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Health and health care applications

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This chapter reviews the applications of GIS in the broad field of health research. Research into the geography of health embraces two main areas: an understanding of spatial epidemiology or the incidence of disease; and the operation of the health care system in a spatial setting. The chapter begins by examining briefly the nature of the spatial objects dealt with in the geography of health, turning next to a review of applications within the first major area. For convenience, this section is divided into three sub-sections, concerned with visualisation, exploration, and modelling. It reviews both applications that look solely at disease incidence and those that make inferences about associations with environmental contamination. Next the discussion examines applications of GIS in health care planning, paying attention to research on the delivery of services and access to those services. It is stressed that the two broad areas – epidemiology and health care planning – are in fact closely linked, and that a focus on spatial decision support systems emphasises such links.

1 INTRODUCTION

Research into the geography of health has expanded dramatically in recent years, as witnessed by the appearance of several major texts (see, for example, Cliff and Haggett 1988; Jones and Moon 1987; Thomas 1992), by the vitality of specialist research groups attached to the major geographical societies, and by the success of a series of international symposia and accompanying publications (see, for example, several special issues of *Social Science and Medicine*; also Gatrell and Löytönen 1997; Lepper et al 1995; Savigny and Wijeyaratne 1994). Approaches to the geography of health take a variety of forms and methodological perspectives, some researchers choosing to create statistical models of the incidence of disease, others adopting qualitative approaches to an understanding of ill-health, or exploring the geographical expression of the politics of health (to give but three broad examples). Among this diversity of approaches and methodologies, a growing number of researchers have found value in the use of GIS. These approaches and the applications they have spawned form the substance of this review.

Given that GIS are, at heart, tools for analysing spatial data it comes as no surprise that they have been embraced warmly by those approaching the geography of health from a 'spatial analysis' tradition (that is, the quantitative analysis of health-related phenomena in a spatial setting). This intellectual tradition is described in the various contributions to the 'Spatial Analysis' Section 1(c) of the Principles Part of this Book (Chapters 16–20). A corollary of this approach is that the relative locations of such 'phenomena' are crucial in analysis and subsequent interpretation. The following section unpacks briefly what these phenomena might be in a health setting, but before doing so there are some remarks on how the subject matter is organised.

It is conventional, and useful, to divide the geography of health into two broad areas: the geography of disease and ill-health; and the geography of health care. In the first, interest is in describing, exploring, and perhaps modelling, the spatial incidence of disease or illness. Important questions that arise here concern whether there is evidence for 'clustering' of disease, or whether there are areas that have unusual 'clusters' of health events. Some studies go beyond this in the search for causal explanations by seeing if there is an association between the spatial patterning of disease and environmental contamination. The second broad area of research is concerned with the delivery of, and access to, health services. Clearly, health care resources have to be located somewhere. But what are the population 'needs' for health care, how should resources be allocated over space, and how accessible are such resources to the populations they are designed to serve? These are very important issues for the planning of any health care system, and this section reviews case studies that have used GIS to help such planning and evaluation.

Having made a distinction between these two broad research areas, it should be emphasised that, in policy terms at least, they are interlinked. If research identifies an uneven patterning of disease, with an excess risk of, say, heart disease in certain areas, health care planners will wish to address this spatial variation, perhaps by targeting resources to try to reduce the elevated rates in certain areas. Such planners need a spatial decision support system that allows them to explore and model the consequences of alternative health care scenarios and resource configurations.

2 SPATIAL DATABASES FOR HEALTH RESEARCH

This section considers briefly the kinds of spatial objects that arise in health research, and the variety of attributes that may be attached to those objects. Some applications find it useful, for the purposes of analysis, to transform one type of object into another (Gatrell 1991; Goodchild 1987). Conventional typologies (see, for example, Bailey and Gatrell 1995; Unwin 1981) recognise some or all of the following classes of spatial data: points, areas, lines, spatially continuous or 'field' data, and spatial interaction or 'flow' data. Examples of each in a health setting are discussed next.

2.1 Point data

Point data include, as objects, the residential locations of individuals, whose attributes might include presence or absence of a disease (known, respectively, as 'cases' and 'controls' in epidemiology: see Kelsey et al 1986), together with other features (age, gender, occupation, and so on) that are relevant to an understanding of that disease. As the following discussion shows, there are plenty of examples where residential location is considered useful, but it must be acknowledged that individuals do not spend 24 hours a day at home; rather, they have variable, and perhaps quite complex, activity spaces that result in potential exposure to various pathogens. Schaerstrom (1996) has begun to investigate how the classic ideas of 'time geography' that originated with the Swedish geographer Torsten Hägerstrand (explored in a GIS context by Peuquet, Chapter 8; Miller 1991) must be brought into the geography of health (Figure 1). Researchers also need to recognise the dynamics of any disease database; new cases may appear because of infection or inmigration, while others are 'lost' to the system by death or by outmigration. A major problem for spatial epidemiologists, except in rare but welcome cases, is the lack of information on migration histories.

Further problems with creating point-based databases for individuals concern the quality of both the locational and attribute data. In the western world researchers may take for granted the availability of high resolution geocoded health data (Gatrell et al 1996; Rushton and Lolonis 1996). Elsewhere such data must be collected 'from scratch', employing technologies such as Global Positioning Systems (GPS) to record, for example, the locations of cases of malaria (Sharp and Le Sueur 1996). It is always necessary to ask whether addresses are recorded accurately, whether all cases are included (Jacquez 1996), and if there is agreement about case definition. It is also important to examine what kinds of health databases should be created. Typically, these deal with mortality (death) or morbidity (disease) data; it is the absence of 'health' that defines the database.

Other relevant point data relate to the health care system; for example, the locations of primary health care clinics, of hospitals, of ambulance stations, and of general practitioner surgeries. These may create fewer problems of 'entitation' or definition, but while having identifiable and accurately recorded locations the spatial pattern will alter as the service delivery system is reshaped; the set of facilities for accident and emergency care in 1997, for example, is unlikely to be the same as that in 1987.

Finally, as section 3 illustrates, some epidemiological applications have considered the association between respiratory disease and proximity

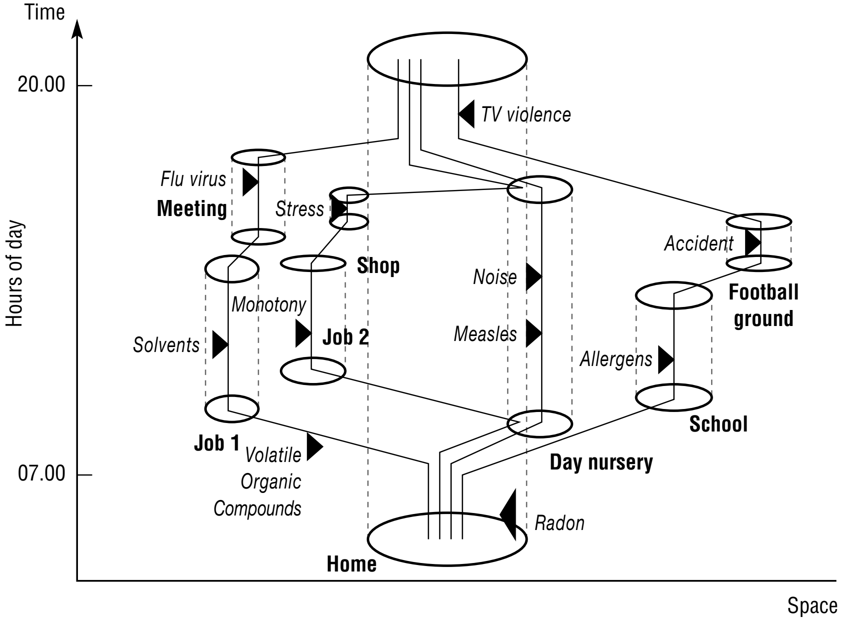

Fig 1. The daily life of a family, and health impacts, in a 'time geography' framework.
Source: Schaerstrom 1996

to point sources of pollution, such as coking works, landfill sites, and incinerators. Databases on the locations of these may be used in association with large epidemiological databases to assess health risks. For example, Elliott et al (1992b) followed up evidence of an association between larynx cancer and industrial waste incineration in south Lancashire, UK (Diggle et al 1990) with a nationwide study that failed to confirm the association.

2.2 Area data

Cartographic display and analysis of area-based epidemiological data represent a long-standing tradition in the geography of health (Cliff and Haggett 1988). Typically, the zones are population census-based areal units, permitting a simple link between measures of disease risk and demographic or socioeconomic covariates. Such zones are also important in policy-making; for example, area-based data on socioeconomic deprivation are used in Britain to make payments to general practitioners for treating patients in deprived areas (Senior 1991).

In some applications it is appropriate to transform point objects into area objects, or vice versa. For example, the point locations of hospitals could be used to define a set of catchment areas, or areal units might be replaced, for visualisation purposes, by data mapped at the centroids of such areas.

2.3 Line data

Line data used in health applications include road network databases used to define travel times to centres of treatment. For example, Ball and Fisher (1994) used data on assumed travel speeds along particular classes of road to define a probabilistic catchment around the major hospital in Leicester, UK, while Tinline (1988) outlined a system for the routing of emergency service vehicles in rural Ontario, Canada.

In environmental epidemiology there has been considerable interest in the association between traffic levels on roads and respiratory ill-health. A transformation from one type of spatial object (lines) to another (areas) is frequently adopted, by placing buffer zones around the linear features.

2.4 Spatially continuous data

Spatially continuous or 'field' data arise mainly in the environmental sciences, where a continuous surface is sampled at discrete point locations. For example, attempts to explore the links between outdoor air pollution and respiratory ill-health are hampered by the lack of good data on air quality. Ideally, this should be monitored, although often it is modelled (Collins et al 1995). If data are collected over a network of monitoring stations, a spatially continuous surface may be created via Kriging (Bailey and Gatrell 1995: 176–201; Isaaks and Srivistava 1989) or other interpolation procedures. Some attempts (see, for example, Oliver et al 1992) have been made to use Kriging in an exploratory epidemiological context in order to produce optimal maps of disease risk. Environmental data relevant in some epidemiological contexts include those on radon (Geiger and Barnes 1994) and complex organics such as polychlorinated biphenyls and dioxins (Lovett and Tate 1992), as well as standard climatic data used in predicting the incidence of both human and animal disease (Lessard et al 1990).

2.5 Spatial interaction data

The significance of these data types arises in market-led health care planning. Here, a researcher may have a set of locations at which health care may be supplied, together with a set of locations at which (or within which) health care is demanded. There are then flows of patients, or consumers of health care, from a set of origins to a set of destinations. Understanding the pattern of flows, and seeking to modify that pattern, is a key task in health care planning. Spatial interaction models (Birkin et al, Chapter 51; Fischer, Chapter 19; Getis, Chapter 16; Mayhew 1986) may be used to predict flows, for example using attributes such as age–gender composition at the origin end and numbers of hospital beds at the destination end. The spatial separation of origins and destinations can be represented simply as Euclidean distance, or perhaps using assumed travel times.

3 EPIDEMIOLOGY AND GIS

Since epidemiology is concerned with describing and explaining the incidence of disease, it follows that spatial epidemiology requires methods that will provide good descriptions of the spatial incidence of disease, together with methods that offer the prospect of modelling such incidence. This section, therefore, considers briefly methods for visualising, exploring, and modelling the geographical incidence of disease, a division that follows the classification adopted in Bailey and Gatrell (1995). Relatively few applications focus specifically on the linking of health databases to those on environment.

Much of the literature discussed in the present section was created by statisticians and epidemiologists (for overviews see Diggle 1993; Elliott et al 1992a; Jacquez et al 1996; Marshall 1991; Nobre and Carvalho 1995). A challenge for the health researcher is to see whether, and if so how, to link often quite complex analytical tools to a GIS. In the early 1990s it was common to see papers (for example, Anselin and Getis 1993; Bailey 1994; Goodchild et al 1992) criticising the lack of spatial analysis functionality in GIS. However, such functionality is now appearing in commercial and research-based products such as SAS-GIS, S-Plus for ARC/INFO, Regard (Haslett et al 1991), and LISP-STAT (Brunsdon and Charlton 1996). Pedagogic material such as INFO-MAP (Bailey and Gatrell 1995) is also available. At its best, such software is genuinely interactive and employs linked windows, so that, for example, the results of queries in one window can be seen in other linked windows. In a similar vein, a choropleth map of incidence rates can be displayed in one window, the results of spatial smoothing of this map in another, a graph relating rates to data on socioeconomic deprivation in a third, and a tabulation of data in a fourth (see Egenhofer and Kuhn, Chapter 23). The linking of these 'views' means that selection of objects in one causes them to be highlighted in others (Brunsdon and Charlton 1996).

3.1 Visualisation of epidemiological data

Although point data on disease cases (and perhaps controls too) can be visualised, such maps are of little value unless an attempt is made to control for underlying population distribution or 'heterogeneity'. Frequently in geographical epidemiology researchers do not have access to point data (perhaps for reasons of confidentiality) and instead are provided only with data for a fixed set of areal units, such as census tracts. Such data might include incidence rates, suitably age-standardised to control for variations in age structure. There are important issues concerned with visualisation of such choropleth maps and how meaningful information is derived from them (Walter 1993).

One particular issue concerns the variable size of spatial units. Typically, the eye is led to large areal units, which will usually be located in rural areas. High rates in such areas then have a very dramatic impact, unlike those in smaller, urban areas which are dwarfed visually. This problem has led to the use of cartograms or 'density-equalised' maps in disease mapping. In such maps, the size of an areal unit is proportional to population at risk, and disease rates (Dorling 1994a), or individual point data where available (Selvin et al 1988), are mapped onto this new base-map (Figure 2). However, while such cartograms are important visualisation tools the widespread availability of digital boundaries, at both small and large scales, means that choropleth maps will be hard to displace. Indeed, the emergence of electronic atlases of health (Braga et al 1998), complementing earlier paper-based products (for example, Smans et al 1992) will give them a new lease of life!

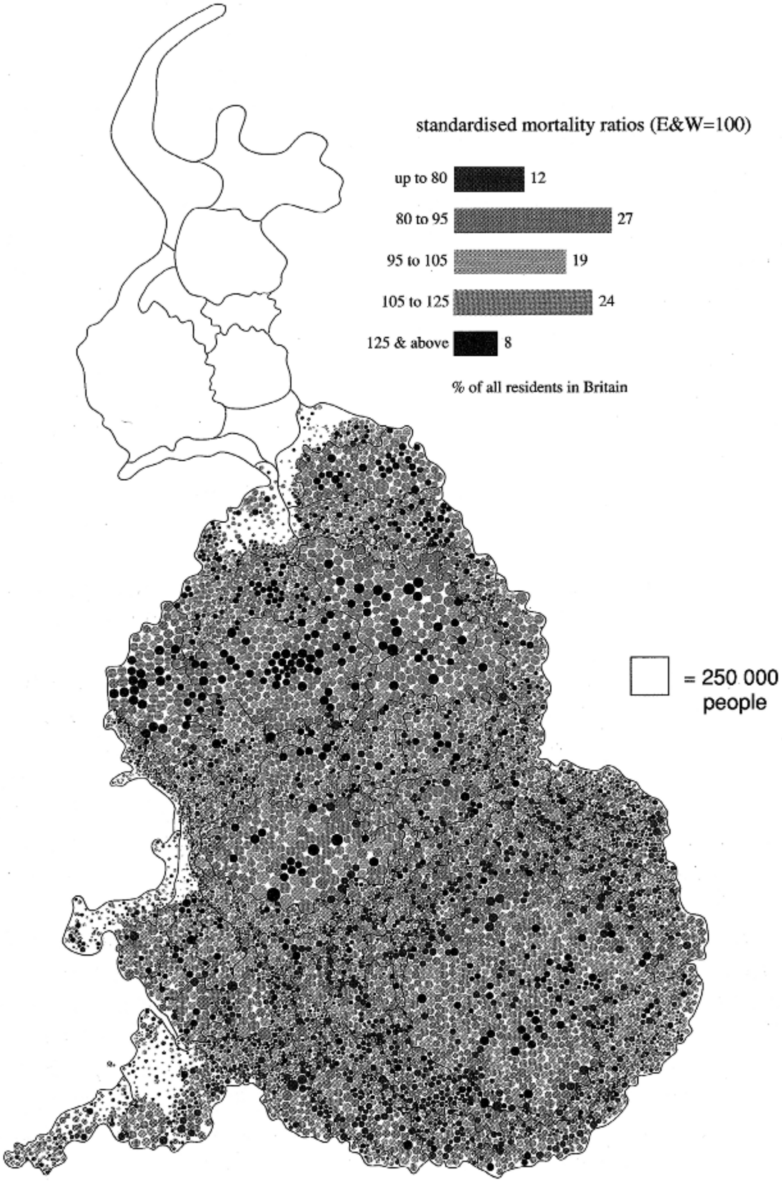

Fig 2. Mortality from all causes in England between 1981 and 1989 (relative risks for ward population).

3.2 Exploratory spatial data analysis

Exploratory data analysis goes 'beyond the map' to use statistical tools in an informal, pattern-seeking vein (Anselin, Chapter 17). It is here that major research efforts have been expended (Cislaghi et al 1995; Rushton et al 1996).

This section discusses the methods available for analysing health data for areal units. Initially it is important to recognise the problems that arise when there are low numbers of cases, problems that tend to emerge either when the areal units are small or when the disease is rare. Techniques such as empirical Bayes estimation (Bailey and Gatrell 1995: 303–8; Langford 1994) are valuable in these situations. Where disease incidence is low, the estimate for any area is 'shrunk' towards the mean value for the study area, implying that there is little confidence in the observed disease rate in that area. Where the rate is based on large numbers of cases it is not shrunk or smoothed so much. The smoothing can be either 'global', in which case the overall mean is used, or 'local', where the estimate is adjusted to a neighbourhood mean such as that for the contiguous zones. Such methods are being used increasingly in modern electronic atlases of mortality and morbidity (see, for example, the Spanish cancer atlas: Centro Nacional de Epidemiologia 1995). They can be used to highlight areas where rates are unusually high or low.

If point data are available there are other methods for estimating spatial variation in disease risk, known as kernel or density estimation (also capable of being used for areal data: Braga et al 1998). These techniques show how the density, or 'intensity' of a point pattern varies spatially (Bailey and Gatrell 1995: 84–8). A moving window, or 'kernel', is superimposed over a fine grid of locations, and the density of point 'events' estimated at each location; the bandwidth or spatial extent of the kernel function plays a key role in determining the degree of smoothing. If it is too small, the original map of health events is merely duplicated, while too large a bandwidth over smooths the map, obscuring any useful local detail. Visualising the results, either as a contour map or raster-like image, shows regions where there is a high incidence of disease, and therefore possible 'clusters', though if the underlying population distribution is uneven or heterogeneous this is of little value. Consequently, other research (Bithell 1990; Kelsall and Diggle 1995) has shown how the ratio of two density estimates (one for disease cases, the other for healthy controls) provides a powerful exploratory tool for cluster detection. Rushton and Lolonis (1996) used a similar approach to identify areas with significantly high rates of birth defects in Des Moines, Iowa (Figure 3),while other methods for cluster detection, such as the use of spatial scan statistics, are similar in spirit and have been applied to the study of childhood leukaemia in Sweden (Hjalmars et al 1996).

Methods such as these help to pinpoint possible clusters, in much the same way as does Openshaw's well-known Geographical Analysis Machine (Openshaw et al 1987), the first attempt to use modern GIS in epidemiological research (for a discussion of this general approach, see Openshaw and Alvanides, Chapter 18). Authors such as Openshaw and Rushton stress the potential usefulness of such methods in disease surveillance, arguing that the 'tendency to investigate specific disease clusters should give way to more sensible disease surveillance programs based on automated approaches that address-match event data to the new digital geographic data products' (Rushton and Lolonis 1996: 725).

The question of whether there exist 'clusters' of health events needs to be distinguished from whether or not there is generalised 'clustering' of such events across a study region as a whole, and from the testing of specific hypotheses concerning the association with point sources of pollution. There are statistical tools to assess whether cases of disease aggregate more than might be expected on a chance basis. One approach (Cuzick and Edwards 1990) looks at each case of disease in turn and asks whether nearest neighbours are themselves more likely to be cases than controls; this is then evaluated statistically. Other approaches use the so-called K-function (Diggle 1993), which gives an estimate of the expected number of point events within a given distance of an arbitrarily chosen event (Bailey and Gatrell 1995). The K-function determines whether a spatial distribution is random, clustered, or dispersed, at particular spatial scales. If estimated for both cases and controls the statistical comparison of the two K-functions shows whether cases display more, or less, tendency for aggregation or clustering than we would expect, given background variation in population at risk. Statistical details are given in Diggle and Chetwynd (1991) and applications in Gatrell et al (1996).

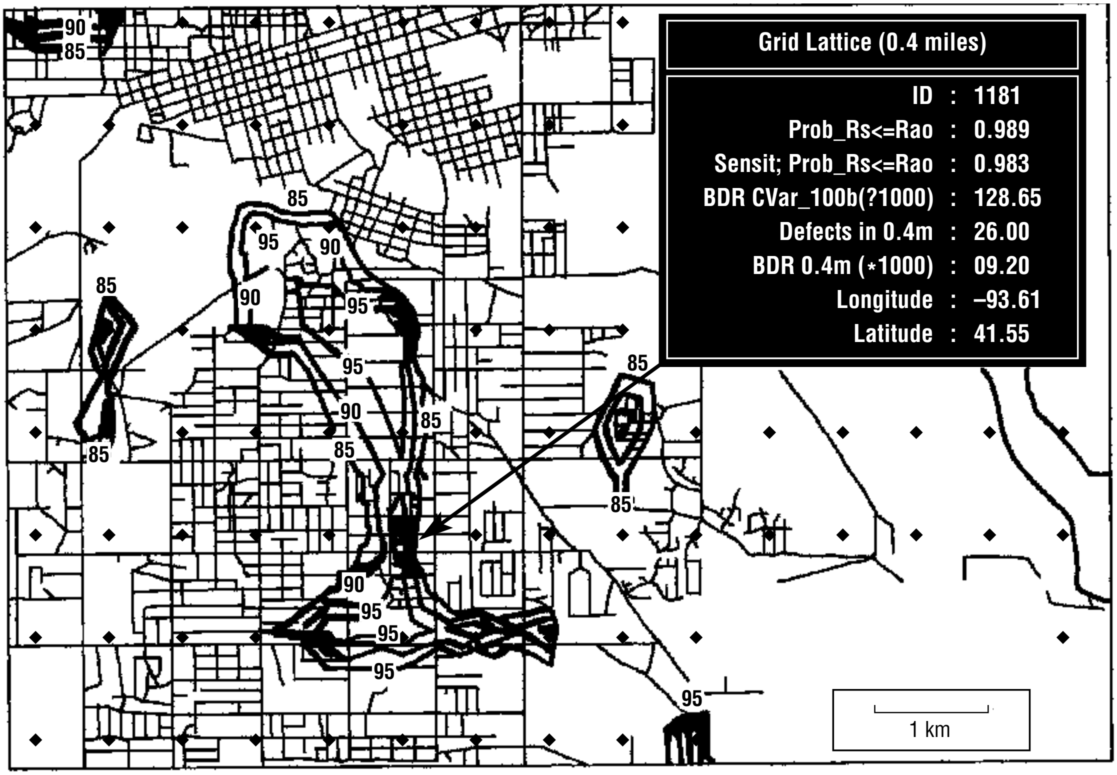

Fig 3. Areas (numbered) with significantly high rates of birth defects in Des Moines, Iowa, 1983–90. *Source*: Rushton and Lolonis 1996

The space-time incidence of disease may be explored if the GIS database includes as an attribute the date of infection, or date of notification. If cases that cluster in space also cluster in time this may give clues to a possible infective mechanism in disease causation. Various techniques are available here, including those which extend the K-function (Bailey and Gatrell 1995: 122–5). Applications include research on Legionnaires' disease (Bhopal et al 1992) and on cancer (Gatrell et al 1996). Given very detailed longitudinal information on residential histories, space-time clustering can be examined in a historical setting. For example, a test of space-time interaction among cases of multiple sclerosis in part of Norway (Riise et al 1991) showed convincing evidence of clustering of patients in their late teenage years.

Other, essentially exploratory, GIS-based investigations of ill-health give more attention to possible links to environmental quality, even though they do not go so far as to try to model the incidence of disease. For example, Openshaw et al (1990) developed a procedure to search a spatial database for permutations of coverages (such as geology, soil type, and proximity to power lines) that were associated with significant numbers of cases of childhood leukaemia. Dunn et al (1995) investigated the association between asthma and proximity to a factory producing wallpaper in northeast England. The GIS was used to define a set of sectors and radii around the factory. Standardised incidence rates were estimated in each zone with significantly elevated rates detected in zones immediately to the northeast of the plant. Spatial statistical models can be fitted to such data, as described below.

In the developing world, a growing body of researchers is exploring the usefulness of satellite imagery (Barnsley, Chapter 32; Estes and Loveland, Chapter 48) in understanding the ecology of tropical diseases such as malaria. Noteworthy examples of the possibilities are the attempts to predict and control the incidence of malaria in parts of Africa. Thomson et al (1996), working in the Gambia, illustrate the potential for using coarse-resolution satellite imagery and derived normalised difference vegetation index (NDVI) measurements in modelling malaria transmission. Depending on the time of year, particular values of NDVI may be used to identify possible breeding sites for mosquitoes; in this way, knowledge of spatial and temporal variation in the environment may be used within a decision-support system for malaria control (Thomson et al 1996). Such research parallels other work on malaria in southern Africa where Sharp and Le Sueur (1996) demonstrate how GPS can be used to record the locations of 35 000 homesteads at risk from malaria in KwaZulu-Natal. These locations may then be related to clinic catchments. Clearly, both studies demonstrate the link between traditional epidemiology and health care planning.

3.3 Modelling spatial data in epidemiology

In examining point-based data in geographical epidemiology a common emphasis has been the exploratory detection of generalised clustering of disease, or in identifying the location(s) of disease 'clusters'. More 'focused' studies (Besag and Newell 1991; Kulldorff 1998) are required where hypotheses need testing about possible raised incidence of disease around suspected sources of pollution. Various approaches have been adopted (for example, Diggle et al 1990; Lawson 1993; Waller and Lawson 1995) and attempts have been made to link these to a commercial GIS (Gatrell and Rowlingson 1994). However, these methods generally assume that distance from such pollution sources is a reasonable marker of exposure. In addition, there is a need to control for 'confounders', or other variables that may themselves be associated with proximity to the source(s) being examined. For example, there should be control for smoking behaviour or socioeconomic status, since it may be that any observed elevated risk near pollution sources is attributable to such factors rather than to emissions from the plant (Diggle and Rowlingson 1994). An interesting application is the possible health effects of electromagnetic radiation, microwaves, and radiowaves, about which there has been scientific and public concern for some years. In a study on Oahu, Hawaii, Maskarinec (1996) conducted a case-control study in which the proximity of children's homes to low-frequency radio towers was examined as a risk factor for acute lymphocytic leukaemia. Allowing for parental occupation, domestic smoking, and exposure to X-rays (as possible confounders) there was some support for the hypothesis of exposure to radiowaves, though the definition of proximity (within, or more than, 2.6 miles) seems arbitrary.

For areal data there is a substantial literature on modelling disease incidence, with regression-type models used to explain incidence in terms of available covariates. It is often important to allow for spatial dependence (autocorrelation) among the set of areal units (Bailey and Gatrell 1995; Haining 1998; Marshall 1991). Applications are presented in Elliott et al (1992a), and in a recent study Lopez-Abente (1998) has included covariates such as the application of insecticides, in an ecological analysis of cancers among Spanish provinces.

As in exploratory analyses, issues of exposure come to the fore in modelling disease incidence. For example, in modelling the incidence of respiratory disease in the vicinity of main roads, or the distribution of odour complaints around a hazardous waste site (Lomas et al 1990) GIS can be used to define areas of risk, by placing buffer zones around such roads, and perhaps varying the width of these zones to reflect estimated traffic densities. There are important epidemiological issues to address in any analysis. Again, allowance must be given for confounders (is incidence high along busy roads because damp housing is found there too, for example?) and to acknowledge that indoor exposure to pollutants may also be a serious problem. If detailed measurements of air quality are not available, exposure must be modelled using Kriging or other interpolation techniques (Collins et al 1995).

4 HEALTH CARE PLANNING

The incidence of disease or ill-health creates spatial needs for health care, whose locational configuration and delivery require planning. The interaction of needs and services raises accessibility and utilisation issues.

4.1 Locality planning and needs assessment

Planning health care for local communities is receiving greater attention in many countries. In Britain, where the imposition of an 'internal market' has for some years separated purchasers from providers of health care, purchasers are increasingly adopting locality commissioning. This requires locality definition and health needs assessment.

Bullen et al (1996) have shown how GIS can be used to define localities for West Sussex in southern England. This involved: digitising and then rasterising the perceived neighbourhoods of 500 residents to identify common community areas; defining theoretical school catchments using Thiessen polygons (see Boots, Chapter 36); linking patient postcodes to census areas and doctors' locations; and isolating the dominant patient–doctor linkages. Subsequent overlays (Figure 4) revealed close correspondence between the school catchments and the patient–doctor connections.

Assessing the needs of such localities often involves matching point-referenced, postcoded health data with area socioeconomic data, particularly deprivation indicators (Carstairs and Morris 1991). The geodemographic approach (Brown et al 1991) uses small area population census data to derive socioeconomic classifications which are attached to postcode units each containing about 15 addresses. Local profiles of residents by socioeconomic and health status can then be constructed, tabulated, and mapped, possibly using a rasterised topographic backdrop (Brown et al 1995). Hirschfield et al (1995) use such an approach in their study of community health services in Wirral, UK. The GIS is used to identify catchment areas for various services and to produce associated patient profiles. Andes and Davis (1995) provide an example from Alaska of how birth and infant mortality data are linked to census areas using a GIS.

Localities may be too inflexible when needs information is required by doctors' practices, as patient catchment areas typically overlap. Hennell et al (1994) use a geodeomographic classification to group small census areas by type, for which age–gender standardised illness probabilities are calculated. By linking patient postcodes to the classified census areas, illness probabilities are associated with the practice population and

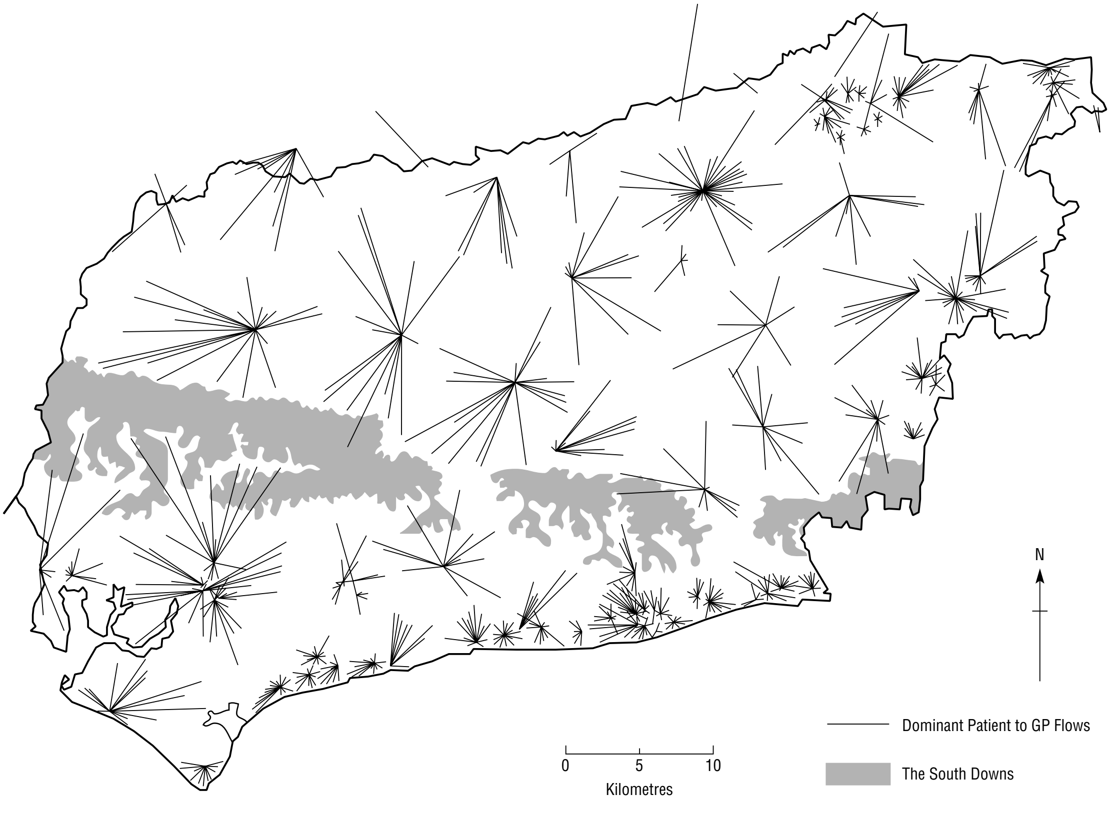

Fig 4. Flows of patients to general practitioners in West Sussex, UK. *Source*: Bullen et al 1996

aggregated to form a synthetic practice illness score, which was used to predict practice expenditure on prescribing. Various methods of deriving census health indicators for doctors' practices are evaluated by Haynes et al (1995).

4.2 Locational planning of health services

Having estimated health needs, how can GIS assist in planning supply?

Forbes and Todd (1995) use GIS to evaluate potential locations for a new radiotherapy unit for cancer treatment in northwest England. Travel time isochrones for five potential locations are estimated using assumed speeds over links in a digital road network and are overlaid onto census areas to define travel time zones. Population and postcoded cancer registration and admissions data are attached to the census areas to allow the calculation of population and patient numbers within various time bands. The best location is the one containing the maximum population within desirable maximum travel times. The study assumes access to facilities is by private transport or ambulance. However, there is no reason in principle why public transport networks should not be digitised and timetable information used, although this does imply issues of car availability and transport mode choice will have to be addressed (see Waters, Chapter 59).

The above example is a type of location-allocation problem, which has been of interest to geographers for many years. Hodgson (1988) applies such a model in an exploratory way to locate primary health care facilities among settlements of varying size in a rural area of Goa, India. While such location–allocation problems are now capable of being solved within modern proprietary GIS there is a need for continuing research into issues of error that arise in such applications (Hodgson and Storrier 1995).

4.3 Access to health services

The examples above take the potential accessibility of the population as the key indicator of 'optimum' locations for new facilities. Utilisation of health facilities represents how that potential is realised as revealed accessibility.

Love and Lindquist (1995) argue that crude access measures based on data for large areal units are no longer necessary given developments in GIS and spatially referenced data. They calculate the potential accessibility of the elderly, geographically referenced to the centroids of 10 796 census blocks, to 214 point-referenced hospitals, 67 with specialised geriatric services, in Illinois, USA. They use simple accessibility measures based on straight line distances to the nearest five hospitals for each block. Rural residents are found to have substantially inferior access compared to their metropolitan counterparts.

Use of GIS in studies of health care utilisation are relatively rare. Gatrell et al (1995) show how uptake of screening for breast cancer can be found for doctors' practices in South Lancashire, UK. Postcoded patient data, including details of screening status and doctor, were linked to small census areas, for each of which a deprivation score was calculated. For each doctor's practice, an average deprivation score was calculated from the area scores associated with each patient. Using regression analysis, uptake rates for screening were related to the practice deprivation score and the number of female doctors. Large residuals from the regression are of potential policy relevance for identifying practices performing well or poorly after allowing for deprivation and the availability of female doctors. Thompson and Bush (1995) illustrate how the deprivation indexes used in such uptake studies can be more closely tailored to the characteristics of the patients.

Jones and Bentham (1995) use GIS to test for a relationship between health outcomes and accessibility. Using grid referenced police records on serious and fatal road traffic accidents and a digital road network for Norfolk, England, a routing procedure simulated the dispatch of ambulances from their stations to accident sites and then to hospitals, and estimated associated travel times (Plate 56). A logistic regression was subsequently used to test whether the probability of fatal rather than serious injury could be explained by ambulance access times, whilst simultaneously considering other possible influences, such as age of victim and speed limit on each road. In this case, accessibility had no significant effect on outcome, but this finding cannot necessarily be generalised to more remote and sparsely populated areas.

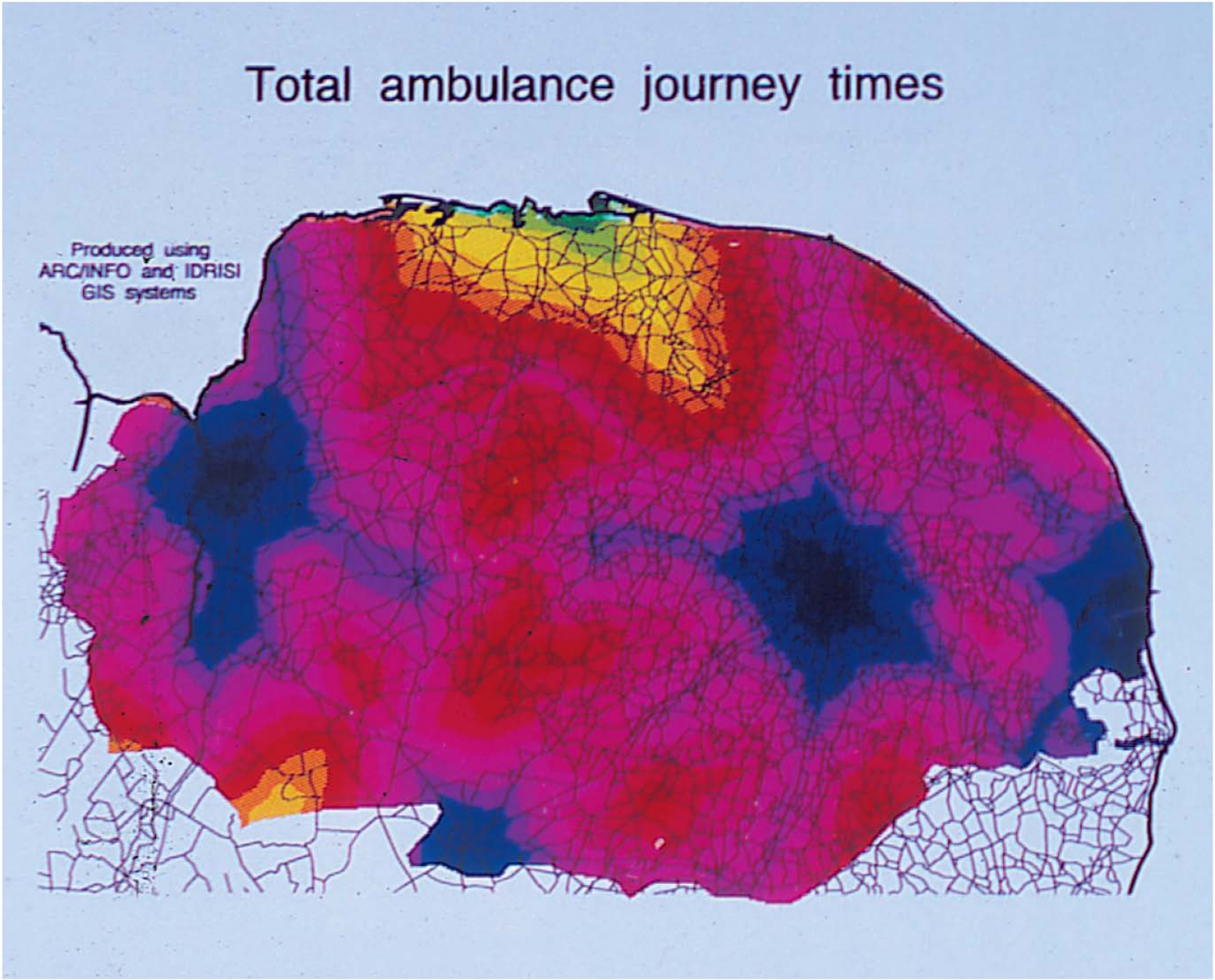

Plate 56 Assessing emergency medical service accessibility in Norfolk, UK. Black represents an estimated journey time of less than five minutes, whereas green shows an estimated time of up to 55 minutes.

4.4 Spatial decision support for health care planning

Demographic and financial pressures on health care systems are encouraging greater emphasis on measuring health needs accurately and dealing with them in ways that are both clinically effective and cost effective. In such an environment, Birkin et al (1996) argue that health care planners need 'intelligent GIS', including a modelling capability to answer 'what if' questions and the functionality to produce performance indicators: see also Birkin et al, Chapter 51. They describe their Health Information for Purchaser Planning System (HIPPS), which includes spatial interaction models for patient registrations with doctors (cf. Martin and Williams 1992) and for doctor referrals of patients to hospitals by specialism. They illustrate the use of such models in predicting the effects: of reducing doctor numbers at a health centre; of changing bed availability by specialism at a hospital; and of concentrating specialised facilities in fewer hospital sites. Efforts to link the visualisation capabilities of GIS with spatial interaction modelling and location–allocation analysis (Densham 1994) will continue to attract research attention.

5 CONCLUSIONS

Considerable progress has been made over the past ten years in the use of GIS and spatial analysis for health research; indeed, health applications were absent from the previous edition of this book (Maguire et al 1991). Within epidemiology there have been considerable advances in the development of methods for the detection of clustering and clusters of health events, together with productive links between statisticians, epidemiologists, and geographers in demonstrating the usefulness of GIS-based approaches. One research need is to continue to develop seamless interfaces between different kinds of software. For example, multilevel or hierarchical methods (Langford and Bentham 1996) are being promoted actively in health research, and given an explicitly spatial dimension; links are needed between these tools and GIS environments. At the same time, other kinds of interfaces and software are needed for the researcher who lacks expertise in the fitting of often very complex statistical models and whose requirements are for quite routine monitoring of health data.

The earlier discussion has drawn attention to the problem of assessing exposure; does current residential address (or, more broadly, zone of residence) give useful information? It was noted that, over the short term, the complexity of individuals' activity spaces limits the usefulness of residential locations, while over a longer timescale so too does the migration behaviour of individuals. Even where researchers are prepared to assume that residential location carries useful information – and it undoubtedly does to some extent – there is a need to go beyond rather crude distance-based models and link to the GIS models of air dispersion and groundwater contamination, for example. While this may be reasonably straightforward to do for a single point source (Dunn and Kingham 1996; Kingham 1993) it is much more complicated where, as in many urban areas, there are multiple point and line sources of pollution. There need to be closer associations developed between experts in environmental modelling and monitoring, and those in epidemiology. Given, for example, the recent concerns about radon and its effects on human health (especially as a possible risk factor for lung cancer) experts on modelling spatial variation in radon levels (Geiger and Barnes 1994) and those who have access to the highest quality georeferenced epidemiological data should be brought together.

The use of GIS in epidemiology sits comfortably within a conventional 'biomedical' approach to health, where the focus is on disease rather than on health and illness, and where the analysis is distanced from the individuals concerned. Other health researchers argue instead that a 'social' model be adopted that gives less emphasis to the clinical diagnosis of disease and more to the self-perception of illness. One of the tasks for GIS-based health research is to examine the extent to which more qualitatively-based research can be incorporated within a GIS approach. A further task is to ensure that, in health care planning, and especially in developing countries, those affected by such plans are themselves involved in the decision-making. A key item on the research and policy agenda is 'participatory' GIS (Hutchinson and Toledano 1993), where individuals and groups can be empowered to help in decisions about, for instance, where to locate primary health care services.

Finally, emphasis should be given to the importance of building closer research links between those using GIS for epidemiology and those using it in health care planning. If resource allocation is to have any meaning, it must endeavour to target health resources in areas of need. GIS can and should be used in the needs assessment process, such 'needs' being represented, in part at least, by the areas of high mortality and morbidity – the 'clusters' to which so much attention has been given - identified by other GIS-based analyses. There is a real sense in which GIS, in the reshaped form of a spatial decision support system, can play a valuable role in bringing the two health research traditions together.

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