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GISDATA 6

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EDITORS

ANTHONY C.GATRELL
AND
MARKKU LÖYTÖNEN

GISDATA VI

SERIES EDITORS

I.MASSER and F.SALGÉ

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The GIS Data Series

Series Editors' Preface

Over the last few years there have been many signs that a European GIS community is coming into existence. This is particularly evident in the launch of the first of the European GIS (EGIS) conferences in Amsterdam in April 1990, the publication of the first issue of a GIS journal devoted to European issues *(GIS Europe)* in February 1992, the creation of a multipurpose European ground-related information network (MEGRIN) in June 1993, and the establishment of a European organisation for geographic information (EUROGI) in October 1993. Set in the context of increasing pressures towards greater European integration, these developments can be seen as a clear indication of the need to exploit the potential of a technology that can transcend national boundaries to deal with a wide range of social and environmental problems that are also increasingly seen as transcending the national boundaries within Europe.

The GISDATA scientific programme is very much part of such developments. Its origins go back to January 1991, when the European Science Foundation funded a small workshop at Davos in Switzerland to explore the need for a European level GIS research programme. Given the tendencies noted above it is not surprising that participants of this workshop felt very strongly that a programme of this kind was urgently needed to overcome the fragmentation of existing research efforts within Europe. They also argued that such a programme should concentrate on fundamental research and it should have a strong technology transfer component to facilitate the exchange of ideas and experience at a crucial stage in the development of an important new research field. Following this meeting a small coordinating group was set up to prepare more detailed proposals for a GIS scientific programme during 1992. A central element of these proposals was a research agenda of priority issues groups together under the headings of geographic databases, geographic data integration, and social and environmental applications.

The GISDATA scientific programme was launched in January 1993. It is a four-year scientific programme of the Standing Committee of Social Sciences of the European Science Foundation. By the end of the programme more than 300scientists from 20 European countries will have directly participated in GISDATA activities and many others will have utilised the networks built up as a result of them. Its objectives are:

- to enhance existing national research efforts and promote collaborative ventures overcoming European-wide limitations in geographic data integration, database design and social and environmental applications;
- to increase awareness of the political, cultural, organisational, technical and informational barriers to the increased utilisation and inter-operability of GIS in Europe;
- to promote the ethical use of integrated information systems, including GIS, which handle socio-economic data by respecting the legal restrictions on data privacy at the national and European levels;
- to facilitate the development of appropriate methodologies for GIS research at the European level;
- to produce output of high scientific value;
- to build up a European network of researchers with particular emphasis on young researchers in the GIS field.

A key feature of the GISDATA programme is the series of specialist meetings that has been organised to discuss each of the issues outlined in the research agenda. The organisation of each of these meetings is in the hands of a small task force of leading European experts in the field. The aim of these meetings is to stimulate research networking at the European level on the issues involved and also to produce high quality output in the form of books, special issues of major journals and other materials.

With these considerations in mind, and in collaboration with Taylor & Francis, the GISDATA series has been established to provide a showcase for this work. It will present the products of selected specialist meetings in the form of edited volumes of specially commissioned studies. The basic objective of the GISDATA series is to make the findings of these meetings accessible to as wide an audience as possible to facilitate the development of the GIS field as a whole.

For these reasons the work described in the series is likely to be of considerable importance in the context of the growing European GIS community. However, given that GIS is essentially a global technology most of the issues discussed in these volumes have their counterparts in research in other parts of the world. In fact there is already a strong UK dimension to the GISDATA programme as a result of the collaborative links that have been established with the National Center for Geographic Information and Analysis through the United States National Science Foundation. As a result it is felt that the subject matter contained in these volumes will make a significant contribution to global debates on geographic information systems research.

Ian Masser
François Salgé

Editors' Preface

Among the many domains of application for GIS technology and methodology, few can be as significant as that of health. Whether helping in the detection of tendencies for diseases to show departures from non-randomness, the identification of areas of elevated relative risk, or associations between disease incidence and social and environmental factors, GIS has a role to play. GIS also has a role to perform in health care planning and the efficient and equitable distribution of resources, and while this parallel area of application is, deliberately, not emphasised here, it is nonetheless important and merits full attention elsewhere. The emphasis here, then, is very much on the relevance of GIS for public health, and both the technical contributions and the applications (broadly epidemiological) reflect this.

A small task force, comprising Professor Tony Gatrell (Lancaster University, UK), Professor Markku Löytönen (University of Turku, Finland), and Dr Max Craglia (University of Sheffield, UK) met in late 1995 to begin to organise a specialist meeting on GIS and health. A total of 16 participants were invited to the meeting, which was held near Helsinki, in June 1996. In keeping with the ethos of other GISDATA meetings, the main aim was to bring together a number of scholars, mostly from Europe but with some participation from the USA, who were either using GIS in their health-related research or who were using health as a platform or testing ground for their developments of new GIS-linked methodology. As is clear from the list of contributors, the research area of GIS and health is no respecter of arbitrary disciplinary boundaries, and the skills of geographers, statisticians, epidemiologists and environmental scientists are all brought to bear in what follows.

The work presented in this volume inevitably represents only a partial picture of the 'state-of-the-art' of GIS and health, since the remit of the programme was to ensure as wide as possible a representation from across Europe, with emphasis given to countries within the EU.

In seeking to put together a list of invitations, it became apparent that, despite the buoyancy of health-related GIS work in some countries of Europe, there was arelative dearth of such activity in others. For example, France, Portugal, Belgium and Denmark—to mention only a few—are not represented in this volume. We hope that publication will give encouragement to those working across Europe to consider pursuing this area of research and, where appropriate, to forge links with those European colleagues already working in this field.

Tony Gatrell
Markku Löytönen

Notes on Editors

Tony Gatrell graduated with a First Class Honours degree in Geography from the University of Bristol. At Bristol his interests in quantitative human geography developed, largely under the influence of Peter Haggett. He then spent four years at Pennsylvania State University, completing a Masters and a PhD under the supervision of Peter Gould. He returned to the UK to take up a Lectureship in Human Geography at Salford University before moving to Lancaster University in 1984. He is now Professor of the Geography of Health and is currently on secondment to direct the Institute for Health Research at Lancaster. His research interests are in the geography of health, focussing in particular on geographical epidemiology and health inequalities. The use of GIS in both areas is of special interest.

Markku Löytönen graduated from the University of Helsinki with a degree in Human Geography. He remained at Helsinki to complete his PhD on the spatial development of intercommunications systems in Finland, 1860–1980. He became Assistant Professor, and later docent (senior lecturer) at the University of Helsinki. He is currently Associate Professor of Geography at the University of Turku, maintaining his docentship in Helsinki. His research interests range from the history of geography and exploration to quantitative methods and GIS with special interest in the geography of health. He uses GIS in his research on forecasting epidemics and analysing longitudinal data.

Contributors

Graham Bentham
School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

Mario Braga
Instituto Dermopatico del l'Immacolata, viai dei Monti di Creta 104, 00167 Roma, Italy

Julii Brainard
School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

Cesare Cislaghi
Instituto di Biometria e Statistica Medica, via Venezian 1, 20121 Milano, Italy

Susan Collins
Department of Geography and Sheffield Centre for Geographic Information and Spatial Analysis, University of Sheffield, Sheffield S10 2TN, UK

Sue Gale
School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

Anthony C.Gatrell
Institute for Health Research, Lancaster University, Lancaster LA1 4YT, UK

Christopher Grundy
Environmental Epidemiology Unit, Department of Public Health and Policy, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK

Robert Haining
Department of Geography and Sheffield Centre for Geographic Information and Spatial Analysis, University of Sheffield, Sheffield S10 2TN, UK

Robin Haynes
School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

Geoffrey M.Jacquez
BioMedware, 516 North State Street, Ann Arbor, Michigan 48104, USA

Martin Kulldorff
Biometry Branch, National Cancer Institute, 6130 Executive Boulevard, Bethesda, Maryland
20892, USA

Megan Landon
Environmental Epidemiology Unit, Department of Public Health and Policy, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK

Gonzalo López-Abente
Centro Nacional de Epidemiologia, Instituto de Salud Carlos III, Sinesio Delgado 6–28029, Madrid, Spain

Andrew Lovett
School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

Markku Löytönen
Department of Geography, University of Turku, FIN-20014 Turku, Finland

Giorgio Luppi
Ufficio Statistica—Regione Emilia-Romagna, Viale Silvani 4/3, Bologna, Italy,

Gerard Rushton
Department of Geography, University of Iowa, Iowa City, Iowa 52242, USA

Simon Stevenson
Environmental Epidemiology Unit, Department of Public Health and Policy, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK

Gisela Suennenberg
School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

Carola Tasco
Osservatorio Epidemiologico—Regione Lombardia, via Stresa 3, 20100 Milano, Italy,

Lyly Teppo
Finnish Cancer Registry, Liisankatu 21B, FIN-00170, Helsinki, Finland

Stefania Trinca
Servizio Elaborazione Dati, Istituto Superiore di Sanità, Viale Regina Elena 299, 00161 Roma, Italy

Nanja van den Berg
Zentrum für Raumbezogene Informationsverarbeitung, Brandteichstrassee 19, D17489, Greifswald, Germany

Paul Wilkinson
Environmental Epidemiology Unit, Department of Public Health and Policy, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK

The **European Science Foundation** is an association of its 55 member research councils, academies, and institutions devoted to basic scientific research in 20 countries. The ESF assists its Member Organisations in two main ways: by bringing scientists together in its Scientific Programmes, Networks and European Research Conferences, to work on topics of common concern: and through the joint study of issues of strategic importance in European science policy.

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This volume is the sixth in a series arising from the work of the ESF Scientific Programme on Geographic Information Systems: Data Integration and Database Design (GISDATA). The programme was launched in January 1993 and through its activities has stimulated a number of successful collaborations among GIS researchers across Europe.

Further information on the ESF activities in general can be obtained from:
European Science Foundation
1 quai Lezay Marnesia
67080 Strasbourg Cedex
tel: +3388767100
fax: +3388370532

EUROPEAN SCIENCE FOUNDATION

This series arises from the work of the ESF Scientific Programme on Geographic Information Systems: Data Integration and Database Design (GISDATA). The Scientific Steering Committee of GISDATA includes:

Dr Geir-Harald Strand
Norwegian Institute of Land Inventory
Box 115, N-1430 Ås
Norway

Dr Antonio Susanna
ENEA DISP-ARA
Via Vitaliano Brancati 48
00144 Roma
Italy

PART ONE

Methodological Issues

CHAPTER ONE

GIS and Health Research: An Introduction

ANTHONY C.GATRELL AND MARKKU LÖYTÖNEN

1.1 Introduction

There is a long and rich tradition of investigating the spatial patterning of health events and disease outcomes, stretching back at least as far as the nineteenth century. Such investigations have used classical tools of visualisation, as well as methods of data exploration and modelling drawn from the statistical and epidemiological sciences. Paralleling such studies in geographical and environmental epidemiology have been others, set less within a natural science paradigm and more within a social science context, that have involved a study of health variations and inequalities, not only in terms of health outcomes but also in terms of access to, and the provision of, services. What both areas of research have in common is the recognition that space and place 'make a difference'.

Much of this work predates the revolution in spatial data-handling that has come about because of the development of Geographical Information Systems (GIS). The question then arises as to what extent health research can be given added value by using the tools of modern GIS. Here, we aim to review some of the ways in which GIS and health research come together, but emphasising the research needs at the end of the century, in a European setting. This is not the first time that GIS and health research have been discussed in a European context. For example, the Regional Office of WHO convened a meeting of health and GIS professionals in 1990, at the National Institute of Public Health and Environmental Protection in Bilthoven. One outcome was to suggest the setting up of a Health and Environment GIS (HEGIS), the nature of which is discussed in de Lepper *et al.* (1995, pp. 333–348).

We need to be clear about precisely what GIS involves, since there still seems to be a perception among some that it involves simply desktop mapping systems. We do not seek to denigrate the important role of visualisation (indeed, we give it due acknowledgment later); it plays a valuable role in hypothesis generation, for example. But a comprehensive definition is that GIS are systems for the collection, storage, integration, analysis and display of spatially-referenced data; in the present context such data are those representing, or associated with, health and disease.Below, we touch on data collection, say nothing about data storage, say something about integration, quite a lot about analysis (historically, rather neglected in GIS) and something about display or visualisation.

Implicit in our opening remarks is a tension in health research between those engaged in looking at disease incidence from a biomedical standpoint and those approaching their studies from the viewpoint of health as a social product. Put crudely, are we studying the geography of disease—and thereby drawing on a biomedical model of enquiry—or are we engaged in a study of the geography of health, where as much priority is given to lay perceptions of health and illness as to quantitative expressions of ill-health? It is important to recognise that many of the widely-used health indicators, such as measures of standardised mortality, paint a very partial picture of either disease incidence or health status. Further, we tend to dwell usually on areas of high disease risk, often neglecting to note that areas with low rates may also give clues about disease causation. Morbidity data will often be more valuable, though these too may be subject to variations in diagnosis behaviour, and there may be intra-national as well as inter-national variations in the quality and availability of such data. But there may be scope for collecting data on qualitative health variations and perceptions, and the way in which these might be incorporated in a GIS framework bears examination. There might also be greater scope for using GIS to paint a picture of 'health' as well as ill-health, though given that health is a 'contested concept' this may be a vain hope!

That said, GIS has most commonly been used within a biomedical framework, in studies of disease incidence. But what sorts of disease should we focus effort on? Those which attract most publicity are often those whose incidence is actually rather low. For example, in Britain there have been press reports in the past three years about children born with eye malformations and with limb defects, and, very recently, about meningitis outbreaks. Also, enormous research effort has gone into the study of leukaemia in children, a research area that produced the first really original investigations into the use of GIS in a health context (Openshaw *et al.,* 1987). However, devastating as these diseases are, in terms of numbers of people affected they pale into insignificance compared with the incidence of lung and breast cancer, or mental health problems, for example.

What, then, is covered in this edited collection, and what is ignored? Nothing is said here about the use of GIS in the study of communicable disease or links to forecasting models (see, for example, Cliff *et al.,* 1986) and GIS; one could argue that this work has developed well in the absence of 'GIS input', so the 'added value' (de Lepper *et al.,* 1995) provided by GIS is perhaps very marginal. Nor do we say much about service provision, or using GIS as a decision support tool to plan the spatial configuration of services. Also omitted from the chapters is any focus on the provision of emergency services, or planning responses by health service workers to major disasters and emergencies. Some of these applications are considered in another overview of the field (Gatrell and Senior, 1998).

A major aim of the GISDATA research programme is the wish to bring together experts from many different backgrounds and sciences. A study of geographical variations in health across Europe requires the skills and expertise of geographers, environmental scientists, statisticians, epidemiologists and sociologists, to name but a few. No one discipline can speak with authority in such a diverse and socially relevant field. Having begun to establish the beginnings of a wider European network of those with a common research interest, the next aim is to focus on a set of research themes and to identify some priority areas for research at the end of this century and the start of the next. This introduction offers a few initial thoughts, but the hope is that like-minded individuals begin to collaborate, to exchange experience and to provide cross-national input into major European initiatives.

One such initiative is already in the pipeline. This is the ESF initiative on Environment and Health (ESF, 1995), which is addressing a broad set of research issues concerned with the interaction between environmental quality and human health. A question we need to address is to what extent GIS can 'feed into' this work? To some extent these issues have already been debated (de Lepper *et al.,* 1995), but this new initiative calls for further inputs. And, as the authors themselves acknowledge (ESF, 1995) the 'environment' is a social setting as well as a physical one, with socioeconomic and lifestyle factors playing as much of a role in disease incidence as environmental pollution. For example, if we wish to understand the observed pattern of throat cancer we will need information not only on exposure to dioxins but also on cigarette and alcohol consumption.

We structure the present chapter into two main sections: one of these is concerned with environmental and geographical epidemiology. The second is more concerned with a social science perspective on health, where the focus is on health inequalities and health 'promotion'. We conclude with our own tentative indication of where we see promising areas of research.

1.2 GIS in environmental and geographical epidemiology

One major area in which GIS and health research have come together is via the study of environmental epidemiology. Here, we look for links between disease and the physical environment, while controlling for the impact of lifestyle factors such as smoking, diet and physical exercise. We can contrast this with the more narrowly defined geographical or spatial epidemiology, where description, exploration and modelling of disease incidence does not necessarily involve making direct links to environmental contamination. Here, studies of disease clustering, of cluster identification, of association with potential point and line sources of pollution, and of space-time disease incidence, are given priority (see Elliott *et al.,* 1992, for numerous examples). Ideally, these should use data at a fine level of spatial resolution and should relate to the individuals themselves (disease 'cases', possibly compared with 'controls').

1.2.1 Environmental epidemiology

There is a considerable literature on using GIS to explore environmental correlates of disease. ESF (1995) has called in particular for further work on risks from ambient and indoor air pollutants; those due to vehicular traffic and radon are mentioned explicitly; and on reproductive toxicology (birth defects, environmental oestrogens). There is clearly scope for a GIS input here, especially in the first area. What, for example, do we know about low-level ozone across Europe? In the UK the Photochemical Oxidants Research Group has used data from a network of monitoring sites to create interpolated maps of risk. What is the current configuration of monitoring sites in other European countries? To what extent is it possible, in 1998, to assess broad-scale correlations between, say, the incidence of asthma and ozone levels across the continent? Where are the standard errors of prediction of ozone levels particularly high, suggesting the need for additional monitoring sites?

Some work on using GIS to explore links between air pollution and health has been reported by Dunn *et al.,* (1995), and also by Kingham (1993), who has sought to link models of air pollution to GIS, using output from the models to define areas of exposure and then relating disease incidence to these rather than simply drawing circular buffer zones around a possible point source and assuming this defines an appropriate area of risk. This work needs building on. We see one of the primary areas for research that of integrating environmental modelling and health databases, within a GIS framework.

Within this environmental epidemiological framework we also need to give due weight to human behaviour. People do not sit at home waiting to be polluted by air! This social dimension also arises in other contexts, such as food poisoning (mainly salmonella and campylobacter), an area of investigation also flagged by ESF (1995). Some work has been done on this in the UK from a GIS perspective (Brown *et al.,* 1995), but more needs to be done on the relative importance of behavioural factors (such as food preparation in the home) and environmental factors (contamination of water supplies). ESF have also called for work on deaths and injuries from all forms of accidents, and on urban health. While some work in such areas falls very much within environmental epidemiology (for example, links between air pollution and respiratory disease in large cities), in both areas we need data both on the socioeconomic backcloth and on individuals in order to assess the relative importance of environmental and social variables. Put crudely, is the incidence of asthma in large European cities a function of exposure to air pollutants or to exposure to poor housing conditions, for example? We return to this theme later.

1.2.2 Geographical epidemiology

Given a set of individuals diagnosed with some disease, together with some form of address reference, we can aggregate the cases into any fixed set of areal units (counties, departments, communes, or whatever) and define measures of relative risk, such as standardised mortality or morbidity ratios, given appropriate denominators. One virtue of GIS is that we are freed from the tyranny of census-based areal units; we might explore disease risk around a point source of pollution, or along a busy motorway instead. However, this does lead to severe problems of data integration or ‘areal interpolation’, reviewed by Flowerdew and Green (1991), for example. Once we have done this we can bring to bear various mapping and smoothing techniques (such as empirical Bayes estimation: see Langford, 1994; Bailey and Gatrell, 1995) to help interpret the data. Tests of spatial (auto) correlation are also likely to prove useful. Such tools (see Douven and Scholten, 1995, for a review) can be useful at a variety of scales, varying from broad-scale investigations across Europe (see, for example, the European Cancer Atlas) to national cancer atlases (including several very distinguished examples), down to small-scale studies within local areas.

However, if we have addresses of individual cases (and, ideally, matching controls) it seems perverse, from an analytical point of view, to lose this detail. As a result, several groups of researchers (for example, Rushton in the USA, Kulldorff in Sweden, and Lawson in the UK; see Bailey and Gatrell, 1995, and Gatrell *et al.,* 1996, for a partial review) have been exploring the use of modern point pattern methods in exploring and modelling disease risk. This has included the use of so-called second-order methods for detecting whether there is disease clustering; the tendency for cases to cluster or aggregate more than the population at risk. Extensions to this have examined space-time clustering; that is, whether events that are spatially proximate are also 'close' in time, a methodology that has been applied to the study of many diseases, for example Legionnaires' disease (Bhopal *et al.,* 1992). A different problem in geographical epidemiology is that of detecting clusters. Here, the classic work is by Openshaw and co-workers (1987), but other approaches include the use of density or 'kernel' estimation to define a continuous surface of disease risk and relative risk; see Kelsall and Diggle (1995) for a modern view, and Bailey and Gatrell (1995) for an introduction to this method. Yet another problem is that of assessing whether there is a raised relative risk around some pre-specified point or line source of potential pollution. Again, there are various statistical methodologies proposed in the literature; see for example Bithell and Stone (1989), Diggle *et al.,* (1990) and Diggle and Rowlingson (1994).

What are the data requirements for such investigations? Generally, such work will take place at the small area level, and the need for comparative data across more than one country may be slight. But some of the methods, for example kernel estimation, could be employed cross-nationally, for example looking at the incidence of neural tube defects, or road traffic accidents, or asthma on the French-Belgian-German border. Quite apart from national differences in diagnosis, to what extent would this work be hampered by variations in spatial referencing? At what level of resolution are such data available? In the UK the unit postcode can be matched to grid references of 100 or 10 metres; in some instances (and subject to confidentiality restrictions) data may be available down to 1 m resolution. The OS ADDRESS-POINT product permits this if the full address of a patient is known. We do not want to dwell over-long on issues of data integration across national boundaries, nor do we wish to say too much about issues of data quality, since these have been addressed in other GISDATA meetings, but the issue does need raising here. So too do issues of data availability. As pressures grow for legislation on data protection, what are the prospects for obtaining access to (suitably anonymised) patient records? It may be easier to get access to environmental data for some studies, though such data bring with them their own problems of 'fitness for purpose', and the problems of data quality (for example, in measuring dioxins in soils) are well known.

One of the key issues that arises in geographical epidemiology concerns the representation of exposure. Typically, this is represented by address at date of diagnosis. But this may be a far from perfect representation. How can GIS help us to represent exposures in other contexts (such as the workplace)? Can we model action and activity spaces, for example within a time-space framework suggested originally by Torsten Hägerstrand? Can we incorporate information about residential histories into our analyses? Perhaps we can use measures of exposure such as years spent at a particular location rather than current address, address at diagnosis, or address at birth. Research into the geographical patterning of motor neurone disease, based at Lancaster University, is attempting to do just this (Sabel and Gatrell, 1998). It parallels some fascinating work on multiple sclerosis in Norway (Riise *et al.,* 1991) and also by David Barker in Southampton (Barker, 1994), the work of whose team suggests that we can only begin to understand the contemporary pattern of, for instance, cardiovascular disease, if we study the individual's earlier social environment,

1.2.3 Software tools

What software tools are currently available to help the kinds of analysis we seek to do? Here, we need to distinguish between software environments for spatial data analysis and those for GIS. A case can be made for arguing that the former are required for geographical epidemiology, while GIS 'comes into its own' in an environmental epidemiological context. Spatial analysis of epidemiological data has proceeded quite comfortably without GIS! The added value of GIS is in the linking of databases; for example, in seeking to explore links between cancers and high voltage power lines, where different spatial databases are required. But if we seek solely to establish whether there is clustering of disease, or whether there is raised incidence of cancer around an incinerator (Diggle *et al.,* 1990) we can do such analysis using software for interactive spatial data analysis. Such software includes that for spatial point pattern analysis (SPLANCS, run within S-Plus: see Rowlingson and Diggle, 1993) and, more generally, packages and environments such as INFO-MAP (Bailey and Gatrell, 1995) and LISP-STAT (Tierney, 1990). If we particularly wish to employ a GIS then there are links between some proprietary GIS and statistical software (for example, S-Plus for ARC/INFO).

Other tools for visualisation are required that free us from an over-reliance on conventional choropleth maps. Good examples are cartograms or 'isodemographic maps', which have been used for many years by epidemiologists (Selvin *et al.,* 1988; Dorling, 1995), and which express the area of a zone on a map in proportion to some measure of population at risk rather than physical area; as a result, large rural areas 'shrink' while more prominence is given to otherwise small urban areas in which most of the health events of interest are concentrated.

1.3 GIS and the 'new' public health

In Britain, Directors of Public Health are sometimes very much engaged in studies of a geographical or environmental epidemiological nature (as when, for example, there are local concerns expressed about 'cancer clusters'). However, the bulk of their work tends very much to be community-orientated and, at least in the 1990s, draws as much strength from a tradition of social medicine as from bio-medicine (Ashton, 1995). As suggested earlier, this 'new' public health sees health as more than the avoidance of early death, convenient though it is to measure this! It gives due weight to quality of life for the individual in the community, recognising that this is partly to be explained by individual decision-making but also by the wider socioeconomic settings (at both a national and local scale) within which the individual is situated.

Much public health medicine, therefore, tackles issues at a fairly local level. In Britain health care planning and some provision takes place at a 'locality' scale and is, increasingly, primary care based. This means that there is an interest in health needs assessment at quite a small scale, requiring the use of census and other data in order to identify what services are required, and where. It also means that there is a growing interest in how well primary health care practitioners are delivering services.

GIS enters here in a number of different ways. Some use has been made of GIS in determining the boundaries of localities, for example (Bullen *et al.,* 1994). In other areas, census-based deprivation scores (for example, due to Townsend and Carstairs: see Morris and Carstairs, 1991) have been incorporated into health databases in order to identify areas of need. Such deprivation indices may also be used to paint often vivid pictures of health inequalities at small area level. What scope there might be for creating an index that permits comparison between European states is a topic worth further investigation. A substantial, and coherent programme of research into health 'variations' (inequalities) is currently underway in Britain, commissioned by the UK Economic and Social Research Council; there is a parallel initiative funded by the Department of Health. Some of the research projects within those programmes involve GIS.

What specific areas of public health might benefit from a GIS approach? Those which spring immediately to mind are the uptake of services for preventive medicine, such as childhood immunisation and the screening of breast and cervical cancers in women. In Britain these services are arranged via the general practitioner, though the 'delivery' of the care may well take place elsewhere. The question then arises to what extent does distance to the surgery or health care centre constrain the uptake of services? Such accessibility questions operate not just in remote rural areas (where use might be made of 'branch' or mobile services) but also in urban settings. These issues of accessibility suggest that GIS might prove useful as a framework within which to couch an investigation, since data on the road network and on patterns of public transport will be more sensitive than simply measuring straight-line distances. While some use has been made of notional travel speeds to define journey times along road networks, we are not aware of any work that uses timetables to define journey times by public transport.

Suppose we wish to examine the uptake of services by health centre, and relate this to the social environment or characteristics of that centre in order to see whether uptake is explained by neighbourhood deprivation. One of the difficult problems in doing so is that health centre or practitioner catchments, in Britain at least, do not follow census area boundaries. Rather, patients are drawn from different small areas; we will have census-based data for these, but unless we carry out expensive, large-scale surveys we will not have detailed individual data. Some work is being done on trying to circumvent this problem (Haynes *et al.,* 1995; Scrivener and Lloyd, 1995). The same issue arises in dental care too.

Others have argued that in order to understand health behaviour or outcomes we need to recognise influences at different scales. For example, respiratory ill-health may depend upon individual-level factors (such as smoking behaviour), on household factors (the presence of damp or mould), and on local environmental factors (such as traffic levels in adjacent streets). Some health researchers (for example, Jones and Duncan, 1995) have sought to make use of multi-level models as an appropriate modelling framework; one obvious research task is to embed these within a GIS framework, or at the very least to couple them to a proprietary GIS. Jones and Duncan (1995) have suggested that such models allow us to give due weight to the importance of 'place'. We need to recognise that the quality of local environments, and the services that are provided, has a very real impact on people's quality of life. Access to good, reasonably priced food, health and leisure facilities, crime-free zones, and so on (Sooman and Macintyre, 1995) are all important measures of one's well-being. We need to explore the potential of GIS to define areas, or preferably continuous surfaces, of differential access to health; not solely access to health services, important though this is.

1.4 Some research themes

In this final section we draw on what has been discussed earlier and relate some of these themes to the chapters that follow.

The methodological section begins with a critique by Geoff Jacquez of the scientific basis of much recent GIS-related research in health. He argues that too many applications have been technology-driven, and that the mere production of mapped output can reveal spatial patterns and associations that are quite spurious. Such patterns, he argues, need to be rigorously assessed using spatial statistical analyses, a task rendered difficult by the relative lack of such tools in proprietary systems and lack of an appreciation of the importance of such evaluation. Too many applications suffer, he claims, from what he calls a 'gee whiz' effect; data are mapped and apparently 'interesting' patterns lead to the drawing of possibly wholly inappropriate conclusions. Jacquez suggests that we could do a lot worse than revisiting some of Karl Popper's strictures on scientific explanation, setting up theories which one attempts constantly to refute or falsify. Whether or not one agrees with Jacquez that Popper's critical rationalist approach to scientific reasoning is the appropriate one to follow, it is surely the case that GIS researchers could profit from frequent critical reflection on their analyses and that the scientific basis of such research is given due consideration.

Jacquez' chapter sets the scene for the next three chapters, all of which in different ways address the need for more thorough and rigorous spatial analysis of health data. Bob Haining deals comprehensively with the analysis of health data that have been aggregated into a system of areal units. Invariably, such units comprise a 'patchwork quilt' of irregularly-shaped zones, the varying size and shape of which, together with their differing populations at risk, render spatial analysis a tricky task. Haining considers methods for both informal, exploratory data analyses, where pattern detection is required in order to answer the kinds of criticism raised by Jacquez, and also methods for fitting models to health data, particularly where there are covariates available that might explain spatial variation in health outcomes. In terms of exploratory data analysis the distinction between 'global' and 'local' measures is particularly important, since the use of a single number—what some call a 'whole-map' statistic—to represent the entire spatial distribution may mask a considerable amount of spatial heterogeneity.

But Haining also answers Jacquez' criticism of the lack of spatial analysis capability in GIS, since he reports on an important project (known as SAGE) that seeks to add spatial analysis functionality to a well-known proprietary GIS. Such functionality involves the ability to construct particular aggregations of areal units and to perform various exploratory data analyses; the links between tabular data, maps and other graphics (such as histograms and boxplots) facilitate the kind of interactive spatial data analysis that others (for example, Bailey and Gatrell, 1995) have promoted.

Coming from a background in medical and spatial statistics, Martin Kulldorff is less concerned with the overt links to GIS than with ensuring that the tests called for by Jacquez and others are carefully chosen and properly evaluated. His particular emphasis is on tests for spatial randomness, where it is important to distinguish between several problems, as noted above. Different methods are needed to ascertain whether there is disease clustering than if the detection of clusters is the focus of endeavour. Kulldorff reviews a number of such methods, both those for purely spatial analysis as well as extensions to the space-time domain. He does not consider explicitly the implementation of these methods within a GIS environment, but his work has implications for those who would wish to see such methods either embedded within proprietary systems or with some form of coupling to such systems.

Gerry Rushton follows Kulldorff in preferring an approach to spatial data that uses the geographical locations of the cases of illness or disease, rather than aggregating these to fixed systems of areal units. His goal is that of exploratory spatial analysis, conducted within a spatially continuous setting, but the audience Rushton has in mind is that of the public health specialist who has to evaluate 'cluster alarms' (a type of spatial problem also reviewed by Kulldorff). Rushton has developed and implemented his exploratory spatial analysis modules on CD-ROM, in order to assist such specialists in their work. One technique he develops is based on spatial filtering (what we have earlier called kernel estimation). This is illustrated using individual, address-matched data on infant mortality for the city of Des Moines in Iowa. The significance of particular 'clusters' is evaluated statistically, using Monte Carlo simulation. Such tools are likely to prove invaluable in disease surveillance systems.

There is a need, within environmental epidemiology, to link environmental monitoring and modelling (for instance, of air and water quality) to a GIS so that health event data can be associated with the modelled outputs. Susan Collins' work is motivated by this research need. But in order to establish links between air quality and health we need good spatial representations of the former; to achieve this by a dense network of monitoring stations is clearly expensive and in many cases unrealistic. Instead, we must rely on the outputs from running air dispersion models, but such models need evaluating against the available, but limited observable data. Collins examines two broad approaches to modelling air quality: one, a hybrid approach that links dispersion modelling with interpolation methods; the other, a regression-based approach that links GIS and statistical techniques. The interpolation (kriging) approach results in an over-smoothed map of pollution levels and a regression approach yields better results. The goal of a comprehensive software package, or at least a set of closely-coupled modules, that allows the user to run a dispersion model, define a possible area of exposure, associate this with health events, and fit some spatial statistical models to such data is surely not that far off.

As Collins' work has indicated, we seriously need, in geographical and environmental epidemiology, accurate models of exposure. We cannot always rely on residential address at the time of diagnosis if we wish to understand the processes giving rise to spatial patterning of disease events. We need to model activity patterns and use the results from these to inform epidemiological studies. This need is particularly acute in the case of possible links between vehicular traffic pollution and respiratory illness, the main motivation for Collins' work. We tend typically to assume fixed and certain locations of exposure; in reality these are fluid and uncertain. To what extent can we incorporate into our analyses recognition that exposure is 'fuzzy'; that there is a field of exposure rather than a fixed point represented by home address?

This kind of issue is considered by Markku Löytönen, who draws upon the rich vein of work on time-geography, originated by Torsten Hägerstrand and subsequently developed by his colleagues. The relevance of this is over both short and long time scales. In the short term, as indicated above, and especially in Section 1.2.2, we need adequate representations of the daily activity spaces of individuals, while over the long term we require detailed information on previous place of residence, and duration thereof. Löytönen provides an introduction to time geography for those to whom it is unfamiliar, and then considers recent and current progress being made in embedding time into GIS. Although only a hypothetical example, he goes on to explore the possibilities of linking data on migration to that on environmental radiation. Given the quite superb spatially-referenced data on historical migration, along with detailed measurements of radon gas levels and of caesium-137 fallout from Chernobyl, the time is ripe for some innovative work using GIS to examine, in a robust and meaningful way, links between environment and health.

Part 2 of the book considers the application of GIS to health problems in particular European settings. With two contributions from the UK, and two from Italy, coverage of applications across the European Union is inevitably selective and partial. Nonetheless, the chapters give an overview of the breadth of application of GIS-based analyses.

Stefania Trinca considers a number of such applications in Italy, drawn from geographical and environmental epidemiology, risk assessment, and public health in general. Her description of the Rome-based GEO.S.I.M system and, notably, its use of sophisticated Bayesian smoothing and modelling techniques, illustrates the calls made earlier by Haining for area-based analyses to be soundly based on best statistical practice. The fact that the system also permits analyses to detect possible elevated relative risks near point sources of pollution echoes Kulldorffs discussion of 'focused' tests of clustering. Trinca also draws attention to work on a system, EUPHIDS, for assessing the risk of exposure to pesticides, though, as she notes, there are difficulties in linking such exposures to data on morbidity and mortality; as with so many GIS-based applications, the incompatibility of areal units, and of geographical scales, renders analyses extremely problematic.

In a companion paper, Mario Braga develops further one of the applications areas considered by Trinca, that of visualising and exploring data on mortality. Braga's work is very much in the spirit of contemporary visualisation research in epidemiology, seeking to move away from static, paper-based mortality atlases, towards electronic, interactive products with spatial statistical capability. Comprising data for over 8000 municipalities in Italy, the interactive atlas Braga describes incorporates the ideas of kernel estimation outlined earlier and tests for spatial correlation in the data, and will shortly have the Bayesian estimation implemented. Braga illustrates the functionality of the atlas with reference to data on lung and stomach cancer in Tuscany and Lazio respectively.

The application of Bayesian estimation to epidemiological data is developed fully in the chapter by Gonzalo López-Abente, who applies these techniques to cancer mortality data in Spain. The particular cancers with which he is concerned are those of relatively low incidence, such as multiple myeloma, non-Hodgkin's lymphoma and connective tissue tumours, and López-Abente attempts to relate geographical variation in the incidence of these cancers to data on insecticides, herbicides, pesticides and other organic control agents. Since numbers of cases are small, even for the quite large provinces of Spain, Bayesian techniques are used, as in the Italian studies, to smooth the raw rates in order to avoid random fluctuations. But López-Abente goes beyond such exploratory methods to model his data using so-called Markov Chain-Monte Carlo (MCMC) methods. The model of relative risk allows for both unstructured and structured variation ('heterogeneity' and 'clustering' respectively), the latter allowing the relative risk in an area to be influenced by those in nearby zones. Output from the model includes both the estimated effects of the explanatory variables and an indication of whether there is significant heterogeneity and clustering.

López-Abente performs all his analyses without the aid of a proprietary GIS. However, like others keen to see more links between GIS and statistical spatial analysis he calls for both greater awareness of contemporary developments in such analysis and for the development of links between such tools and geographical information systems. But it should be noted that the data assembled by López-Abente for his study are based entirely on a fixed set of (quite large) areal units; the data are stored, conventionally, as flat files and the 'added value' of a GIS remains to be more fully explored. Nonetheless, the kind of analytical approach he espouses is 'state-of-the-art' in spatial analysis, and anyone using 'ecological' data on health needs to consider using such methods in their analyses.

Nanja van den Berg outlines the development of a project to create an epidemiological GIS for the region of Western Pomerania in Germany. The project is still in its early stages, concentrating on database development and preliminary visualisation of data (comprising information on asthma and other respiratory illnesses among children). Data are explored at a sub-regional (ZIP-code) scale, where van den Berg is faced with the common problem of the highly variable number of cases among the set of zones, and uses the chi-square statistic (cf. Brown *et al.*, 1995) as a transformation to map data on eczema, hay fever and asthma. Contrasts between urban and rural areas are highlighted. Data are also available at a finer scale, for the city of Greifswald, where individual addresses are obtained, and although no results are available at present there is clearly scope, as van den Berg indicates, for research to explore associations with attributes of cases and controls, as well as with environmental variables; it is here that the spatial information system will prove particularly valuable.

Lyly Teppo looks specifically at spatially-referenced data on cancer in Finland. Data from cancer registries are, in general, of very high quality, and since they deal with incidence rather than mortality, overcome a number of problems involving specifying cause of death. Even so, there are problems of variable diagnoses, coverage and accuracy to consider, and while such problems are unlikely to be serious from place to place within a country, variations between countries may well make analyses across borders somewhat problematic. Teppo also lays emphasis on the lengthy, and probably quite variable, latency periods for some cancers, echoing the calls made by Löytönen and others for due acknowledgment to be made of changing residential location. This is relatively unproblematic in Finland and other Nordic countries, and surely the number of GIS-based epidemiological studies in such countries will grow as researchers seek to exploit the wealth of good historical data available there. Teppo himself reviews a number of studies that exploit the spatial detail of the Finnish cancer data. These include: the possible associations between high voltage power lines and childhood cancer; possible links between exposure to fallout from Chernobyl and childhood leukaemia; and the relationship between exposure to indoor radon pollution and lung cancer.

Paul Wilkinson and his colleagues outline the research possibilities using highly disaggregated (postcode-based) data in Britain. Such data include not only those on mortality and cancer incidence, but also on births and congenital malformations, and on uptake of primary and community services. Denominator data, on the age-sex structure of populations, are available only for census units such as electoral wards or enumeration districts, and there are thorny problems in matching postcodes to census areas (see Scrivener and Lloyd, 1995, for example). Like others in the book, Wilkinson draws attention to the visualisation and analytical problems involved in examining small area data, reporting results from a ward-based analysis of hospital admissions for asthma. Despite the fact that such admissions are the ‘tip of the iceberg’ in asthma morbidity there are some suggestive correlations with socioeconomic measures, which Wilkinson suggests may be useful in needs assessment, a prime task in public health. Wilkinson also endorses points made elsewhere in the book, for example concerning ‘cluster’ detection (Jacquez, Kulldorff), surveillance of public health (Rushton), and the difficulties of adequate exposure assessment (Collins).

Andrew Lovett and his co-authors are also concerned with the nature and quality of census-based denominator data in Britain, but suggest that patient-based denominator data (from the National Health Service Central Register) may have a role to play in deriving useful health needs indicators. Ward-level resident populations at the time of the 1991 census are compared with NHSCR estimates on census day; the conclusion is that using patient registers to produce small area population estimates remains problematic, but that with improvements they should provide a valuable resource. Lovett also compares the use of census-based unemployment data with that on people claiming unemployment benefit, and the close match suggests that the latter may be a useful needs indicator, given that census information is only available every ten years. Finally, he reports the results of analyses that seek to derive census-based indicators for general practices (providing primary care at surgeries or clinics).

The chapters by Wilkinson and Lovett are an appropriate pair to bring the volume to a conclusion, since they begin to address issues concerned partly with environmental epidemiology but more with needs assessment. While we, like others, have made a distinction between applications of GIS that are primarily epidemiological, and those that are concerned with health care planning, it is clear that there is, in fact, a continuum of approaches, since identification of ‘high risk’ areas, for example, presumably demands fresh looks at resource allocation in order to address them. As a result, we perhaps need to concern ourselves in future work less with GIS and more with spatial *decision support* systems.

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