Using Geographic Information Systems to Examine Distance as a Barrier to Health Care

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Workshop Outline

- Presentation
  - Geographic methods
  - Access to health services
  - Distance measures
  - Urban and rural examples
- Hands-on Interactive Session
  - Urban and rural groups
  - Work with actual data, overlays in table-based groups

What Are Geographic Methods?

- Take into account location, area, neighbourhood, human and natural environments, flows of factors and people across space
- Take into account spatial concentrations of certain phenomena, causes of such clusters and their impact on other variables

Are Geographic Methods Sufficiently Utilized?

"Yet, despite epidemiology's longstanding concern with "time, place, and person"…, "place" had receded into the background by the mid-20th century… . Fortunately, GIS has contributed in recent years to a reviving awareness that any epidemiologic explanation worth its salt must encompass geographic-and temporal-variations in population health."

Nancy Krieger, *Place, Space, and Health: GIS and Epidemiology,* Epidemiology, vol. 14, no. 4, July 2003

What Methods Were Described in the Two Previous Symposium Workshops?

2003: Issues in Spatial Analysis:

- What is GIS, spatial data types, GIS data models
- Census geographic levels
- Spatial autocorrelation (global), spatial data aggregation
- Cartography: thematic maps, data classification, map's elements, scale, colour

2004: Using Spatial Analysis and Maps to Understand Patterns of Health Services Utilization:

- Review of 2003 topics, buffers,distance calculations,
- Location quotient, spatial neighbours
- Local Indicator of Spatial Association (LISA)
- Spatial regression models, point data cluster analysis

Rationale for Focusing on Accessibility Issues

Access is near the top of the health care agenda

- Waiting lists for surgery and diagnostic tests
- Shortages of health personnel
- Primary care reform
- Regionalization

Time and distance are among key non-financial barriers to care

Elements of Access to Health Services

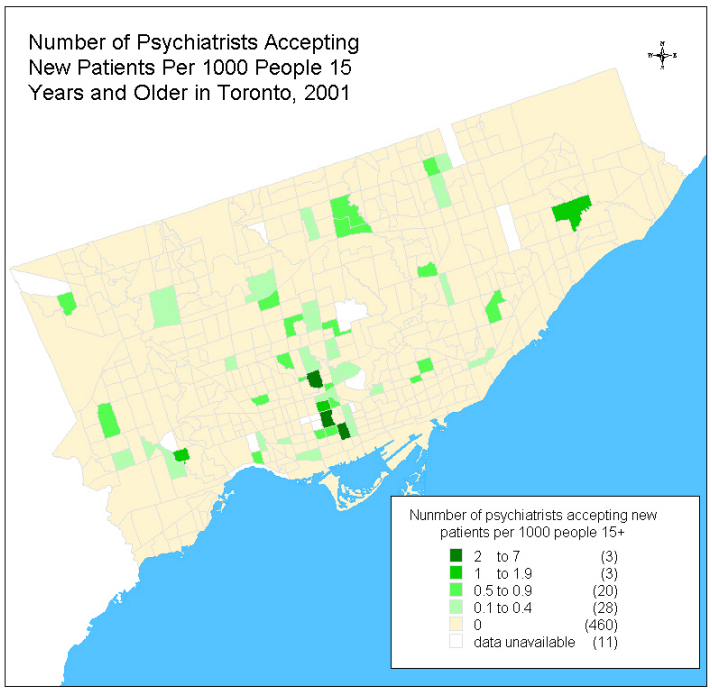
- Availability (what services are available)
- **Accessibility (geographic access to services)**
- Accommodation (how services are set up in order to meet patients' needs)
- Affordability (how affordable services are)
- Contact and effectiveness (who of the eligible population does use services and how effective these contacts are)

Geographic Accessibility

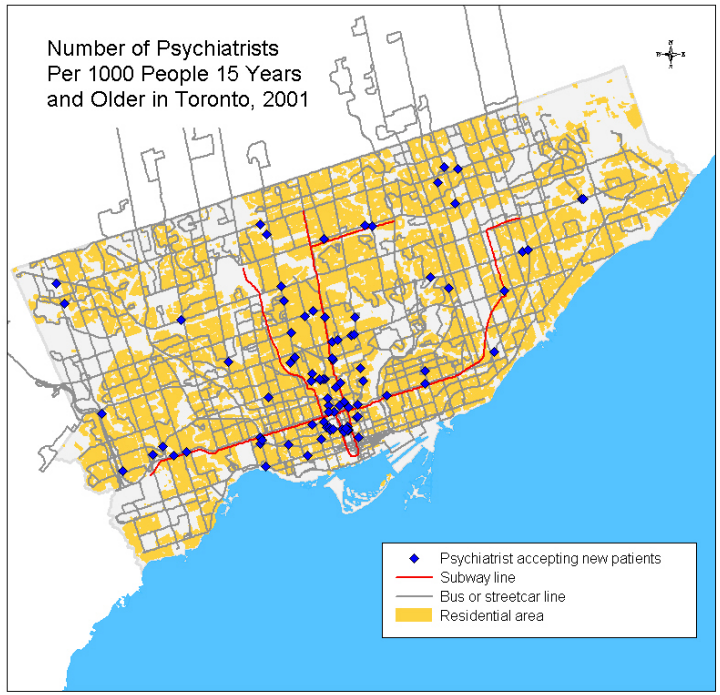
- Measures of accessibility: area-density of services vs. travel to services
- Absolute vs. relative measure of distance
- Distance decay
- Differences between urban and rural accessibility
- Ways of defining distance
- Ways of defining travel routes

Area-Density of Services vs. Travel to Services

Density of Services



Travel to Services



Absolute vs. Relative Measure of Distance

- Air travel

  shortens effective distance and time

- Public transit

  relative distance smaller where transit available

- Perception of time and distance

  2h travel a rural area could be considered normal, while the same travel time in urban settings may be unacceptable

- Ability to seek care

  lower among people with disabilities

- Appropriateness of services

  services may be available close by but inappropriate

Distance Decay

- Jarvis in 1852 reported patients in mental hospitals were more likely to come from the surrounding areas
- Principal remains true today but travel distance also affected by type of problem, socio-economic status, etc.
- Important to examine the friction of distance (slopes of the curve)
  - Individuals willing to travel long distance resource can be centralised

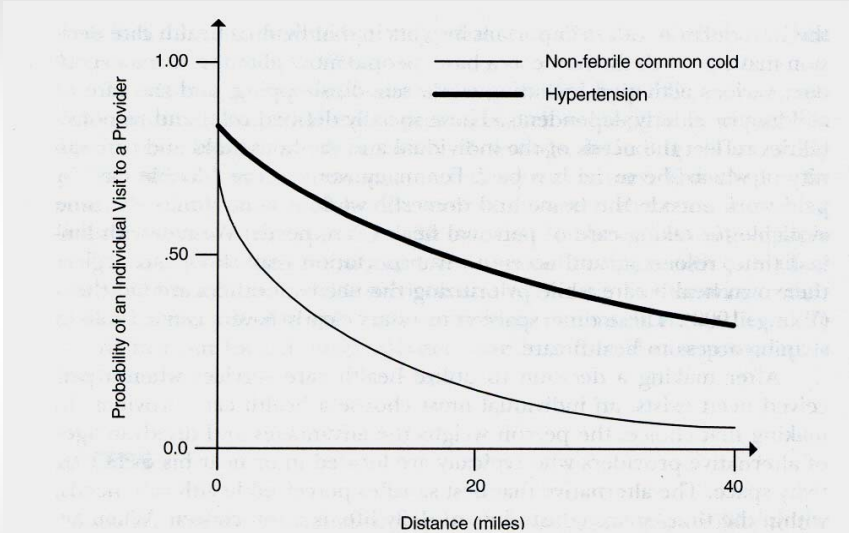


FIGURE 9.1. Distance decay in the utilization of health services. The frictional effect of distance varies among health services.

Source: 2002, *GIS and Public Health*, Ellen. K. Cromley and Sara L. McLafferty

Differences Between Urban and Rural Accessibility

Urban settings:

- Short absolute distances to services
- High density of services and people
- Dense network of roads and public transit routes
- High reliance on public transit

Rural settings:

- Long absolute distances to services
- Low density of services and people
- Sparse network of roads and public transit routes
- High reliance on personal automobiles

Ways of Measuring Distance

Distance units:

Route length (measured in km, mi etc.)

Travel time (measured in required travel time)

Accumulative impedance (measured in some units showing level of travel difficulty, e.g. number of delay points)

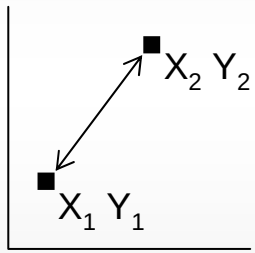
Cost (measured in monetary or non-monetary travel costs)

Ways of Measuring Distance

Straight-line

- Euclidean distance or as the crow flies
  - Pythagorean theorem used to find the distance between two points

$$d_{1,2} = ((x_1-x_2)^2 + (y_1-y_2)^2)^{0.5}$$



  - Can be used for only short distances (< 20km)

- Spherical Distance
  - Take into account the curvature of the earth
  - Two methods to calculate
    - Law of cosines for spherical trigonometry
    - Haversine formula

Ways of Measuring Distance

Manhattan Metric

Minkowski Metrics

- In urban areas, Euclidean distance does not take into consideration buildings

$$\left[\sum_{k=1}^{p}\left(x_{ik} - x_{jk}\right)^{p}\right]^{1/p}$$

- Equal to Euclidean distance when p = 2
- When p = 1 it is called the **Manhattan metric**, city-block or taxicab distance

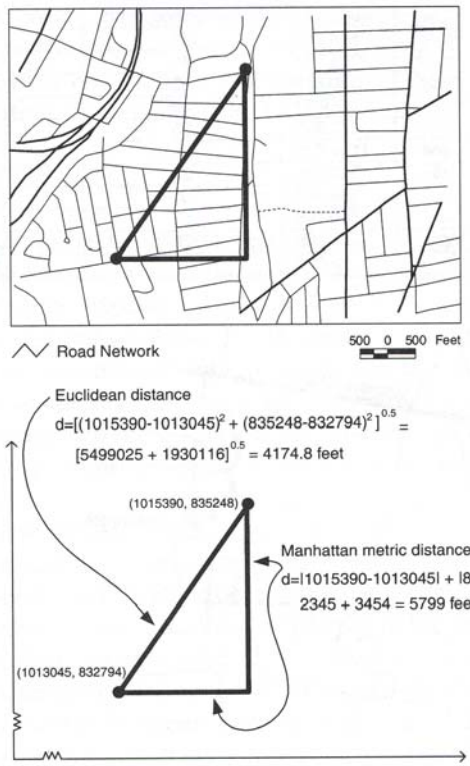


FIGURE 9.3. The calculation of Manhattan metric distance between an origin and a destination.

Sources: 1) 2002, *GIS and Public Health*, Ellen. K. Cromley and Sara L. McLafferty
2) 2000, Quanitative Geography Perspectives on Spatial Data Analysis, AS Fotheringham, C Brunsdon and M Charlton

Ways of Measuring Distance

Network Analysis

ID	Name	Type	Length_ft	Travel Speed_mph	Travel Time_min
544	Country Club	Road	424.544	45	0.11
565	Country Club	Road	3094.514	45	0.78
580	Country Club	Road	830.618	45	0.21
584	Country Club	Road	519.34	45	0.13
557	Winding	Lane	443.895	25	0.20
611	Winding	Lane	1154.725	25	0.52
638	Stony	Way	519.055	25	0.21
655	Stony Corners	Cir	338.462	25	0.15
666	Stony Corners	Cir	399.896	25	0.18
695	Cotswold	Way	697.009	25	0.32
			8422.028		2.84

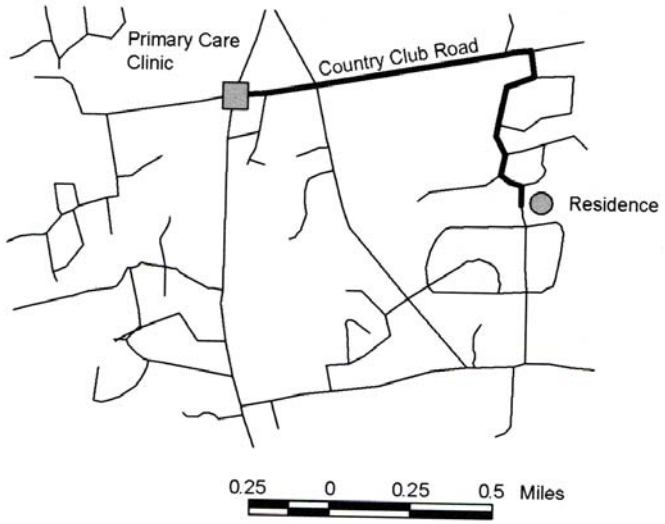
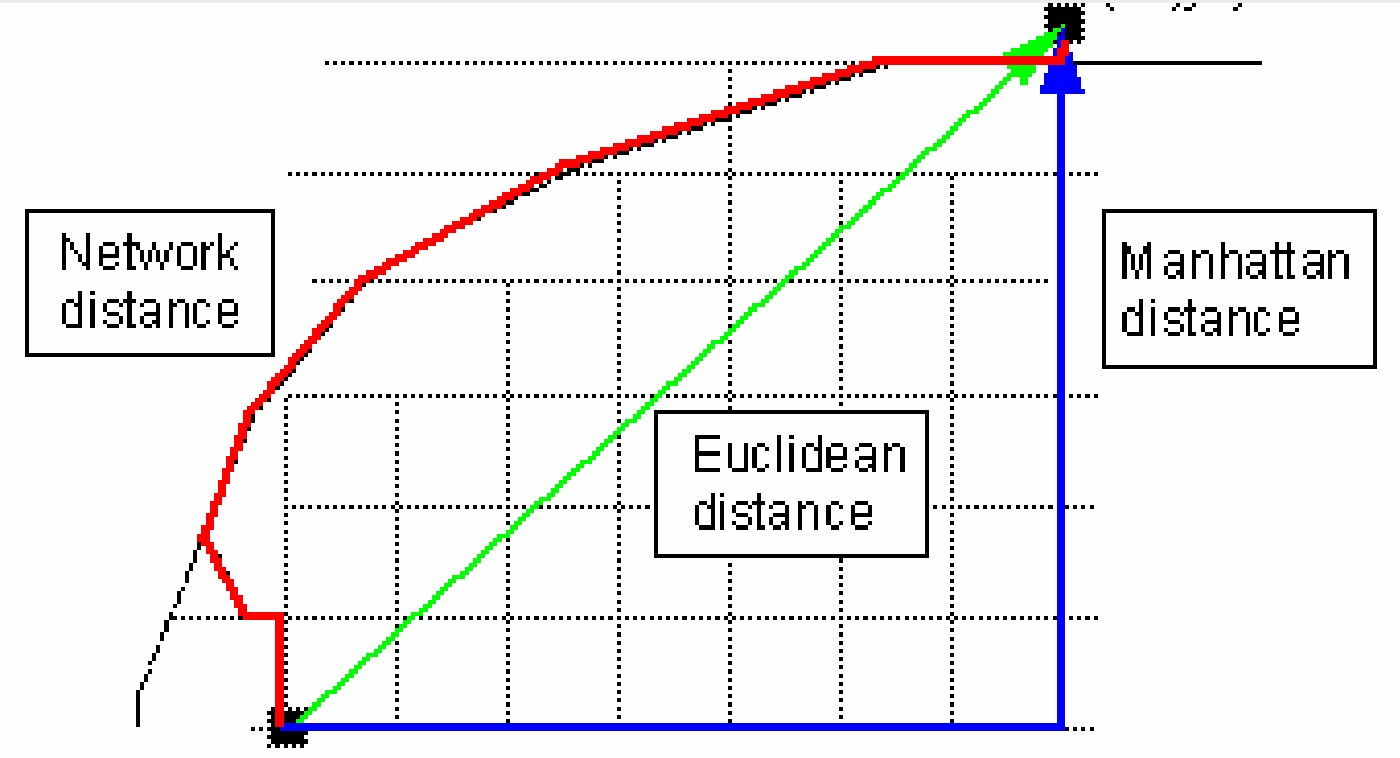


FIGURE 9.4. The measurement of travel time between an origin and a destination can be implemented in a GIS provided that data are available on the amount of time it takes to traverse a segment along the route of travel. For an automobile user traveling the speed limit, the 1.6-mile trip from the primary care clinic to the residence using the highlighted route would take about 3 minutes.

Source: 2002, *GIS and Public Health*, Ellen. K. Cromley and Sara L. McLafferty

Ways of Measuring Distance



Network Analysis

- Basic concepts
- Types of possible analysis
- Application example

Network Analysis – Basic Concepts

- NA is more accurate than straight-line or Manhattan metric measure
- Takes into account real-life factors associated with travel:
  - Possible travel routes
  - Travel speed
  - Need to stop and turn
  - Possibility of changing of mode of travel
  - Other considerations

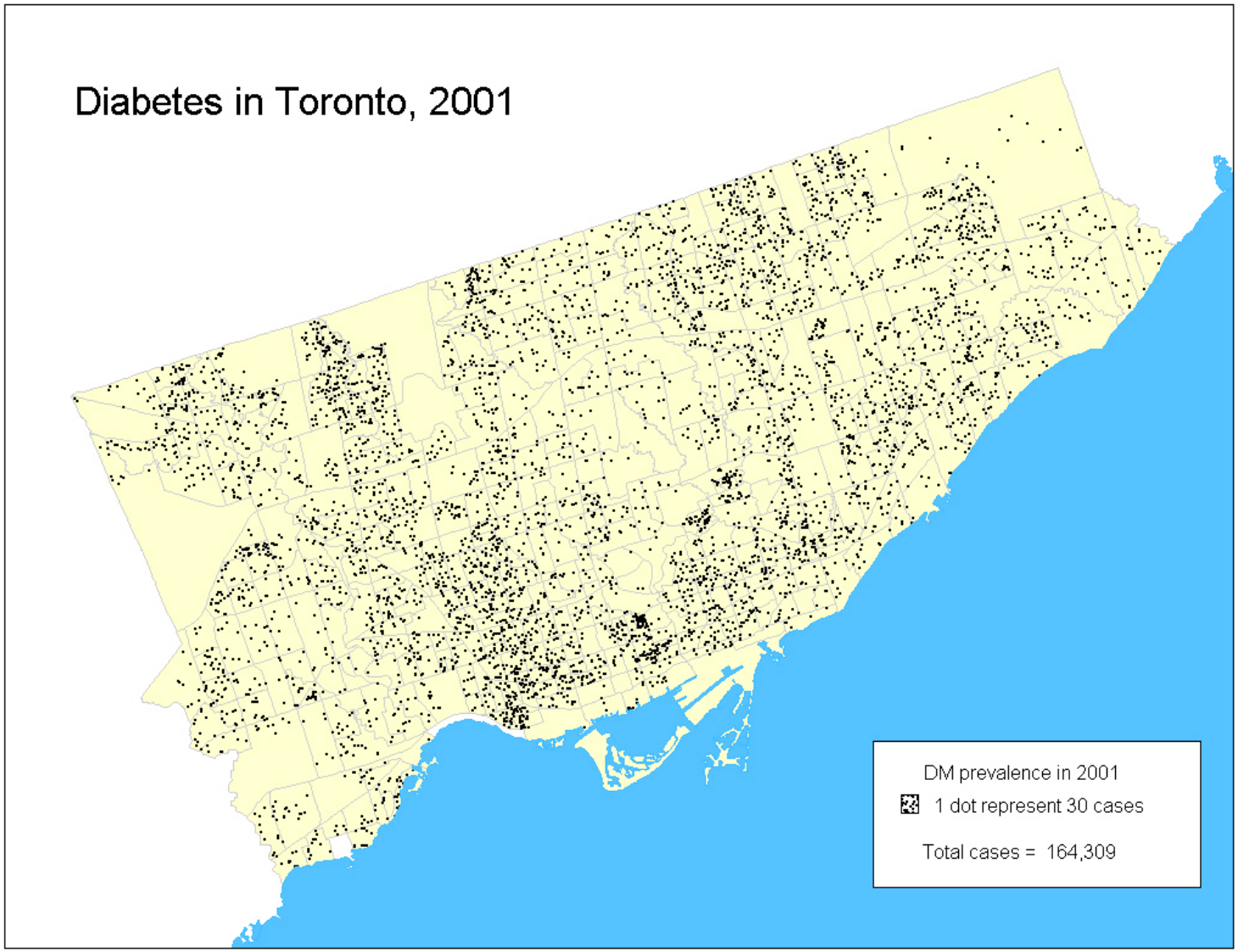
Network Analysis – Types of Analysis

- Minimum cost 'PATH' - with user-determined sequence of stops
- Minimum cost 'TOUR' - with algorithm-calculated sequence of stops
- 'SERVICE AREA' – parts of the network that can be reached from a service point within a given time
- 'ACCESSIBILIY' – level of accessibility to desired services given their attractiveness and the distances from trip origins
- 'INTERACTION' – level of use of services given their attractiveness and existing demand
- 'LOCATION-ALLOCATION' – to calculate the optimal new location of a service given the network characteristics, demand, supply, competition etc.

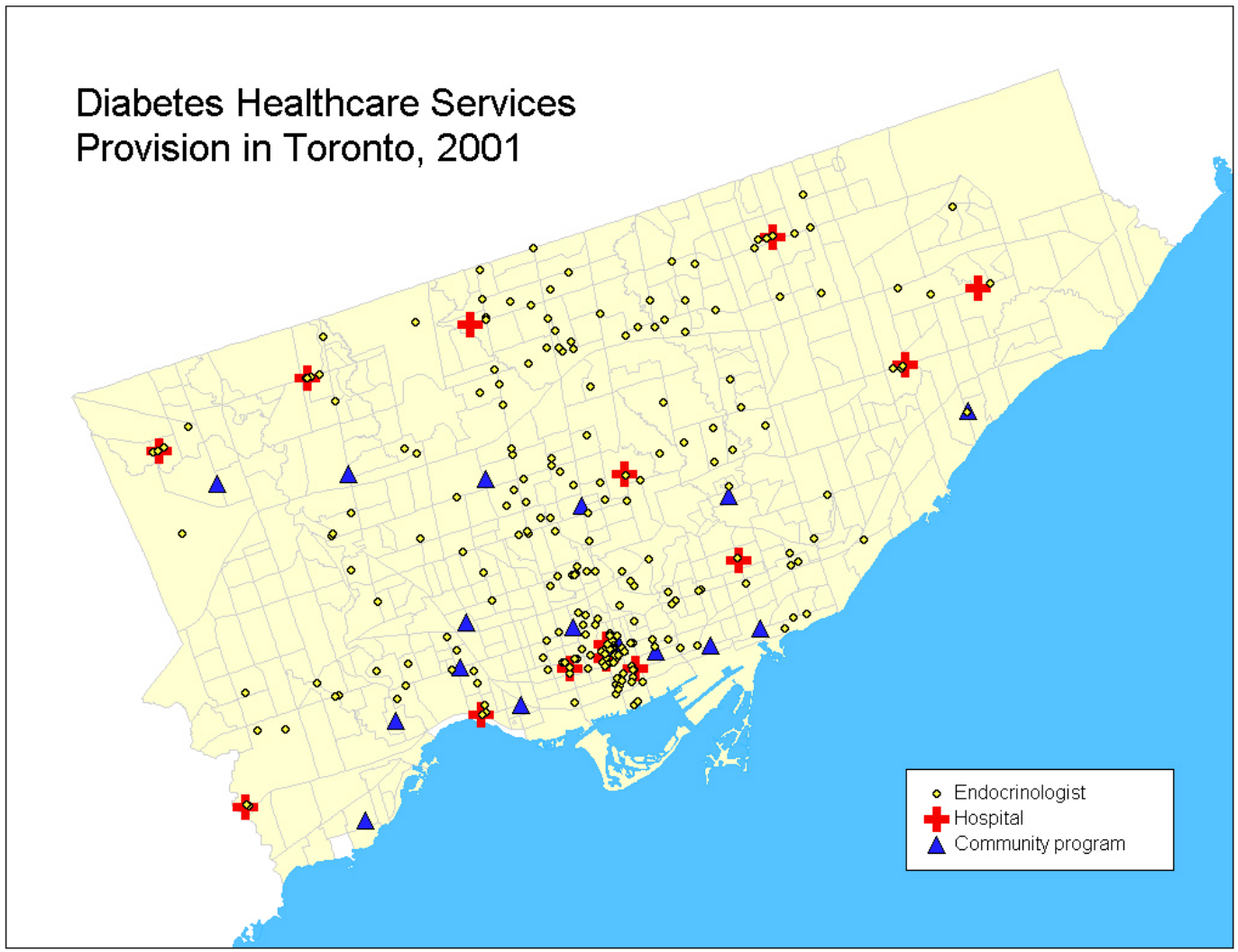
Toronto Diabetes Atlas

Example of an application of network analysis

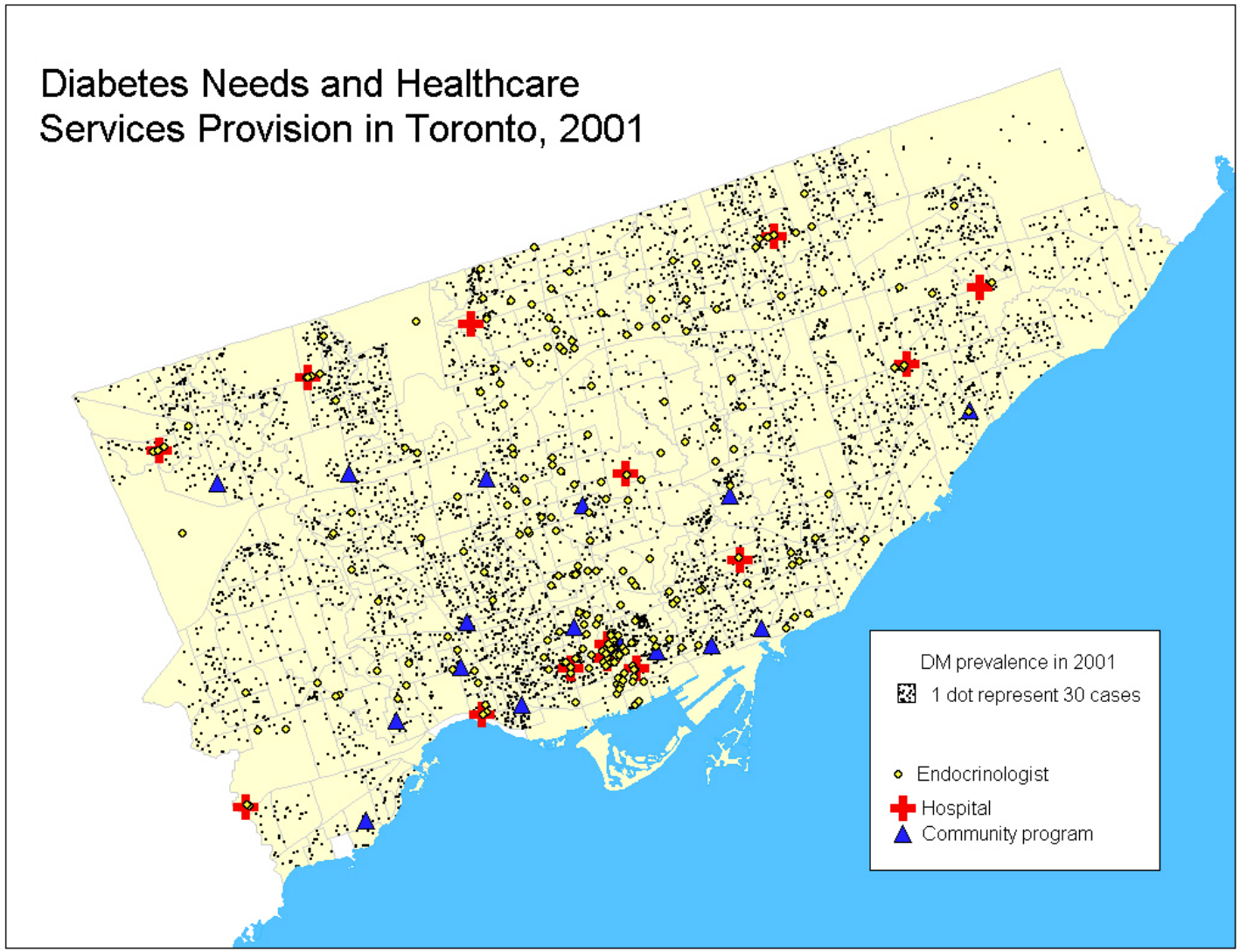
Diabetes Needs



Diabetes Healthcare Provision



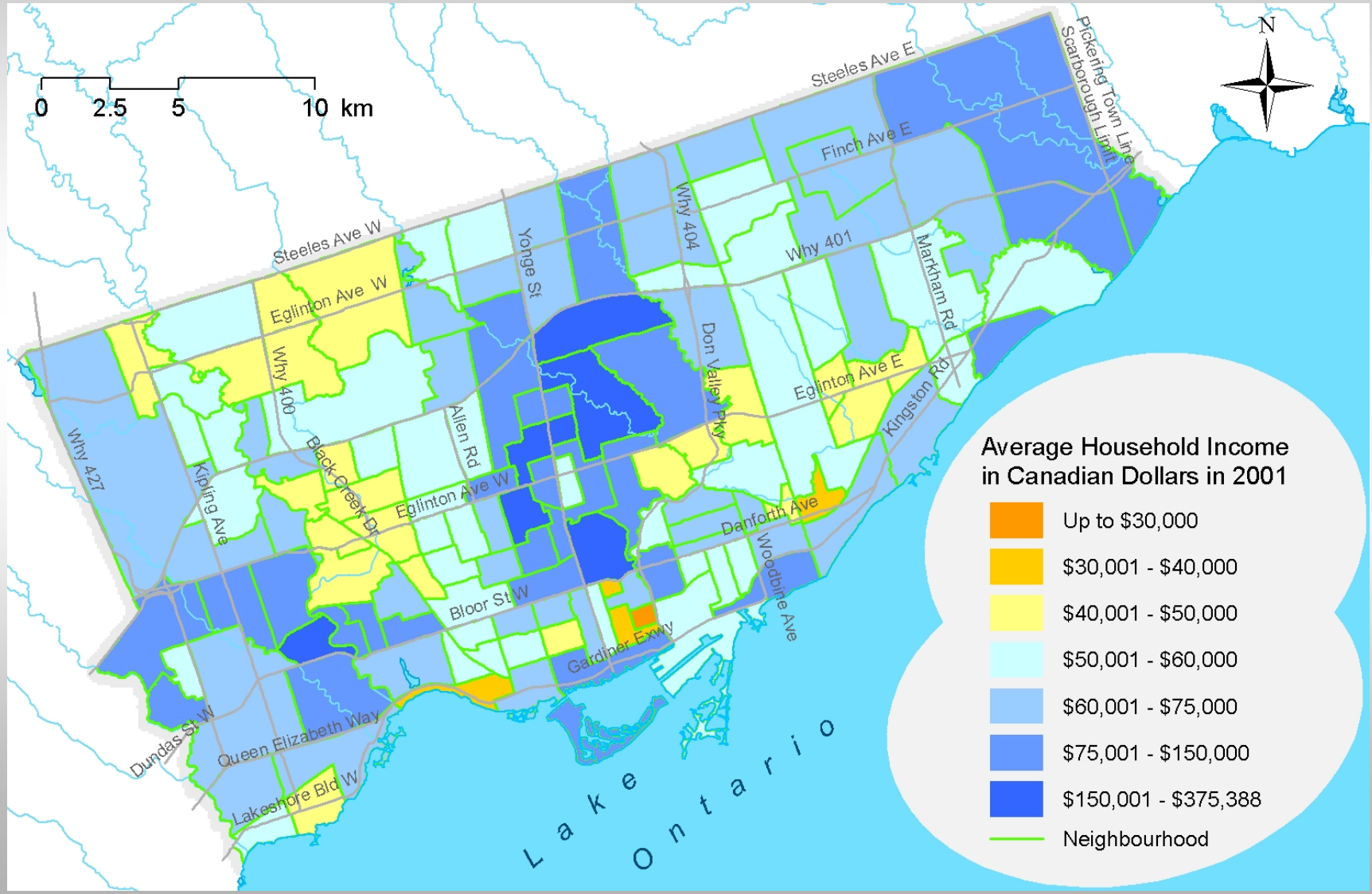
Diabetes Needs and Healthcare Provision



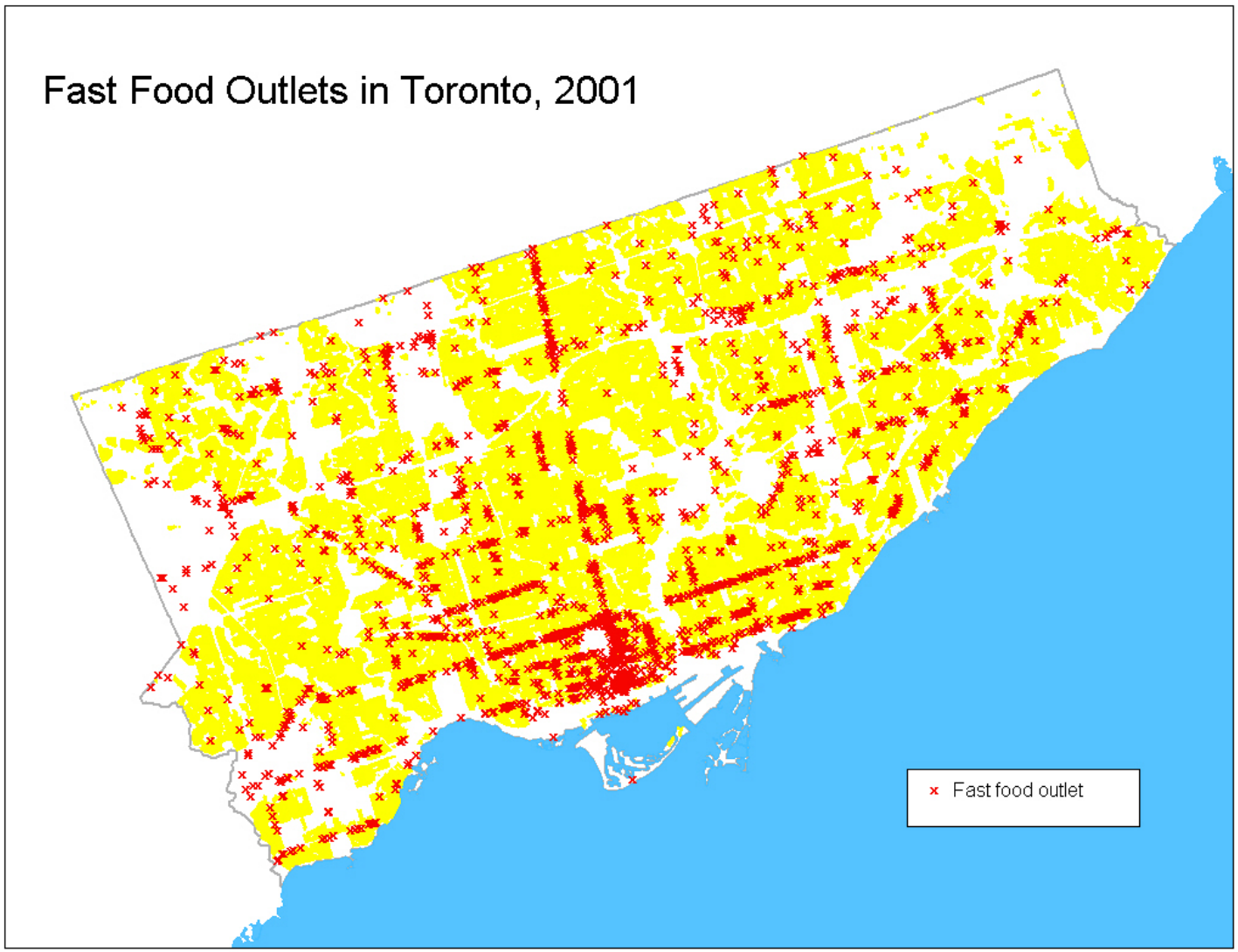
Methodology

- Define residential points with SES characteristics
- Define DM prevalence across the study area
- Define points with factors affecting DM status (fast food, parks etc)
- Using Network Analysis determine how access to healthy and unhealthy factors differs by population SES status
- Using spatial statistical procedure of Local Indicator of Spatial Association (LISA) identify areas with:
  - High levels of DM and poor access to opportunities for health
  - Low levels of DM and good access to opportunities for health

Factors Affecting DM: SES

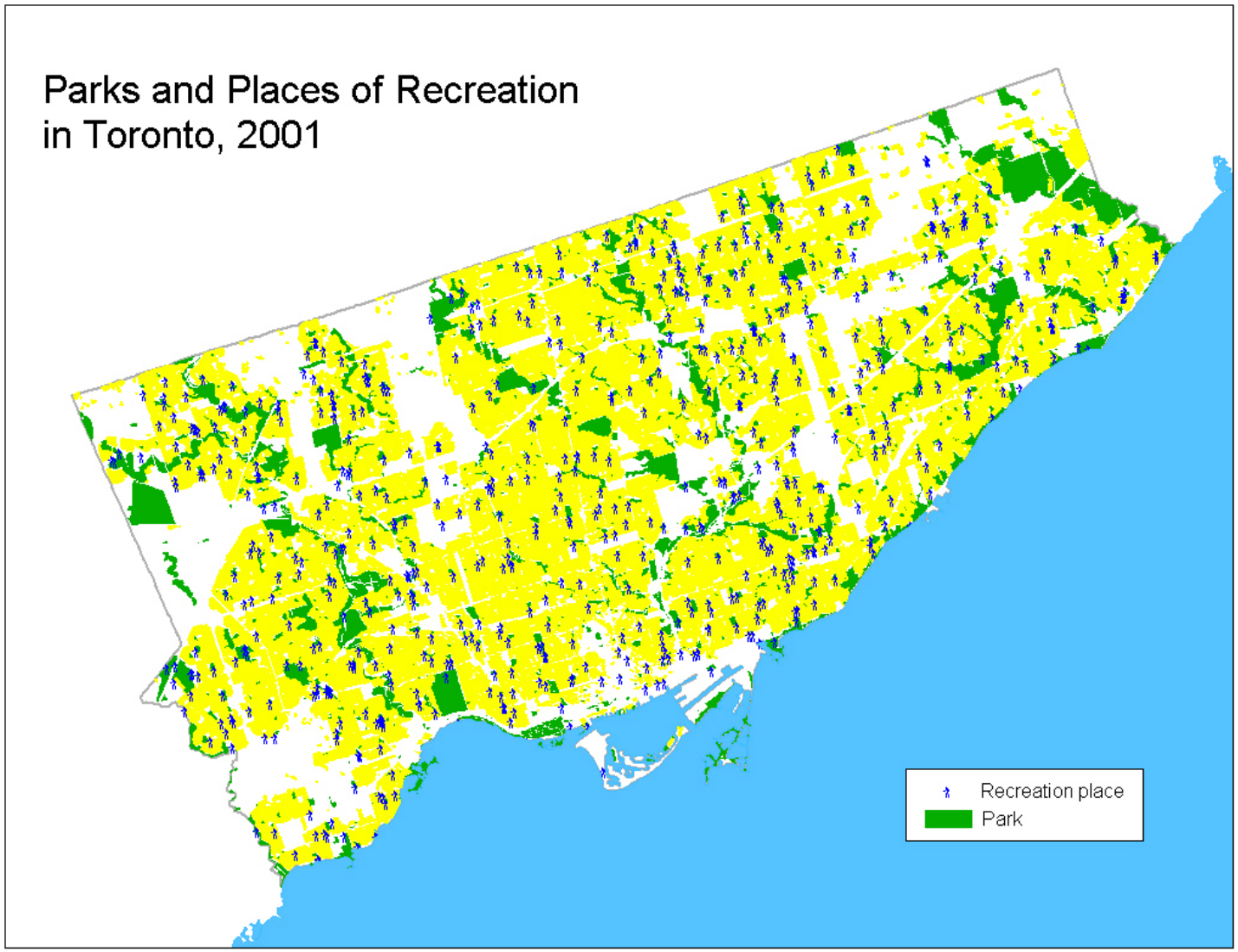


Factors Affecting DM: Fast Food

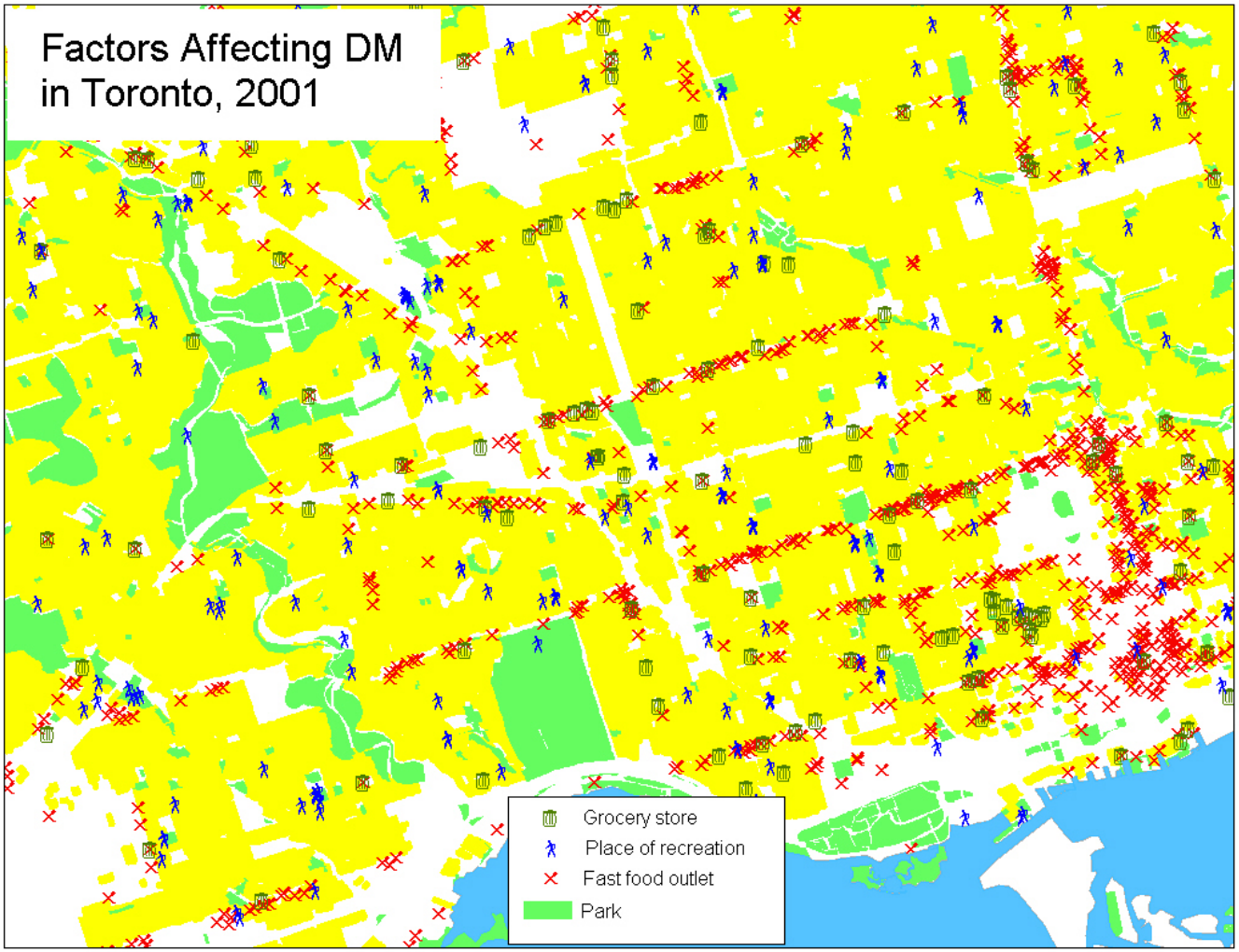


Factors Affecting DM: Grocery Stores

Factors Affecting DM: Parks and Rec Places



Factors Affecting DM: Fast Food, Grocery Stores, Parks and Recreation Places

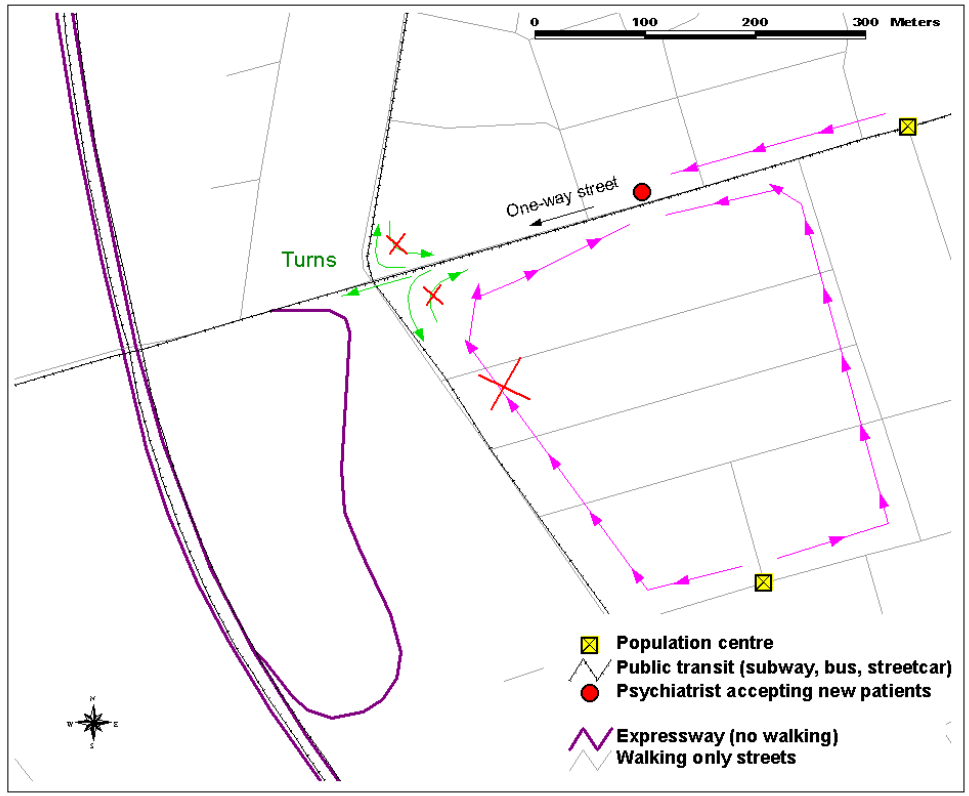


Building the GIS Network

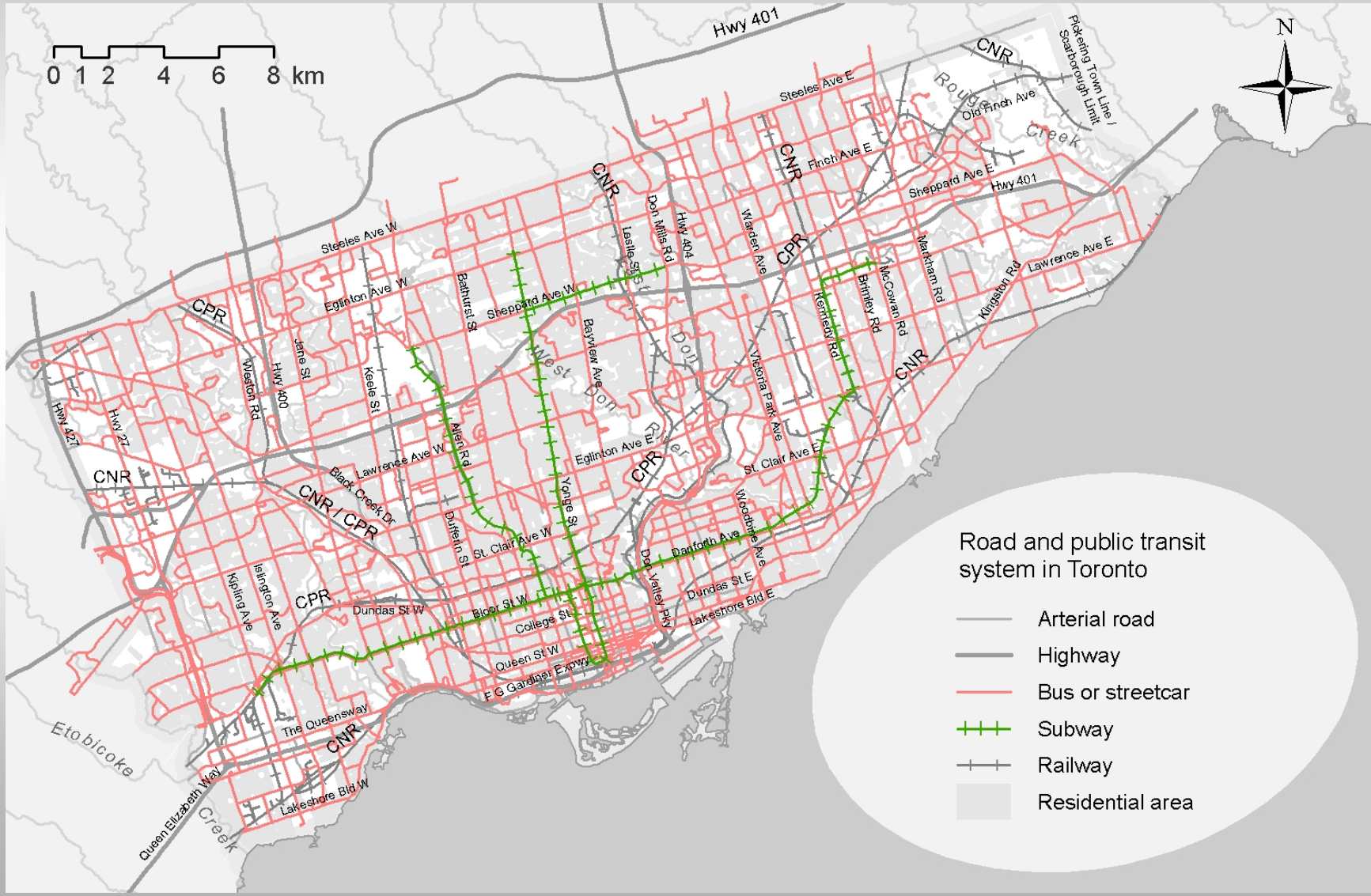
Procedure:

1. Compile street file with the following data:

   | speed limits | one-way streets | expressways (no walking) |
2. Create turn table with turn impedances
3. Compile public transit file
4. Combine all files into one network file

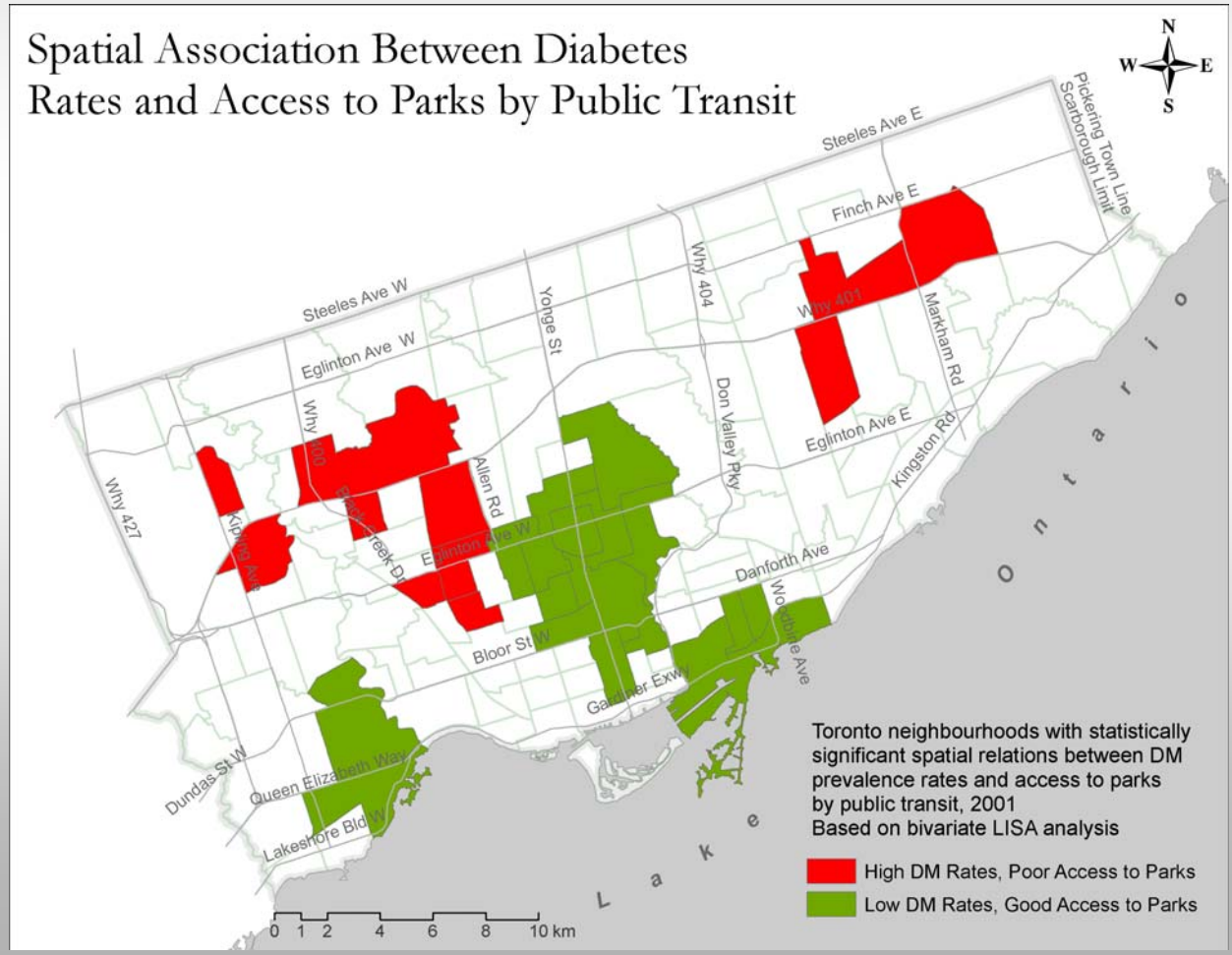


Toronto Public Transit Network



Local Indicator of Spatial Association

Statistical procedure seeking spatial relationships between high and low values of one or two variables, e.g.: DM rates and access levels to parks



Limitations of Network Analysis

- Complexity of analysis and required system and data set-up.
- Some elements of the network may not be easily assessed or incorporated, e.g. precise transit schedules, delays due to traffic congestion.
- Accuracy of data, e.g.: ‘Accepting new patients’ status from the doctors database may not reflect the true status, or long wait times for the first visit.
- People may choose travel patterns that do not correspond to the most efficient solution as defined by network analysis.

Access to Orthopaedic Surgeons in Ontario

Example of an Application of Straight-line and Area Density Analysis

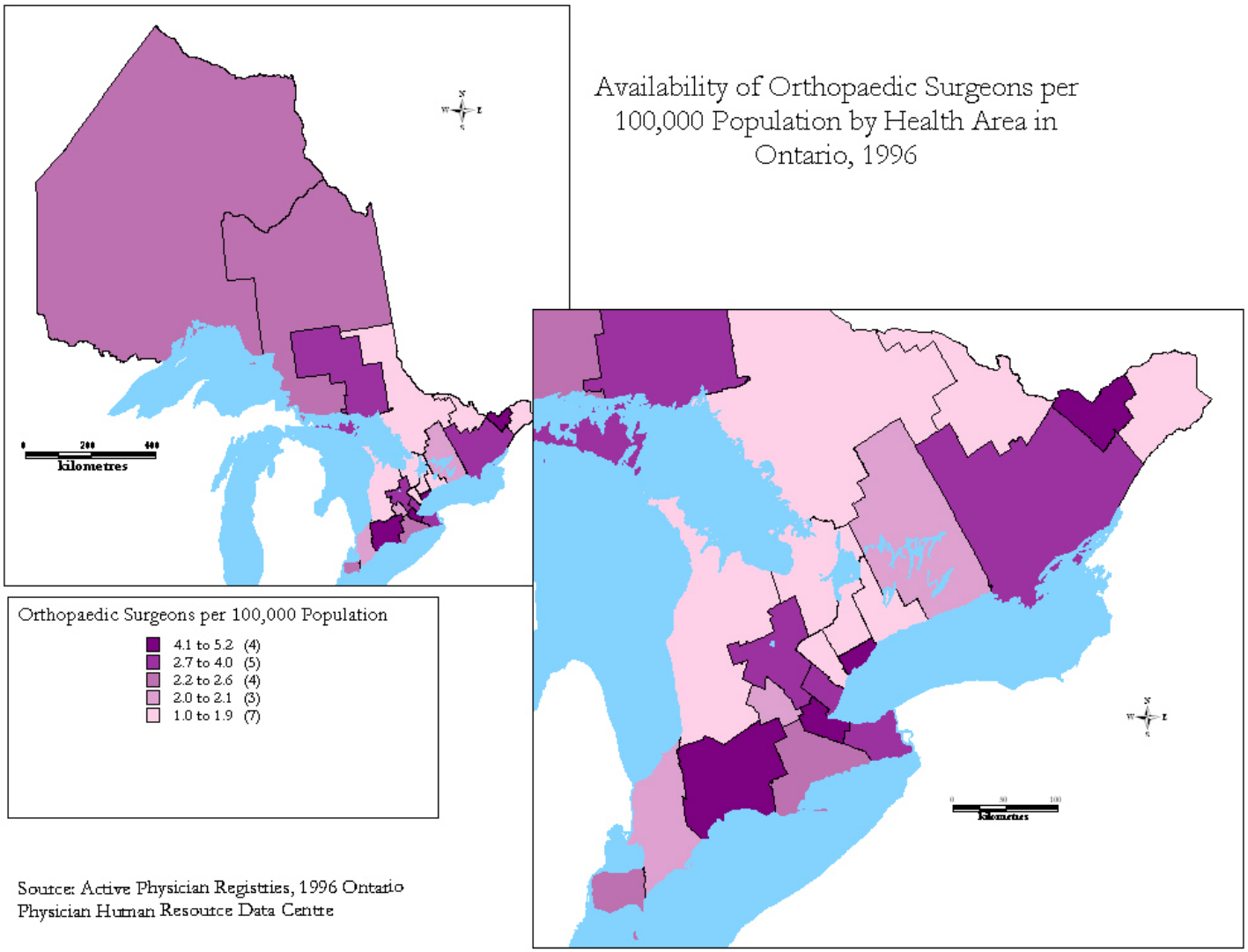
Methods

- Sample
  - Respondents of the 1996 Ontario Health Survey linked to their health care utilization data
- Additional Data Sources
  - RPDB for respondent's postal code
  - CPD for surgeon's postal code

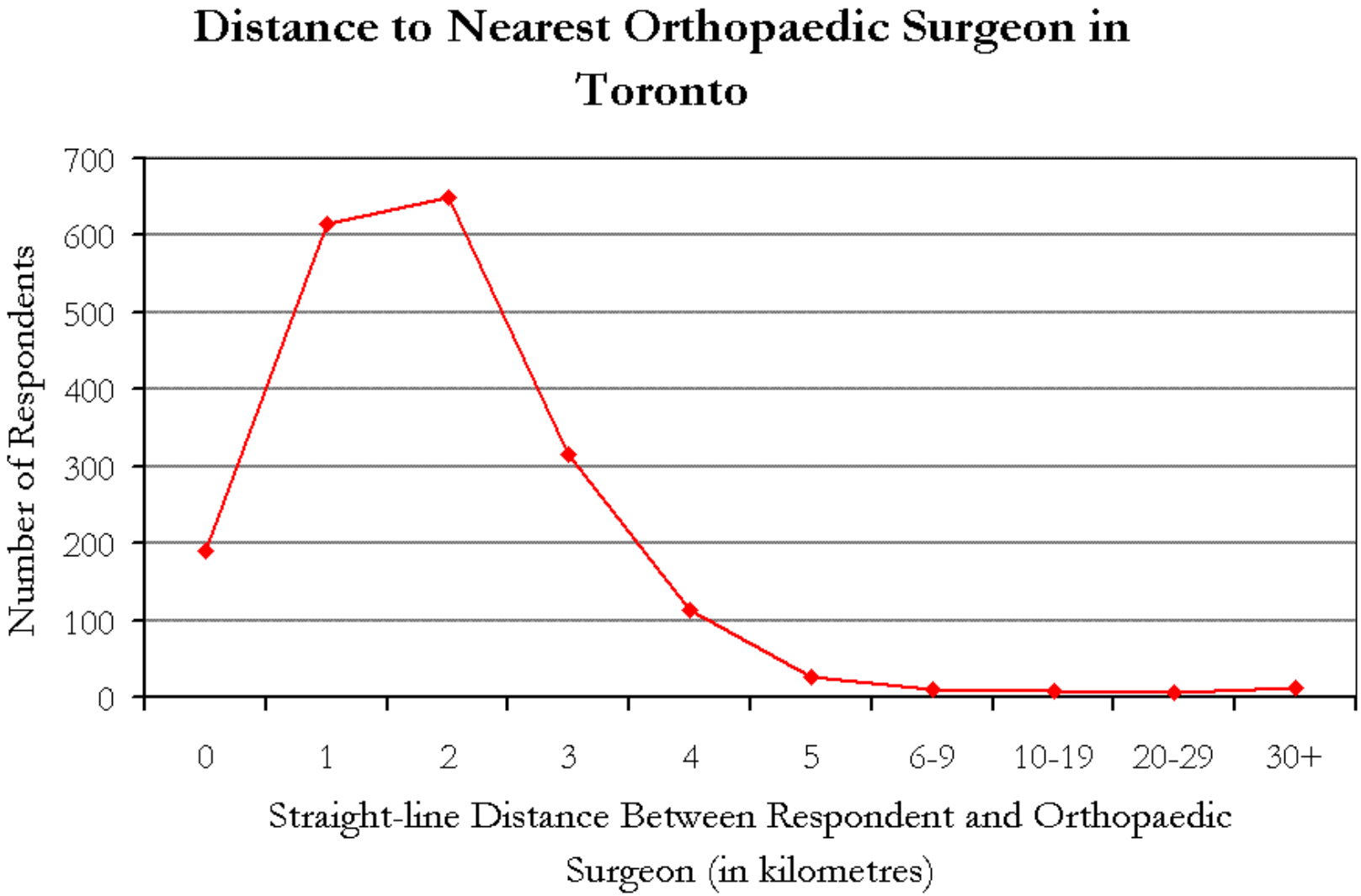
Accessibility

- Density of providers within a geographic area
- Straight-line distance to nearest provider
- Combination of the above two
  - Density of providers within a certain distance of the respondent

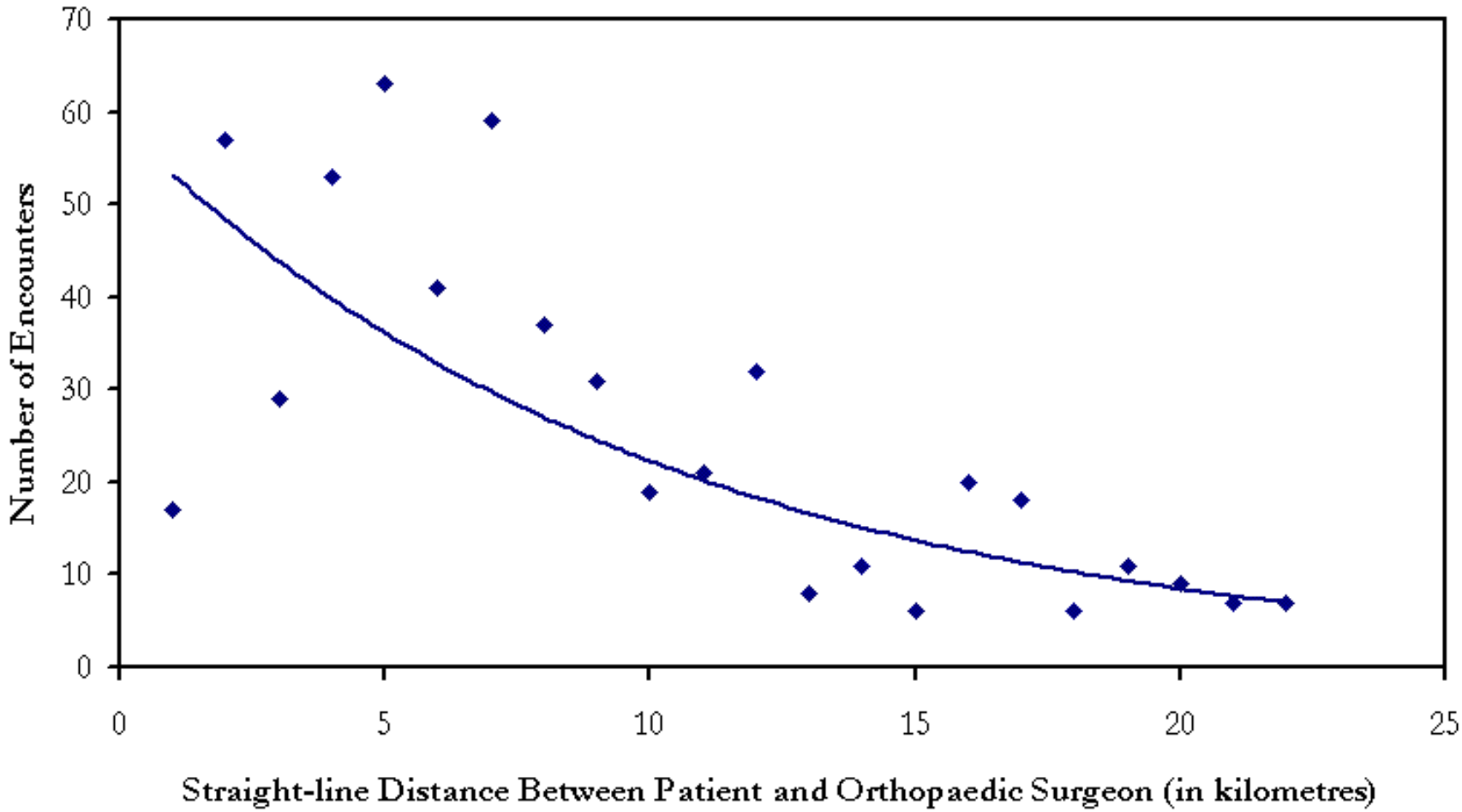
Density Analysis



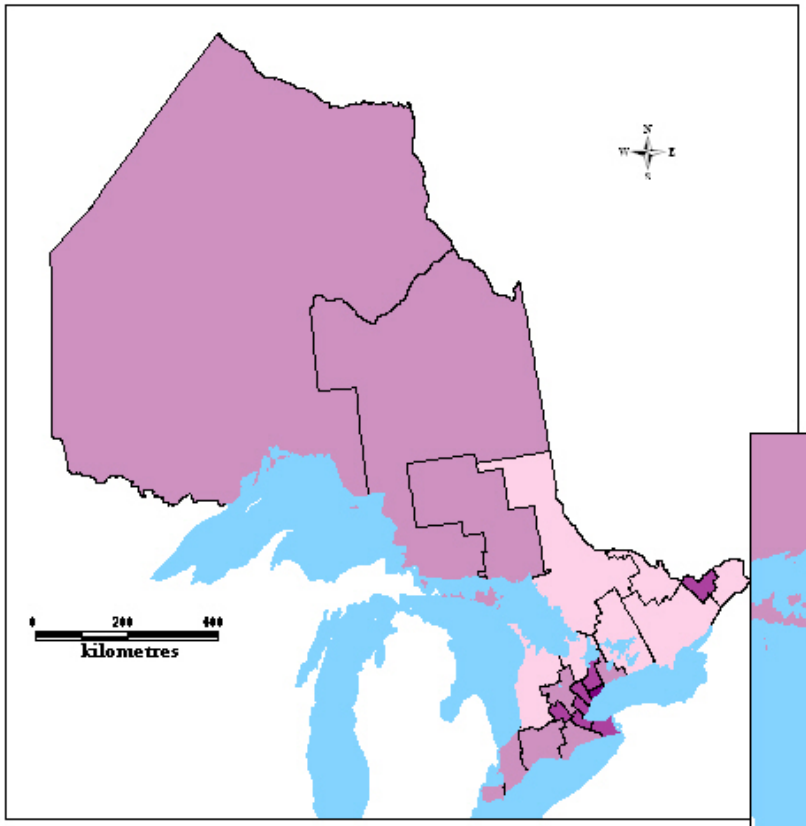
Distance Decay Analysis

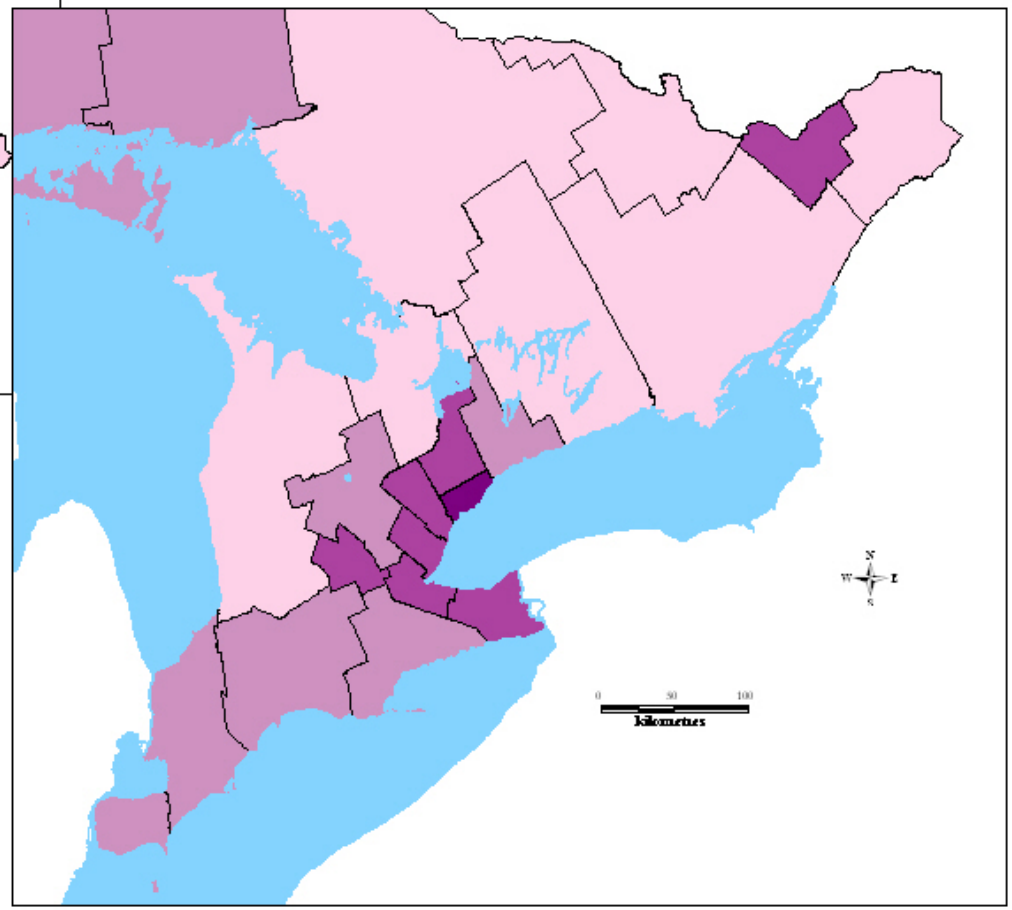


Distance Decay Analysis



Percentage of 1996 Ontario Health Survey Respondents Who Have At Least One Orthopaedic Surgeon Within a Five Kilometre Radius From Their Home



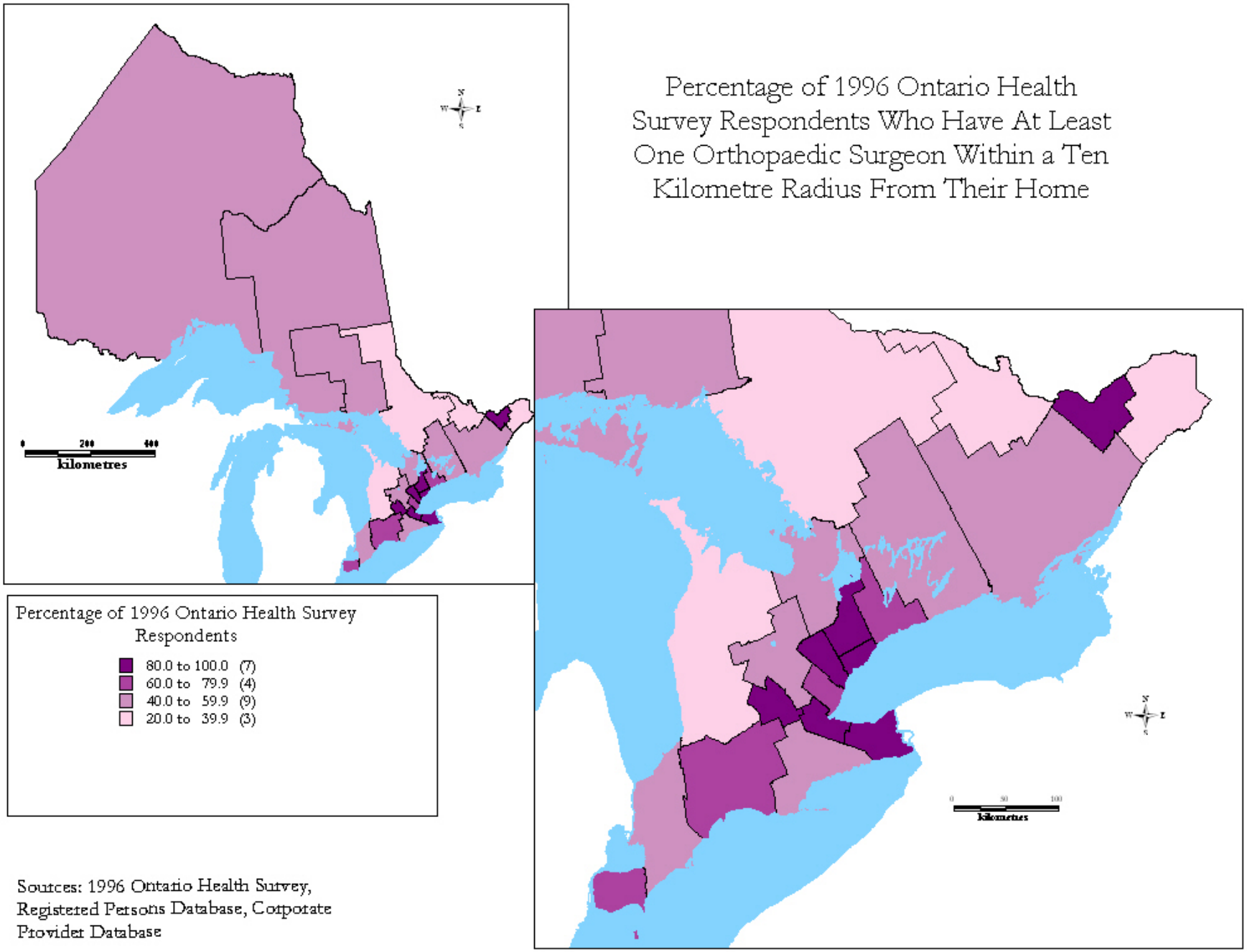


Percentage of 1996 Ontario Health Survey Respondents

- 80.0 to 100.0 (1)
- 60.0 to 79.9 (7)
- 40.0 to 59.9 (9)
- 20.0 to 39.9 (6)

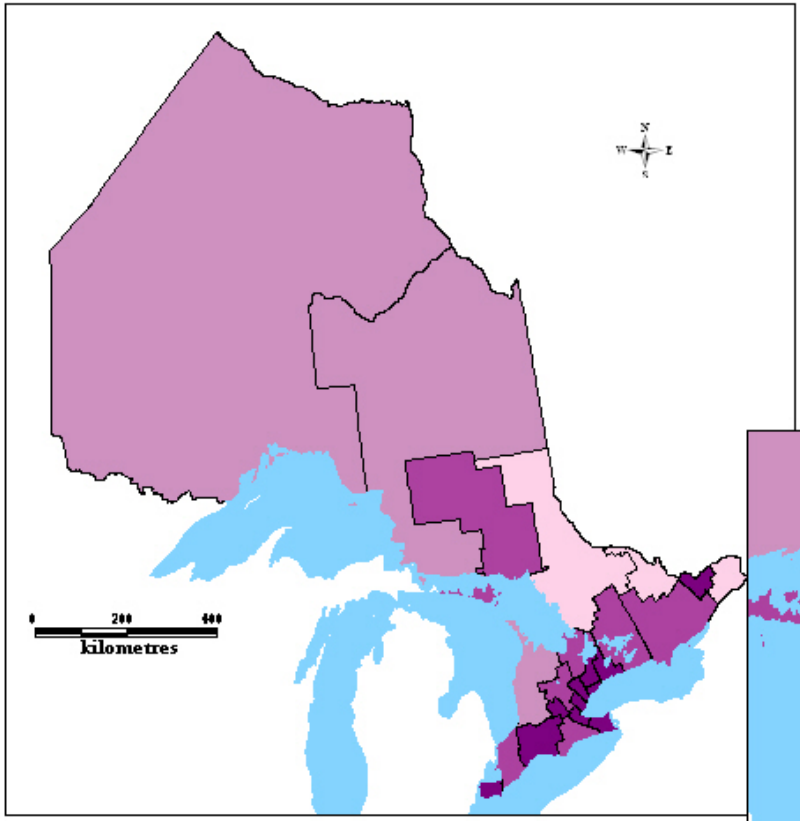
Sources: 1996 Ontario Health Survey, Registered Persons Database, Corporate Provider Database

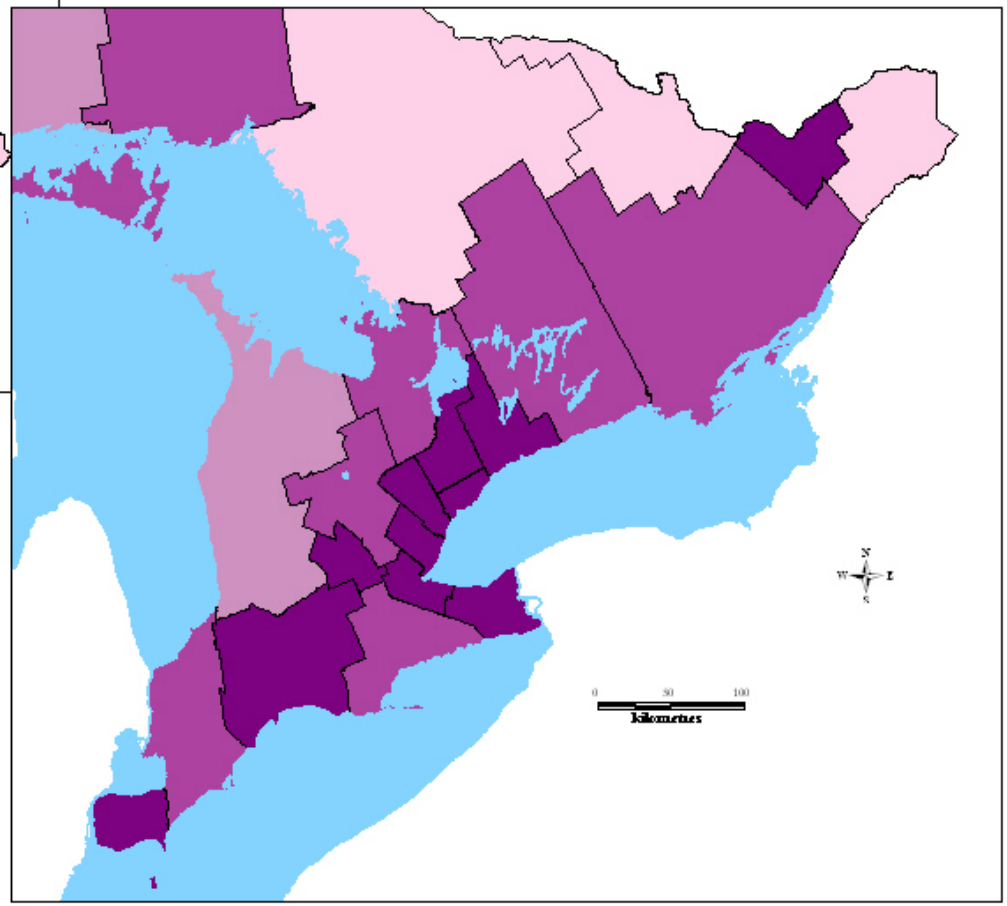
Percentage of 1996 Ontario Health Survey Respondents Who Have At Least One Orthopaedic Surgeon Within a Ten Kilometre Radius From Their Home



Sources: 1996 Ontario Health Survey, Registered Persons Database, Corporate Provider Database

Percentage of 1996 Ontario Health Survey Respondents Who Have At Least One Orthopaedic Surgeon Within a Twenty Five Kilometre Radius From Their Home



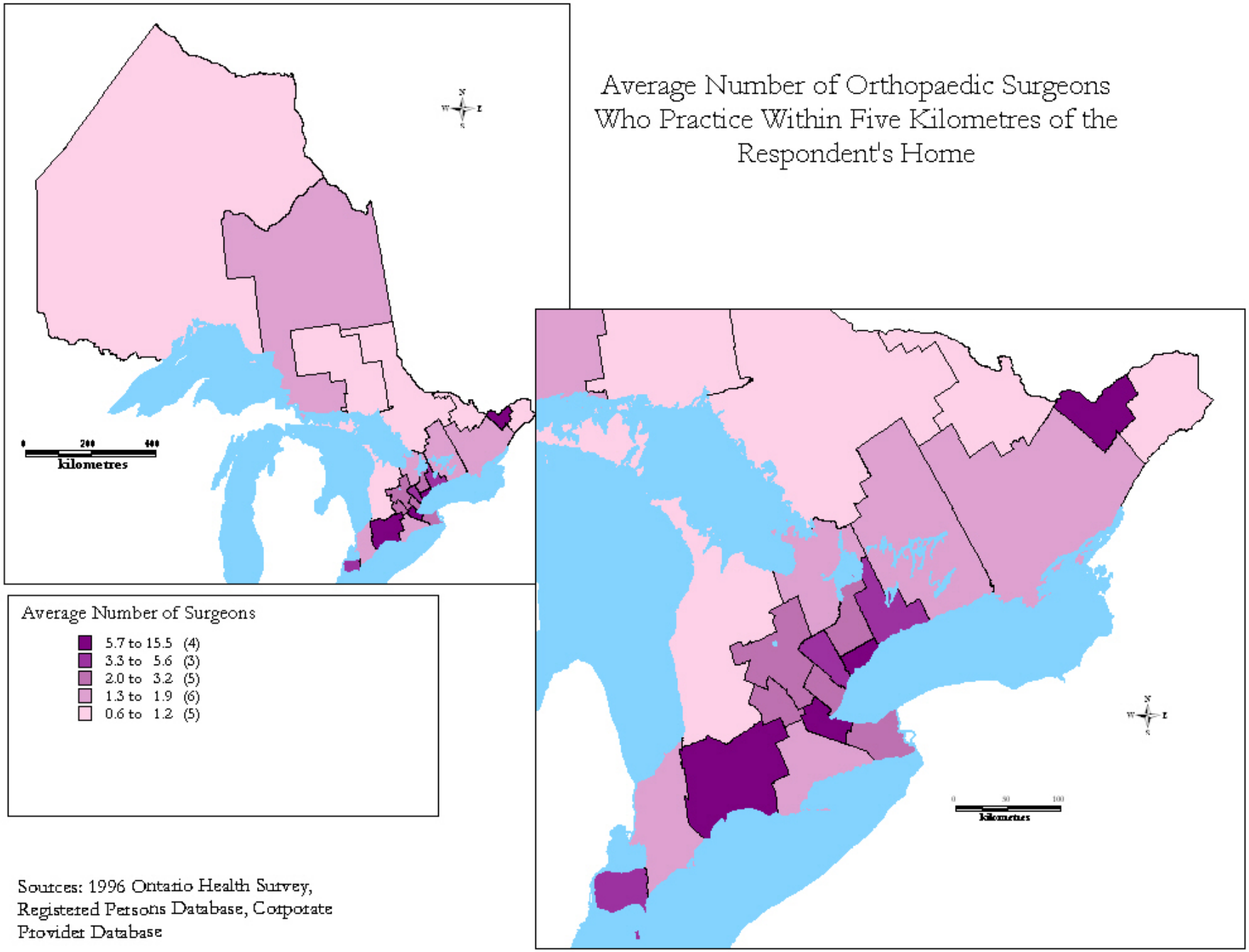


Percentage of 1996 Ontario Health Survey Respondents

- 80.0 to 100.0 (11)
- 60.0 to 79.9 (7)
- 40.0 to 59.9 (3)
- 20.0 to 39.9 (2)

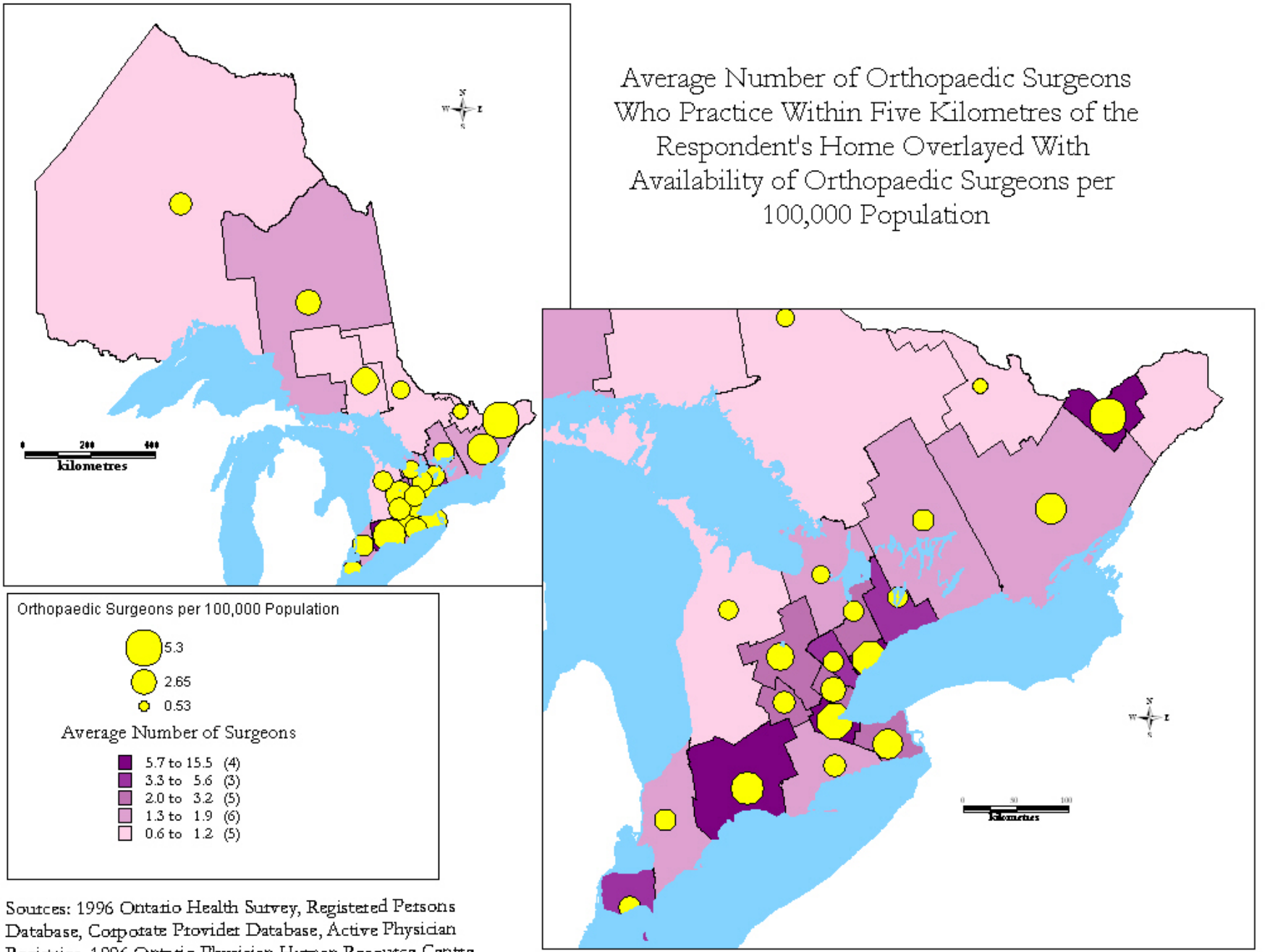
Sources: 1996 Ontario Health Survey, Registered Persons Database, Corporate Provider Database

Average Number of Orthopaedic Surgeons Who Practice Within Five Kilometres of the Respondent's Home



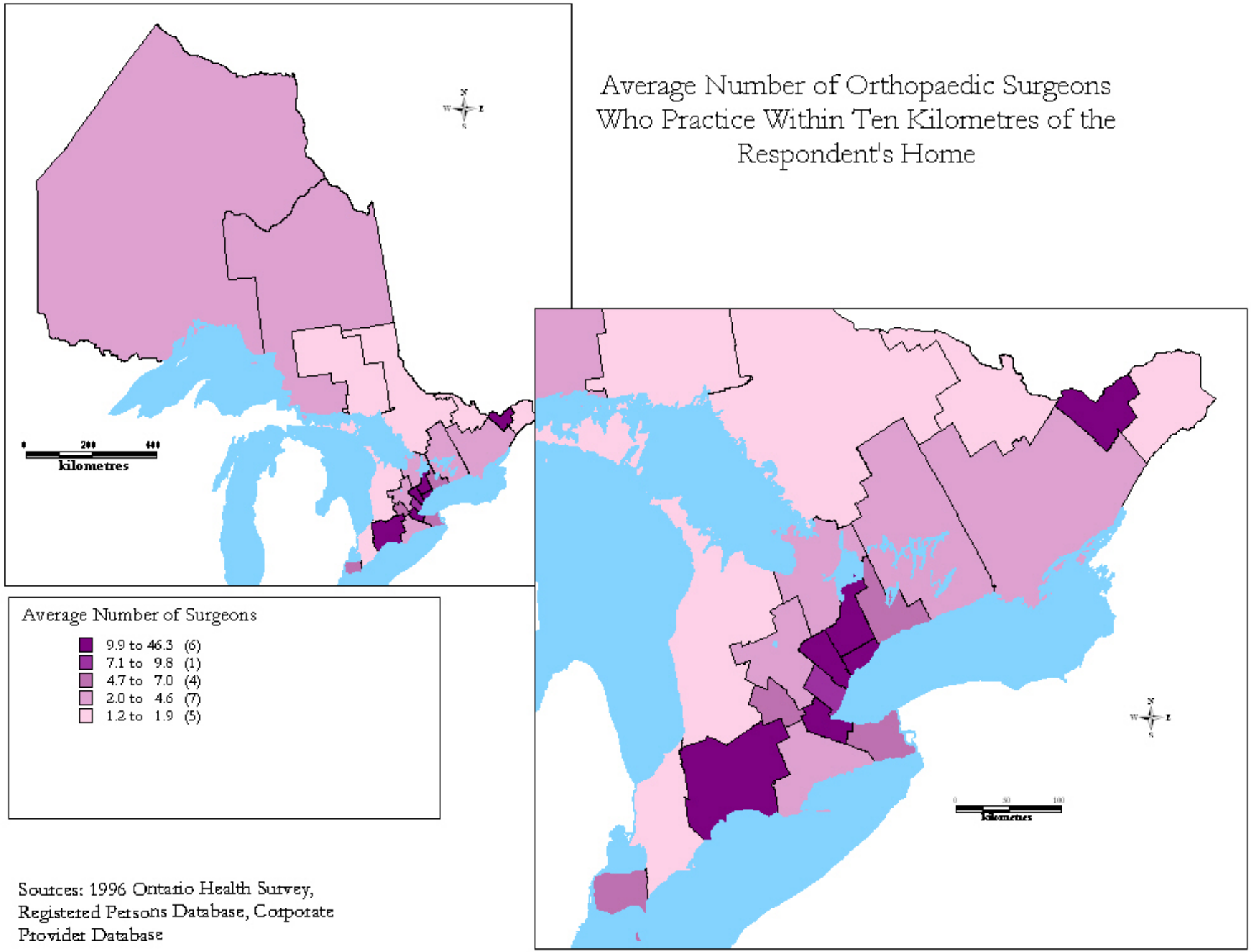
Sources: 1996 Ontario Health Survey, Registered Persons Database, Corporate Provider Database

Average Number of Orthopaedic Surgeons Who Practice Within Five Kilometres of the Respondent's Home Overlayed With Availability of Orthopaedic Surgeons per 100,000 Population



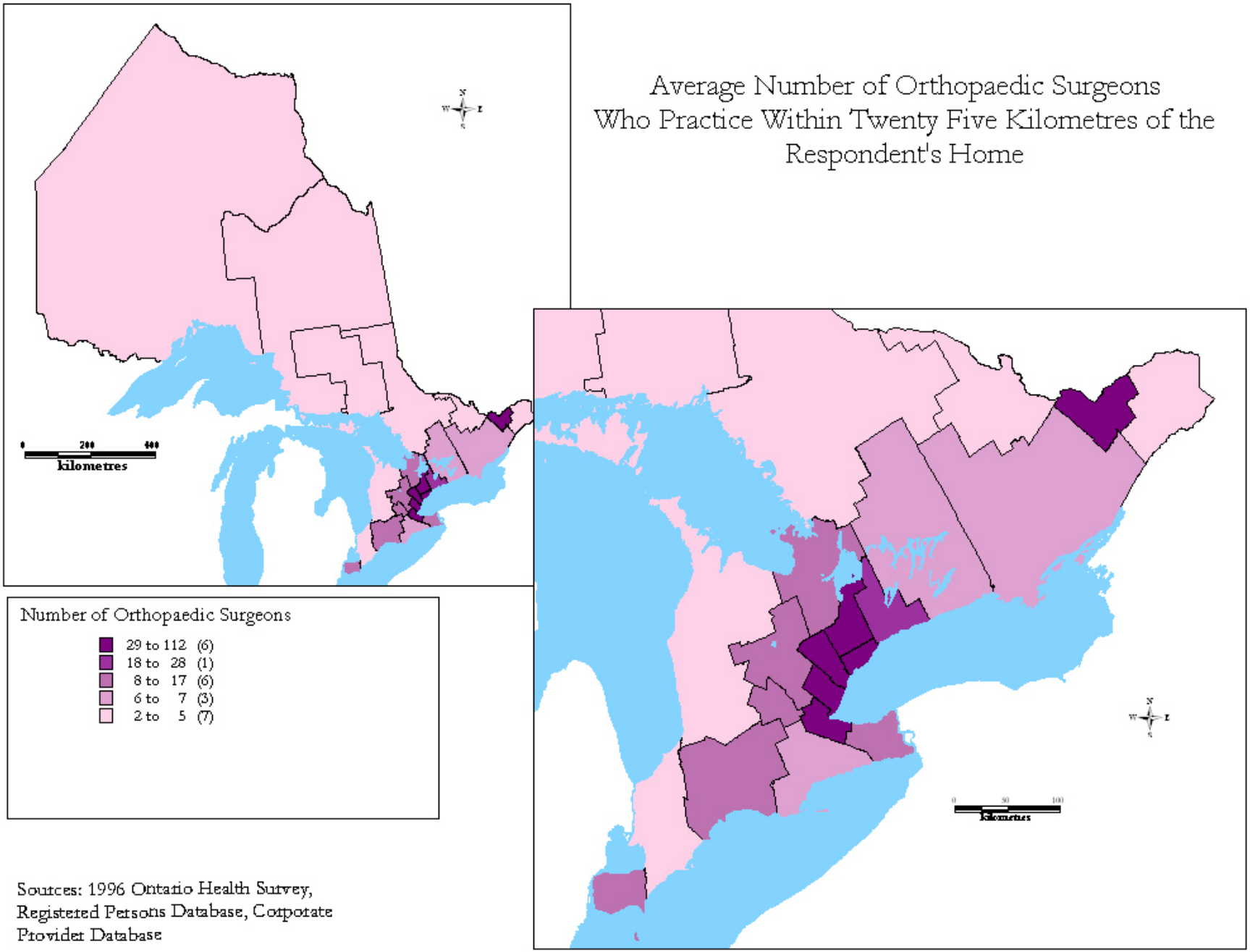
Sources: 1996 Ontario Health Survey, Registered Persons Database, Corpotate Provider Database, Active Physician Registries, 1996 Ontario Physician Human Resource Centre

Average Number of Orthopaedic Surgeons Who Practice Within Ten Kilometres of the Respondent's Home



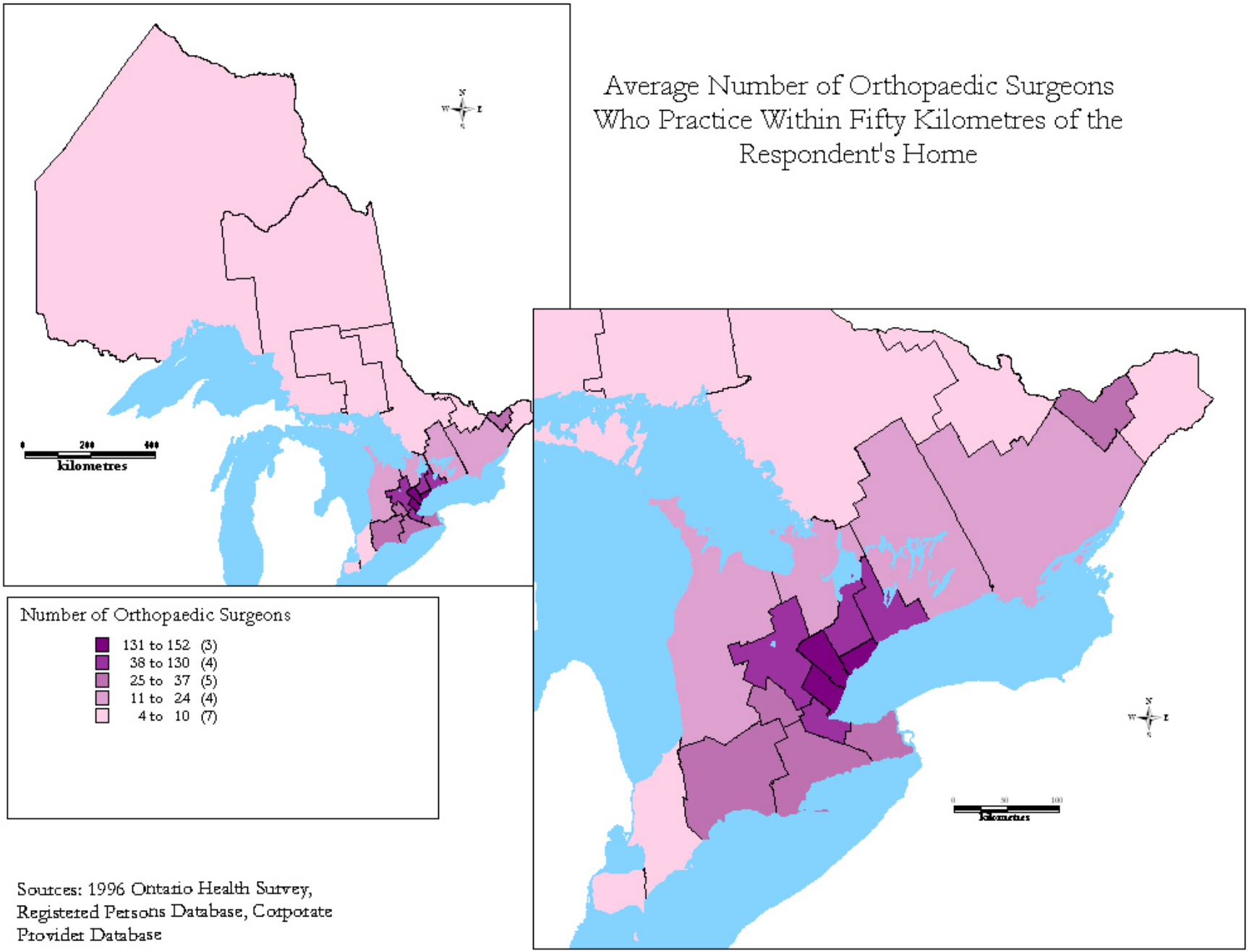
Sources: 1996 Ontario Health Survey, Registered Persons Database, Corporate Provider Database

Average Number of Orthopaedic Surgeons Who Practice Within Twenty Five Kilometres of the Respondent's Home



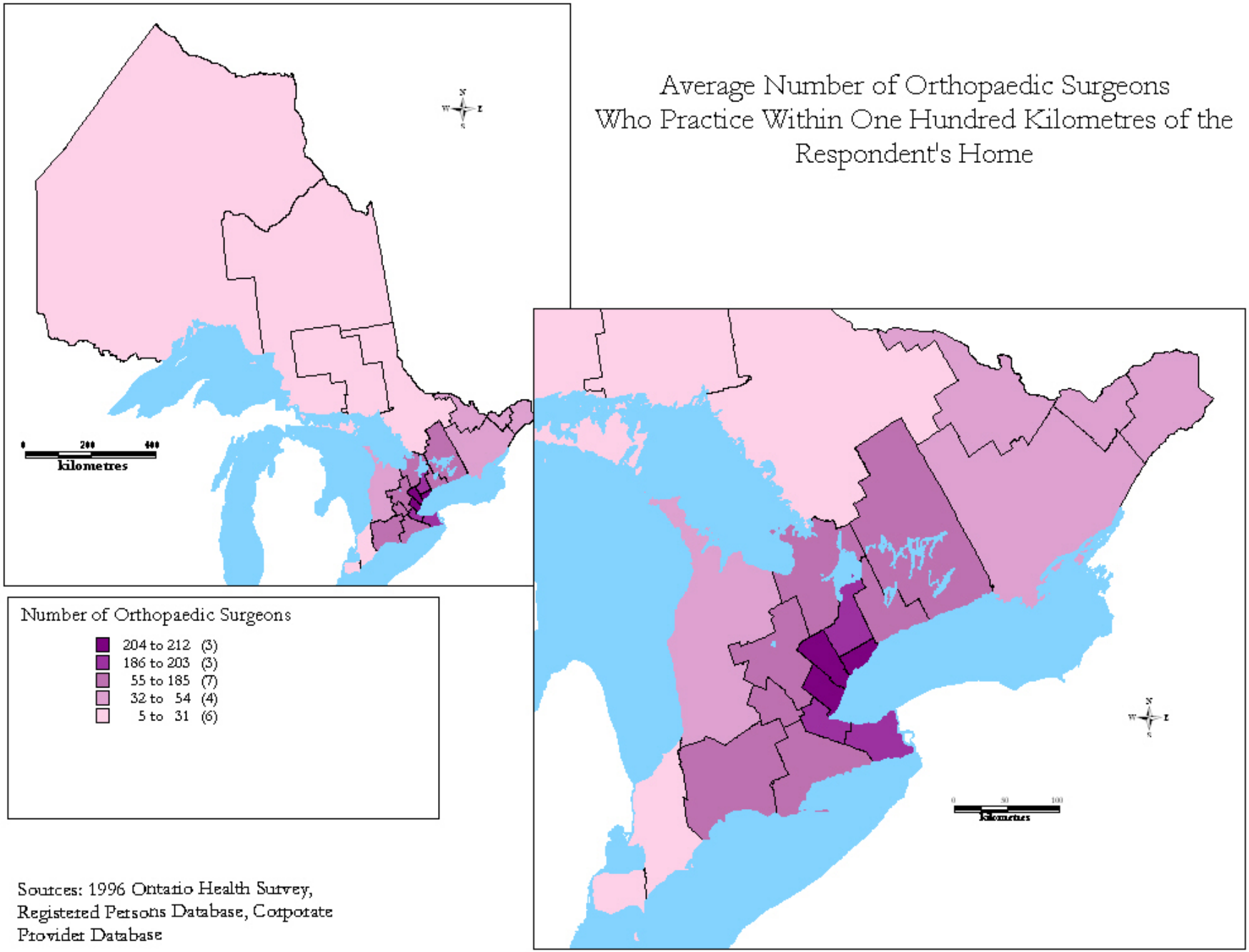
Sources: 1996 Ontario Health Survey, Registered Persons Database, Corporate Provider Database

Average Number of Orthopaedic Surgeons Who Practice Within Fifty Kilometres of the Respondent's Home



Sources: 1996 Ontario Health Survey, Registered Persons Database, Corporate Provider Database

Average Number of Orthopaedic Surgeons Who Practice Within One Hundred Kilometres of the Respondent's Home



Sources: 1996 Ontario Health Survey, Registered Persons Database, Corporate Provider Database

Straight-Line Distance Calculation

Straight-line distance otherwise known as the crow flies is the simplest way of measuring distance between two destinations. However, this distance can be calculated using different formulas based on a variety of assumptions.

Pythagorean Theorem or Euclidean Distance

Distance = sqrt((X2 - X1)^2 + (Y2 - Y1)^2)

where X1, Y1 and X2, Y2 are the Cartesian coordinates of your destinations.

The above equation you may remember from your high school math. It is what you used to find the length of the hypotenuse for a right angle triangle given two points.

You can only use this equation when your coordinates are projected geographical coordinates and the distance between the two destinations is less than 20 kilometers (12 miles). The programs that convert postal codes (zip codes or post codes) into latitude and longitude values are using the spherical coordinates.

Spherical Distance

As you are aware, the earth is not a flat surface. The Pythagorean theorem does not consider the curvature of the earth in its calculation. We can use spherical trigonometry to determine the straight-line (curvature) distance between two destinations.

Earth’s Radius

Firstly, you have to determine what radius of the earth you would like to use in your equation. The earth’s radius is longest at the equator (6378km) and shortest at the north and south poles (6357km). The average radius of the earth is 6371km. This value is generally used. If a majority of your destinations are at the same latitude you may want to calculate the radius of the earth at that specific latitude.

radius(in km) = 6378 - 21 * sin(lat)
radius(in mi) = 3963 - 13 * sin(lat)

where lat is a latitude of the area.

A more accurate calculation of the earth’s radius can be calculated as the following:

radius' = a * (1 - e^2) / (1 - e^2 * sin^2(lat))^(3/2)

where a is the equatorial radius, b is the polar radius, and e is the eccentricity of the ellipsoid = (1 - b^2/a^2)^(1/2). This radius takes into consideration that the earth is not really a sphere but rather an ellipsoid.

Conversion of Coordinates

Latitude and longitude must be in decimal coordinates (degrees). In order to convert degrees, minutes and seconds into decimal coordinates the following equation can be used:

Decimal degrees = degrees + minutes/60 + seconds/3600

This calculation can be found at the following url:

http://andrew.hedges.name/experiments/convert_lat_long/

Most computers use radians when calculating the trigonometry functions such as, sine, cosine, arccosine, etc. In order to convert the decimal degrees into radians:

Decimal degree = Pi/180 = 3.141592654…/180

Law of Cosines for Spherical Trigonometry

```
a = sin(lat1) * sin(lat2)
b = cos(lat1) * cos(lat2) * cos(lon2 - lon1)
c = arccos(a + b)
d = R * c
```

where R is the radius of the earth.

Haversine Formula

```
dlon = lon2 - lon1
dlat = lat2 - lat1
a = sin^2(dlat/2) + cos(lat1) * cos(lat2) * sin^2(dlon/2)
c = 2 * arcsin(min(1,sqrt(a)))
d = R * c
```

where c is the great circle distance in radians and R is the radius of the earth.

The Haversine Formula is more accurate than the law of cosines formula because of problems associated with small distances. For both methods, you need to have double precision in the decimal place (i.e. keep at least 14 digits after the decimal place). This will avoid any round-off errors and as well any problems that may occur when the computer calculates either the arccosine or the arcsine.

Websites

There are numerous websites that you can use to calculate the spherical distance by plugging in your decimal degrees coordinates or your degrees/minutes/seconds coordinates.

http://efficacy.net/experiments/haversine/

http://williams.best.vwh.net/gccalc.htm

Resources

Reference type	Slides
Books	
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Fotheringham A Stewart, Brunsdon Chris, Charlton Martin. *Quantitative Geography Perspectives on Spatial Data Analysis*. Sage Publications, Thousand Oaks, 2000	14-15
Ricketts Thomas C., Savitz Lucy A., Gester Wilbert M., Osborne Diana N. *Geographic Methods for Health Services Research*. University Press of America, Inc., 1994	7-8
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Atlases	
Arthritis and related conditions in Ontario. Institute for Clinical Evaluative Sciences, 2nd edition, September 2004	Regional level hands-on exercise
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Guagliardo Mark F., 2004. *Spatial accessibility of primary care: concepts, methods and challenges*. International Journal of Health Geographics 2004, 3:3	7, 9, 11, 13, 16
Jordan Hannah, Roderick Paul, Martin David, Barnett Sarah, 2004. *Distance, rurality and the need for care: access to health services in South West England*. International Journal of Health Geographics 2004, 3:21	14, 16-17
Krieger Nancy, 2003. *Place, Space, and Health: GIS and Epidemiology*. Epidemiology, vol. 14, no 4, July 2003, pp 384-385	4
Lovett A., Hayes R., Suennenberg G., Gale S., 2002. *Car travel time and accessibility by buy to general practitioner services: a study using patient registers and GIS*. Social Science & Medicine 55 (2002), pp 97-111	12, 16, 18-20
Talen Emily, 2003. *Neighborhoods as service providers: a methodology for evaluating pedestrian access*. Environment and Planning B: Planning and Design, vol 30, pp 181-200.	11, 13-20
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Software and algorithms	
Arc/Info (ESRI). <www.esri.com>. ArcPlot module used for network analysis. ArcInfo software Help tool was used for accessing the knowledgebase on network analysis-related methods and algorithms.	20-34
Mapinfo. www.mapinfo.com. Mapinfo was used to map the choropleth maps and the choropleth map with the proportional symbol overlay	41-49
GeoDa http://www.csiss.org/clearinghouse/GeoDa/ for LISA analysis	33

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