Measuring local segregation in Northern Ireland

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Abstract. Segregation measures have been applied in the study of many societies and traditionally such measures have been used to assess the degree of division between social and cultural groups across national or regional areas. The degree of segregation can vary substantially from place to place even within cities. In this paper, the concern is with religious/political segregation – particularly the proportion of Protestants (often taken as an indicator of Unionism) to Catholics (often taken as an indicator of Nationalism). This paper examines a variety of global measures and also local measures that account for spatial variation in segregation. The dissimilarity index *D* is one widely used measure and this can be adapted to account for spatial variation. Wong (2003) discusses a range of spatial segregation measures including a variant of the *D* index. In the present paper, global and local (spatial) variants of *D* and other indices are computed based on the religious/political composition of Northern Ireland with 2001 census Output Areas as the measurement unit. The paper demonstrates (i) the high degree of spatial variation in segregation in Northern Ireland and (ii) compares results obtained using a variety of global and local measures of segregation.

1. Introduction

The measurement of segregation in populations has been the focus of a large amount of research and a variety of segregation indices have been proposed and examined. The dissimilarity index *D* was proposed by Duncan and Duncan (1955) and it has been very widely used. *D* can be seen as a measure of evenness; it measures the proportion of the population of a group that would have to move for each neighbourhood to have the same proportion of that group as the whole of the study area (Iceland *et al.*, 2002). Aspatial measures like *D* have been widely used in geographical applications, but two key criticisms have arisen about such methods: the 'checkerboard' problem and the 'modifiable areal unit problem' (MAUP) (Reardon and O'Sullivan, 2004).

Aspatial segregation measures do not account for the proximity of zones, rather they provide a measure of the composition of neighbourhoods (Reardon and O'Sullivan, 2004). A checkerboard pattern is used to visualise the problem that leads from this – if all of the black squares in the checkerboard are moved to one side of the board and all of the white cells to the other side of the board an aspatial measure of segregation would not register this change as the compositions of the neighbourhoods are the same despite the marked local differences in the two configurations.

There are many areal units that are used to display information about population. None of these has intrinsic meaning for the underlying populations – the units are 'modifiable'. Therefore, any observed pattern in areal data could be due in part to the zoning system (Martin, 1996). Any aspatial or spatial measure of segregation will be affected by the MAUP unless the boundaries used are meaningful (Reardon and O'Sullivan, 2004). The MAUP could be handled more robustly if results across different aggregations could be considered.

In this paper, several variants of *D* are applied for the analysis of segregation in Northern Ireland. Poole and Doherty (1996) and Doherty and Poole (1997) applied *D* in Northern Ireland for the analysis of segregation between Protestants and Catholics and the present work builds on this by analysing population counts deriving from the 2001 census of population using both global and local versions of *D*.

2. The Northern Ireland Context

The data used in this study are population counts for output areas derived from the 2001 census of population in Northern Ireland. Figure 1 shows the counties of Northern Ireland as well as major cities. Residential segregation has major political and policy implications in Northern Ireland because of the legacy of communal division and conflict (Anderson and Shuttleworth, 1998). It is therefore unsurprising that there is a significant Northern Ireland tradition of research into this topic which has contributed to research agendas more widely in social and population geography. Jones (1960) might be viewed as one of the founders of this tradition with his landmark *A Social Geography of Belfast* and others built on this work with analyses of segregation as the Troubles developed through the 1970s, 1980s, and 1990s (Boal, 1972; Murtagh, 2002). The most commonly-used indices used have been the Dissimilarity Index (*D*) and the Isolation Index (*P**). The extent of segregation in Northern Ireland as a whole has been a focus particularly in media discussions (see, for example, Anderson and Shuttleworth, 1994) which have attempted to evaluate the extent to which Northern Ireland has become a more communally-divided society in terms of residence. The general consensus has been that segregation in general has increased through time in a 'ratchet effect', with large increases particularly after outbreaks of violent conflict, with little or no decrease when violence declines. Undoubtedly, violence has been an important element in driving changes in the geographical distribution of population since 1969 (Poole and Doherty, 1996) but other forces driving changes in the distribution, such as counter-urbanisation as seen in other cities (Power and Shuttleworth, 1997), cannot be discounted.

Besides a focus on segregation in Northern Ireland as a whole, there have also been analyses of residential patterns in sub-units such as Belfast and its various parts, as well as selected towns and rural areas (Doherty and Poole, 1997; Poole and Doherty, 1996). Doherty and Poole (1997) consider the evolution of residential segregation in the Belfast Urban Area (BUA) and sub-areas through time using grid-square data[1] to calculate *D* and *P**. There are significant differences between various locations in the city with increasing segregation, as measured by *D*, in Lisburn, East Belfast, Newtownabbey, and Castlereagh but decreasing segregation in other parts of the BUA. The analysis was extended by Poole and Doherty (1996) who outlined segregation patterns in towns and in locations such as the border. High levels of segregation were found in Belfast, Derry, Lurgan, Portadown, and Armagh with lower levels in locations like North Down and parts of East and North Antrim.

This approach moves quite a way to recognising that residential segregation varies between places and that presenting information on Northern Ireland as the 'given unit' of analysis conceals significant local variations. However, there are some shortcomings with this type of analysis which are a consequence of spatial scale. Poole and Doherty (1996), for example, recognise that scale issues are a 'minefield' and that there is a need for more sophisticated approaches. In particular, it is

[1] Population counts for 100m or 1km grid squares available from the Census Office for Northern Ireland

observed that the scale of analysis might be varied according to the type and size of the settlement to be studied. There is a requirement to escape the 'given area' for analysis as a category imposed by official data formats and to use instead more flexible units which might have more meaning for peoples' perception of neighbourhood.

3. Methods

The initial picture is given by Figure 2 which shows the percentage of Catholics by OA in Northern Ireland while Figure 3 gives the percentage of Catholics in Belfast. Across Northern Ireland as a whole there are clear zones of consistently high or low proportions of Catholics as well as some mixed areas. Clearly a global measure of segregation will fail to account for this spatial variation. The distinction between predominantly Catholic areas in the west of Belfast and the predominantly Protestant areas in the east of the city is apparent in Figure 3.

The paper explores these patterns through the use of several variants of the index of dissimilarity, *D*. The original form of *D* is given by:

$$D = 0.5 \times \sum_i \left| \frac{b_i}{B} - \frac{w_i}{W} \right|. \qquad (1)$$

where b_i and w_i are counts of population in two groups for areal unit *i*. These are often referred to as the black and white population counts (Wong *et al*., 1999). *B* and *W* are the total population counts across the whole of the study area. *D* indicates the total differences between the spread of the two population groups over all of the areal units. *D* takes a value between 0 and 1 where a large value implies a high degree of segregation (Wong, 2003).

The checkerboard problem has led to the development of a range of alternative measures of spatial segregation. One such measure, the *D*(adj) index, was introduced by Morril (1991) and it is *D* with the amount of potential interaction between different groups across areal unit boundaries removed – the level of potential interaction is obtained using the differences in the mixes (e.g., racially) of neighbouring units. It is given with:

$$D(adj) = D - \frac{\sum_i \sum_j \left| c_{ij} \times (z_i - z_j) \right|}{\sum_i \sum_j c_{ij}} \qquad (2)$$

where z_i and z_j are the proportions of minority or majority between the areal units *i* and *j*; c_{ij} is zero if *i* and *j* are not neighbours and one if they are neighbours.

D(adj) was modified by Wong (1993) on the basis that interaction across boundaries is not a function of adjacency alone; rather the length of the common boundary is important. The index was modified to incorporate a boundary-length component. The modified index, *D*(*w*), is given as:

$$D(w) = D - \frac{1}{2} \sum_i \sum_j \lambda_{ij} \left| z_i - z_j \right| \qquad (3)$$

where

$$\lambda_{ij} = \frac{d_{ij}}{\sum_j d_{ij}} \qquad (4)$$

where d_{ij} is the length of the shared boundary between the areal units *i* and *j*. The denominator represents the total length of the boundary for areal unit *i* (Wong, 2003). A further modification led to the *D*(*s*) index:

$$D(s) = D - \frac{1}{2} \sum_i \sum_j \lambda_{ij} \left| z_i - z_j \right| \times \frac{1/2[(P_i / A_i) + (P_j / A_j)]}{\mathrm{MAX}(P/A)} \qquad (5)$$

where P_i / A_i is the perimeter/area ratio for the areal unit *i* and $\mathrm{MAX}(P/A)$ is the maximum perimeter/area ratio for all areal units (Wong, 2003). In the present case, indices which are based on two sets of population counts are adequate, but multigroup measures are also available (see, for example, Wong, 2003). Another way of summarising the structure of population groups is to apply measures of spatial autocorrelation and one such approach is outlined next.

3.1. Measures of spatial autocorrelation

Another way to assess spatial composition of a population is to apply a measure of spatial autocorrelation such as Moran's I. Moran's I is obtained using:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}\lambda_{ij}(y_i - \bar{y})(y_j - \bar{y})}{\left(\sum_{i=1}^{n}(y_i - \bar{y})^2\right)\left(\sum_{i\neq j}\sum\lambda_{ij}\right)}$$

where λ_{ij} is the spatial proximity matrix with the attribute values y_i with the mean $\bar{y}$. The number of zones is given by n and $\sum_{i\neq j}\sum\lambda_{ij}$ is twice the number of adjacent zones. In this paper, λ_{ij} was 1 where zones were neighbours and zero where they were not; a weighting scheme based on distances could be used instead. Recognition that global I obscured local variation led to the development of a local form of I that could be mapped. The local form of Moran's I for observation i is given by (Anselin, 1995):

$$I_i = z_i \sum_j \lambda_{ij} z_j, \quad j \neq i$$

the observations z_i are deviations from the mean and the summation includes only the neighbouring zones. The spatial weights λ_{ij} may be in row-standardised form (that is, they sum to one) to facilitate comparison of different sets of results. The sum of local Moran's I is given as:

$$\sum_i I_i = \sum_i z_i \sum_j \lambda_{ij} z_j$$

and Moran's I is given as:

$$I = (n / S_0)\sum_i \sum_j \lambda_{ij} z_i z_j / \sum_i z_i^2$$

3.2. Geographically weighted *D*

There has been a large amount of research in recent years by geographers concerned with modifying standard statistical approaches through geographical weighting. For example, geographically weighted regression (GWR) is now widely used in the exploration of variation in spatial relations (Fotheringham *et al.*, 2002). An application of GWR for the analysis of commuting in Northern Ireland is given by Lloyd and Shuttleworth (2004). Segregation measures that employ a spatial weighting (distance decay) function have been discussed by Morgan (1983). In the present paper, a modified version of *D* is used where the counts are weighted using a Gaussian kernel function which obtains a weight, λ, for the observation *i* with:

$$\lambda_i = \exp[-\tfrac{1}{2}(d / a)^2] \qquad (6)$$

where *d* is the Euclidean distance between the location of observation *i* (in this case, the centroid of a zone) and the centre of the kernel and *a* is the bandwidth of the kernel. Geographically weighted *D* is given by:

$$D(gw) = 0.5 \times \sum_i \left| \frac{\lambda_i b_i}{\sum_i \lambda_i b_i} - \frac{\lambda_i w_i}{\sum_i \lambda_i w_i} \right|. \qquad (7)$$

So, the sum of the weighted counts is obtained first and then the individual weighted counts are obtained.

4. Results

The *D*, *D*(adj), *D*(*w*) and *D*(*s*) indices were calculated using the ArcView GIS routines provided by Wong (2003)[2]. Geographically weighted *D* was calculated using a purpose written Fortran program. Global and local *I* were computed using the GeoDa[3] software (Anselin, 2003). Values of *D*, *D*(adj), *D*(*w*) and *D*(*s*) are given in Table 1.

Index	Value
D	0.672
D(adj)	0.558
D(*w*)	0.564
D(*s*)	0.672

Table 1. Values for variants of *D*.

Table 1 indicates differences in the values of the variants of *D*. *D*(adj) and *D*(*w*) indicate less segregation between Catholics and Protestants than do *D* and *D*(*s*). In this case, accounting for the length of the shared boundary (i.e., *D*(*w*)) suggests less segregation than unmodified *D* but accounting for perimeter/area ratios (using *D*(*s*)) leads to similar results to *D*.

4.1. Interpreting local residential segregation patterns in Northern Ireland

The local *D* and local *I* indices capture different dimensions of residential segregation. The local *D* index is a measure of unevenness of distribution of Catholics and Protestants. The *I* index, in contrast, is a measure of how similar an output area is to its neighbours and so in other words is a measure of homogeneity. In interpreting local *D* there are interesting issues of scale and also related questions about the social meaning of the index. In areas with high values of *D* there is great unevenness in the geographical distribution of the population. This can be viewed as being *segregated* but it could also be conceptualised as being *mixed* at another spatial scale. Likewise some areas with low values of *D* have a relatively even spread of the two population groups but in a situation where one is a large majority and the other a small minority.

[2] http://geog.gmu.edu/seg/
[3] http://sal.agecon.uiuc.edu/geoda_main.php

Bearing these considerations in mind the maps that have been presented can tell us quite a lot about the geography of Northern Ireland's population.

Figures 4 and 5 present the results of the local *I* index. They show, at the Northern Ireland level in Figure 4, large positive autocorrelation values in South Armagh, Derry, the Moyle district of the North East, and rural areas in County Tyrone, and moderately high values across parts of the East. These are areas, looking back to Figure 2, which are either largely Catholic or Protestant. The Catholic 'core areas' of Derry and South Armagh have higher values than the areas of Protestant majority in the East suggesting that in some parts of Northern Ireland Catholics live in more homogenous areas than Protestants. Figure 5 looks just at Belfast. The findings here are interesting and accord well with what is known of the social geography of the city. The Catholic heartland of West Belfast is outlined. The small Protestant enclave of the Suffolk Estate stands out as being dissimilar from the surrounding Catholic output areas. This is an interface area with cross-community conflict but it has similar scores to the low values apparent in South and East Belfast. In South Belfast, however, it is probable that the low values are a result of 'mixing' arising from increases in the Catholic share of the population in some output areas as a consequence of suburbanisation. On the Eastern fringe of Belfast areas which are largely Protestant are picked out by the index but again the values are not as high as for Catholic areas suggesting that Protestant areas are not quite as homogenous as some Catholic majority locations.

As an initial means of examining spatial variation in segregation across Northern Ireland, *D* was calculated for output areas within each of the 26 District Council Areas (DCAs) in Northern Ireland and Figure 6 shows *D* calculated by district. With values of *D* ranging from 0.23 to 0.78 there is clearly much variation in segregation at the district level. The Belfast, Derry, Portadown, and Moyle areas have high values of *D* indicating that they have a highly uneven communal population distribution. In contrast, North Down, Carrickfergus, Coleraine and Armagh have low *D* values indicating a relatively even population distribution. For the first two of these DCAs at least there is a Catholic minority population but the results indicate that it is fairly evenly distributed between output areas.

Geographically weighted *D* was calculated using the population-weighted centroids of the OAs. Figure 7 shows *D*(gw) with a 1 km bandwidth while Figure 8 shows the same, but for the Belfast area. This size of bandwith is too small to capture information from neighbouring rural output areas and, at this scale, values of *D* are small over much of Northern Ireland. At the Northern Ireland level it picks out Belfast, the Portadown/Lurgan areas, Derry and some towns such as Omagh as being segregated in the sense that the geographical distribution of population by community is relatively uneven. This matches well with what is known about the geography of Northern Ireland segregation and the identification of these areas as being associated with communal division. In Belfast, the North and the West of the city have high *D* values, showing that the population is unevenly distributed. In contrast, the South has lower values indicating a more even population spread. In Belfast (Figure 8), the North and the West of the city have high *D* values, showing that the population is unevenly distributed. In contrast, the South has lower values indicating a more even population spread. Comparison of this map (Figure 8) with the map of *I* for Belfast (Figure 5) reveals some important points. The two measures are different in nature but, broadly speaking, areas with large values of *I* should correspond to segregated areas while area with low values of *I* should indicate mixed areas. However, Figures 5 and 8 are very different in appearance. These differences are due, in part, to scale: *I* is calculated using only neighbouring OAs whereas *D*(gw) is calculated within a Gaussian kernel with a 1 km bandwidth. So, the latter approach smoothes variation that may be indicated by the former approach. Figure 8 indicates high levels of segregation over much of Belfast.

Geographically weighted *D* for a 5 km, 10 km, 15 km and 20 km bandwidth is given in Figures 9, 10, 11 and 12 respectively. Figure 9, using the 5km bandwidth, shows the highest values of *D* for Belfast, Portadown/Lurgan, and Derry with low values in Coleraine. Figure 10, at 10km, expands these high segregation area and joins Belfast to Portadown/Lurgan, Figure 11 (15km bandwidth) shows an area with relatively high values in the East whereas Figure 12 (20km) shows a swathe of high *D* values from Belfast towards the border. It is clear that the maps become smoother as the size of the bandwidth is increased. That is, for small bandwidths local details are emphasized but for larger bandwidths densely occupied areas with many output areas have a marked effect on local values of *D*(gw) over large areas. This series of maps represent a continuum from indicating locally highly segregrated or mixed areas (Figure 9) to broad scale trends in segregation influenced by the densely occupied areas (with corresponding numerous OAs) around, in particular, Belfast and Derry. There are areas which are similarly represented in Figures 9 to 12 inclusive. As noted, the Belfast and Derry areas appear highly segregated at all spatial scales. In contrast, the band running from the south west (Fermanagh) to the central north (northern County Londonderry/Antrim coast) has comparatively low levels of segregation indicated with the County Londonderry/Antrim coast area most clearly indicated in all of the maps. Some areas appear mixed locally but appear more segregated as the neighbourhood (i.e., bandwidth) is increased; for example, this is the case with south west Armagh.

5. Discussion

This paper has a number of methodological outcomes and substantive outcomes. The importance of assessing different measures of segregation is made clear in this study. There is variation between the single figure summaries provided by *D*, *D*(adj), *D*(*w*) and *D*(*s*). More clearly, the use of a geographically weighted version of *D* indicates clearly variation in segregation (i) geographically and (ii) with change in spatial scale of measurement. Where we lack individual level data it is necessary to refer to segregation as being measured at a certain scale. As noted, there is much variation in results as the spatial scale of measurement is varied. While a geographically weighted approach is still affected by the MAUP, in that the data are provided as counts over areas, the approach is not constrained by the need to construct aggregates of the data over larger areas (e.g., districts or counties) to provide measures of segregation. Rather, it is possible to provide a variety of different outputs that indicate how segregation varies as a function of neighbourhood size (in this case determined by kernel bandwidth). The approach developed in the paper could also be generalised to other situations such as the cities of Northern England where local patterns of segregation (at a variety of spatial scales) could also be mapped.

The results of the analysis also have applied implications for Northern Ireland. They build on the earlier work of Boal, Doherty and Poole and offer a more sophisticated approach to the analysis of local segregation patterns. They also offer insights into the geography of population at a variety of spatial scales and using contrasting indices of segregation. These can be used to gain a much deeper understanding of the nature of residential segregation. In policy terms this is useful given the imperative to address communal division and to direct resources to areas which are perceived as having social problems. The ability to use different sized neighbourhoods and to lessen the constraints of administrative geographies is important in understanding more about the social geography of Northern Ireland. Anderson and Shuttleworth (1998) argued that wards were meaningless for most people as a social unit and so looking at segregation using these units was questionable. However, the possibility of using flexible geographies through different kernel bandwidths allows segregation to be assessed at spatial scales that are perhaps more closely related to the geographies of everyday life. This goes someway to meeting the call by Boal (Poole and Doherty 1996) for more flexible approaches to segregation analysis. It should be noted that the analysis is restricted to residential segregation – and that this is only one dimension of segregation. More widely, there is a need for segregation analyses to include other dimensions such as work and leisure to give a broader conceptualisation of social division and interaction.

6. Summary and conclusions

The paper shows that residential segregation changes markedly between different places and that it also varies as a function of spatial scale. This indicates some of the limitations of much previous work in the area that has been reliant on administrative units as the ‘given’ for analysis. There are obvious difficulties with the MAUP in these cases. The type of analysis we propose does something to lessen these difficulties although it does not entirely escape them since the base unit is the Census Output Area although in using a local approach we are not constrained by administrative aggregations of these units. The only way to be free of the MAUP would be by the use of individual-level data. Indeed, Reardon and O’Sullivan (2004) have raised the possibility of computing segregation indices from individual level data. If such data were made available the checkerboard and MAUP problems could be eradicated. More broadly, the methods used in this paper enable us to explore spatial scale more completely. At one scale an area might look segregated, but at a different scale it may appear less so. The ability to change the scale of analysis provides a means of examining the persistence of patterns at different scales.

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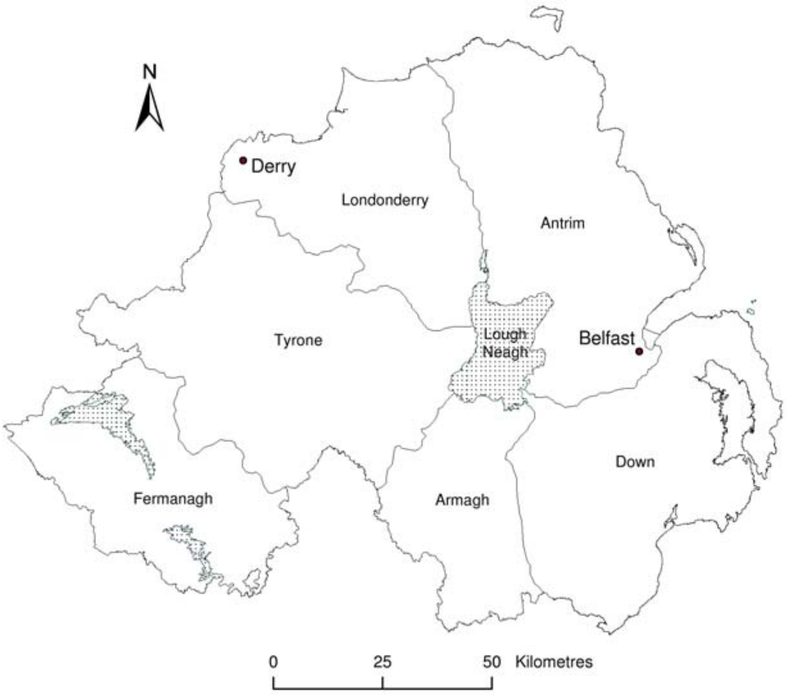

Figure 1. Counties and major cities.

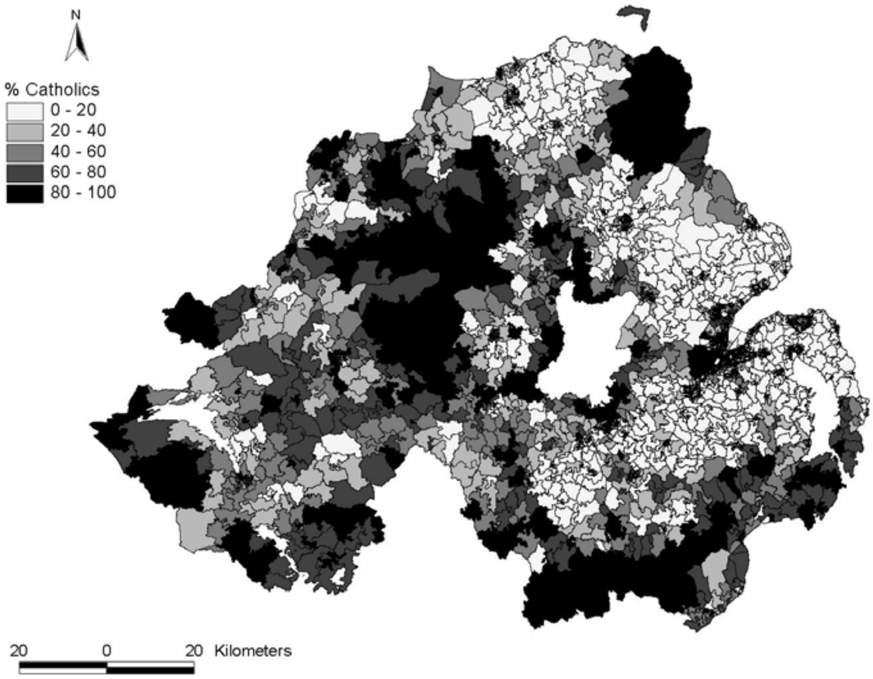

Figure 2. Percentage of Catholics.

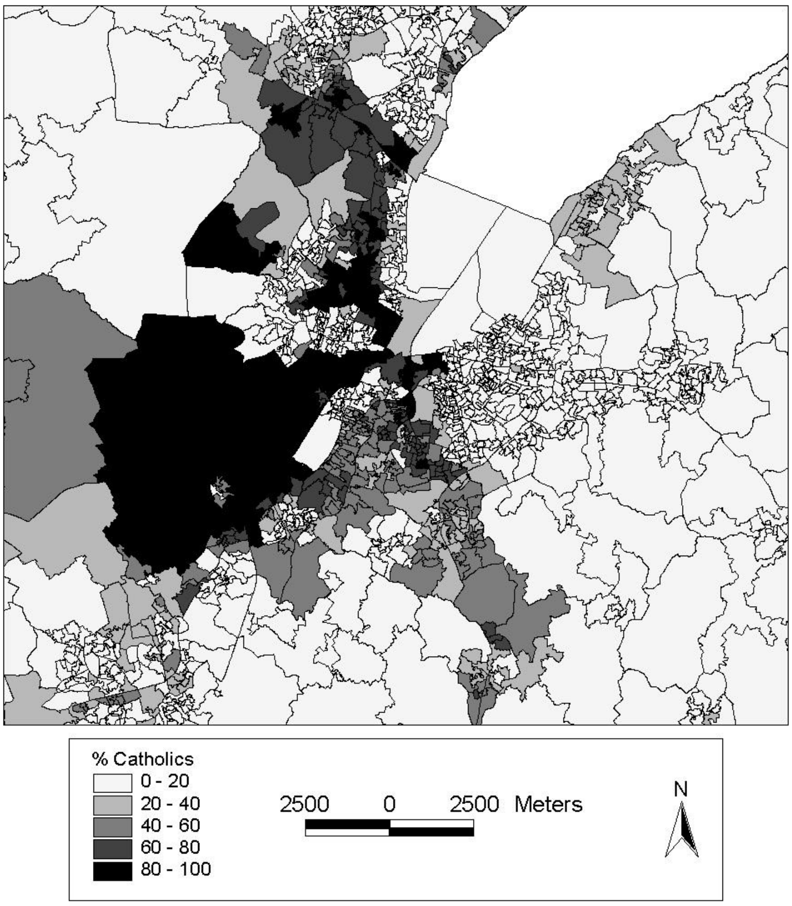

Figure 3. Percentage of Catholics in Belfast.

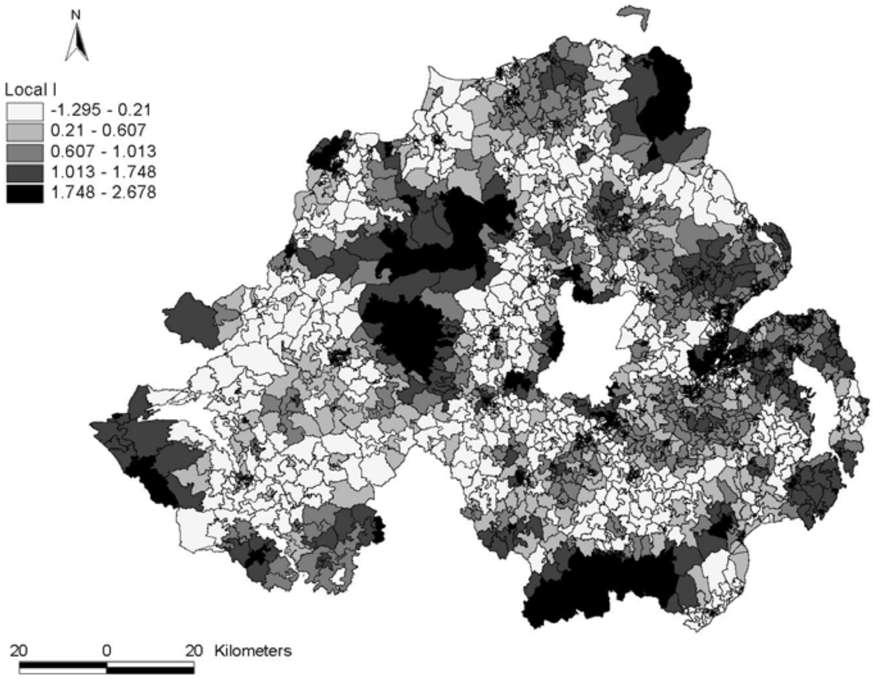

Figure 4. Local *I*.

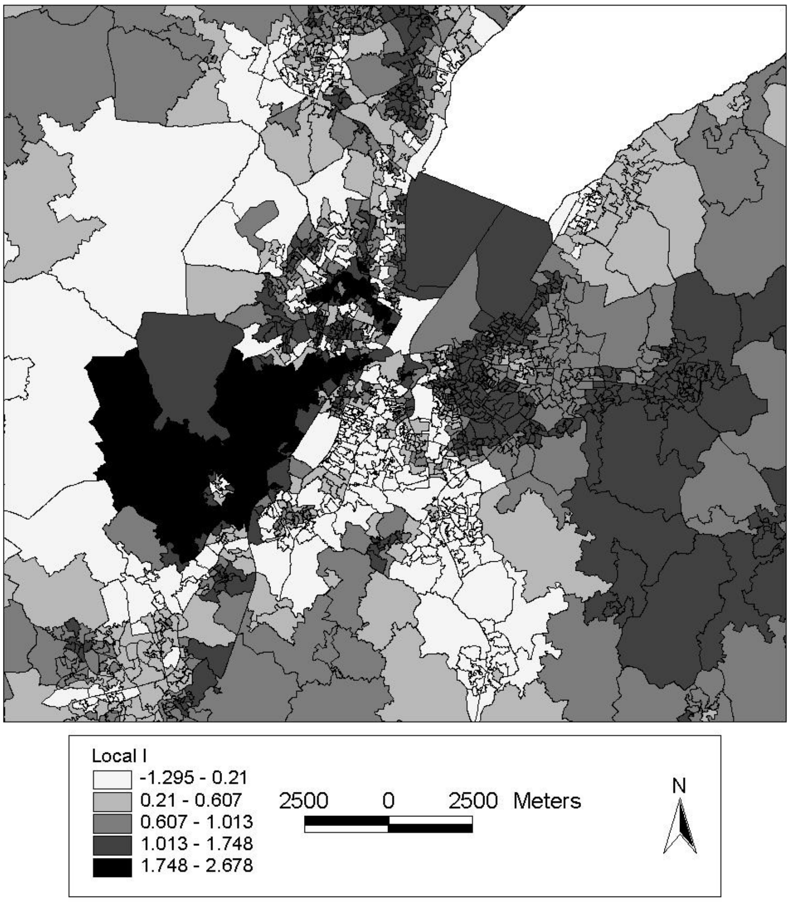

Figure 5. Local *I*: Belfast.

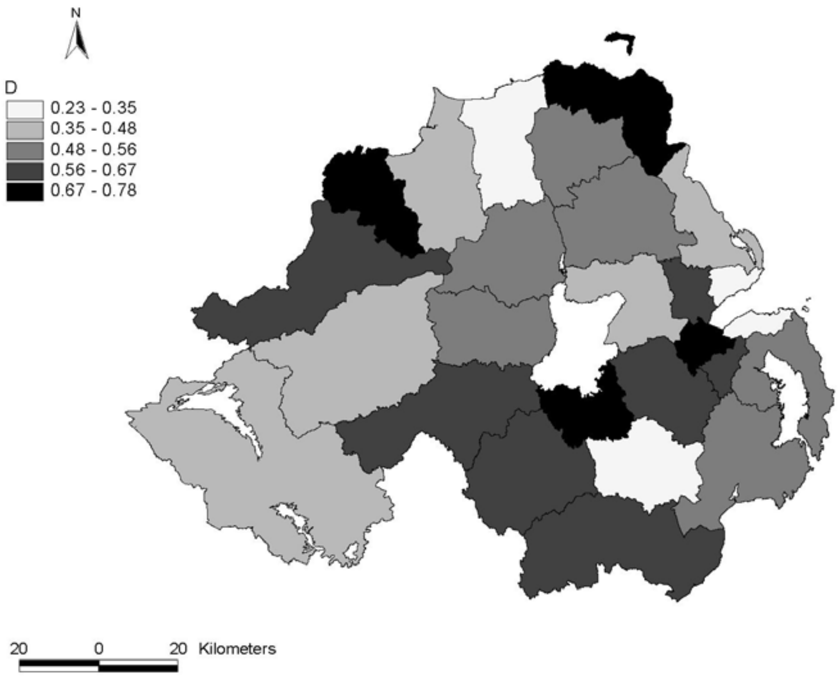

Figure 6. *D* by district.

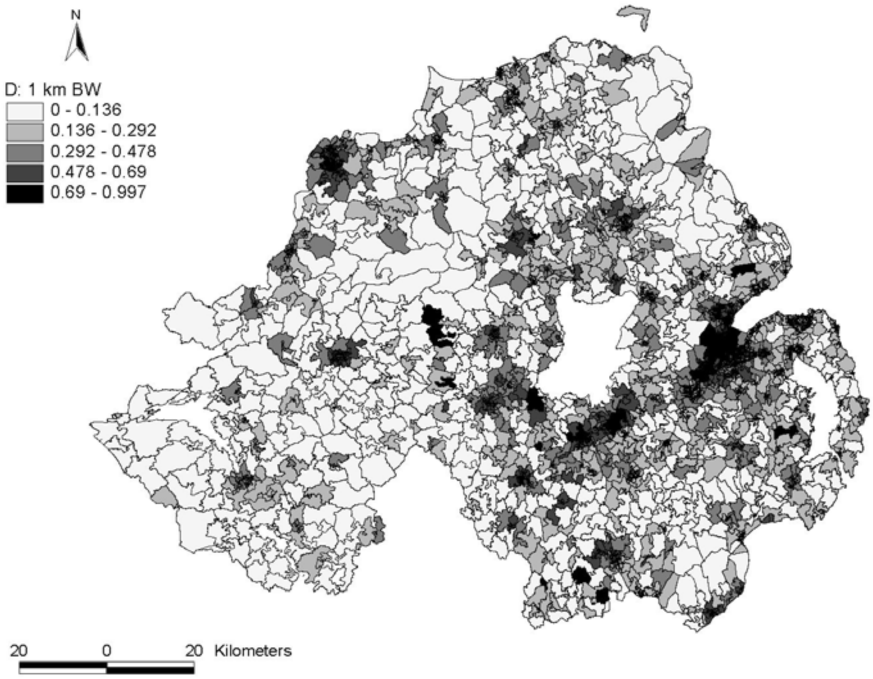

Figure 7. Geographically weighted *D*: 1 km bandwidth.

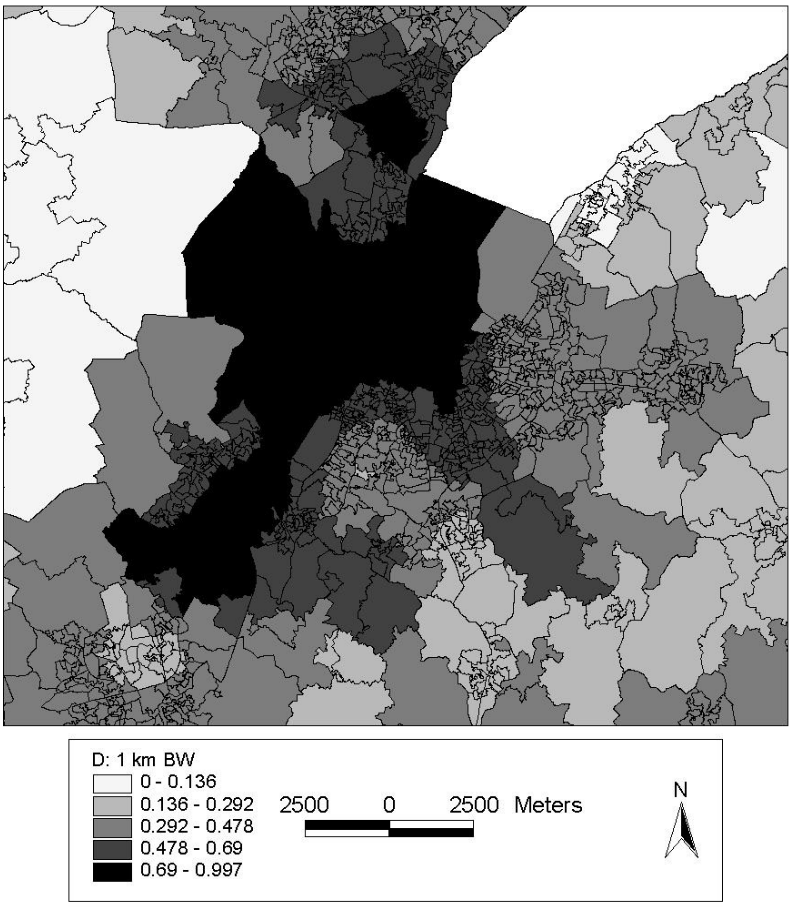

Figure 8. Geographically weighted *D*: 1 km bandwidth for Belfast.

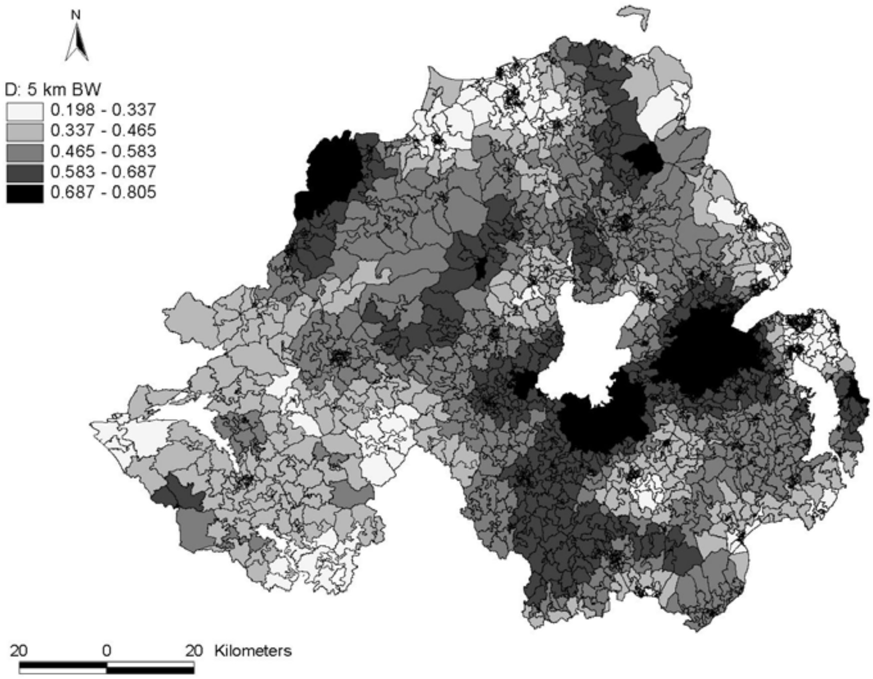

Figure 9. Geographically weighted *D*: 5 km bandwidth.

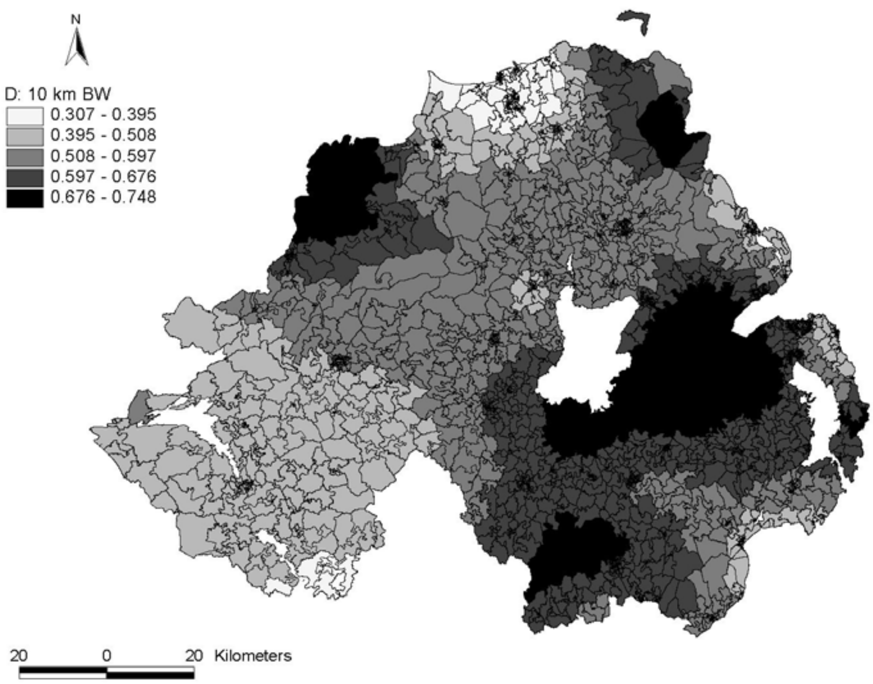

Figure 10. Geographically weighted *D*: 10 km bandwidth.

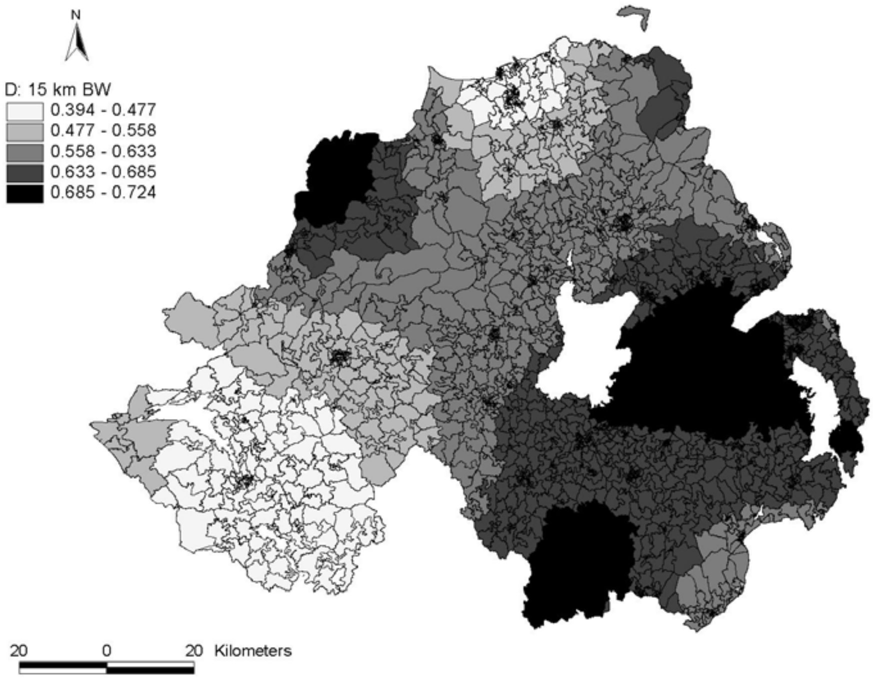

Figure 11. Geographically weighted *D*: 15 km bandwidth.

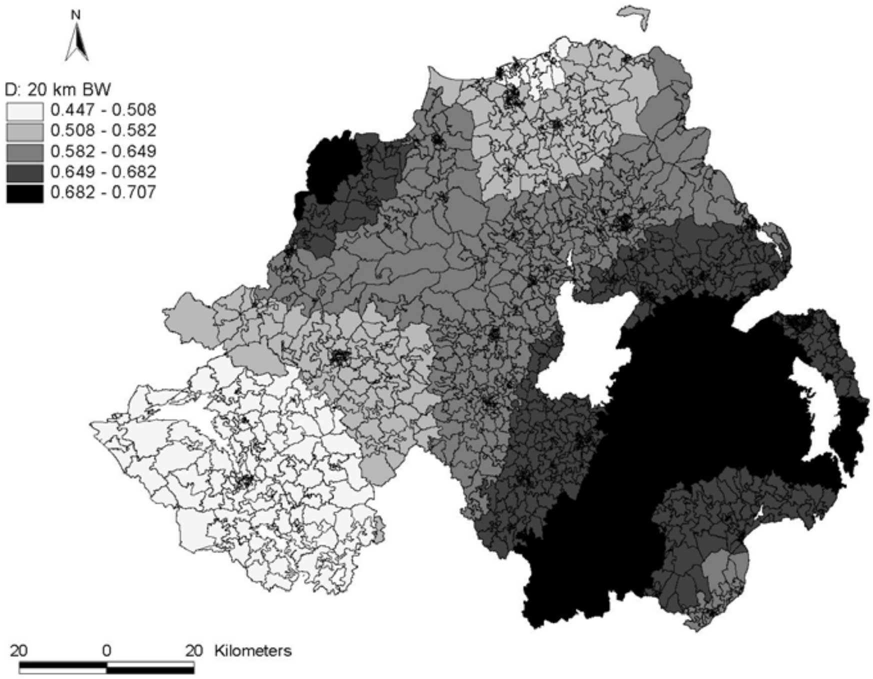

Figure 12. Geographically weighted *D*: 20 km bandwidth.