Measuring spatial accessibility to services within indices of multiple deprivation: implications of applying an enhanced two-step floating catchment area (E2SFCA) approach

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Conflict of Interest
None declared.

Abstract

Approaches to calculating spatial accessibility within existing indices of multiple deprivation (IMD) methodologies are based on ‘traditional’ accessibility metrics and tend not to adopt more recent methodological enhancements. In particular, the last decade has seen a relatively large body of studies that have applied floating catchment area (FCA) methods that account for both service supply and potential demand interactions, mediated by the impact of distance, in a wide range of application areas. In this paper, we investigate potential implications of incorporating an FCA-based approach to measuring spatial accessibility within an existing IMD framework. Using the Welsh Index of Multiple Deprivation (WIMD) as a case study, FCA-derived accessibility scores were substituted for the existing approach used to calculate accessibility and a revised index was computed. The published methodologies used to construct the other ‘domains’ within the WIMD were followed and the implications for the overall deprivation measure were assessed. Statistical and visualisation tools revealed implications for both the access and overall IMD rankings, with sparsely populated (predominantly rural) areas tending to receive higher accessibility scores from FCA-based approaches than more densely populated (predominantly urban) areas. These areas in turn showed the greatest decline in ranking on the WIMD calculations following the application of FCA approaches. Potential reasons for such trends are posited before we conclude by drawing attention to the implications of adopting FCA-based approaches to calculate IMDs particularly for those policies designed to distribute funds or allocate resources to areas of need.

Keywords: Accessibility; Indices of multiple deprivation; Two-step floating catchment area; Reproducible Research

1. Introduction

Indices of Multiple Deprivation (IMDs) are designed to identify areas where different aspects of deprivation are most highly concentrated, and are thus important tools used by planners and policymakers to aid in decision-making processes, such as those concerning resource allocation and targeted policy interventions. Instances of IMDs can be found internationally in, for example, Germany (Hofmeister et al., 2016; Maier et al., 2012), Italy (Caranci et al., 2010), Spain (Sanchez-Cantalego et al., 2008) and other European countries (see Fairburn et al., 2016: 175), as well as wider afield such as within New Zealand (Exeter et al., 2017) and South Africa (Noble et al., 2010). In the UK, separately developed variants exist for England (Department for Communities and Local Government [DCLG], 2015a), Wales (Welsh Government, 2014a), Scotland (Scottish Government, 2016a), and Northern Ireland (The Northern Ireland Statistics and Research Agency [NISRA], 2010). Following the now well-established 'domain' approach to constructing composite indices of deprivation (Noble et al., 2006), spatial accessibility to services has become an important indicator of relative levels of deprivation at the small-area level. Generally defined as "a household's inability to access a range of services considered necessary for day-to-day living" (Welsh Government, 2014; p. 20), the inclusion of spatial accessibility to services within such indices is intended to capture both material and social aspects of deprivation that result from difficulties in accessing basic amenities such as general practice (GP) surgeries, supermarkets, and leisure centres, for example.

Currently, the methodological approaches to calculating spatial accessibility in existing UK IMDs are all grounded within traditional spatial accessibility metrics that are based upon service supply details such as the travel distance or time taken to reach the nearest available service, both of which fail to account for other potential barriers to access including for example aspects relating to service demand. Failing to account for service demand is likely to have implications for service accessibility outcomes in more ruralised settings, where travel time/distance to services is likely to be greater than those within urban environments (see for example, Welsh Government, 2015), but where the demand for services may be considerably less. Thus from this perspective there is an argument to be made that current approaches to measuring accessibility to services within existing IMDs are failing to keep pace with methodological enhancements that have taken place within the broader field of spatial accessibility metrics, and in particular the strong trend towards the wider use of gravity models and their derivatives such as the increasingly popular floating catchment area (FCA) technique.

FCA-based approaches are increasingly being adopted within the spatial accessibility literature, particularly within the field of healthcare (Luo and Wang, 2003; Luo and Qi, 2009; Luo, 2004; McGrail and Humphreys, 2009; Langford et al., 2016), but also more recently in alternative application areas such as transport (Langford et al., 2012), childcare (Fransen et al., 2015), and leisure (Higgs et al., 2015), among others. As a more spatially sophisticated approach to calculating accessibility, FCA methods account for both service supply capacity and potential demand volume, as well as considering both the proximity and choice of centres of provision available to potential users within their local neighbourhood (Luo and Wang, 2003; Luo and Qi, 2009). However, despite the increased interest in the application of FCA methods, to the authors' knowledge, no studies have applied such an approach to measuring accessibility within a composite index of deprivation.

The purpose of this study is to examine potential implications of incorporating recent developments in spatial accessibility measurement into an existing IMD framework. This is achieved through the application of an enhanced two-step floating catchment area (E2SFCA) approach, which estimates supply-to-demand ratios within user defined time/distance thresholds (Luo and Qi, 2009). Our primary focus is to establish the extent to which a methodological change to measurement could potentially impact upon accessibility scores within an IMD, and to examine the wider implications of adopting such an approach within overall IMD calculations. In so doing, it is hoped that the findings presented here will draw attention to wider debates surrounding the conceptualisation of accessibility within current IMDs and the potential implications for applying a similar approach within other IMDs both nationally and internationally. The structure of the paper is as follows; in the Literature Review section we briefly summarise the development of deprivation measures from those based on predominantly census-based approaches through to the introduction of IMDs, before focusing on the ways in which accessibility measures are incorporated into such approaches. The strengths and limitations of FCA methods relative to more traditional accessibility metrics are then highlighted before an examination of the methodologies used to derive existing UK IMDs is presented in section three of the paper. This highlights the reliance on 'traditional' accessibility measures, before providing a specific account of the evolution of the accessibility domain within the case study IMD. Sections 4 and 5 present the data/methodological approaches used within this study and the results of our empirical analysis respectively with a focus upon the potential implications of applying E2SFCA approaches across rural-urban contexts. The Discussion and Conclusions section provides an overview of the main findings, highlighting prospective implications of adopting FCA methods within existing IMDs and the broader policy relevance, along with study limitations and some suggestions for taking such research forward.

2. Literature review

2.1 Measuring deprivation

Deprivation is a fundamentally different construct to poverty. Deprivation, as defined by Noble et al (2006; p. 172), "refers to unmet need, which is caused by a lack of resources of all kinds, not just financial." This is in contrast to poverty which is often defined in terms of low income. Therefore, whilst the terms are often used interchangeably it is important to note these conceptual differences – for example, as noted by Townsend (1987; p. 130), "[p]eople can experience one or more forms of deprivation without necessarily being in poverty…people may be said to deprived if they do not have, at all, or sufficiently, the conditions of life – that is, the diets, amenities, standards and services – which allow them to play the roles, participate in the relationships and follow the customary behaviour which is expected of them by virtue of their membership in society…" Prior to the construction of IMDs, traditional UK-based deprivation measures included, for example, the Jarman (Jarman, 1983), Townsend (Townsend , 1987), and Carstairs Indices (Scotland only: Carstairs and Morris, 1989), as well as the predecessors to the first IMD – the 1991 Index of Conditions and the 1998 Index of Local Deprivation (Department of the Environment, Transport and the Regions [DTER], 1998). Perhaps the most well-known example, the Townsend Material Deprivation Score (or simply, the 'Townsend Index') measured deprivation at electoral ward level using four variables (based on unemployment, car and non-home ownership, and overcrowding) originally drawn from the 1981 Census of England and Wales (and which has subsequently been updated by various authors hereafter). An additive measure, the Townsend Index was constructed by simply summing the standardized z-score of each variable for a particular ward. Traditional deprivation indices had numerous limitations which made them imperfect measures of levels of deprivation – for example, a common over-reliance on census variables meant that indices could not be routinely updated, and whilst this was less of an issue for those indices that supplemented census variables with other sources (such as national or local surveys), indices wholly reliant on the Census such as the Townsend, Jarman, and Carstairs measures could only be updated decennially.

The use of IMDs in the UK were born from New Labour's desire to tackle deprivation through evidence-based policies and made possible through advancements in technologies and methods, including the creation of digital spatial boundary data at small-area level, the adjoining of socio-economic data with spatial information, and the availability of and access to administrative datasets (Fairburn et al., 2016). The first IMD (Indices of Deprivation 2000 or 'IMD (2000)') was developed by the Department of Social Policy and Social Work at the University of Oxford as an update to the previous 1998 Index of Local Deprivation (DTER, 1998). Based on a pioneering domain-centred approach to measuring multiple aspects of deprivation (see Noble et al., 2006), the index was, at the time, widely considered the most detailed and up-to-date source of information on the geographical distribution of deprivation across England. It was also the first UK-based deprivation index to include a measure of spatial accessibility to services (DTER, 2000) – a measure of which has now been included in each subsequent version (in 2004, 2010, and 2015), as well as within equivalents in Wales (in 2000, 2005, 2008, 2011, and 2014), Scotland (in 2004, 2009, 2012, and 2016), and Northern Ireland (in 2001, 2005, 2010, and 2017 forthcoming). The methodological approach to measuring deprivation used within existing IMDs is detailed in Noble et al (2006) and is based, conceptually, on Townsend's notion that a person can be multiply deprived through an accumulation of singular aspects of deprivation (Townsend, 1987). Whilst there have been criticisms of IMD frameworks, for example in relation to the lack of methodological transparency (Deas et al., 2003), the broad approach has been replicated in other national contexts such as Germany (Hofmeister et al., 2016; Maier et al., 2012) and South Africa (Noble et al., 2010). The focus in this study is on the implications of altering the approach taken to calculate spatial accessibility measures within such frameworks. Before describing these in more detail for UK-based IMD measures, we briefly review traditional and relatively new approaches to calculating accessibility drawn from the Geographical Information Systems (GIS) literature.

2.2 Traditional versus FCA-based Approaches to Calculating Spatial Accessibility

Traditional methods for calculating spatial accessibility to services have included computing basic supply-to-demand ratios as reported within pre-existing administrative areal boundaries, and computing the distance or time taken to reach a nearest service from a specified point of origin. The former is generally referred to as a *'container-based*' approach because it involves calculating a ratio of the available supply of a service relative to a population of potential users (the demand) within the bounds of a given area. One strength of this approach is that it is typically easy to compute, and another is that it is relatively intuitive to comprehend; however, it fails to account for cross-boundary movements which can be particularly problematic when considering services that are situated near to areal boundaries and which may thus be similarly accessible for users in neighbouring areas. Any within-zone variance in accessibility is also ignored by the container approach. In contrast, a *'distance-based'* approach generally computes the shortest distance (or travel time) to the nearest available service supply point. This may either be the Euclidean (straight-line) distance from the demand centre (commonly specified using a population-weighted centroid of a census tract or similar), or can be based on a more accurate road network model. However, while comparatively speaking a distance approach starts to incorporate a more spatially sophisticated element to measuring accessibility when a road network is employed, it fails to take any account of service demand or individual agency and in disregarding the latter it makes the assumption that users will automatically chose to use the nearest facility regardless of quality or personal preference.

Enhancements in methodological approaches to measuring spatial accessibility in the form of two-step floating catchment area (2SFCA)-based techniques now provide potentially more sophisticated measures of service accessibility which include elements of both the traditional container and distance-based approaches (Luo and Wang, 2003; Luo and Qi, 2009). Specifically, 2SFCA methods account for demand-weighted service provision levels as well as considering the choice available to all potential users within a computed time/distance catchment, which itself aims to overcome the problems associated with cross-boundary flows (Higgs, 2004) and is an undoubted strength of the metric. As its name implies, 2SFCA consists of two computational steps. Firstly, a user-defined threshold is used to construct a time or distance based catchment zone around each service supply point (for example, a 15 minute drive time radius might be placed around each public library). A supply-to-demand ratio is then calculated using the service supply magnitude and the number of potential users falling within this catchment. In the second step, a similar catchment is constructed around each demand centre and the sum of all supply-to-demand ratios that fall inside of it constitutes the final spatial accessibility score.

Some notable criticisms of 2SFCA-based approaches to measuring spatial accessibility are that it is a static measure in that travel times and both the supply and demand side variables are unable to vary temporally; that it yields biased supply-to-demand ratios due to an overestimation of local demand as a result of overlapping catchment areas (Neutens, 2015); that it relies on user designated catchment zones which tend to be arbitrarily defined; and that it assumes all population within a given catchment have equal access irrespective of the distance or time between the demand and supply points (Wang, 2012). The latter of these criticisms has since been resolved by the inclusion of a distance-decay parameter within the time/distance catchment that applies a stepped weighting structure (Luo and Qi, 2009). In summary, less weight is given to those supply points which are further from the demand centre. Further enhancements made to the traditional 2SFCA approach that have addressed some of the initial concerns with applying such techniques include, for example, the use of multiple modes of transport (Mao and Nekorchuk, 2013), variable catchment sizes (McGrail and Humphreys, 2009), and age-adjusted demand populations (Ngui and Apparicio, 2011). As previously stated, 2SFCA-based approaches have become increasingly popular in the spatial accessibility literature in a wide range of application areas following advancements in GIS technologies and the increased availability of spatially disaggregated data regarding both service supply and demand features (Neutens, 2015). Arguably, 2SFCA methods are now the preferred method for calculating spatial accessibility among many academics. Despite this, we are unaware of any approach to calculating the accessibility element of an IMD that has incorporated 2SFCA methodologies. In the next section we briefly review the types of approaches that have been traditionally taken to measure accessibility within IMD approaches using the example of their application in the UK.

3. Existing IMDs

3.1 Approaches taken to calculate accessibility within existing UK IMDs

Spatial accessibility to services has become an important area-based indicator of relative levels of deprivation at small-area level. For example, a measure of spatial accessibility to services is included in recent versions of the English Indices of Deprivation (Department for Communities and Local Government [DCLG], 2015a), the Northern Ireland Multiple Deprivation Measure (NIMDM: NISRA, 2010), the Scottish Index of Multiple Deprivation (SIMD: Scottish Government, 2016a), and the Welsh Index of Multiple Deprivation (WIMD: Welsh Government, 2014a). Table 1 summarises the methods used to calculate the access domain within each of the aforementioned UK-based IMDs. Briefly, the weight assigned to the accessibility domain does not vary significantly between the different approaches used in these countries; generally representing around 10% of the total score. Reviewing the technical documentation that accompanies these indices suggests that the domain weights are commonly based on combinations of available evidence, expert opinion, and public consultation (see for example, Welsh Government, 2014b; p. 52).

However both the number and the type of services sampled do differ quite considerably between the indices; for example, in regards to the latter, while consensus would suggest that the average travel time or distance taken to reach a GP surgery or post office are seemingly of some importance to assessing levels of accessibility (both these services are sampled in each of the four UK IMDs), there is clearly less consensus concerning the importance of access to other services such as public libraries, job and retail centres, NHS dentists, and Accident and Emergency (A&E) departments, which feature on a less consistent basis. Such variation may reflect contextual differences between the four countries regarding perception of what services are most important for everyday life (for example, A&E's are given double weighting in the NIMDM 2010: NISRA, 2010), or simply differences in the availability of spatially disaggregated data on service provision. In addition, although all the UK IMDs apply a network-based approach to calculate accessibility, very different travel time/distance metrics and transport options are employed; including average road distance (Department for Communities and Local Government [DCLG], 2015b), average road travel time (NISRA, 2010), weighted average travel time by public and private transportation (Scottish Government, 2016b), and weighted average travel time for a return journey by public and private transportation (Welsh Government, 2014b). Overall, since their initial inception there has been a general trend towards the adoption of more sophisticated approaches to calculating accessibility within each successive version of the UK IMDs. For example, in the English Indices of Deprivation 2000 spatial patterns in service accessibility were based on simple Euclidean distances (Department of the Environment, Transport and the Regions, 2000), whereas a network-based model has since become the preferred method for calculating accessibility (Department for Communities and Local Government [DCLG], 2015b).

Whilst one might expect the approaches taken to measuring accessibility within UK IMDs to closely mirror wider advancements in the spatial accessibility literature, there have arguably been relatively few improvements since this general move away from the use of straight-line distances despite some of the computational advancements made in the interim period. UK IMDs have been used in many application areas, such as studies that have explored associations between deprivation and disease prevalence (Whynes et al., 2003; O'Flaherty et al., 2009; Whyte et al., 2014), and investigations of spatial patterns in resource access (Macintyre et al., 2008; Jones et al., 2009), as well as other examples shown in Table 1. Further to this, IMDs have clear policy relevance and have been (and continue to be) widely used by policymakers to aid in decision-making processes. For instance, WIMD 2011 was used to inform the selection of areas to be included in Communities First Clusters in Wales (a former scheme aimed at tackling poverty in the most disadvantaged communities: Welsh Government, 2013a), whilst the 2010 English Indices of Deprivation has recently been used by NHS England to help inform resource allocations for Clinical Commissioning Groups (formerly Primary Care Trusts) for the period 2016/17 to 2020/21 (NHS England, 2016). Although the reasons for constructing IMDs are multifaceted, it is likely that the benefits to policymakers, for example in relation to identifying areas for targeted interventions and informing broader resource allocation, have also influenced the types of approaches used to calculate IMDs in other national contexts. In the rest of this paper we focus in more detail on the approach taken to incorporate accessibility measures within one particular such IMD; namely the Welsh Index of Multiple Deprivation (WIMD).

[Table 1]

3.2. The Welsh Index of Multiple Deprivation 2014

The WIMD is an area-based measure of relative deprivation designed to identify those areas of Wales with the greatest need across multiple deprivation domains, including income, employment, health, education, service accessibility, community safety, the environment, and housing. Measured at lower layer super output area (LSOA) level (of which there are 1,909 within Wales with an average population of approximately 1,600 people), each domain is composed of a number of key indicators that are detailed in Table 2, along with the weights used to combine the domains into a single composite index of deprivation. As with other UK IMDs, WIMD is a rank-based index whereby rank 1 represents the most deprived LSOA across all domains and 1,909 the least deprived. Thus the index provides a way of identifying which areas of Wales are more or less deprived, relatively speaking. It does not provide comparable data concerning levels of deprivation, and thus it would be incorrect to say that one LSOA is twice as deprived as another based solely on its ranking within WIMD. Whilst comparisons can be made regarding the ranking of an LSOA across the different domains of deprivation within any given WIMD, they cannot be made with other versions of WIMD or other UK IMDs due to underlying definitional and methodological differences.

[Table 2]

As evident from Tables 1 and 2, relative levels of service accessibility among Welsh LSOAs, represented by the 'Access to Services' domain of WIMD 2014, are based on geographical access to the following nine services; GP surgeries, pharmacies, primary and secondary schools, public libraries, post offices, food shops, leisure centres, and petrol stations. Demand points (or origins), in this instance, consist of approximately 1.3 million Welsh residential dwellings, with travel times calculated from each demand point to the nearest available service supply point. For each LSOA, the average travel time (in minutes) for a two-way journey to the nearest supply point is calculated for each service using both public (bus, train, coach, and foot) and private (car) transport, with the exception of access to petrol stations which is only measured using private transport. Travel time indicators are a weighted average of these public and private transport times with weights calculated for each LSOA using UK census data on car ownership and population counts for those of legal UK driving age (i.e. 17 years and over: Welsh Government, 2014b). Public travel times are estimated using the Mapumental API and the National Public Transport Data Repository dataset, while private travel times are estimated using RouteFinder 4.02 for Mapinfo and a road network based on Ordnance Survey's Integrated Transport Network (ITN) (Welsh Government, 2014b; p. 52).

The methodological approach used to calculate accessibility within the access domain of WIMD 2014 has evolved since the initial WIMD 2000 (see Table 3). Originally, accessibility was measured using Euclidean distance to the nearest available service supply point, i.e. a basic straight-line accessibility metric from the point of origin to the nearest facility (Noble et al., 2000). Accessibility modelling was greatly enhanced within WIMD 2005, however, with the application of a more spatially sophisticated network-based approach considered to be more representative of real life scenarios (Welsh Government, 2005). Whilst this demonstrates a more sophisticated approach to calculating access to key services, between WIMD 2005 and WIMD 2014 there have been only small enhancements in applied methodology which have arguably not kept pace with developments taking place in the spatial accessibility literature, where there has been a strong trajectory towards the use of gravity models and their FCA derivatives (see Neutens, 2010). Whilst the inclusion of private transport alongside an increased number of public transport options in the most recent version of WIMD is arguably the most sophisticated methodological enhancement for some time, it remains a relatively simplistic accessibility metric that fails to account for supply-demand interactions or distance-decay effects.

[Table 3]

In the remainder of this paper we put forward the argument that FCA-based approaches should be considered as the next step in the methodological evolution of the access domain of WIMD, and within IMDs more generally. The potential strengths of an FCA approach were discussed within section 2.2, most notably the ability to account for service supply and demand and the adoption of realistic travel catchments inside of which distance-decay effects are modelled, and yet no studies to date have attempted to examine the implications of deploying FCA models within an existing IMD. Going forward, the paper aims to address this research gap through an investigation of the potential impacts of using an E2SFCA model to calculate levels of service accessibility among small-areas of Wales as an input into a WIMD, as well as examining potential rank-based changes in both the access domain and for the combined deprivation rankings. In the next section we describe the data and methodological approaches adopted to achieve these aims.

4. Data and methods

4.1. Supply- and Demand-side Data

To be clear, we have endeavoured to replicate the data and methodologies used to calculate the 2014 version of the WIMD as closely as possible in an attempt to substitute FCA scores into the access domain. However, with neither the original service supply-side dataset upon which the access domain is based, nor a detailed summation of the methodological approach employed being publicly available, the reproducibility of WIMD is somewhat compromised. For this reason the supply points used in our study were chosen as 'best-fit' alternatives. Our data were obtained from multiple sources (mostly freely accessible) and were pre-processed and cleaned in accordance with the variable descriptions published in the WIMD 2014 Technical Report (Welsh

Government, 2014b; p. 21). For the purpose of transparency, in Table 4 we highlight a number of apparent discrepancies that remain between the service supply points used in this study and those adopted by WIMD 2014. Whilst some minor disparity is inevitable, we have sought to identify potential explanations for the larger discrepancies. First, it was necessary to make certain assumptions regarding the inclusion/exclusion of potential supply points in cases where they were insufficiently defined in the technical guidance. Perhaps the best example here is in the identification of sites to represent a 'food shop' – which was simply described as any store where bread and milk can be purchased (ibid: p. 21). Second, some temporal effects are likely due to changes in the provision of services over time. In respect to public libraries and post offices, for example, it is highly probable that some services have been lost since 2014 or earlier. Third, we acknowledge minor border issues may arise due to the fact that WIMD 2014 included supply points located on or near the border between Wales and England, whereas our study only includes data relating specifically to Wales. Notwithstanding these recognised issues, other discrepancies such as the substantial variation in the numbers of GP surgeries and leisure centres identified for inclusion remain largely unexplained. In these cases we have simply been unable to replicate from currently available and reputable sources a service side dataset that closely matches that reported to have been used in the original WIMD 2014 methodology. Regarding demand-side variables, population weighted centroids for Welsh Output Areas (OAs, n=10,036) were obtained from the Office for National Statistics (ONS) Open Geography Portal (http://geoportal.statistics.gov.uk/), while census-based estimates of the usual resident population of each OA were downloaded from NOMIS (https://www.nomisweb.co.uk).

[Table 4]

4.2 Methodological approach

The E2SFCA methodology was first proposed by Luo and Qi (2009). It was presented as an improvement on the earlier two-step approach of Luo and Wang (2003), specifically addressing the effects of distance decay by applying a stepped weighting structure. A brief algorithmic description of the E2SFCA methodology is provided below:

Step 1

To determine the availability of a service at each provision point j, a supply-to-demand ratio is computed based on the supply volume S_j, and the sum of all demand centre populations P_k that fall within a threshold distance d_0, and weighted by a coefficient W_{jk} based on the distance d_{jk} between the supply and demand points:

$$R_j = \frac{S_j}{\sum_{k \in (d_{kj} \leq d_0)} P_k W_{kj}} \quad (1)$$

The E2SFCA specification uses a geographical weighting function to account for the effects of distance decay. In this study, a continuous linear decay function was used:

$$W_{kj} = \frac{(d_0 - d_{kj})}{d_0} \quad if \;\; d_{kj} \leq d_0 \quad (2)$$

$$W_{kj} = 0 \qquad otherwise$$

Step 2

The E2SFCA score assigned to each demand point *k*, is the sum of all supply-to-demand ratios R_j that fall within the threshold distance d_0, again weighted by the distance-decay coefficient W_{jk}:

$$A_k = \sum_{j \in (d_{kj} \leq d_0)} R_j \, W_{kj} \quad (3)$$

E2SFCA scores for each of the nine services (i.e. pharmacies, GP surgeries, food shops, public libraries, post offices, primary and secondary schools, leisure centres, and petrol stations) were calculated using a network model constructed using Ordnance Survey (OS) ITN layer data (Ordnance Survey, 2015) and the Network Analyst extension in ArcGIS™ version 10.4 (ESRI, 2015). Due to a lack of detailed data on public transport routes and times, accessibility scores were calculated assuming private transport only. To preserve as much spatial accuracy as possible, E2SFCA models were run for each service using population weighted centroids of Welsh OAs as the demand centres. The LSOA level scores were then derived from these by computing the population weighted mean OA score. To explore any sensitivity of the E2SFCA scores to varying travel time thresholds, models were constructed using 5, 15, and 30 minute travel times.

4.3 Incorporation of E2SFCA scores into a new WIMD

In order to best reflect the access domain of WIMD 2014, our E2SFCA scores for each service were aggregated into three separate indices (one for each of the travel time thresholds adopted) using service weights supplied by the WIMD 2014 Technical Report. The individual service weights were as followed: pharmacies, 0.29; GP surgeries, 0.14; food shops, 0.14; public libraries, 0.10; post offices, 0.095; primary schools, 0.08; leisure centres, 0.06; petrol stations, 0.05; and secondary schools, 0.045 (Welsh Government, 2014b; p. 20). LSOAs were then ranked from least to most access-deprived based on these weighted-aggregate scores and assigned to a normal distribution, where low ranks received a low normalised value. In accordance with the recognised method for constructing domain scores (Noble et al., 2006), and as documented in the WIMD 2014 Technical Report, an exponential transformation was applied to the normalised ranks to create domain scores that ranged from 0 (least deprived) to 100 (most deprived). The exponential transformation of domain indices is detailed below:

$$-23 \times \log \{1-R \times [1-\exp(-100/23)]\} \qquad (4)$$

Where *R* is the normalised rank scaled to the range 0-1, with R=1/1909 for the least access deprived LSOA, and R=1909/1909 for the most access deprived LSOA; *log* is the natural logarithm and *exp* the exponential transformation. This process is designed to reduce the extent to which deprivation in some domains can be cancelled out by a lack of deprivation in others (for further details: see Noble et al., 2006; p. 179-181).

Domain scores for all other deprivation domains included within WIMD 2014 are freely accessible from the Welsh Government website.[1] Using the domain weights highlighted in Table 2, a weighted domain score for each LSOA was calculated based on all eight indicators of deprivation, replacing the original access domain score with that calculated using the E2SFCA approach. Once aggregated, the weighted domain scores were ranked from most to least deprived in accordance with the existing WIMD methodology.

4.4. Analytical approach

Four strands of analysis are used in this study to examine changes in LSOA ranking, both specifically within the access domain of WIMD 2014, and also in the overall WIMD score following the substitution of the original travel-time based metric with an E2SFCA-based metric. First, associations between the revised WIMD (hereafter 'WIMD-FCA') and the published original (hereafter 'WIMD-2014') were examined using Spearman's rho; a nonparametric measure of rank correlation that assesses the monotonic relationship between two variables (Corder and Foreman, 2014). Second, in order to highlight any spatial patterns in rank change following the adoption of the E2SFCA method, such as evidence of clustering for example, a series of choropleth maps were created using ArcGIS™. Third, box and scatter plots were plotted to investigate the range of movement in ranks according to a breakdown of rural-urban geography in Wales based on the ONS 2011 Rural Urban Classification (RUC11) of LSOAs (accessed via the ONS Open Geography portal). An official UK geographical classification scheme, the RUC11

[1] http://gov.wales/statistics-and-research/welsh-index-multiple-deprivation/what-is-wimd/?lang=en

classifies settlements at OA level, with urban areas defined as populations of 10,000 or more and all else defined as rural. Overall, there are 10 classification strata ranging from ‘major conurbation’ (RUC11 code A1) to ‘hamlets and isolated dwellings’ (RUC11 code F2) with an LSOA classified based on the majority classification of its residing OAs (Department for Environment, Food and Rural Affairs, 2016). The RUC11 was applied in this context due to the aforementioned likelihood that an E2SFCA-based approach to measuring accessibility will have substantial implications regarding levels of service accessibility across both rural and urban settings. Finally, rank movement among the twenty most- and least-deprived LSOAs in Wales was examined using descriptive statistics. All statistical analysis was undertaken using RStudio 1.0.143 (R Core Team, 2017), with spatial analysis undertaken in ArcGIS^{TM} 10.4 (ESRI, 2015).

5. Results

5.1 Impacts on the accessibility domain

The results of the Spearman’s rank-order correlation for each of the chosen travel time thresholds are shown in Table 5. The coefficients suggest a positive association between the rankings of WIMD-FCA and the original access domain of WIMD-2014, with the strength of association, as indicated by the size of the correlation coefficients, suggesting some degree of variation between the two sets of ranks. When examining this variation spatially, Figure 1 reveals clear patterns of change regarding the rankings of some LSOAs following estimation of levels of service accessibility using an E2SFCA metric (the result shown is that obtained from the 5 minute travel time threshold). By accounting for potential levels of service supply and demand rather than being solely based on proximity, Figure 1 suggests that the higher potential demand placed upon services in urbanised areas has resulted in a number of LSOAs ascending the rankings and in so doing becoming relatively more strongly access-deprived. This is in contrast to the more rural areas of Wales where less potential demand for services relative to supply has meant that some LSOAs achieve a higher access score using E2SFCA methods, regardless of whether the travel time taken to access these services is generally greater than that in urbanised areas.

[Table 5; Figure 1]

The implications of accounting for potential levels of service demand when calculating levels of accessibility are further highlighted in Figure 2. By categorising LSOAs according to their rural-urban geography, it becomes apparent that it is predominantly those LSOAs classified in the ONS RUC11 as a ‘sparse setting’ that have tended to experience the greatest decline in rank position following the adoption of E2SFCA methods, i.e. the LSOAs with RUC11 code C2 (‘urban city and town in a sparse setting), D2 ('rural town and fringe in a sparse setting'), and E2 ('rural village and dispersed in a sparse setting'). Building on previous findings, this would seem to suggest that less potential demand for services in the "sparser" areas of Wales ultimately leads to larger accessibility values being recorded when applying an E2SFCA approach.

[Figure 2]

Lastly, an examination of the twenty most and least access-deprived LSOAs regarding their rank movement following implementation of E2SFCA methods gives further credence to the findings presented above. Indeed, when access is calculated using a purely distance-based accessibility metric a clear pattern of access deprivation is apparent which broadly conforms to standard rural-urban geography, with the most access-deprived LSOAs located within rural settings and the least access-deprived within urban areas. In contrast, when the methodology is based on E2SFCA scores, the average change in rank for the current twenty most access-deprived LSOAs was -722.5 positions (again for the 5 minute travel time threshold) with max = 11, min = -1790, and SD = 657.6. Using a 15 minute threshold the comparable figures are an average movement of -683.2 positions (max = 3, min = -1822, SD = 665.3), while for a 30 minute threshold these become -597.1 positions (max = 10, min = -1867, SD = 664.4). Meanwhile, for the current twenty least access-deprived LSOAs, the average change in ranking were as follows; +530 positions (max = 1223, min = 100, SD = 379.8), +807.9 positions (max = 1662, min = 204.5, SD = 451.6), and +786.8 (max = 1484, min = 157, SD = 431.7) respectively.

5.2 Impacts on the overall WIMD 2014

Spearman's rank-order correlations presented in Table 5 suggest a high level of congruence between the overall WIMD-FCA and WIMD-2014 deprivation rankings across all three travel time thresholds. This is most likely due to the access domain only accounting for 10% of the overall rankings and so this outcome is not entirely unexpected. However, spatial examination of WIMD-FCA does reveal that clear patterns of movement are evident within the overall deprivation rankings of Welsh LSOAs after the application of E2SFCA methods. For instance, Figure 3 reveals that the improved accessibility scores for the sparser (and generally more rural) LSOAs which were reported in the previous section following the E2SFCA approach are also reflected in changes to the overall index; namely that a number of rural LSOAs have become relatively less deprived on the new measure, whilst there is evidence of the reverse regarding some of the more urbanised LSOAs. This is despite the access domain only representing 10% of the overall IMD rankings. Further support for these findings is presented in figure 4. Here the box plots clearly show that those LSOAs classified by the ONS RUC11 as 'rural village and dispersed in a sparse setting' (RUC11 code E2) have experienced the greatest decrease in rank, and have thus become less deprived, relatively speaking, following the adoption of E2SFCA methods. This finding is further emphasised in Figure 5 where a breakdown of the association between WIMD-FCA and WIMD-2014 rankings, subdivided by RUC11 classification, clearly shows that correlations are weakest among those LSOAs classified as 'rural village and dispersed' (RUC11 code E1) and in particular 'rural village and dispersed in a sparse setting' (RUC11 code E2).

[Figures 3, 4 and 5]

Lastly, on average the implementation of an E2SFCA approach resulted in a rank change of -1.2 positions among the top twenty most deprived LSOAs for a 5 minute travel time threshold (max = 10, min = -9, SD = 3.91), -0.9 positions for a 15 minute threshold (max = 4, min = -5, SD = 2.6), and -0.2 positions for a 30 minute threshold (max = 4, min = -5, SD = 2.6). For the twenty least deprived LSOAs, the average change in rank was as follows; +108.4 positions (max = 335, min = -13, SD = 105.5), +51.7 positions (max = 235, min = 241, SD = 58.2), and +73.2 positions (max = 468, min = -18, SD = 136.8) respectively. Thus, while the adoption of E2SFCA methods appears to lead to relatively little change in overall rank position among the most deprived LSOAs in Wales, the same cannot be said for the least deprived LSOAs, some of which have substantially ascended the WIMD rankings.

5.3. Summary of results

Overall, it is clear from this case study that applying an E2SFCA approach to measuring accessibility may have implications for the rankings of small areas within both the access domain of the WIMD but also potentially, and more importantly from a policy perspective, in the rankings of some LSOAs on the overall WIMD. While the former is to be expected due to the considerable differences in the methodological approach used to estimate accessibility, the consequences of the latter, despite the fact that the domain accounts for only 10% of the weighting of the overall index, could suggest that continuing to calculate accessibility using simplistic travel time/distance metrics may be leading to a degree of undue bias within the overall index - particularly when viewed across rural-urban settings.

6. Discussion and conclusions

6.1. Principal findings

In this study we examined the potential implications of incorporating recent advancements in spatial accessibility measurements, in the form of floating catchment area techniques, into existing IMD methodologies in order to investigate prospective effects on levels of both access and overall deprivation rankings. Firstly, results suggest that there was only a weak (albeit significant) positive association between the accessibility ranks of WIMD-2014 and the revised WIMD-FCA at each travel time threshold; highlighting the potential sensitivity of IMD rankings to contrasting measures of spatial accessibility. Secondly, the variation in ranks between the two approaches suggest that sparser (generally more rural) areas, commonly identified as having greater levels of access deprivation in WIMD 2014 due to longer travel times to access available services (Welsh Government, 2015), tended to receive higher accessibility scores following the application of E2SFCA methods and thus received a lower ranking in the access domain of WIMD-FCA. As suggested previously, this is likely the result of lower levels of service demand in sparsely populated areas.

In contrast, some of the more densely populated urban areas received lower E2SFCA-derived accessibility scores, and were thus placed higher in the rankings, because despite the advantages of being in closer proximity to a range of basic services, the higher levels of potential competition that users could face increased the cost of access. This finding was particularly evident when considering the change in ranks of those areas deemed to be the most and least access-deprived within WIMD-2014 – with an average drop in ranking of circa 650 places among the twenty most access-deprived (predominantly rural) areas following the application of an E2SFCA approach, compared to an increase of around 700 places among the twenty least deprived (predominantly urban) areas. Thirdly, although overall WIMD-FCA was strongly correlated with WIMD-2014 (which, as previously stated, was to be expected considering that the other domains are unaltered) the application of E2SFCA methods has still resulted in notable changes to the deprivation rankings of LSOAs, despite it only accounting for 10% of the index. Most notably, the rankings of areas classified within the ONS RUC11 as 'rural village and dispersed in a sparse setting' were comparably lower within WIMD-FCA. This would seem to suggest that sparser, more ruralised areas may receive a higher overall ranking within WIMD-2014 simply because the extra time taken to reach a service is perceived to equate to a lack of accessibility. This is an important finding considering that rural areas are generally shown to be less deprived than urban areas on the other deprivation domains and thus the current accessibility metric may be concealing greater levels of inequality between rural and urban areas.

Lastly, in light of the use of IMDs to measure relative levels of multiple deprivation, it is noteworthy that the application of E2SFCA methods did not drastically alter the ranks among the most and least deprived areas that were identified by the overall WIMD-2014 – for example, calculating accessibility based on a 5 minute travel time threshold, the average decrease in multiple deprivation rankings among the twenty most deprived areas was as little as 1.2 places. Thus while the evidence presented here has clear implications for how accessibility is conceptualised and measured, especially in rural-urban contexts, this may not equate to wholesale changes regarding the identification of the most and least deprived areas, particularly whilst the access domain continues to represent only a relatively small influence (weighting) on the overall index.

6.2 Study strengths and limitations

The aim of this study has been to replicate as far as is feasible from published and open sources the approach taken to calculate an IMD for Wales using potentially more sophisticated methods for measuring accessibility. In so-doing we have tried to follow the exact methodologies used to calculate the latest version of the WIMD (2014) whilst acknowledging some of the problems highlighted by Brunsdon and Singleton (2015) with regards to 'reproducible research'; particularly, in this instance, relating to the need to make available explicit details of the datasets and the computational methods used to derive the IMD. This study has provided a practical example of the types of issues outlined by Brunsdon and Singleton, where details such as data provenance and other aspects of meta-data are not immediately transparent or where aspects of the methodological approach are either not explicitly stated or where the software required to replicate the approach is not open source. In the case of the latter, they suggest that a study approach may not be reproducible where such software is not open source or where the procedures used in the analysis are not made more widely available to researchers. We have tried to address the latter by making the plug-in used to calculate the FCA scores in ArcGIS™ more widely available (with appropriate training and guidance notes) so as to encourage the practical application of these methods by researchers and policymakers alike (Langford et al., 2015).

There are a number of limitations to this study, both data driven and methodological, which illustrate the types of concerns highlighted by Brunsdon and Singleton. For instance, whilst it would have been preferable to apply E2SFCA methods to exactly the same service supply-side datasets used to calculate the accessibility component of WIMD 2014, this was not possible because we have been unable to acquire the precise data used in the WIMD 2014 calculations. Likewise, whilst it would have also been preferable, as an alternative, to apply the same methods to generate a new supply-side dataset, this too was impossible due to the lack of published details on all aspects of the methodology used to calculate accessibility. For these reasons, we are unable to comprehensively state whether variations in LSOA rankings between the published WIMD 2014 and our WIMD-FCA result from differences in data or method; although where possible we have tried to obtain data from the same if not similar sources in order to maximise the representativeness of our sample and minimise any potential biases. However, despite this unavoidable degree of ambiguity, the magnitude of the differences in access deprivation, especially across rural-urban settings, strongly suggests the latter. We were also unable to compute equivalent E2SFCA scores for every mode of transportation used to calculate accessibility within WIMD 2014 due to a lack of detailed information on public transportation routes and times at the all-Wales level. Furthermore, as part of this study we have computed E2SFCA scores for three separate travel time thresholds. Whilst these thresholds have been selected pragmatically, evidence on the time (or distance) that users are prepared to travel to access certain amenities are lacking and thus these thresholds could be investigated in more detail in a sensitivity analysis of findings. Moreover, one could argue that it may be more appropriate to calculate FCA scores based on distance cost rather than time due to rural drivers being more deprived in terms of distance travelled and associated running and petrol costs for the same drive time. This would be an easily computable change to make in the current analysis. Finally, whilst we acknowledge potential ecological fallacy concerns surrounding area-based measures, FCA is not a technique specific to areal measures and through data linkage at individual or household level it could allow for more accurate measurement of access deprivation in the future.

6.3 Policy implications and future research

The implications of this study are threefold. Firstly, there are methodological implications for those charged with calculating IMDs relating to the appropriateness of 'traditional' approaches to measuring accessibility. As this study clearly demonstrates, the application of simplistic accessibility metrics based on travel time/distance-only are likely to result in densely populated urban areas receiving higher accessibility scores simply because their proximity to services is likely to be greater than in more rural settings. Indeed, the FCA approach is especially useful for identifying areas where physical access to services is good but supply is low in comparison to demand (a low supply-to-demand ratio). This is important for measuring multiple deprivation because local services may simply be overwhelmed by the level of demand that prevails in disadvantaged areas. This calls for more research to re-evaluate the usefulness of existing accessibility measures applied within current IMDs. Secondly, there are conceptual implications regarding how access is defined within existing IMDs and whether such definitions are appropriate within the context of both rural and urban areas. For example, WIMD conceptualises accessibility as an 'enforced lack' of access, i.e. "when a person cannot acquire a good or service because they don't have the financial or other means to do so" (Welsh Government, 2013b; p. 13). However, whilst residents of rural areas may be deemed to have an enforced lack of access because they have to travel further than their urban counterparts to attend a GP surgery, for example, it could be postulated that the likelihood of obtaining a prompt appointment could in theory be greater in more sparsely populated areas due to there being less demand placed upon these services (depending of course on supply-side factors available at such locations, such as GP numbers within individual practices which have not been explicitly considered in this study). Finally, and most importantly, there are also implications for policy. As previously noted, IMD approaches have been used by policymakers to identify areas for targeting resources, such as selecting areas for funding under the Communities First initiative which aimed to address poverty in the most deprived communities of Wales (Welsh Government, 2013a). However it is possible that policies designed to distribute funds or allocate resources that could, for example, have consequences for the provision of public services, may not necessarily be targeting the most appropriate areas if based on existing approaches to measuring geographical aspects of accessibility. The overall index is next due to be updated in 2019; it is to be hoped that the findings from this study could be used to enable a consideration of the use of FCA-based techniques in the construction of the accessibility domain for the next version of the WIMD.

Acknowledgements

This paper is based on research supported by the Wales Institute of Social and Economic Research, Data and Methods (WISERD). Funded by the Economic and Social Research Council (ESRC), WISERD is a collaborative venture between the Universities of Aberystwyth, Bangor, Cardiff, South Wales and Swansea (Grant number: ES/L009099/1).

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Figure 1: Change in LSOA ranking for the 'Access to Services' domain of WIMD-2014 based on ES2FCA-derived accessibility scores (5 minute catchment zones)

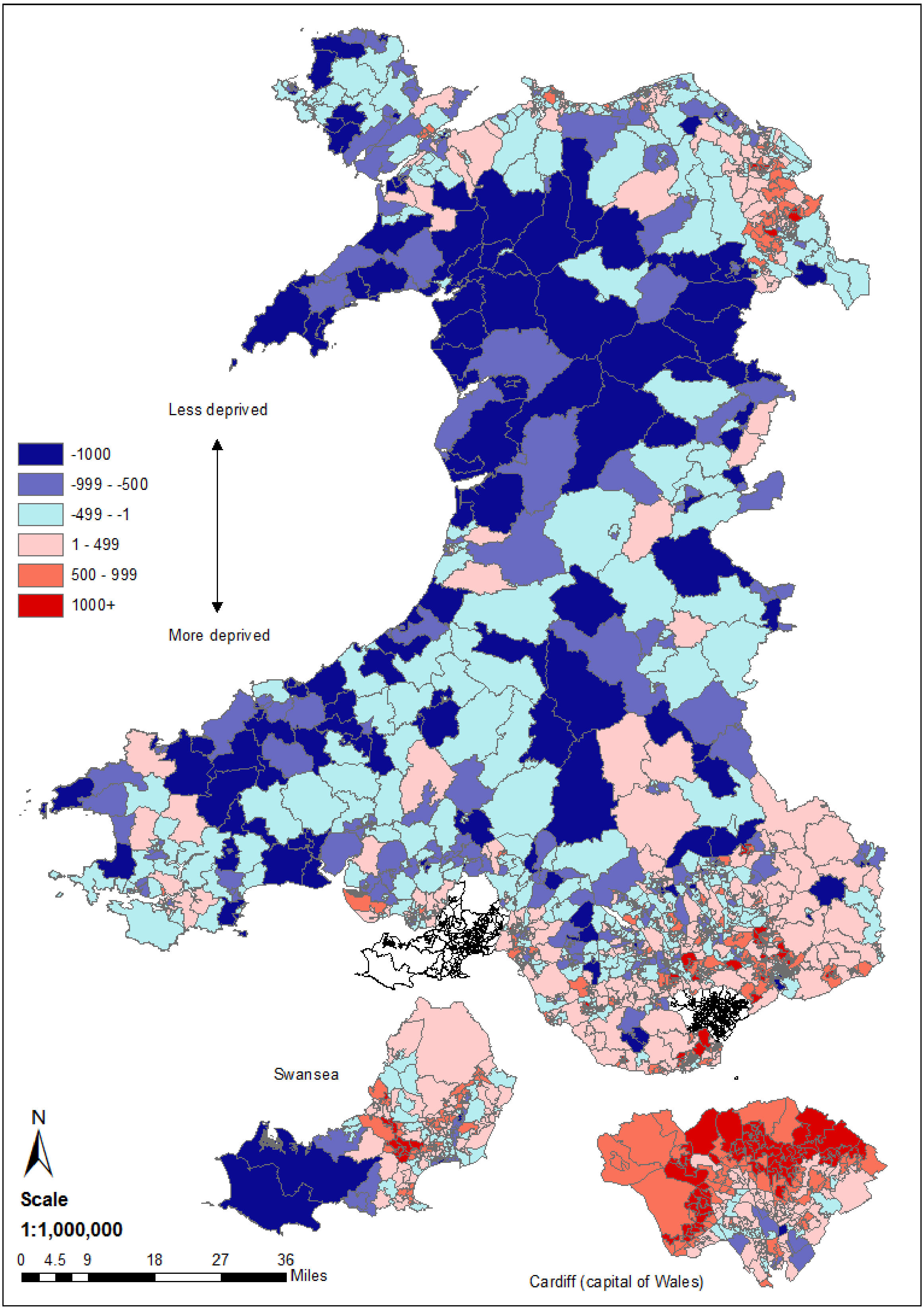

Figure 2: Change in LSOA accessibility ranking in WIMD-FCA by rural urban classification (5 minute catchment zones)

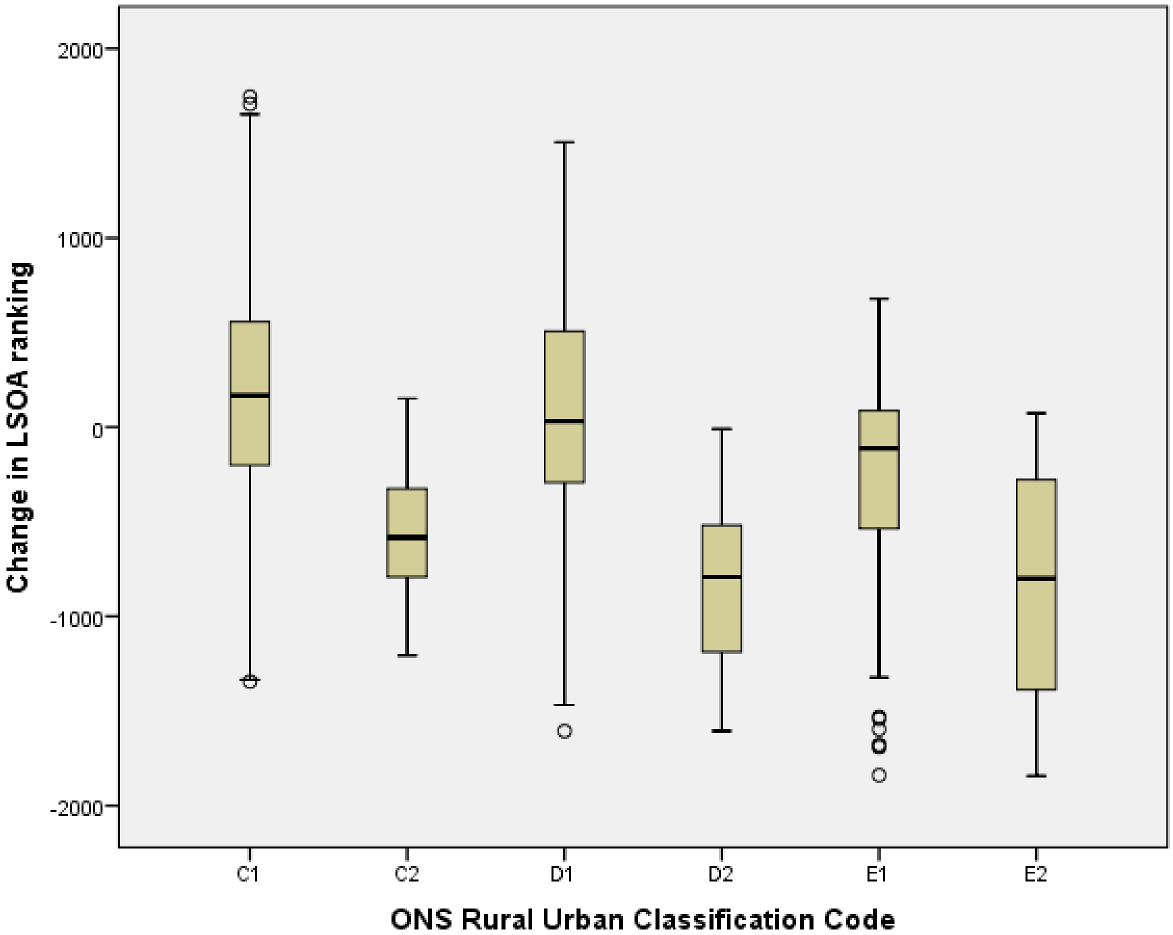

Figure 3: Change in LSOA ranking for overall WIMD-2014 based on ES2FCA-derived accessibility scores (5 minute catchment zones)

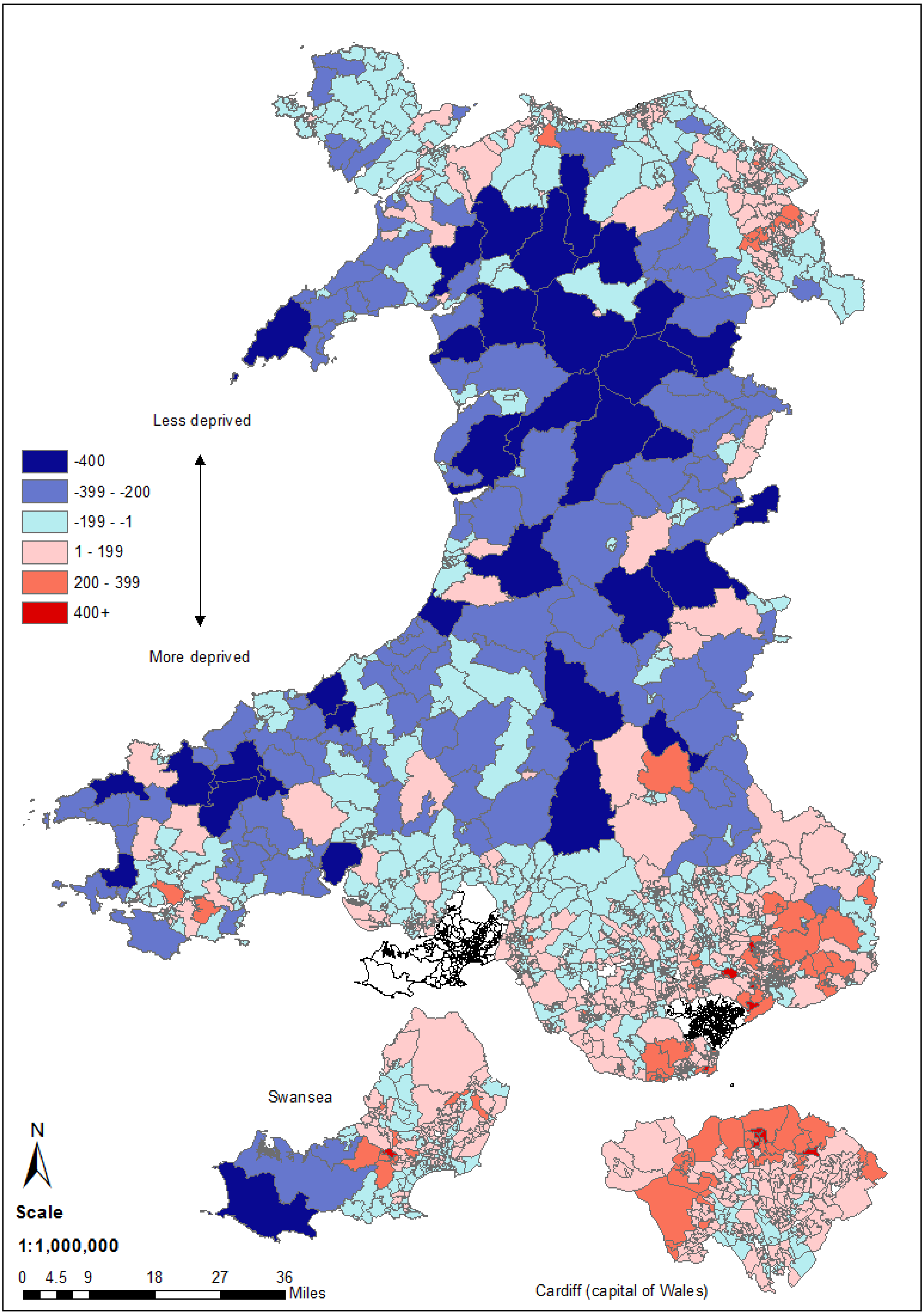

Figure 4: Change in LSOA ranking in overall WIMD-FCA by rural urban classification (5 minute catchment zones)

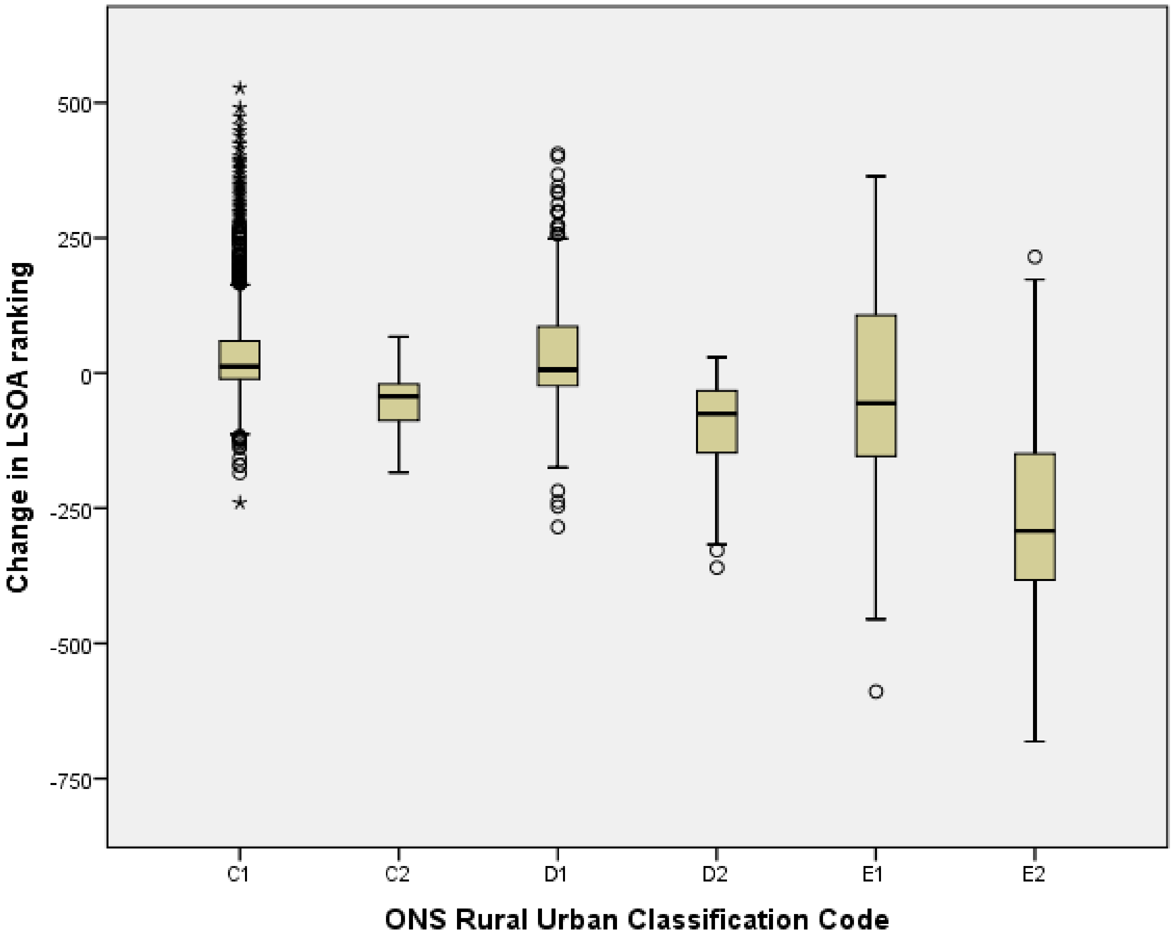

Figure 5: Linear association between WIMD-FCA and WIMD-2014 LSOA rankings both overall and when subdivided by rural urban classification

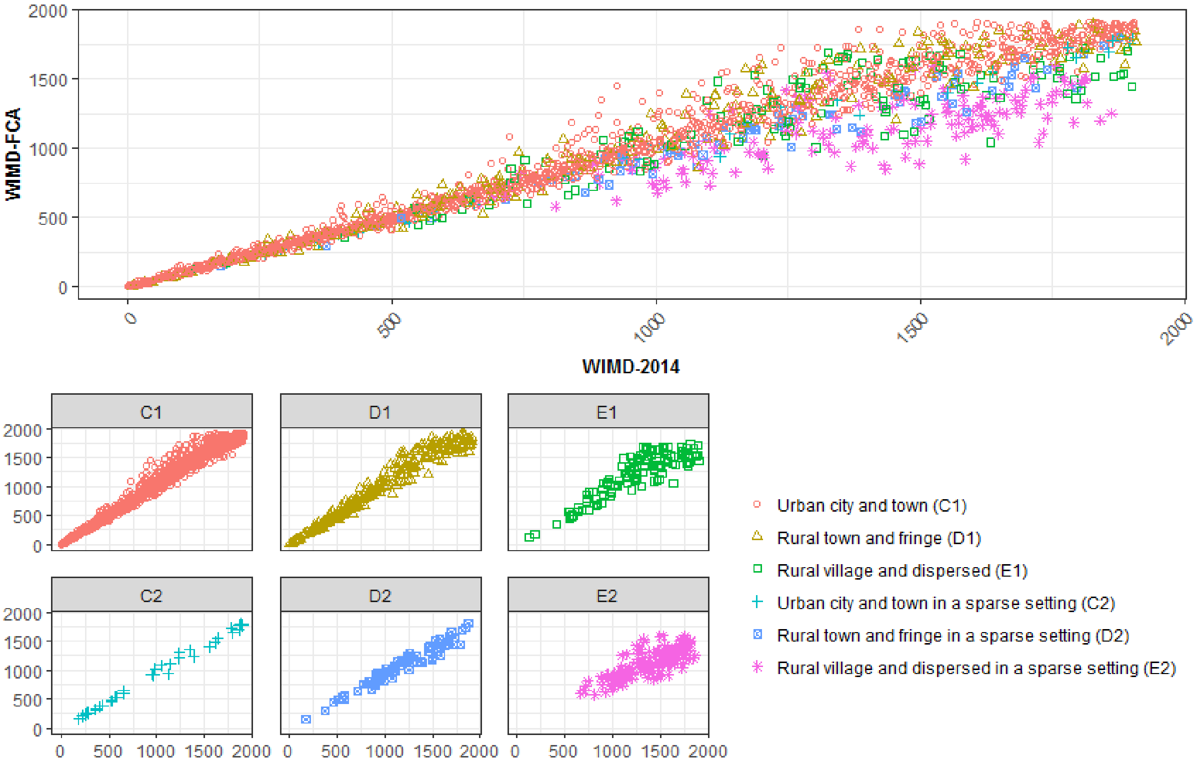

Table 1: Approach taken to calculate the accessibility domain within existing Indices of Deprivation in England, Northern Ireland, Scotland and Wales

Country and version of Index	Domain	Weight of 'accessibility' domain within overall IMD	Services used to calculate index	Approach taken to measure accessibility	Examples of IMD application areas
England (2015)	'Barriers to Housing and Services' Domain	9.3%	'Geographical barriers' - GP, food shop, primary school, and post office. Domain also includes 'wider barriers' – i.e., household overcrowding, homelessness, and housing affordability.	Average road distances (km) to the closest service from the OA population weighted centroid are calculated for each service and aggregated to LSOA level using population-weighted means. Average distances are standardised and weighted equally (DCLG, 2015a, b).	Access to greenspace (Jones et al., 2009); prevalence of colorectal cancer (Whynes et al., 2003); density of fast-food (MacDonald's) restaurants (Cummins et al., 2005).
Northern Ireland (2010)[a]	'Proximity to Services'	10%	GP, A&E hospital, dentist, pharmacy, optician, job centre, post office, supermarket/food store, large service centre, leisure centre, financial services, and 'other' general services.	Fastest road travel times to services from OA population-weighted centroid. An average overall travel time for all services is calculated, giving double weight to Accident and Emergency Services to reflect their perceived importance (NISRA, 2010).	Neonatal outcomes (Scott-Pillai et al., 2013); school performance (Ferguson and Michaelson, 2013); mental health (Tseliou et al., 2016).
Scotland (2016)	'Geographic Access to Services'	9%	GP, retail centre, petrol station, primary and secondary school, and post office.	Weighted average drive time (mins) to all 6 services and public transport times (bus, train, underground, ferries, foot) to 3 services (GP, post office, retail centre) are calculated for OAs using Basemap TRACC and population weighted to data zone level. Travel times are standardised and weighted according to factor analysis (Scottish Government, 2016).	Density of fast food restaurants (MacDonald et al., 2007); coronary heart disease (O'Flaherty et al., 2009); resource access (Macintyre et al., 2008).
Wales (2014)	'Access to Services' Domain	10%	GP, food shop, leisure centre, pharmacy, public library, post office, primary and secondary school, and petrol station (private transport only).	For each service, a weighted average of public (bus, train, foot, coach) and private (car) travel times (mins) for a two-way journey from all households to their nearest supply point are calculated within the LSOA using Mapumental API and Route Finder 4.02 for MapInfo. Travel times are standardised and weighted according to factor analysis (Welsh Government, 2014).	Renal transplantation (Stephens et al., 2010); celiac disease (Whyte et al., 2014); child obesity (Beynon, 2016); epilepsy (Pickrell et al., 2015).

[a] An update to the 2010 Northern Ireland Multiple Deprivation Measure is expected by late 2017 (see NISRA, 2016)

Table 2: Deprivation domains and their underlying indicators, WIMD 2014

Domain (weighting)	Indicator(s)
Income (23.5%)	Percentage of population who are: in receipt of income related benefits; in receipt of tax credits with an income 60% below the Wales median; or a supported asylum seeker.
Employment (23.5%)	Percentage of working-age population in receipt of employment-related benefits.
Health (14%)	All-cause death rate; cancer incidence; long-term limiting illness; low birth weight.
Education (14%)	Key stage 2 average point score; key stage 4 capped point score; key stage 4 level 2 inclusive; repeat absenteeism; proportion of 18-19 year olds not entering higher education; and proportion of 25-64 year olds with no qualifications.
Access to services (10%)	Average travel time by public and private transport to the nearest: food shop; general practitioner (GP) surgery; post office; public library; leisure centre; primary school; secondary school; pharmacy; and petrol station (private transport only).
Community safety (5%)	Police recorded violent crime; police recorded criminal damage; police recorded burglary; police recorded theft; anti-social behaviour; and fire incidence.
Physical environment (5%)	Air concentrations; air emissions; flood risk; and proximity to waste and industrial sites.
Housing (5%)	Overcrowding (bedroom occupancy); and lack of central heating.

Source: Welsh Index of Multiple Deprivation 2014 Technical Report (Welsh Government, 2014b)

Table 3: The evolution of the 'Access to Services' domain of WIMD

	WIMD2000	WIMD2005	WIMD2008	WIMD2011	WIMD2014
Domain weight	10%	10%	10%	10%	10%
Services	Post office; large food shop; GP; A&E	Food shop (bread & milk) – 10mins; GP; primary school; post office; public library – 15mins; leisure centre; NHS dentist – 20mins; secondary school – 30mins	Food shop (bread & milk); GP; primary school; post office; public library (inc. mobile libraries); transport node; leisure centre; secondary school; NHS dentist	Food shop (bread & milk); GP; primary school; post office; public library (inc. mobile libraries); transport node; leisure centre; secondary school; NHS dentist	Food shop (bread & milk); GP; primary school; post office; public library (inc. mobile libraries); leisure centre; secondary school; petrol station (private travel only); pharmacy
Method	Euclidean (shortest distance to nearest service)	Road network (percentage of address points within chosen time threshold of the closest service)	Road network (average travel time – 10 shortest journeys)	Road network (average travel time – 10 nearest service points)	Road network (average travel time to nearest service point– return journey, 180 minutes max)
Transport	Public only	Public only (bus & foot) – 800 metres max walking distance	Public only (bus & foot) – 800 metres max walking distance	Public only (bus & foot) – 800 metres max walking distance	Public (bus, foot, coach, train) & private (car)
Demand	Low income people (means tested benefit claimants)	Royal mail address points (commercial address points excluded in urban areas)	Royal mail address points (commercial address points excluded in urban areas)	Royal mail address points (commercial address points excluded in urban areas)	Residential dwellings from the AddressBase Premium dataset (Epoch 22) - OS
Scale	Electoral Divisions (n=865)	LSOAs (n=1,896)	LSOAs (n=1,896)	LSOAs (n=1,896)	LSOAs (n=1,909)
Service weights	Factor analysis (weights not published)	Factor analysis – GP (0.15); food shop (0.08); primary school (0.24); post office (0.24); library (0.07); leisure (0.06); NHS dentist (0.12); secondary school (0.12)	Factor analysis – GP (0.18); food shop (0.14); primary school (0.16); post office (0.10); library (0.09); leisure (0.06); NHS dentist (0.12); secondary school (0.07); transport (0.07)	Factor analysis – GP (0.18); food shop (0.14); primary school (0.16); post office (0.10); library (0.09); leisure (0.06); NHS dentist (0.12); secondary school (0.07); transport (0.07)	Factor analysis – GP (0.14); food shop (0.14); primary school (0.08); post office (0.095); library (0.10); leisure (0.06); secondary school (0.045); petrol (0.05); pharmacy (0.29)

Table 4: Comparison of service supply points used within this study with those reported within the WIMD 2014 Technical Manual

	WIMD-FCA			WIMD-2014		
Service	**n**	**source**	**date**	**n**	**source**	**date**
Pharmacy	714	Extracted from NHS sources	February 2017	819	NHS Wales Directory (Wales); Local Authorities (England)	January 2014
GP surgery	453	Welsh Government	November 2015	983	NHS Wales Directory	January 2014
Food shop	3,444	OS Points of Interest (Digimap)[a]	December 2016	2,656	OS Points of Interest (Landmark Interestmap)	January 2014
Public library	207	OS Points of Interest (Digimap)	December 2016	297	Local Authorities	January 2014
Post office	807	OS Points of Interest (Digimap)	December 2016	1,000	OS Points of Interest (Landmark Interestmap)	January 2014
Primary school	1,093	Welsh Government	January 2016	1,522	Local Authorities	September 2013
Leisure centre	195	Local Authorities (compiled by Sport Wales)[b]	February 2015	319	Local Authorities (compiled by Sport Wales)	January 2014
Petrol station	540	OS Points of Interest (Digimap)	December 2016	860	OS Points of Interest (Landmark Interestmap)	January 2014
Secondary school	205	Welsh Government	January 2016	258	Welsh Government (Wales); OS Points of Interest (Landmark Interestmap: England)	September 2013

[a] Points of Interest is Ordnance Survey's location-based directory of public and private services in Britain; [b] Sports Council for Wales

Table 5: Spearman’s rank-order correlation coefficients comparing associations between access domains and overall IMDs

Access domain (n=1909)			
	WIMD-FCA (5 min)	WIMD-FCA (15 min)	WIMD-FCA (30 min)
WIMD-2014	0.274*	0.174*	0.195*
Overall IMD (n=1909)			
	WIMD-FCA (5 min)	WIMD-FCA (15 min)	WIMD-FCA (30 min)
WIMD-2014	0.967*	0.966*	0.969*

* p<0.01