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# An exploratory spatial analysis of pneumonia and influenza hospitalizations in Ontario by age and gender

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## SUMMARY

Pneumonia and influenza represent a significant public health burden in Canada and abroad. Knowledge of how this burden varies geographically provides clues to understanding the determinants of these illnesses, and insight into the effective management of health-care resources. We conducted a retrospective, population-based, ecological-level study to assess age- and gender-specific spatial patterns of pneumonia and influenza hospitalizations in the province of Ontario, Canada from 1992 to 2001. Results revealed marked variability in hospitalization rates by age, as well as clear and statistically significant patterns of high rates in northern rural counties and low rates in southern urban counties. A moderate yet significant level of positive spatial autocorrelation (Moran's $I=0{\cdot}21$, $P<0{\cdot}05$) was found in the global data, with significant, age-specific clusters of high values or 'hot spots' identified in several northern counties. Findings illustrate the need for geographically focused prevention strategies, and resource and service allocation policies informed by regional and population-specific demands.

## INTRODUCTION

Pneumonia and influenza are the leading causes of death from infectious diseases and among the leading causes of death overall in Canada and other Western nations [1–3]. With between 60 000 and 70 000 hospitalizations per year in Canada, and direct expenditures of more than $100 million annually [2], pneumonia and influenza represent a significant public health and health-care system burden. Despite this, we know little about how pneumonia and influenza vary geographically. Prevention programmes and health-care policies are thus developed based on assumptions of spatial homogeneity of rates, despite evidence to the contrary [4]. Understanding spatial patterns of pneumonia and influenza provides clues to the broader determinants of these illnesses as well as health-care system use, and can inform the effective allocation of resources and services based on geographic and population-specific demands.

There is a significant body of epidemiological literature examining different pneumonia and influenza end-points, including mortality [5, 6], hospitalizations [4], and illness acquisition [7, 8]. These studies have revealed associations with age, comorbidities such as asthma, cancers, cardiovascular disease (CVD), recent viral infections and antibiotic use.

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Also, lifestyle factors such as physical activity, smoking, and occupation, as well as various socioeconomic factors, have been linked to pneumonia and influenza outcomes [6, 7, 9, 10]. Highly seasonal patterns that vary by age and gender have also been identified [11]. While these studies have added to our understanding of the nature and determinants of pneumonia and influenza, we know very little about how these illnesses or their determinants vary over space. This is a significant shortcoming given that many of the identified risk factors including climate, smoking rates, health-care services and so on, are known to be spatially variable [12–15].

A knowledge of the geographical variation in infectious diseases has, in the past, significantly added to our understanding of disease distribution and diffusion as well as the causal factors and mechanisms associated with the risk of infection or developing the disease [4, 16, 17]. An historical study by Cliff *et al*. [16] for example, examined the introduction, spread and disappearance of multiple epidemics of influenza in Iceland, finding associations with various structural features including road connections and population size. Cliff & Smallman-Raynor [18], using an ecological study design, examined the spatial distribution of AIDS in Uganda, revealing positive associations with proximity to trucking routes and army recruitment rates. Despite this, spatial analyses of infectious diseases and their associated risk factors remain under utilized [19]. This point is made evident by the paucity of studies examining the spatial variation of pneumonia and influenza.

One US study has tried to address this research gap by examining the geographic variability and determinants of different acute respiratory illness hospitalizations, including pneumonia [4]. While this study was limited to an elderly population, findings revealed marked regional elevations in pneumonia that were found to be associated with socioeconomic and health-care system factors including education, income and physicians *per capita*. A significant body of work also exists in the area of infectious disease surveillance using physician sentinel networks [20]. While influenza is frequently monitored, pneumonia typically is not.

The purpose of the present analysis is to begin to address these gaps in pneumonia and influenza research by examining the spatial patterns of pneumonia and influenza hospitalizations in Ontario, and to determine how these patterns vary by age and gender.

## METHODS

We conducted a retrospective, population-based, ecological-level study to assess spatial patterns in hospitalizations for pneumonia and influenza in the province of Ontario (Fig. 1). Ontario is a geographically diverse region covering an area larger than France and Spain combined. Northern areas of the province are sparsely populated with economies primarily focused on resource extraction. Southern Ontario is made up of both sparsely populated rural agricultural areas, and the province's major urban centres (i.e. Toronto, the provincial capital, Hamilton, Windsor and London). Ottawa, the nation's capital, is located in the far east of the province. For residents of Ontario, access to health-care services is universal through the Ontario Health Insurance Program.

The geographical unit used in this analysis was the census division ($n=49$) (Fig. 1). Census divisions correspond to the political regions, counties and districts of the province. For convenience, census divisions will be referred to as 'counties'. There were approximately 12 million residents in Ontario in 2001 [21].

The Canadian Institute for Health Information (CIHI) Discharge Abstract Database was used to obtain information on hospitalizations, by county of patient's usual residence, for pneumonia and influenza as the principal diagnoses. This database records discharges from all in-patient hospital stays in Ontario acute care hospitals, documenting diagnoses as coded by the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM). To ensure meaningful and stable results, 9 years of aggregated CIHI hospitalization data were examined, covering the period between 1 April 1992 and 31 March 2001.

Researchers using this database have found that CIHI diagnoses are coded with a high degree of accuracy [22]. There is very little missing information in the Ontario database; other province-level studies have similarly found that $<1\%$ of the basic information on patients is missing [23, 24]. The reliability of the coding of data collected by the CIHI is 74–96% for the ICD-9 diagnoses. For pneumonia, however, the reliability of specific etiological information is low ($\sim 52\%$) [25], although in aggregate form, pneumonia and influenza have been found to be reliably coded (81%) [26].

All records with a principal discharge diagnosis of influenza or pneumonia (ICD-9 code 480-487) were selected ($n=241803$). The total number of discharges

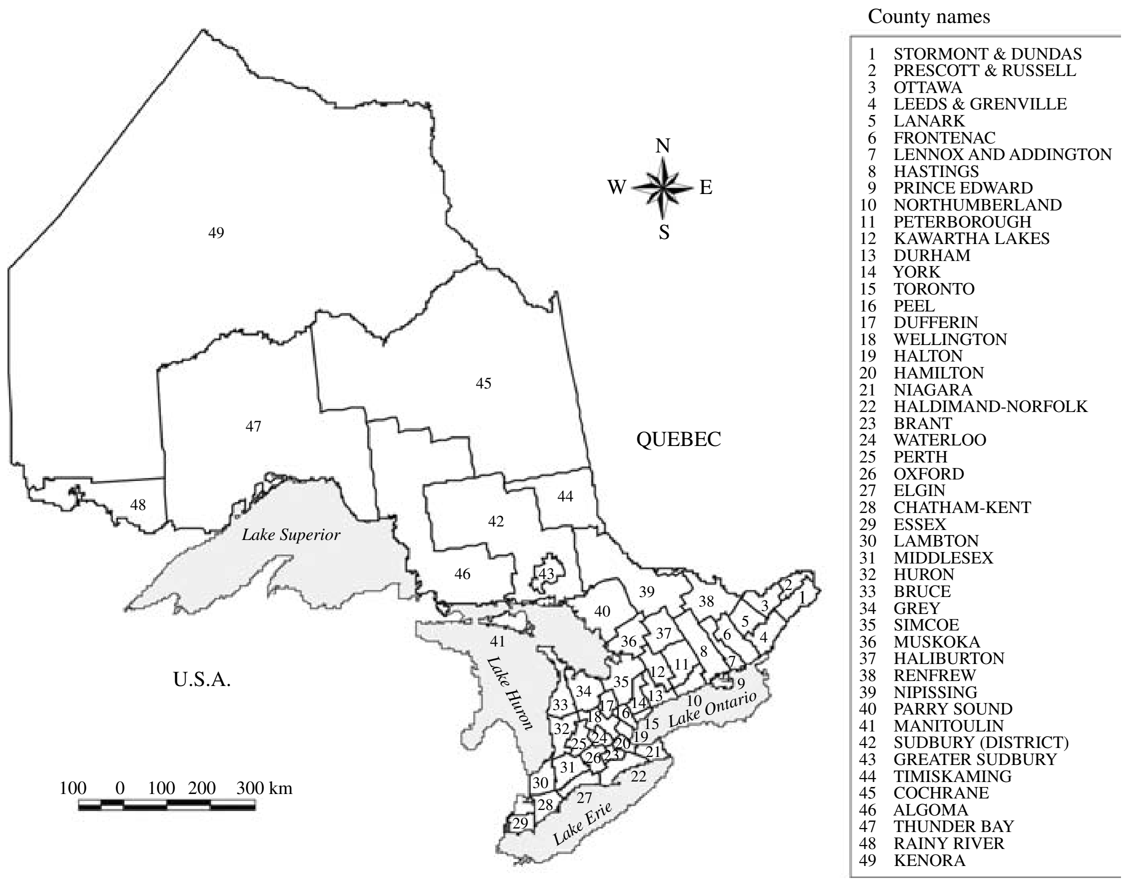


**Fig. 1.** Study area – counties of Ontario, Canada.

for each county by age and gender were assessed over the study period. Using annual demographic statistics [21], directly age- and gender-standardized morbidity rates and comparative morbidity figures (CMFs) were calculated [27]. A CMF is defined as a morbidity ratio between the observed directly standardized morbidity rate of a given county, to the expected rate (i.e. if the outcome had occurred at the provincial rate).

Descriptive summary statistics for the outcome variables were calculated at the province and county levels. CMF confidence intervals were then calculated and CMFs mapped. Following this, analysis was done to assess the degree of spatial autocorrelation in the data using Moran's *I* statistic. Significant spatial autocorrelation indicates a regular pattern in the data over space such that a value at a given location depends on, and is similar to, a value of defined spatial neighbours. Neighbour relationships are typically expressed in a row-standardized spatial weights matrix $W$, the elements of which, $w_{ij}$, represent the binary spatial weights assigned to pairs of units $i$ and $j$ [28, 29]. For this analysis, neighbours are defined using rooks case adjacency, which considers all counties with common borders as neighbours.

Moran's *I* is a global test and does not detect localized patterns. Further analysis was therefore conducted using the local indicator of spatial association (LISA) [30]. LISA allows for the decomposition of Moran's global indicator of spatial association into the contribution of each individual observation.

The LISA statistic indicates the degree of local spatial clustering of similar or dissimilar observations of an attribute. A positive value indicates spatial clustering of similarly high or low values; a negative value indicates a clustering of dissimilar values or local pockets of instability. To test for significant departures from zero autocorrelation, a Monte Carlo permutation approach was used, and a Bonferroni correction applied to adjust for multiple testing.

## RESULTS

There were a total of 241 803 pneumonia and influenza hospitalizations in Ontario over the 9-year study period (Table 1). The yearly hospitalization rate for

Table 1. *Descriptive statistics of pneumonia and influenza hospitalizations for Ontario, 1992–2001*

| | Province level | | County level | | |
|---|---|---|---|---|---|
| | Count | Rate/100 000 | Median | Range | CV* (%) |
| Full (all ages/genders) | 241 803 | 242 | 303 | 171–665 | 30·44 |
| All ages | | | | | |
| Male | 126 674 | 257 | 310 | 181–736 | 31·16 |
| Female | 115 129 | 227 | 289 | 150–595 | 30·24 |
| 0–14 yr | | | | | |
| Male | 26 608 | 258 | 306 | 101–1235 | 55·78 |
| Female | 19 845 | 202 | 245 | 82–1011 | 54·87 |
| 15–64 yr | | | | | |
| Male | 28 073 | 83 | 109 | 48–265 | 35·51 |
| Female | 27 282 | 81 | 120 | 47–302 | 40·21 |
| ⩾65 yr | | | | | |
| Male | 71 993 | 1393 | 1641 | 1139–3775 | 26·57 |
| Female | 68 002 | 969 | 1118 | 689–2094 | 24·20 |

* CV, Coefficient of variation.

the province was 242/100 000. The highest rates were seen among the elderly (⩾65 years) where they were 1393/100 000 for males and 969/100 000 for females. In comparison, rates were 258/100 000 for males in the youngest group (0–14 years) and 202 for females. The lowest rates are seen in the 15–64 years age group. Overall, rates were higher for males than females. County-level data revealed marked differences in rates between counties, before and after controlling for age and gender. The coefficient of variation (CV), defined as the standard deviation expressed as a percentage of the mean, shows a large variability in county rates in aggregate and for all age and gender groups. The variability is most pronounced in the youngest age group where the CVs for both genders are approximately 55% compared to 26% in the oldest age group.

Figures 2–4 show CMFs for pneumonia and influenza hospitalizations by age and gender. A CMF value of >1 indicates that rates are above the provincial mean, while a value of <1 indicates rates were below the provincial mean. High, statistically significant ($P<0{\cdot}05$) CMFs were generally seen in northern counties including Kenora, Cochrane, Timiskaming and Manitoulin (see Fig. 1). Among males aged 0–14 years, Kenora and Manitoulin have rates that were between 2·2 and 5 times higher ($P<0{\cdot}05$) than the provincial mean (Fig. 2). In the southern areas of the province, significantly high CMFs were predominately found in rural counties such as Stormont-Dundas in the far east, Northumberland and Kawartha Lakes near Lake Ontario, and Huron and Bruce counties along the east coast of Lake Huron. The lowest CMFs were consistently found in Ottawa-Carlton in the east, Toronto, York and Peel in the central-south, and Middlesex in the south. In these counties, CMFs range between 1·4 and 2·6 times below the provincial mean ($P<0{\cdot}05$). Other southern, predominately urban counties such as Halton, Hamilton and Essex were typically below the provincial mean, however, the results were mostly not significant. In Greater Sudbury, a northern urban centre, CMFs were close to 1.

Hospitalizations appear to be somewhat less heterogeneous over space in the older ⩾65 years age groups compared to the younger groups (Fig. 4). Despite this, the geographic pattern described above is persistent; northern rural counties were still typically significantly above the provincial mean and rural southern counties significantly below. Several county-specific differences were also seen. For example, in Niagara, in the female 0–14 years age group (Fig. 2), the CMF was significantly high ($P<0{\cdot}05$) while in the ⩾65 years age group (Fig. 4) the CMFs were significantly low. A similar but opposite pattern ($P<0{\cdot}05$) was seen in Prescott & Russell county.

Although small county-specific differences in hospitalizations can be seen by gender in the 0–14 and 15–64 years age groups, rates and patterns were not markedly different (Figs 2, 3). In the ⩾65 years age group (Fig. 4), differences are somewhat more evident with, for example, Rainy River and Thunder Bay

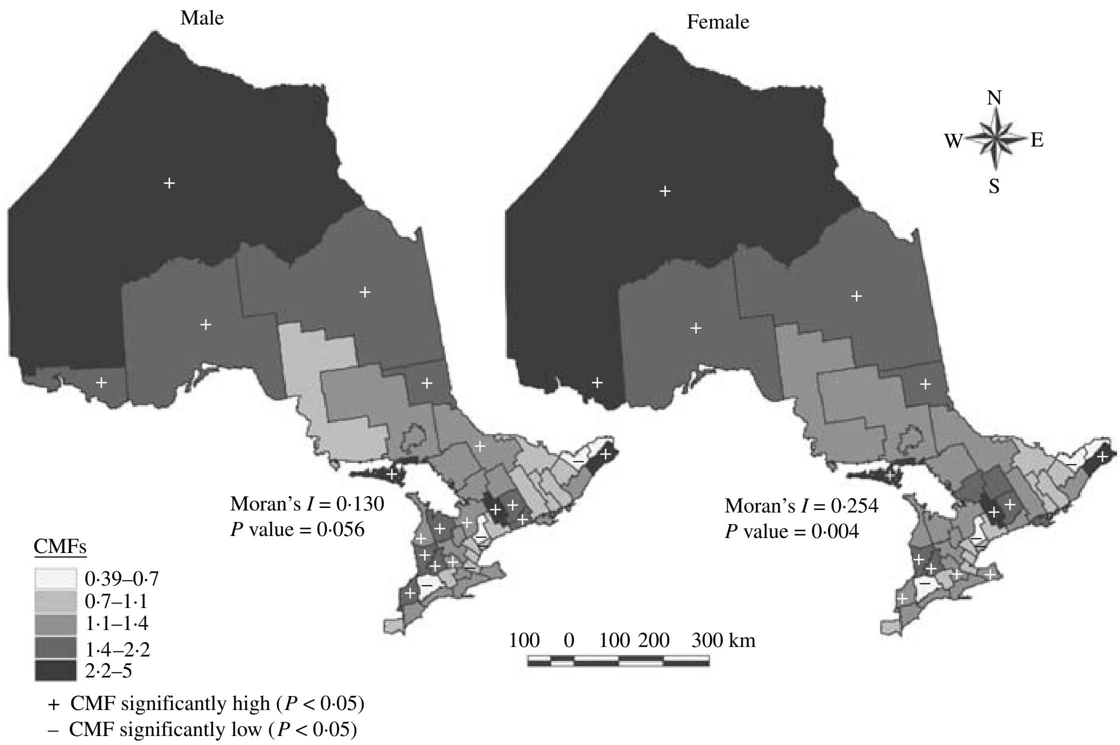


**Fig. 2.** Comparative morbidity figures (CMFs) of pneumonia and influenza hospitalizations for populations aged 0–14 years in Ontario counties, 1992–2001.

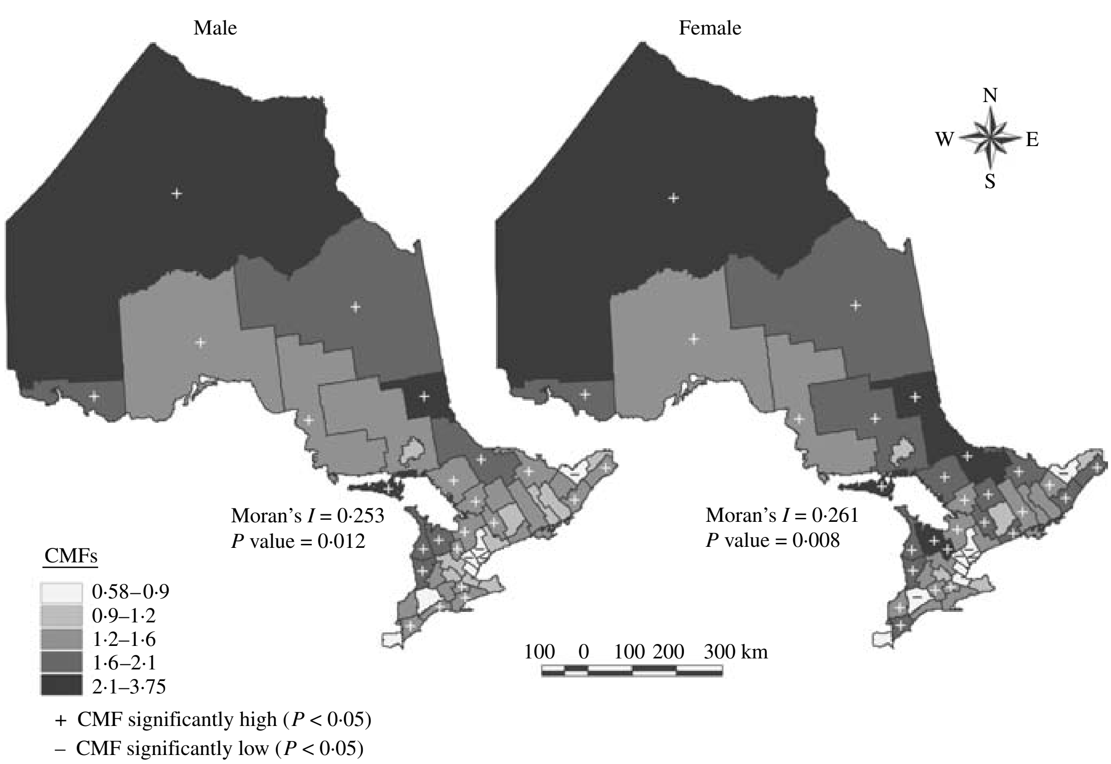


**Fig. 3.** Comparative morbidity figures (CMFs) of pneumonia and influenza hospitalizations for populations aged 15–64 years in Ontario counties, 1992–2001.

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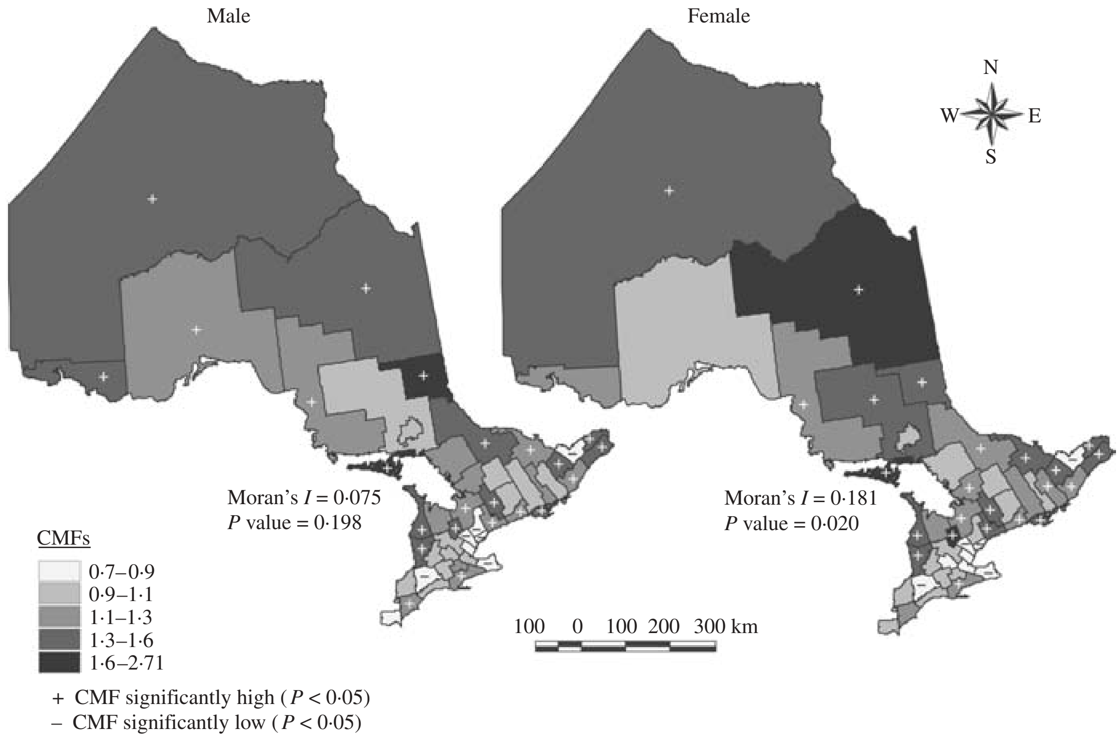


**Fig. 4.** Comparative morbidity figures (CMFs) of pneumonia and influenza hospitalizations for populations aged ⩾65 years in Ontario counties, 1992–2001.

being significantly high for males but not for females. Again, however, the general pattern described above is consistent.

Results from Moran's *I* statistic (Table 2) indicate that overall, there is a moderate, statistically significant degree of positive autocorrelation in the data (Moran's $I = 0{\cdot}21$). A similar level of autocorrelation was detected for all female age groups and in the male 15–64 years age group. Generally, a lower level of autocorrelation can be seen among males than females. In the male 0–14 years age group, the level of autocorrelation was low with *P* values just above 0·05.

Significant clusters of high values or 'hot spots' were detected in the 0–14 years age group for both males and females (data not shown). For females, these were comprised of northern counties, specifically Rainy River and Kenora; while for males, only Kenora. Clusters of low CMFs or 'cold spots' were found in Southern Ontario; specifically Toronto for females in the 0–14 and 15–64 years age groups, and males in the 15–64 years age group. Low clusters were also seen in Hamilton in the ⩾65 years age group for both genders, and Halton, again in the male 15–64 years age group. Several clusters of dissimilar CMFs were also identified. There is a significantly low value surrounded by high values in the rural county of Sudbury district for all males combined, and in the male 15–64 and ⩾65 years age groups. There are high values surrounded by low values in Stormont-Dundas (males 0–15 years) in the east, and in Haldimond-Norfolk (females ⩾65 years) in the south.

Table 2. *Spatial autocorrelation of county level pneumonia and influenza hospitalizations in Ontario, 1992–2001*

| | Moran's *I* | *P* value |
|---|---|---|
| Full (all ages/genders) | 0·211 | 0·028 |
| All ages | | |
| Males | 0·173 | 0·044 |
| Females | 0·242 | 0·015 |
| 0–14 yr | | |
| Males | 0·130 | 0·056 |
| Females | 0·254 | 0·004 |
| 15–64 yr | | |
| Males | 0·253 | 0·012 |
| Females | 0·261 | 0·008 |
| ⩾65 yr | | |
| Males | 0·075 | 0·198 |
| Females | 0·181 | 0·020 |

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## DISCUSSION

This research shows first, that there was marked variability in hospitalization rates in the province with the highest variability occurring in the youngest age groups and the lowest in the oldest. Second, there was a clear and statistically significant pattern of high CMFs in northern rural counties and low CMFs in southern urban counties across all age groups and both genders. Third, while hospitalization rates were higher for males than females, spatial patterns were not markedly different. Finally, a moderate and significant level of positive spatial autocorrelation was found in the global data in most groups. Locally, 'hot spots' were identified in several northern rural counties and 'cold spots' in southern urban counties.

The high degree of variability in pneumonia and influenza rates among the younger age groups (<65 years) compared to the older groups (⩾65 years) (Table 1, Figs 2–4) has not, to our knowledge, been previously reported. Differences in county age structure cannot explain this finding as data have been directly age standardized. Furthermore, hospitalization counts are sufficiently large to ensure stable rates across all groups. Instead, the difference is probably explained by hospitalization criteria. Criteria used to assess the need for hospitalization *vs.* outpatient treatment in Ontario, such as the Pneumonia Severity Index (PSI) [31], are highly age dependent; both directly (age of patient) and indirectly (presence of co-existing illnesses). Thus, other potential geographically variable factors associated with the decision to hospitalize such as home care availability, bed availability [32], and perhaps physician attitudes, may not influence decisions regarding the elderly as they might with younger patients where hospitalization is more discretionary.

The pattern of high CMFs seen in rural areas, and low CMFs in urban areas (Figs 2–4) is consistent with Ontario studies examining several other health outcomes such as CVD [13], congestive heart failure [33] and all-cause mortality [34]. In a study of pneumonia hospitalizations by Morris & Munasinghe [4], a similar urban/rural pattern was identified for US counties. Here, higher rates were found to be associated with socioeconomic factors such as income and education, as well as health-service factors. Similar factors may explain the patterns identified in this study, where high rates of these risk factors correspond to the urban/rural patterns identified here [12–15].

Health-care system factors may also explain part of the urban/rural pattern of pneumonia and influenza hospitalizations identified here. Better access to home care and emergency medical services commonly found in urban areas [32] may reduce the likelihood of hospitalization, and instead lead to greater outpatient treatment. This, however, is only part of the picture. As hypothesized previously, hospitalization criteria probably account for the lower variability in rates among older adults, and yet despite this, urban/rural patterns remain. This finding suggests that the hospitalization patterns here reflect a combination of pneumonia and influenza morbidity *and* health service characteristics.

Although hospitalization rates were found to be higher among males than females in our data (Table 1), spatial patterns of hospitalizations were similar (Figs 2–4). Past studies have consistently identified higher morbidity and mortality rates among males, particularly in the youngest and oldest age groups [7, 11, 35]. Differences in risk factors associated with pneumonia and influenza have also been found to differ by gender [7]. The findings in this study suggest that while male rates are higher, the factors that determine this difference may not be geographically variable at the county level.

The significant positive global autocorrelation identified by Moran's $I$ statistic for most age and gender groups, and the significant local clusters identified by LISA, confirm the patterns of high rates in northern rural areas, and low rates in southern urban areas, identified in the CMF maps (Figs 2–4). These findings suggest similar spatial processes are at play in determining pneumonia and influenza hospitalizations in these areas.

This is largely a descriptive study and as such does not address potential factors which may explain the spatial patterns identified here. The modifiable areal unit problem (MAUP) represents another potential limitation in that the patterns identified here may depend on the areal aggregations used (i.e. counties). Furthermore, the use of hospitalizations is not necessarily reflective of morbidity in the population, and does not account for differential access to services [36]. However, given that health insurance is universal in Ontario, hospitalizations are believed to represent a good estimate of severe morbidity.

The findings point to marked age-specific regional differences in pneumonia and influenza hospitalizations, illustrating the need for regionally focused prevention strategies such as influenza vaccination programmes, and the effective allocation of resources and services based on regional and population-specific demands. These are increasingly important issues as the burden of pneumonia and influenza grows, and health-care resources are further stretched, with Ontario's ageing population. This paper complements previous work that examined temporal patterns of pneumonia and influenza in Ontario [11] and points to the need for further research examining the determinants of these patterns.

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## DECLARATION OF INTEREST

None.

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