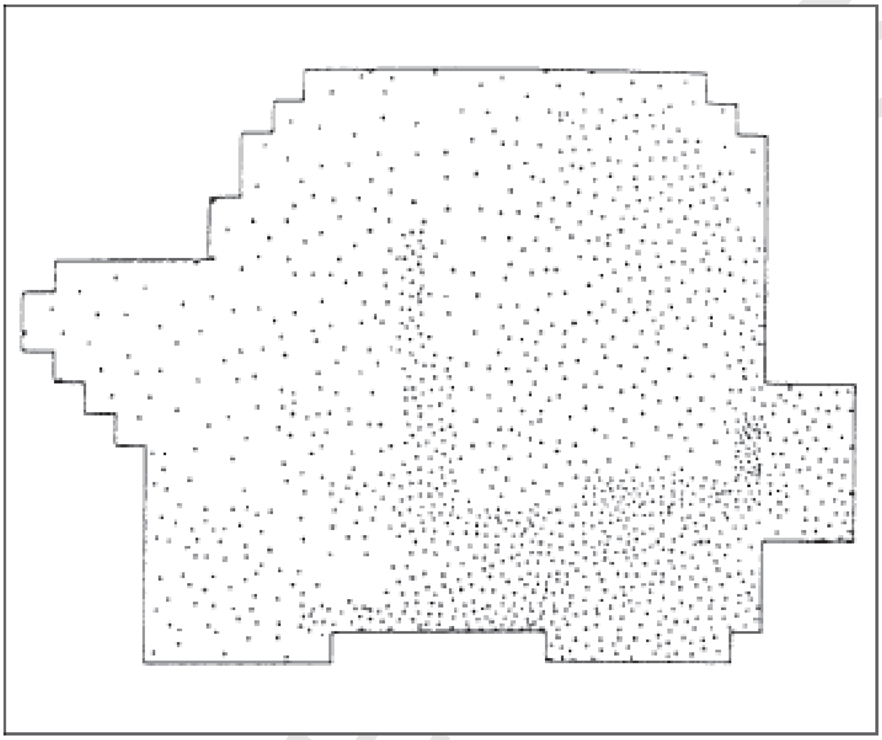

Figure 3. Cholera deaths plotted on a population cartogram. The same data as shown in Figure 2 are plotted here on an isodemographic base map. Again, each dot represents 10 deaths. The authors explain "while some concentration of deaths is still apparent in the southern part of the map, the density is not nearly so marked now that population extent has been allowed for" [1, p. 60]. *Source*: Taken from Cliff and Haggett [1, Figure 1.18D].

The designer of the Iowa cartogram (Figure 5) was a doctor working in the state department of health. Many researchers have been struck by the idea that they could learn more about disease through mapping it in unconventional ways. The first cartogram of London was an "epidemiologic map" produced by a doctor working for the then London County Council Department of Public Health[7]. The cartogram (Figure 6) contained crosses drawn in the borough rectangles to show the incidence of polio during the 1947 epidemic. Because the rectangles were each drawn with the same height, their widths are proportional to population as well as their areas. The borough with the highest rate of polio and hence the tallest column of crosses in the figure was Shoreditch. Almost exactly 100 years separates the two London epidemics, which were first drawn on a map and cartogram, respectively. Cartograms showing distributions within countries came later.

A claim was made to have produced the first cartograms showing national disease distributions only a decade after the crude cartogram of London was first drawn[8]. The nation was Scotland, and a separate cartogram was constructed by hand for each of eight age–sex groups. Figure 7 shows the cartogram being used to study the 1959–1963 mortality of women in Scotland aged 45–54. The author of this cartogram concluded that a national series of cartograms should be produced for each age–sex group for use in epidemiologic studies in Britain. This was never done, and it is debatable whether such an exact mapping base is needed in most studies. A single isodemographic base map of the whole population will usually suffice to uncover all but the most subtle of patterns.

A National Atlas of Disease Mortality in the United Kingdom was published in 1963 under the auspices of the Royal Geographical Society; the atlas contained no cartograms. However, a revised edition was

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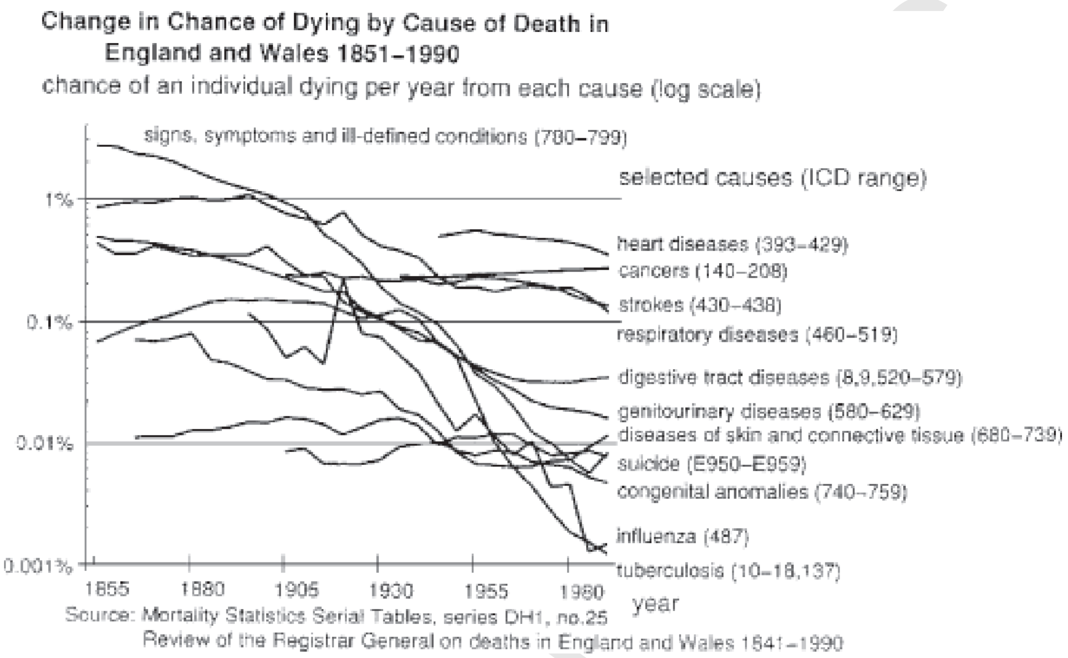

Figure 4. Cause of death 1855–1990. The chance of dying from the infectious diseases tuberculosis and influenza in England and Wales dramatically declines to be just over 0.001% by 1990. Other causes of death, such as heart diseases, cancers, and strokes, are responsible for considerably more deaths by 1990. *Source*: Taken from Dorling [3, Figure 5.21].

published a few years later which made copious use of a "demographic base map"[9]. It is interesting to note that, when the revised edition was being prepared, the president of the Society was Dudley Stamp, who believed that "The fundamental tool for the geographical analysis is undoubtedly the map or, perhaps more correctly, the cartogram" [10, p. 135]. In the cartogram that was used in the revised national atlas (Figure 8), squares were used to represent urban areas, whereas diamonds were used to show statistics for rural districts. No attempt was made to maintain contiguity, but a stylized coastline was placed around the symbols, which were all drawn with their areas in proportion to the populations at risk from the disease being shown on each particular cartogram.

In the *National Atlas of Disease Mortality in the United Kingdom*, Howe used a national cartogram to display the distribution of standardized mortality between 1959 and 1963 from separate as well as all causes of death for both men and women. High rates were seen in northern districts and some Inner London boroughs (including Shoreditch, which is also highlighted on one of the earliest cartograms of London; see above). Extremely high rates in central Scotland were particularly noticeable, as were the low rates in districts that surround London. At the extremes, the average man living in Salford was 50% more likely to die each year than his counterpart in Bournemouth[9]. Both these areas are shrunk on a "normal" map. The pattern for women was very similar to that for men although, in general, it was less pronounced. However, women did have the highest mortality rate of any area on the map in rural Dunbartonshire, where they were more than twice as likely to die each year than were women nationally (allowing for local age structure). The cartogram not only highlights this area but also puts it in the perspective of the populations at risk from the high-mortality rates for women in and around the Glasgow area. Questions for investigation are immediately generated by comparing the maps in Howe's atlases with those produced by Forster for a decade earlier (Figure 7).

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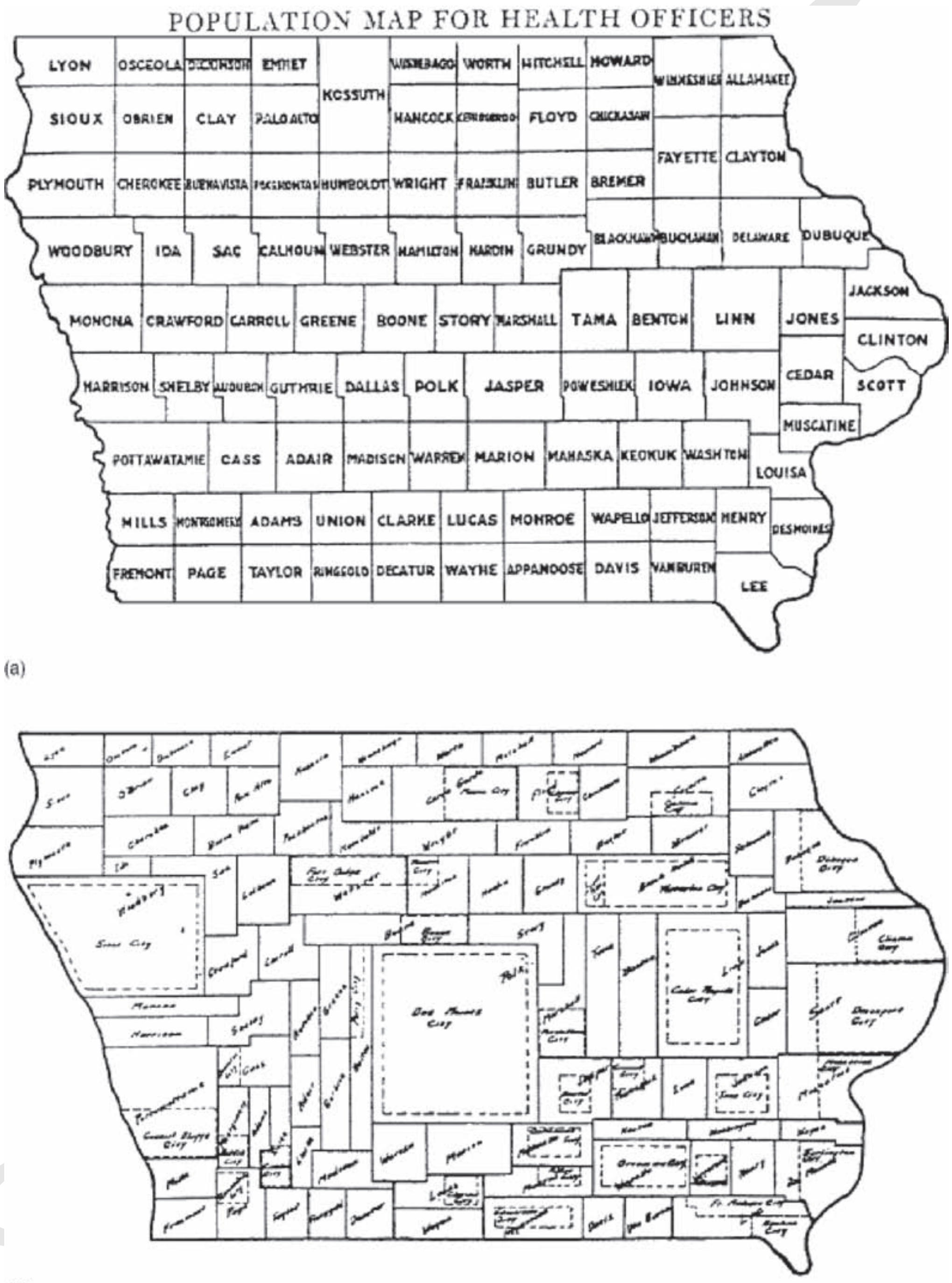

(a)

(b)

Figure 5. The use of cold vaccine in Iowa County Area, 1926–. One of the earliest examples of a cartogram designed for epidemiologic purposes. Figure 5a is the conventional map of the counties of Iowa State, and Figure 5b is an equal population cartogram upon which colored pins were placed to show the locations of reportable diseases. The square in the middle of the cartogram is Des Moines city in Polk County. *Source*: Taken from Wallace [6, p. 1023].

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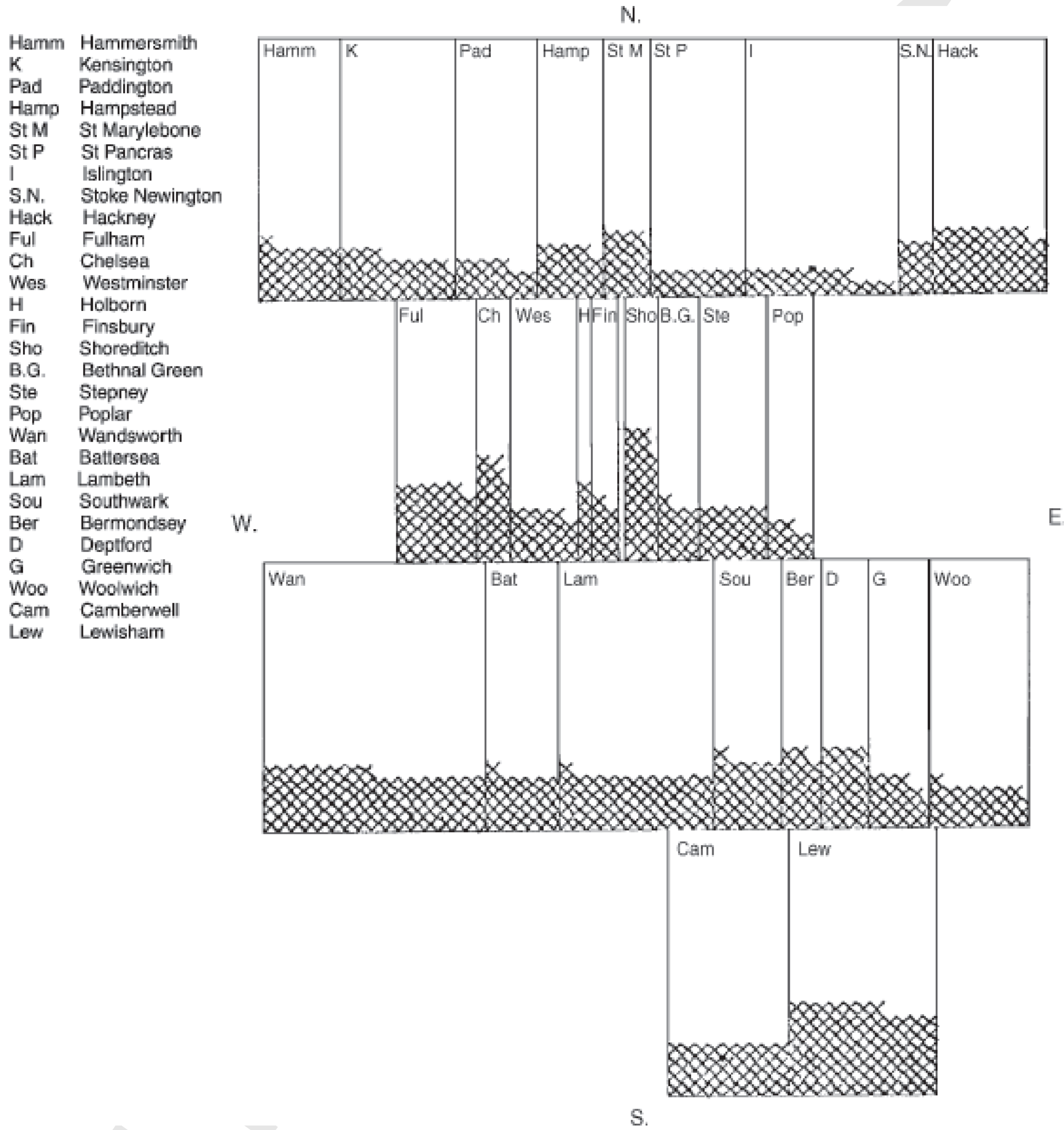

Figure 6. London borough cartogram showing 1947 poliomyelitis notifications. *Source*: Taken from Taylor [7, p. 201].

Cartograms of the prevalence of disease encourage comparisons and raise questions when drawn at the world scale, as very dissimilar countries are juxtaposed and analyzed using the same metrics. In 2005, the Worldmapper project set out to map hundreds of world data sets, using an algorithm for cartograms written by Mark Newman and Michael Gastner. Newman and Gastner's algorithm succeeded in maintaining the detail of territorial borders while boosting or diminishing the area of countries in line with the variable of interest 6[11] (Figure 8). The result is a collection of cartograms, which resemble the familiar world map much more closely than previous world cartograms, which has enhanced the legibility of world cartograms. Within this collection are maps of health care provision, disease morbidity and mortality, and cause of death data from the Global Burden of Disease 2002 data set. When reading world maps, it is worth remembering the limitations of data collected, or estimated, at this scale. Data collection techniques,

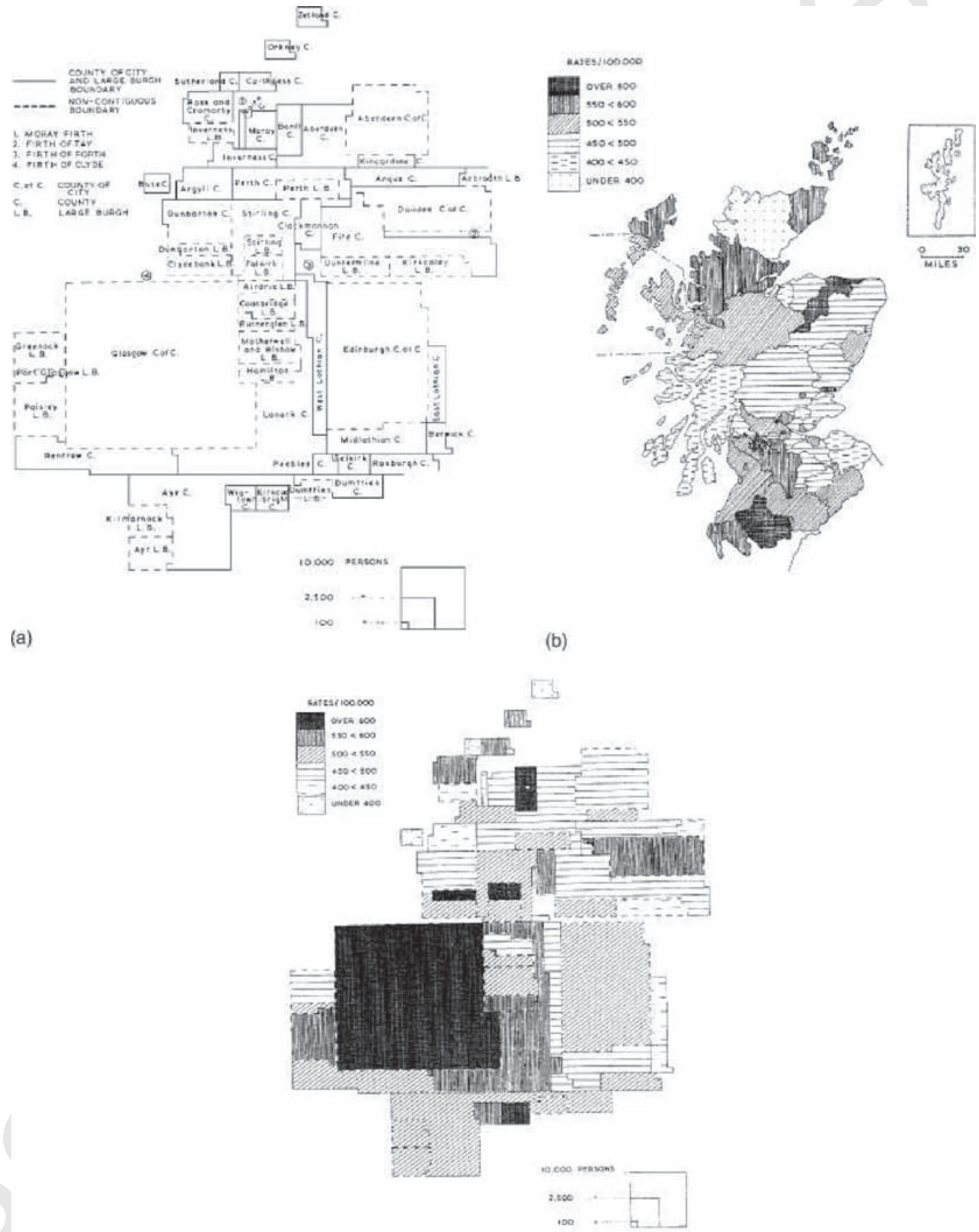

Figure 7. Cartogram and map of Scottish health districts – taken from Forster[8]. (a) Cartogram of females aged 45–54 in 1961 by Scottish health districts; (b) map of 1959–1963 mortality rates of females aged 45–54 by district; (c) 1959–1963 mortality rates of females aged 45–54 shown in (a).

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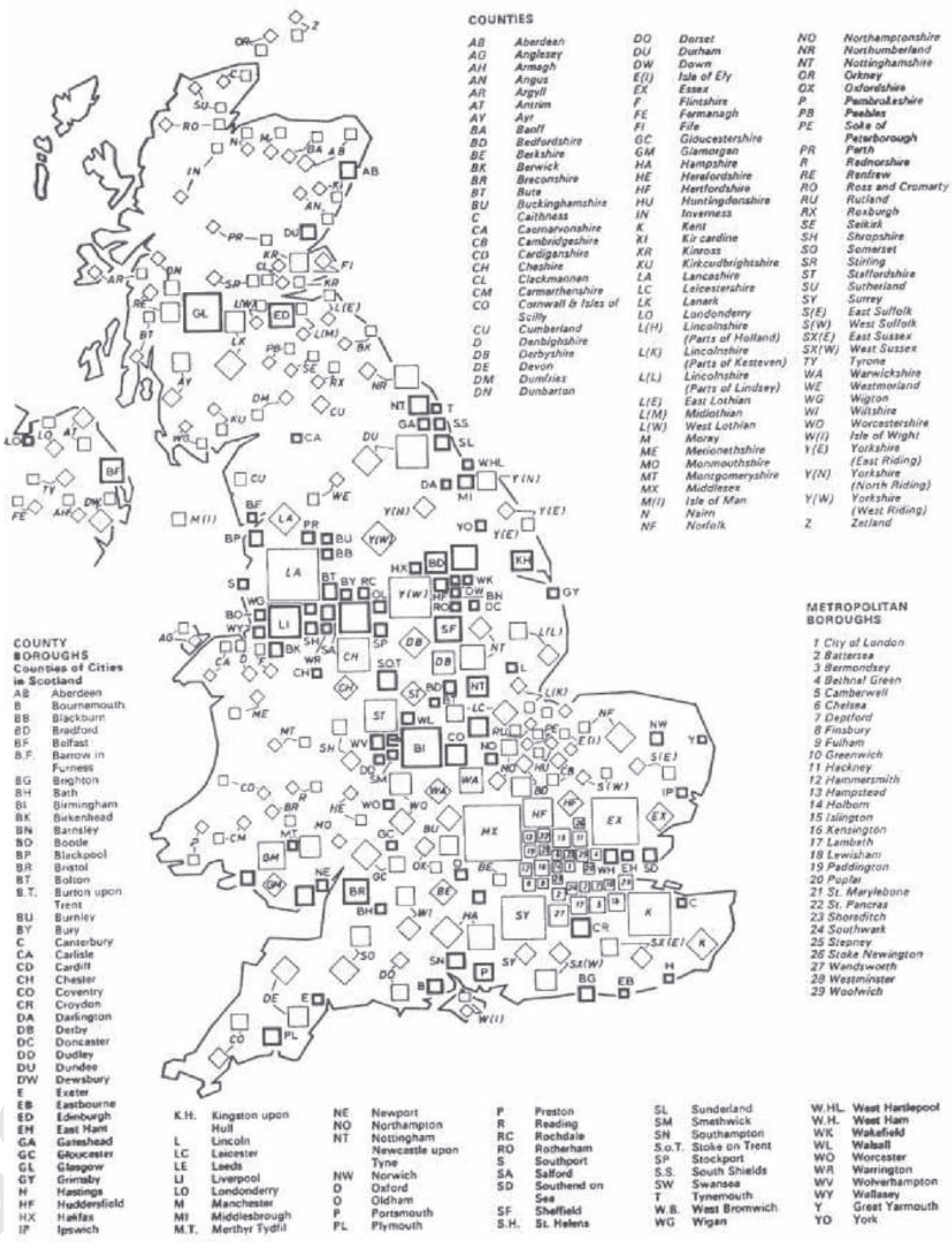

Figure 8. Cartogram of districts of disease mapping in the United Kingdom. This national cartogram shows the distribution of standardized mortality, 1959–1963. *Source*: Taken from Howe[9].

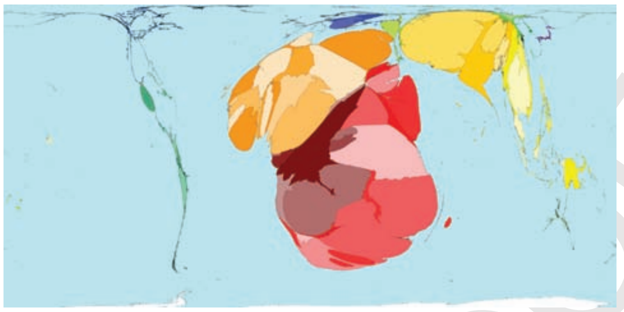

Figure 9. World cartogram of cholera cases. Territory size shows the proportion of all cholera cases that were found there, in 2004 or in the most recent year for which data are available. *Source*: Taken from *www.worldmapper.org*.

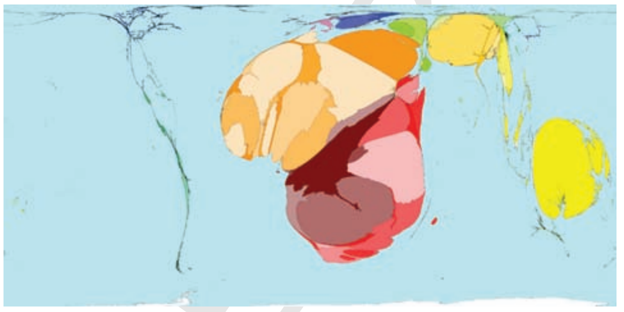

Figure 10. World cartogram of cholera deaths. Territory size shows the proportion of all cholera deaths that were found there, in 2004 or in the most recent year for which data are available. *Source*: Taken from *www.worldmapper.org*.

definitions of variables, availability of medical staff to correctly diagnose disease, and even whether data are collected at all vary between countries[12]. The online atlas now available enables a view of the world in which we can very quickly compare and identify disease burdens (*www.worldmapper.org*).

We return now to cholera, not the cholera of 1848 London, but contemporary cases. Figures 9 and 10 show the worldwide distribution of cholera cases and deaths in 2004. The larger the country on the map, the more cholera cases/deaths were recorded or estimated there. In 2004, the continent of Africa accounted for 70% of all cholera cases. The world total for cholera deaths is just 2.5% of all cases for that year 6[13]. Note how the geographical distribution of cases and deaths differs, largely due to the availability of medical care. Haiti is notable in its absence from Figures 9 and 10. It is thought that there were no cholera cases in Haiti until 2010, when one of the biggest cholera epidemics recorded in recent times began[14,15]. Despite the cholera epidemic only beginning in October 2010, in that year Haiti accounted for 57% of all cholera cases, and 53% of all cholera deaths worldwide, or at least as reported to the World Health Organization (WHO). The equivalent proportions of the world totals for 2011 were 58% of all cases and 37% of all deaths[16]. While cartograms can quickly and effectively communicate the comparative magnitude of cholera cases around the world, mapping the movement of disease at the national and subnational scales offers insight into the how cholera spread so rapidly.

Showing movement and change in maps can help analysts to identify routes of disease transmission. Cholera bacteria are usually transmitted via contaminated water, as identified during the London 1848 outbreak. Figure 11 shows the route of cholera from the supposed source, following the course of tributaries and major rivers downstream to the sea. The epidemic spread initially from Centre Department to Artibonite Department, where the case count escalated. Figure 12 shows the interdepartmental spread

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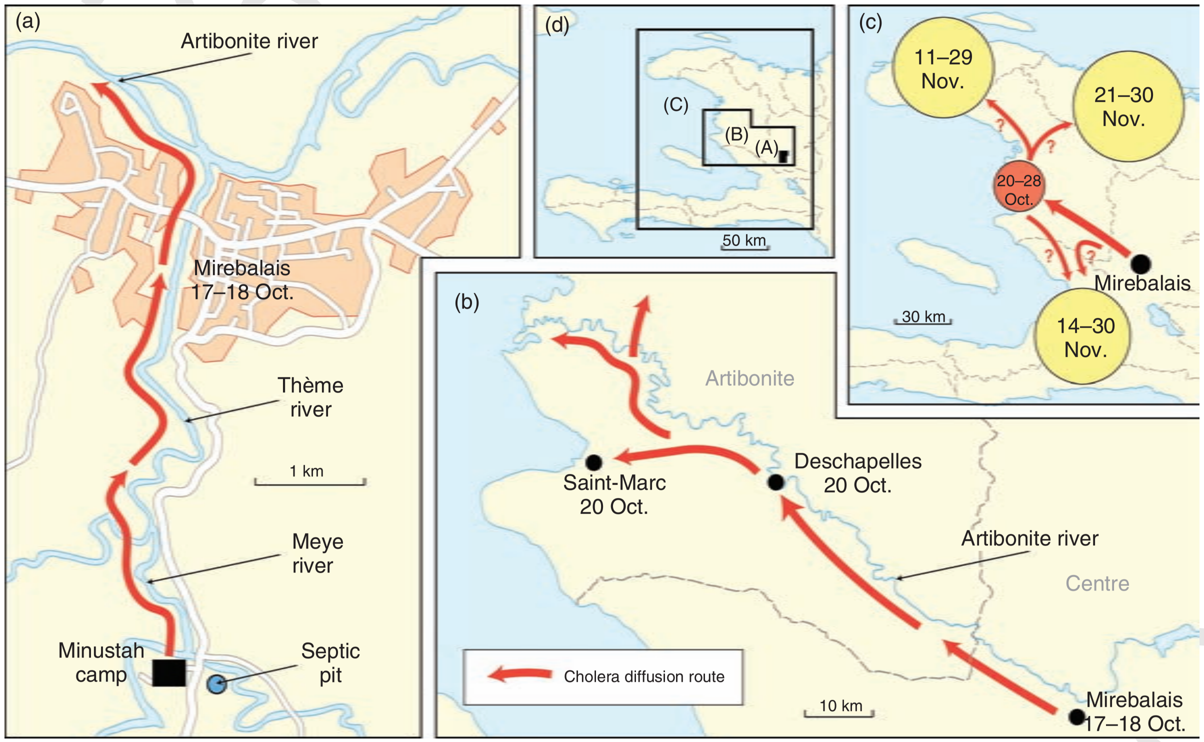

Figure 11. Diffusion of cholera in Haiti, October–November 2010. The inferred route of early cholera transmission is shown by arrows. (a) A United Nations Stabilization Mission in Haiti (MINUSTAH) camp is the likely source of cholera, from where the Meye River carried cholera bacteria to the town of Mirebalais. (b) The Artibonite River carried cholera bacteria downstream from Mirebalais to Artibonite Department. (c) Spatiotemporal clusters of cholera cases, October–November, based on Ref. 17. (d) Location map for (A–C). *Source*: Geographical Perspectives on Epidemic Transmission of Cholera in Haiti, October 2010 Through March 2013, Matthew Smallman-Raynor, Andrew Cliff, Anna Barford, Annals of the Association of American Geographers, 2015, Taylor & Francis; Reprinted by permission of the publisher (Taylor & Francis Ltd, *http://www.tandfonline.com*).

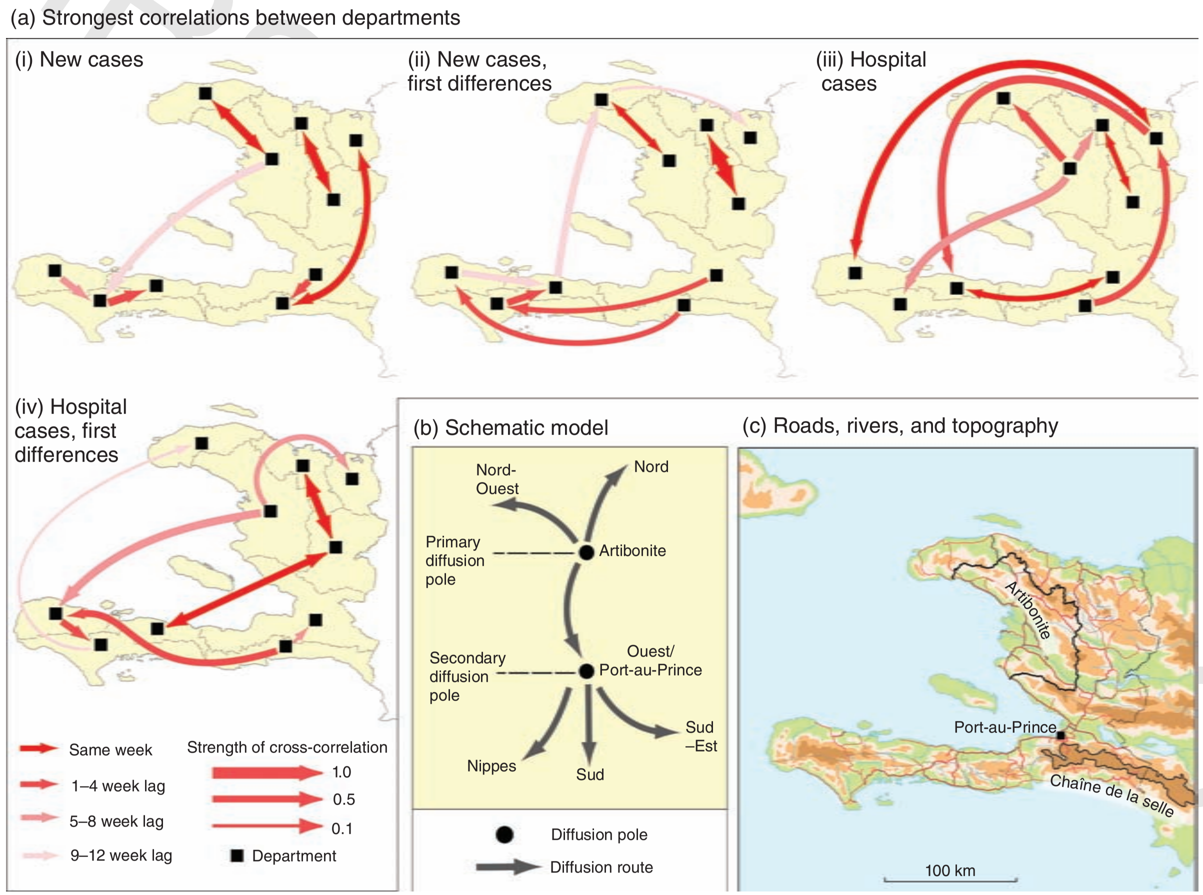

Figure 12. The spread of the cholera in Haiti, October 2010–March 2013. (a) A cross-correlation analysis linked departments with the highest correlation, allowing for time lags of up to +/− 12 weeks. Vector widths show the strengths of cross-correlations. Vector direction shows the apparent direction of cholera diffusion, though for near simultaneous outbreaks vectors point in both directions. Colors indicate time lags. (b) Schematic model of the cholera outbreak, showing the pattern of diffusion between the main diffusion poles in the epidemic. (c) Topographical, hydrological, and transport map of Haiti. *Source*: Geographical Perspectives on Epidemic Transmission of Cholera in Haiti, October 2010 Through March 2013, Matthew Smallman-Raynor, Andrew Cliff, Anna Barford, Annals of the Association of American Geographers, 2015, Taylor & Francis; Reprinted by permission.

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of cholera, based on a cross-correlation analysis of the epidemic curve for each of the departments. The mapping of these cross-correlation functions helps to identify the direction and speed of disease diffusion and resulted in a schematic model of a two-part epidemic with a northern diffusion leading the southern diffusion[15]. Turning back to a very traditional map of roads, rivers, and topography offers some explanation for this wider pattern, where cholera spread downstream along rivers, was carried by people traveling along roads and where chains of hills and mountains act as physical barriers to the diffusion of disease via the movement of people and water courses.

Despite some advantages in conventional mapping when there are clear lines to physical geographical means of transmission, cartograms do offer insight into the mechanics of the 2010-Haitian cholera epidemic. Cholera, transmitted by the fecal-oral route, thrives where there is poor sanitation and untreated drinking water. The population of Haiti has long been underprovided for in terms of water and sanitation quality. Figures 13 and 14 show that on world cartograms of poor water and poor sanitation, Haiti is clearly visible as the lighter green Western part of the Caribbean island of Hispaniola. Around the turn of the millennium, Haiti was on a par with India with 72% of the population living without sustainable access to improved sanitation, and these two countries were among the 10 least well provided for populations worldwide[13]. By 2008, piped and treated drinking water reached just 12% of Haitians and only 17% had the use of adequate sanitation facilities[19,20]. The general absence of good sanitation facilities and clean drinking water meant that once cholera bacteria were introduced to Haiti, they spread quickly. That this epidemic only really spread to neighboring Dominican Republic, with transmission to people in other countries rapidly contained, demonstrates how the Haitian context was vulnerable to cholera in a way that

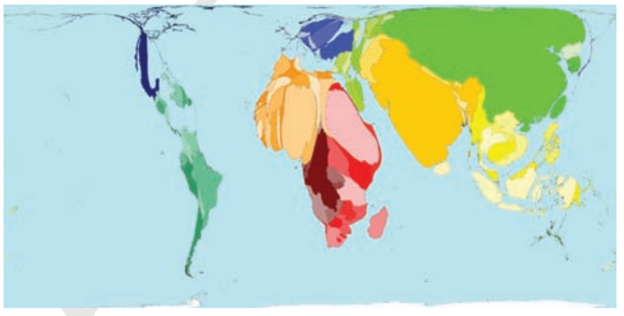

Figure 13. People without reliable access to safe drinking water. Territory size shows the proportion of all people without reliable access to safe water that live there, in 2000. *Source*: Taken from *www.worldmapper.org*.

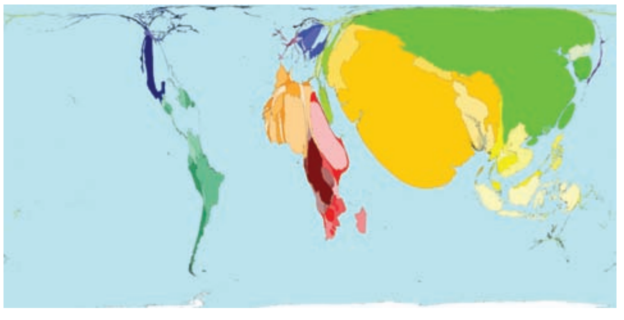

Figure 14. People without access to basic sanitation. Territory size shows the proportion of all people without access to basic sanitation (toilets) that live there. *Source*: Taken from *www.worldmapper.org*.

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many other countries no longer are[21,22]. The example of Haiti shows that the combination of cartograms, flow maps, and topographical maps all adds to a nuanced understanding of the Haitian epidemic.

Mapping of disease patterns is increasingly common due to the proliferation of computer mapping. However, many of these programs were designed to produce general maps of any subject and are often most appropriate to show land use or the distribution of points in physical space. Over most of the course of the past century, doctors, public health officials, and researchers have discovered and rediscovered that traditional maps often do not provide the most appropriate projection to look for patterns of disease. Here, a few alternatives have been presented to try to explain why medical mapping involves more than just sticking pins in paper.

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Geographic Patterns of Disease; **Geographic Epidemiology**; **History of Epidemiologic Studies**; **Infectious Disease Models**; **Leukemia Clusters**; **Disease Mapping, Hierarchical Models For**.

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