The Spatio-temporal Distribution of Notifiable Diseases in Australia

Brett Bryan, Christopher Wright, Errol Bamford

6th National Rural Health Conference
Canberra, Australian Capital Territory, 4-7 March 2001
The spatio-temporal distribution of notifiable diseases in Australia

Brett A Bryan, Christopher Wright, Errol J Bamford, GISCA National Key Centre for Social Applications of GIS, University of Adelaide

INTRODUCTION

Public health practice needs timely information on disease activity to implement appropriate actions effectively. Disease case data usually has a location and time reference. Knowledge that may be generated using this spatial and temporal information increases the value of health data and correspondingly the potential for health action.

The idea that location can influence health is not new. Medical geography has had a long tradition of examining spatial patterns of disease and mortality. Early examples of the influence of location on health includes the oft-cited example of Dr. John Snow who traced the source of an 1854 cholera epidemic in the Soho district of London back to a contaminated communal well. Another example includes the discovery by two dentists in the early 1900s in Colorado that children living in areas with high levels of naturally-occurring fluoride in groundwater had reduced incidence of dental caries.

Being able to see where and when disease outbreaks occur is important for epidemiologists and public health managers. Temporal patterns of disease are routinely analysed by modern epidemiologists for single locations. Spatial patterns of disease may also be presented in the form of maps by administrative areas such as local government areas or postcode. However, the spatial and temporal patterns of disease are rarely assessed together.

Humans are very efficient at the detection of patterns from visual stimuli. Spatio-temporal visualisation allows epidemiologists to easily detect disease outbreaks, trends and clusters in certain areas and at certain times. Being able to detect patterns in disease activity in space and time from media such as animated maps is a useful first step in the exploratory analysis of disease data. Spatio-temporal visualisation can guide subsequent statistical analysis of disease data. Visualisation of patterns can also indicate the effectiveness of control measures on the spread of disease. Cases recorded in the National Notifiable Disease Database (NNDDB) are referenced to a postcode and include a date of onset of the disease. In this paper we aim to use this information in the NNDDB to visualise spatio-temporal patterns of notifiable diseases including Measles, Ross River virus, Pertussis, Dengue fever, Salmonellosis, Hepatitis A, and Meningococcal virus in Australia by postcode using animated mapping. Mapping and analysing the spatio-temporal patterns of disease provides intelligence for managing diseases and assisting in public health programs and health resource management.
METHODS

Overview of the data

Notifiable disease data was provided by the Commonwealth Department of Health and Aged Care from the National Notifiable Diseases Surveillance System (NNDSS). The NNDSS was established in 1990 under the Communicable Diseases Network Australia New Zealand (CDNANZ)\(^\text{12}\). The NNDSS co-ordinates the national surveillance of more than 40 communicable diseases or disease groups endorsed by the National Health and Medical Research Council\(^\text{12}\). Under this scheme, notifications are made to the States or Territory health authority under the provisions of the public health legislation in their jurisdiction. Computerised, de-identified unit records of notifications are supplied to CDNANZ secretariat at the Department of Health and Aged Care for collation and analysis. Final datasets for cases in one year are not usually available until late in the following year. This study is based on the years 1991–1999 for which complete data was available. The database includes information for each disease case notification including a unique record reference number, State or Territory code, disease code, date of onset, date of notification to the relevant health authority, sex, age, Aboriginality, postcode of residence, and the confirmation status of the report.

More detailed data on Meningococcal disease was also provided by the NSW division of the Australian Meningococcal Surveillance Program. This data provided information about meningococcal cases for the period 1994–1999 and included information on disease serotype. Australian Bureau of Statistics (ABS) 1996 Census of Population and Housing data was also used to express case totals as a proportion of the population.

Animated mapping

In this study, several different visualisation techniques are used to assess the patterns of several different diseases on several different scales. Table 1 summarises the types of spatio-temporal visualisation of notifiable diseases in this study. Most commonly assessed is the total case numbers of notifiable diseases and the number of cases as a proportion of the total population. In addition, the number of cases of both pertussis and measles occurring in children under 5 years of age is expressed as a proportion of the total population aged less than 5 years because of established links between these diseases and young children. The incidence of measles in 4 age cohorts (0–4, 5–14, 15–30, and 30+ years) is expressed as a percentage of the total population in these cohorts as measles is known to generally affect the younger population but is becoming increasingly prevalent amongst other age groups.

To visualise the spatio-temporal distribution of notifiable diseases in Australia, static maps were created at various snapshots in time using ESRI’s ArcView GIS and exported as digital images. The images were then animated using Javascript. The Javascript animation technique provided much more flexibility than other animation formats such as MPEG or AVI format. The animation is run using a web browser and the user is able to start and stop the animation at any time and select any of the component images for viewing individually.
Table 1  Summary of the different types of spatio-temporal assessment of notifiable diseases

<table>
<thead>
<tr>
<th>Type</th>
<th>Extent</th>
<th>Diseases</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete picture</td>
<td>Australia</td>
<td>Pertussis (Whooping Cough)</td>
<td>AIM: to give a complete long-term picture of Pertussis activity in Australia. Case totals for each month for 1991–1999 are mapped by postcode and animated.</td>
</tr>
<tr>
<td>Annual activity (simple)</td>
<td>Australia</td>
<td>Hepatitis A, Salmonellosis, Pertussis, Measles</td>
<td>AIM: to visualise annual trends in disease activity. Two animations were created for both Hepatitis A and Salmonellosis. Firstly, case totals for each of the 8 years in the period 1991–1999 are mapped by postcode and animated. Secondly, total annual cases are expressed as a percentage of total population in each postcode for the 8 years 1991–1999, mapped and animated. For Pertussis and Measles total annual cases are expressed as a percentage of the population aged less than 5 years. For Measles the total cases over the period 1991–1999 are expressed as a percentage of the population within 4 age cohorts — 0–4, 5–14, 15–30, 30+ years.</td>
</tr>
<tr>
<td>Annual activity (complex)</td>
<td>NSW</td>
<td>Meningococcal</td>
<td>AIM: to visualise complex disease information including the total number of cases and the proportion of different sub-types. Annual totals for the period 1994–1999 were visualised using complex thematic mapping where disease activity is visualised using variable sized pie charts at the centroids of statistical divisions (SD) for NSW. The size of the pie chart reflects the number of disease cases in the SD and the size of each slice of the pie reflects the proportion of each disease sub-type. These complex maps are animated for the 6 years 1994–1999.</td>
</tr>
<tr>
<td>Monthly activity (simple)</td>
<td>Australia</td>
<td>Ross River Virus, Dengue Fever and Salmonellosis</td>
<td>AIM: to visualise seasonal trends in disease activity. Two animations were created for each disease. Firstly, case totals for each of the 12 months of the year are summed by postcode for the period 1991–1999, mapped and animated. Secondly, total monthly cases are expressed as a percentage of total population in each postcode for the 12 months of the year, mapped and animated.</td>
</tr>
<tr>
<td>Monthly activity (complex)</td>
<td>Brisbane, Qld</td>
<td>Salmonellosis</td>
<td>AIM: to visualise seasonal trends in disease activity on a fine spatial scale. Case totals for each of the 12 months of the year are visualised in 3-dimensions by extruding postcode polygons, with the polygon height and shading being proportional to the case totals.</td>
</tr>
</tbody>
</table>

RESULTS

The animations were effective at showing the patterns of various notifiable diseases in space in time. The animations are impossible to reproduce in paper format but can be seen on the World Wide Web at www.gisca.adelaide.edu.au/~bbryan/notifiable.htm.

DISCUSSION

Complete picture of disease activity

Spatio-temporal visualisation of a complete picture of pertussis activity by postcode for each month for 9 years includes 108 monthly maps. This animation enables the assimilation of a vast amount of disease data very quickly and the easy detection of pertussis outbreaks and epidemics. The animation clearly displays a rather random
spatial and temporal distribution of pertussis which might be considered *background* levels of the disease. Superimposed on this is irregular but spatially and temporally clustered epidemics clearly visible in many rural postcodes over the 9 year period. These epidemics most frequently occurred along the eastern seaboard from central NSW to southern Queensland. Spatio-temporal visualisation by map animation through time provides a most effective way present a complete picture of disease activity, to assimilate disease information and to detect patterns and clusters in time.

Whilst visualising the complete picture of disease activity is very useful for deriving spatial and temporal trends (e.g., pertussis tends to regularly reoccur about every 4 years), to be of maximum value, real-time surveillance is required. Surveillance needs to be supported by regular and timely updates in data and real-time diffusion of information to epidemiologists over the web. This would allow timely and informed decisions by health care professionals regarding the best means of mitigating disease epidemics including disease prevention and management.

**Annual patterns**

Visualising annual disease cases provides historical epidemiological intelligence about where disease activity occurred for each year. The animated maps for Hepatitis A display a high level of prevalence in many rural areas and distinct epidemiological trends can be seen. In 1991, Western Australia displayed a high incidence of Hepatitis A. In following years the incidence in WA was low and became high in NSW and Queensland respectively. In 1997 both NSW and Queensland displayed high numbers of Hepatitis A cases. When displayed as a percentage of the population, similarly uneven distribution in space and time suggesting localised outbreaks of disease.

As rates of vaccination against Hepatitis A are very low in Australia and no specific treatment exists for hepatitis A, prevention is the most effective approach against the disease. Certain groups can be defined as high risk for contracting Hepatitis A, including people in household/sexual contact with infected persons, preschool children attending day-care centres, their parents and siblings, refugees residing in temporary camps following catastrophes, homosexually active men, and intravenous drug users. Spatio-temporal visualisation of Hepatitis A cases can be used to identify areas more severely affected. This can be used to guide the prioritisation of preventative measures and raising awareness among high-risk groups in these areas.

The pattern of salmonellosis displays quite a spatially uniform background distribution of cases with two other distinct features. Firstly, localised outbreaks and epidemics are clearly evident such as in the Kimberley region in 1995. The second distinct feature is the latitudinal trend. Areas across the north of Australia such as Queensland, far north Western Australia and the Northern Territory tend to have a much higher total incidence of cases and rate per population. The obvious explanatory variable is that of the warmer climate which may provide a more favourable environment for Salmonella bacteria\(^{13}\).

There is no vaccination for salmonella and treatment for cases mainly consists of supportive care, including rehydration and electrolyte replacement. Therefore, to be effective, surveillance of salmonella needs to be strongly linked with food safety and hygiene control authorities\(^{14}\). Different areas of Australia with different risks of
salmonella poisoning may require different food safety and hygiene control regulations. These may be used to guide the formation of food policy and monitor the impact of control measures, such as ensuring adequate storage, adequate heating, controlling for environmental factors. High risk areas for specific pathogens may be also identified and located and made more aware of preventative steps that may be taken to avoid contracting the disease. New species and phage types may also be identified and mapped to monitor their spread and impact.

Annual assessment of proportions of the under 5 population affected by Pertussis consistently revealed many intense but localised outbreaks (usually only 1 or 2 postcodes). Many rural areas especially in the eastern states display high percentages of children under 5 infected. Particular postcodes showing repeated high levels of cases were in central Western Australia and western New South Wales. This could be a result of either the natural epidemiology of pertussis or holes in vaccination. If the latter is true these areas should be targeted for vaccination programs.

Certainly, despite the long-term availability of an effective Pertussis vaccine in Australia, vaccination rates remain low, and this low coverage has contributed to outbreaks of the disease. The variation in vaccination coverage from one area to another obviously has implications for the spatial variation in Pertussis prevalence. A report by the Communicable Diseases Network Australia and New Zealand (CDNANZ) provides an overview of Pertussis in Australia and advocates some strategies for the effective reduction of the incidence of Pertussis. These include achieving full vaccination coverage (95% or more), improving outbreak control to reduce transmission of the disease; and increasing public awareness and provider commitment to immunisation. Since the incubation period is short (commonly 7–10 days and not more that 21 days), fast identification of new outbreaks is crucial to preventing further cases. The incidence and severity of pertussis is reduced by immunisation.

The spatio-temporal distribution of rates of infection of children under 5 years by Measles displayed a very distinct outbreaks in certain places at certain times. No background rate of infection is present as it is for salmonella. Rather, Measles tends to be characterised by intense local outbreaks followed by periods of little or no infection. Epidemics can be seen for Tasmania in 1993 followed by NSW and Queensland in 1994. Rural areas displayed some of the highest percentages of Measles cases for the 5–15 and 15–30 age groups, when viewed as a percentage of those age group populations by postcode. Immunisation programs need to be targeted for rural areas as these areas showed high proportions of their young as being affected by these diseases. Lower incidences of Measles was evident in the 30+ age group.

The Meningococcal maps for New South Wales are interesting, shows the change in both the number of disease cases, and their spatial distribution by serotype over time. The total number of cases tends to stay fairly constant in the Sydney statistical division but varies in the non-metropolitan Statistical Divisions (SDs) over the years 1994 to 1999. Serotype B seems to be the most common however, serotype C is also common in certain years and in certain areas. In the Far West and Murray SDs, serotype B was the only one recorded over the period 1994–1999, whereas in the ACT/Canberra, only serotype C was recorded. Other serotypes also display outbreaks in certain areas such as the outbreak of serotype Y in Northern and North Western SDs during 1996. This
type of map animation displays complex information about the spatio-temporal pattern of different disease subtypes. The ability to readily visualise which regions tend to experience which serotype may be valuable in guiding local medical practitioners as to the precise nature of the meningococcal infection.

**Seasonal patterns**

Visualisation of monthly totals for all 9 years revealed some very distinct epidemiological patterns in Ross River virus, Dengue fever and Salmonellosis on a national scale. Incidence of Ross River Virus seems to be closely related to the habitat of its mosquito vector. Several spatio-temporal patterns can be seen in Ross River virus. Firstly, a latitudinal gradient exists whereby the tropical areas of Australia such as far north Queensland exhibit both high numbers of cases and high rates per population. In addition, the Murray-Darling Basin (MDB) also exhibits high incidence of RRV. Thus, high incidences occur in areas where mosquito habitat in the form of standing water is available. Superimposed on this a seasonal pattern in RRV incidence is also evident. The highest number of cases and incidence rates occur in the tropics and in the MDB at the end of the wet season (February, March). This suggests that mosquito vectors require a period of time since the onset of favourable habitat to breed and spread the disease. At other times of the year, incidence of RRV is more sporadic.

Dengue fever occurs much less frequently than RRV on a national scale. Almost exclusively over the 9 years from 1991 to 1999, Dengue fever occurred in the central coastal Queensland area near Townsville. The disease overwhelmingly tended to occur in the drier months April through September.

As with Dengue fever, there is no specific treatment available for Ross River Virus. Thus, prevention must be a major component of any health care strategy aimed at these diseases. The ability to see when and where high incidences of disease tend to occur through the year enable health care professionals to make recommendations for preventative measures. Preventative measures for these diseases involve reducing the likelihood that people get bitten by mosquitos carrying the disease. In certain places at particular times of the year recommendations could be made to locals and tourists alike such as wearing clothing or repellent that provides protection against mosquito bites. For dengue fever, there is no vaccine or specific treatment available.

In addition to the intelligence of the epidemiology of Salmonellosis acquired by visualisation of the annual patterns, much is to be gained from looking at seasonal patterns in disease activity. A similar background infection of Salmonella occurs over much of the country with localised but mild outbreaks constantly occurring. In addition, a similar latitudinal trend is evident whereby the northern part of Australia, particularly Queensland, has high numbers of cases and rates of infection per population. Higher rates in these areas also tend to occur during the warmer months of the year (November through June). Again, this is probably because the warmer climate provides a favourable habitat for Salmonella.

The 3D animation does not convey any more information than the flat 2D animations but it does make it easier to visualise which areas experience increase or decrease in the rate of cases over time because each postcode is especially clearly identified. It also provides a detailed look at the activity of Salmonellosis on a fine scale. Similar
seasonal trends occur as those discussed above. The spatial distribution is also fairly noticeably random, probably resultant of small scale localised outbreaks caused by individual food outlets and the effect is mostly confined within the neighbourhood of outbreak.

Some problems
The continental scale animated maps used here to display the spatio-temporal patterns of disease are too broad for effective local control and preventative measures to be reliably instigated. Rather, the maps are useful for displaying the broad patterns of disease from which national scale priorities and control measures can be prioritised. However, there are obvious dangers in jumping directly from an apparent pattern to intervention, without exploring the data further\(^\text{18}\). This kind of national scale information can be used to guide finer scaled, more detailed research on the epidemiology of notifiable disease for local areas and associated health care policy development.

We also need to be aware of various issues that can affect map interpretation when using postcodes as the spatial unit. Australian postcodes vary greatly in size and this is reflected in the mapping. When viewed at a continental scale, many of the detailed changes taking place in smaller areas such as the 3D Salmonella animation of Brisbane are not obvious. Large remote postcodes dominate the animations, while the urban areas, such as the capital cities cannot be seen. What is needed is a set of similarly sized areal units for mapping and visualisation. An example could involve the conglomerations of postcodes into Statistical Divisions in cities and densely populated rural areas. The Meningococcal animation of NSW using SDs provides a clearer representation of disease activity if more generalised.

Other problems also arise from the NNIDDB data. Firstly, the postcode to which a case is georeferenced may not be the postcode in which the disease was acquired. Secondly, there are problems of reporting of the postcode information, for example many cases in the Northern Territory were referenced simply to Darwin which is a rather small areal unit and difficult to detect on the continental scale. These problems result in inaccuracies in the spatial representation and misrepresentation in the animated maps. The quality and completeness of data compiled in the NNIDDB are influenced by various factors, and these are widely recognised by the NNIDSS itself. It is suspected that records for several diseases for were incomplete or missing (eg especially for the years 1998 to 1999) which causes an under-representation of disease activity.

CONCLUSION
From the animated maps presented in this study it is clear that the activity of notifiable diseases is very different. A complete picture of the disease activity of Pertussis provided an effective way of interpreting a vast amount of disease data. The increased intelligence provided about the epidemiology of Pertussis can be used for control and management of the disease. Assessment of annual patterns of diseases such as Hepatitis A and Salmonella revealed differential incidence of the diseases over space and time including a latitudinal trend in the case of Salmonella. Assessment of seasonal patterns of diseases also revealed useful spatio-temporal patterns. Measles was found to have
negligible background infection rates and occurs in distinct outbreaks and epidemics which can move across the country. Contrasting this, other diseases such as Salmonellosis and Ross River virus displayed a fairly constant background infect rate with regular outbreaks defined by climatic factors and vector habitat. Dengue fever displayed a very localised occurrence and particular serotypes of Meningococcus were more active than others with the less active serotypes causing infrequent and localised outbreaks.

The continental scale of assessment of the spatio-temporal patterns of notifiable diseases in Australia provides some improved knowledge of the epidemiology of the diseases themselves within the Australian population over time. From this increased intelligence of the nature of the diseases, national scale priorities can be set for resources for control and prevention measures for specific areas at specific times to target specific diseases.

REFERENCES


AUTHORS

Dr Brett Bryan recently graduated with a PhD in environmental modelling using spatial information technologies and has worked as lecturer and education co-ordinator at GISCA — a National Key Centre for Social Applications of GIS. His current research interests include the integration of human and environmental issues through spatial technologies and advanced spatial analysis.

Errol Bamford is the Research Manager at the National Key Centre for Social Applications of GIS. He is one of Australia’s most respected GIS practitioners, and has over 20 years’ experience in GIS technologies, particularly applied to social planning issues. He has detailed knowledge of Australian socio-demographic databases and GIS hardware/software packages; extensive experience in application of GIS technologies to health service delivery; and has been involved in the design and development of many health-related, web-enabled spatial information systems. He is currently the team leader of over 12 health and GIS projects.